Title

Adults with overweight or obesity use less efficient memory strategies compared to adults with healthy weight on a verbal list learning task modified with food words

Authors

Eichen, Dawn M

Sim, Dong-Jin E Kang

Appleton-Knapp, Sara L

et al.

Publication Date

2023-02-01

DOI

10.1016/j.appet.2022.106402

Published in final edited form as:
Appetite. 2023 February 01; 181: 106402. doi:10.1016/j.appet.2022.106402.

Adults with overweight or obesity use less efficient memory strategies compared to adults with healthy weight on a verbal list learning task modified with food words

Dawn M. Eichen[a,*], **Dong-Jin E. Kang Sim**[a], **Sara L. Appleton-Knapp**[a,1], **David R. Strong**[b], **Kerri N. Boutelle**[a,b,c]

[a]University of California San Diego, Department of Pediatrics, San Diego, CA, USA

[b]University of California San Diego, Herbert Wertheim School of Public Health and Human Longevity Science, San Diego, CA, USA

[c]University of California San Diego, Department of Psychiatry, San Diego, CA, USA

Abstract

Several studies suggest poorer episodic memory among adults with overweight (OW) relative to those with healthy weight (HW); however, few have used food stimuli. To understand the salience of food-related items when assessing memory, we adapted an episodic memory task, by replacing some non-food words with snack foods. Participants were 96 weight-loss seeking adults with OW compared to 48 adults with HW from the community matched on age, gender, ethnicity, and education. Overall memory ability was similar, although a trend showed the adults with HW performed better than adults with OW on immediate recall ($d = 0.32$, $p = 0.07$). However, there were clear differences in the use of learning strategies. Adults with HW utilized sematic clustering more effectively than adults with OW during all test phases (ds = 0.44–0.62; ps ≤ 0.01). Adults with HW also utilized serial clustering more effectively ($d = 0.51$; $p < 0.01$). Adults with HW showed better semantic clustering for both food and non-food words during immediate and short delay recall (ds = 0.42–0.78; ps ≤ 0.01) but semantic clustering was only better for the non-food category at long delay ($d = 0.55$; $p < 0.01$). These results show that adults with OW utilized less efficient learning strategies throughout the task and food-related content may impact learning. Clinically, these findings may suggest that weight-loss treatments should consider incorporating the teaching of learning and memory strategies to help increase utilization of new skills.

*Corresponding author. University of California, San Diego, 9500 Gilman Drive #0874, La Jolla, CA, 92093, USA., deichen@ucsd.edu (D.M. Eichen).
1Dr. Appleton-Knapp is currently at the University of San Diego, Department of Psychological Sciences, San Diego, CA, USA.

Author contributions
KB & DS designed the Pacific study. KB, DE, SAK, and DS designed the research question for these analyses. DJEKS conducted statistical analyses. DE drafted the manuscript but all authors were involved in writing the paper and had final approval of the submitted and published versions.

Declaration of competing interest
No conflict of interest was declared.

Ethical statement
All adults provided written consent and all study procedures were approved by the University of California San Diego Institutional Review Board (151110).

Keywords

Episodic memory; Semantic clustering; Obesity

1. Introduction

Over 70% of adults in the United States have overweight or obesity (Fryar, Carroll, & Afful, 2020). Given the deleterious consequences of obesity (e.g., diabetes, hypertension, mortality risk, increased psychological comorbidities) (Dixon, 2010; Flegal, Kit, & Graubard, 2013) and increased health care costs resulting from obesity (Cawley et al., 2021; Ward, Bleich, Long, & Gortmaker, 2021), it is important to better understand mechanisms contributing to the development and maintenance of this condition. Growing evidence supports the role that cognitive function plays in overeating which leads to weight gain (Eichen, Pasquale, Twamley, & Boutelle, 2021; Gunstad, Sanborn, & Hawkins, 2020; Smith, Hay, Campbell, & Trollor, 2011) as well as how obesity may further disrupt cognitive function (Farruggia & Small, 2019; Parent, Higgs, Cheke, & Kanoski, 2022).

Obesity more recently has been coined a disorder of learning and memory (Davidson, Tracy, Schier, & Swithers, 2014), further highlighting acknowledgement of the role of cognition. Animal research shows that consumption of a “Western” diet, a diet high in saturated fat and sugar, impairs hippocampal-dependent memory processes (Kanoski & Davidson, 2010), increases appetitive behavior (Clifton, Vickers, & Somerville, 1998; Davidson & Jarrard, 1993; Schmelzeis & Mittleman, 1996) and results in weight gain (Davidson et al., 2009; Davidson, Jones, Roy, & Stevenson, 2019; Davidson, Kanoski, Walls, & Jarrard, 2005). Human research is consistent with these data, similarly showing that consumption of a “Western” diet is associated with impaired hippocampal-dependent memory processes and reduced appetitive control (Attuquayefio, Stevenson, Oaten, & Francis, 2017; Francis & Stevenson, 2011; Stevenson et al., 2020). Evidence from human studies also highlights the impact that hippocampal-dependent episodic memory (e.g., recall of a previous meal) has on subsequent eating behavior (Higgs & Spetter, 2018; Parent et al., 2022). Specifically, several studies demonstrate that recalling the previous meal decreases consumption of a subsequent snack in the laboratory (Collins & Stafford, 2015; Higgs, 2002; Higgs, Williamson, & Attwood, 2008; Szypula, Ahern, & Cheke, 2020; Vartanian, Chen, Reily, & Castel, 2016). Interestingly, recalling a more recent meal (i.e., today’s lunch versus yesterday’s lunch) (Higgs, 2002; Szypula et al., 2020), has a greater impact at suppressing subsequent snack intake; but timing between the meal recalled and snack intake also matters. Participants asked to recall a previous meal at a snack offered 3 h after finishing the meal, showed inhibition of eating compared to those recalling a meal from the day before, whereas those who recalled a previous meal only an hour later did not (Higgs et al., 2008). Deficits in episodic memory are linked to uncontrolled eating (Martin, Davidson, & McCrory, 2018) which is a significant contributor to weight gain. Taken together, research across animals and humans suggests memory has a role in overeating and weight gain.

Several studies demonstrate a cross-sectional relationship between obesity and poorer episodic memory function (Cheke, Bonnici, Clayton, & Simons, 2017; Cheke, Simons,

& Clayton, 2016; Cournot et al., 2006; Gunstad, Paul, Cohen, Tate, & Gordon, 2006; Vainik et al., 2018; Zhang & Coppin, 2018). However, other studies fail to find a difference in episodic memory performance (Conforto & Gershman, 1985; Gonzales et al., 2010; Nilsson & Nilsson, 2009). Much of the research on episodic memory impairment among individuals with overweight compared to healthy weight focuses on general memory as opposed to food-specific memory. This is problematic because across other cognitive domains (i.e., attention and inhibitory control), research shows that cognitive impairments may be heightened or perhaps limited to food-related stimuli among individuals with obesity (Castellanos et al., 2009; Loeber et al., 2012; Nijs, Muris, Euser, & Franken, 2010; Werthmann et al., 2011). These cognitive domains fall under the umbrella of executive function. Several reviews suggest that adults with overweight or obesity have lower executive function than adults with healthy weight (Eichen et al., 2021; Gunstad et al., 2020; Smith et al., 2011). Although episodic memory is not considered an executive function, aspects of episodic memory task performance, namely semantic organization are related to executive function. Performance on episodic-memory tasks reflects several processes: encoding (i.e., getting information into storage), retention (i.e., keeping information within the storage) and retrieval (i.e., accessing information from storage). Importantly, attention plays a critical role in encoding information into memory (Chun & Turk-Browne, 2007; Santangelo, 2015) and anything that does not get encoded cannot be retained or recalled in the future. Few studies to date evaluate the impact of food stimuli on episodic memory performance (Cheke et al., 2016, 2017). One recent study showed that females with obesity have better recognition of food stimuli and poorer recognition of non-food stimuli than females without obesity (Leng et al., 2021). Accordingly, it is possible that food stimuli may enhance memory recall of those stimuli among individuals with overweight or obesity, calling for further investigation of the role food vs non-food stimuli on overall episodic memory.

The current study aims to explore episodic memory processes for food and non-food stimuli by evaluating performance of adults with healthy weight and those with overweight on an adapted version of an episodic list learning task that includes food and non-food categories. Specifically, this study aims to 1) evaluate differences in episodic memory among adults with overweight or obesity and those with healthy weight and 2) evaluate whether adults with overweight or obesity and those with healthy weight utilize different strategies for episodic memory encoding and recall. It is hypothesized that adults with overweight will perform more poorly on the episodic memory task and will not utilize adaptive episodic memory strategies as efficiently during encoding or recall when compared to adults with healthy weight.

2. Methods

2.1. Participants

Adults (n = 48) aged 18–65 years with healthy weight (BMI 19–24 kg/m^2) were recruited from the community to validate the adaptation of the verbal list learning task to include food and non-food stimuli (Kang-Sim, Eichen, Appleton-Knapp, Strong, & Boutelle, In Preparation). The comparative sample of adults with overweight or obesity (OW/OB; n = 96;

BMI 25–45 kg/m2) were gathered from a subset of participants from the Providing Adults Collaborative Interventions for Ideal Changes trial (PACIFIC; NCT02516839) (Boutelle et al., 2022) who were matched to the participants with healthy weight. Coarsened exact matching (Ho, Imai, King, & Stuart, 2011) was used to match participants with OW/OB to participants with healthy-weight based on age, sex, ethnicity, and years of education.

Eligibility criteria for both groups of participants were similar except for the different BMI criteria noted above. Both studies included adults aged 18–65 years and required the ability to read English at the 5th grade level. Exclusion criteria were the same for participants with healthy weight and OW/OB, including: diabetes, any medical condition that would make physical activity unsafe, moderate or severe substance or alcohol use disorder, pregnancy or lactation, and any medical or psychological problem that could make adherence to the study protocol difficult or dangerous. All participants with healthy weight were recruited from the community utilizing methods such as ResearchMatch, emails to listservs and word of mouth. Additional details of the eligibility criteria and recruitment methods for the clinical trial have already been published (Boutelle et al., 2019, 2022). This study was approved by the Institutional Review Board of the University of California San Diego and written consent was obtained from all participants.

2.2. Measure – verbal list learning task with food words (VLLT-food)

The modified Verbal List Learning Task with Food Words (Kang-Sim et al., In Preparation)was developed by replacing the animal category on both lists of the California Verbal Learning Test-II (Delis, Kramer, Kaplan, & Ober, 2000) with a high-fat snack category which included words that were comparable to the original category on frequency of words occurring in American English determined using the SubtlexUS database (Brysbaert & New, 2009). The vegetable (e.g., low-fat food) words and non-food words were maintained from the original measure. The VLLT-Food is administered following the same protocol as the CVLT-II. First, the examiner reads the same list of words (List A; the target words) five times and the participant is asked to recall as many as possible after each recitation (immediate free recall). The examiner then reads a second list with different words (List B, the distractor words) and the participant recalls the second list. Then, the participant is asked to recall as many words from List A as possible for the short-delay free recall. Following that, the examiner provides the participants one of the four categories, and the participant is asked to recall as many words as possible from that category for each of the four categories (short-delay cued recall). After a 20-min delay, the participant is asked again to recall as many words as possible from List A in long-delay free and cued recall. Lastly, the examiner reads a list of 48 words and the participant responds yes or no as to whether the word was part of List A (recognition).

2.2.1. Scoring of the VLLT-FOOD—All variables were scored in R based on the CVLT-II manual's scoring protocol (Delis et al., 2000). All scores reported have been normalized by age and sex based on the standard form except where noted. Although there are numerous memory variables that can be derived from the VLLT-Food, we focused on the standardized performance measures of correctly recalled words across trials 1–5 (T score) and discriminability index (d') during the immediate, short- and long-delay recall portions of the test. The discriminability index considers both the correct words and intrusions recalled such that if individuals recalled the same number of correct words, those with fewer intrusions would score higher on the d'. Learning was evaluated through a) learning slope of trials 1–5, which examines the increase in number of words correctly recalled across each trial with better increase resulting in higher scores; b) recall consistency, which measures the ability to recall the same words on subsequent trials with higher scores indicating more consistent recall; c) chance-adjusted semantic clustering across all trial phases, which evaluates the extent participants used the categories to semantically organize their recall of words with higher scores indicating more effective use of semantic clustering (i.e., measures whether words from the same category are recalled together); d) chance-adjusted serial clustering, which evaluates the extent participants recalled words based on the order they were presented in the original list with higher scores indicating more recall based on order (i.e., measures whether a word is recalled in consistent order with another word); e) subjective clustering, which evaluates the extent participants utilize a more idiosyncratic strategy other than semantic and serial clustering (such as functional or phonemic relationships among words). Raw scores were computed for discriminability index (d') and use of semantic clustering learning strategy for food and non-food stimuli by modifying the formulas for overall discriminability and semantic clustering from the CVLT-II scoring manual to account for the modified food categories (Delis et al., 2000).

2.3. Statistical analyses

All analyses were conducted using R statistical programming language (version 4.0). Between-group comparisons were conducted using the conditional inference procedures in a nonparametric permutation test framework (Hothorn, Hornik, van de Wiel, & Zeileis, 2008). The nonparametric permutation distribution of the estimated differences were derived with 1000 Monte Carlo resampling and Cohen's d were used to estimate between-group differences of memory measures.

3. Results

Descriptive characteristics of the two groups of participants are shown in Table 1. As designed through the matching process, there were no differences in demographic characteristics between the two groups except for BMI.

3.1. Comparison of performance on first five trials

Comparisons of the memory scores from the VLLT-Food measure from the first five trials are shown in Table 2. Overall memory ability was similar between the two groups, although there were trends suggesting that participants with healthy weight performed better than the participants with OW/OB on immediate recall and were better able to discriminate during these first five trials. Although overall memory ability was similar, there were differences in learning rate as participants with healthy weight had a significantly higher learning slope. Participants with healthy weight also had greater recall consistency than participants with OW/OB. Participants with healthy weight also demonstrated use of more efficient learning strategies for immediate recall as they were more likely to use both semantic and serial clustering strategies and less likely to use subjective clustering. Given the relationship between age and memory, we explored the correlations and found no significant correlations between t-score trials 1–5, immediate recall d', or semantic clustering and age in participants with healthy weight or OW/OB with correlations ranging from −0.05 – 0.20.

3.2. Comparison of performance on short and long delay recall

Comparisons between participants on the short and long delay recall portions of the task are displayed in Table 3. There were no differences in short and long delay free recall ability between participants with healthy weight and participants with OW/OB. However, results show that the participants with healthy weight continue to utilize semantic clustering more effectively in both short and long delay free recall. Lastly, there was a trend towards better performance among participants with healthy weight in both short and long delay cued recall. Interestingly, there were no group differences on free recall of long delay as a percent of recall on short delay and both groups recalled more words on average at long delay free recall than short delay free recall. There were also no significant correlations between short delay or long delay d' or semantic clustering and age in participants with healthy weight or OW/OB with correlations ranging from −0.03 – 0.14.

3.3. Impact of food stimuli on semantic clustering performance across participants with healthy weight and with overweight

Raw scores calculated for semantic clustering of only the food categories and the non-food categories for participants with healthy weight and with OW/OB are presented in Table 4. Participants with healthy weight demonstrated significantly greater use of sematic clustering for both food and non-food categories at the immediate recall and short delay recall trials compared to participants with OW/OB. In the long delay recall portion, participants with healthy weight utilized sematic clustering more effectively for non-food categories but showed no difference of use of semantic clustering of the food categories compared to participants with OW/OB. Post-hoc analyses evaluated whether there was an interaction effect between food stimuli and group. Significant interaction effects were observed for immediate recall ($b = 0.48$; $SE = 0.15$; $p = 0.002$; cohen's $d = 0.52$), and long delay recall semantic clustering ($b = 0.53$; $SE = 0.27$; $p = 0.048$; cohen's $d = 0.33$). These interaction effects suggest that when semantic clustering is compared across the two stimuli categories, participants with healthy weight use semantic clustering less effectively for the food categories than they do for the non-food categories while participants with OW/OB use semantic clustering similarly regardless of the type of category. There was no significant interaction effect on short delay semantic clustering ($b = 0.41$; $SE = 0.26$; $p = 0.11$; effect size d: 0.27).

4. Discussion

The purpose of this study was twofold: first to evaluate potential differences in episodic memory performance and second to evaluate strategy usage of adults with OW/OB compared to adults with healthy weight on an adapted version of a list learning task that included food and non-food categories. Our first hypothesis that participants with OW/OB would perform more poorly in episodic memory was partially supported. Our results showed trends toward differences in memory ability based on recall on the first five trials and discriminability during these trials. However, participants with OW/OB had a significantly poorer learning slope and recall consistency scores than participants with healthy weight, suggesting that participants with OW/OB may have difficulty creating or maintaining a learning plan (Delis et al., 2000). There were also no differences on short or long-delay free recall though the study showed a trend towards individuals with healthy weight performing better on cued recall at the short- and long-delay intervals.

Despite not seeing many significant differences in overall memory recall, we did find evidence that participants with OW/OB did not demonstrate use of efficient memory strategies. Across the immediate, short- and long-delay phases of the measure, adults with healthy weight demonstrated significantly greater use of semantic clustering in their recall. Further, adults with healthy weight demonstrated significantly greater use of serial clustering in their immediate recall, while they demonstrated less subjective clustering compared to adults with OW/OB. Semantic clustering is a particularly effective strategy for this task given that it was designed to include words from four different categories, whereas subjective clustering may be less efficient and more idiosyncratic. Overall, adults with healthy weight demonstrated better use of semantic clustering of all category types during the immediate recall and short-delay phases of the task. However, at the long delay adults with healthy weight demonstrated better use of semantic clustering for non-food categories, but there was no significant difference in semantic clustering for food categories.

Though much research to date has shown differences in memory between individuals with OW/OB and healthy weight (Cheke et al., 2016, 2017; Cournot et al., 2006; Gunstad et al., 2006; Vainik et al., 2018; Zhang & Coppin, 2018), our study only showed trends toward significance on a few measures. However, nominally, all results were consistently in the direction of individuals with healthy weight having better memory performance that adults with OW/OB. It is possible that the current study did not have the power to detect a true difference. Additionally, this study included individuals with overweight and obesity and the difference in BMI with the healthy weight individuals may not have been large enough to show differences in cognitive features. Published studies have included adults with obesity and those with a healthy weight (Cheke et al., 2017) and some included adults with higher BMIs than our study which created greater differences in BMI (Cheke et al., 2016, 2017). Further, despite research showing differences across numerous cognitive abilities among individuals with OW/OB compared to individuals with healthy weight, typically the poorer performance among individuals with OW/OB does not reach the level of significant clinical impairment (Gunstad et al., 2020). Lastly, the lack of differences found in our study may be due to use of different tasks. Some previous studies used a “What-Where-When” style Treasure Hunt task which evaluates spatial/temporal memory (Cheke et al., 2016, 2017), while the others used other verbal list learning tasks that included a list of completely unrelated words (Cournot et al., 2006; Gunstad et al., 2006; Vainik et al., 2018). Taken together, these methodological differences may explain why our study did not find differences in memory performance while previous studies did.

There was clear evidence in the current study that individuals with OW/OB were less likely to use efficient recall strategies, namely semantic clustering, which is further demonstrated by a trend of poorer performance in cued recall among adults with OW/OB compared to those with healthy weight. Thus, it is possible that the differences in memory (including the cause behind differences seen in previous research), may lie in the organization of stored memory or during memory encoding, preventing individuals with overweight from recognizing useful strategies such as semantic clustering. Semantic clustering requires executive function, which is attributed to frontal lobe functioning. However, recent research suggests the hippocampus also plays a role in semantic memory and semantic clustering (Duff, Covington, Hilverman, & Cohen, 2020). Previous research shows that people with OW/OB have decreased volume of the frontal lobe (Bruehl, Sweat, Tirsi, Shah, & Convit, 2011; Castro, Venutolo, Yau, & Convit, 2016) and hippocampus (Bruehl et al., 2011; Leigh & Morris, 2020; Mestre et al., 2017, 2020). Decreased volume in the hippocampus and frontal lobe has been attributed to consumption of a western diet through mechanisms such as inflammation, insulin sensitivity, gut microbiome, and insult to the blood-brain-barrier (Castro et al., 2016; Francis & Stevenson, 2013; Leigh & Morris, 2020; Parent et al., 2022). Thus, the overall findings of less utilization of semantic clustering among adults with OW/OB compared to adults with healthy weight is consistent with previous structural research and research demonstrating that adults with OW/OB have lower EF compared to adults with healthy weight (Eichen et al., 2021; Smith et al., 2011).

In line with previous research (Leng et al., 2021), it is possible that the use of additional food stimuli may have impacted performance. We created the VLLT-food by swapping out the animal category with a high-fat snack food category. By having two food categories (vegetables, high-fat snack foods), it is possible that some participants may have not differentiated between those categories as they originally were more distinct categories (animal vs vegetable). Specifically, this may explain the interaction effects which showed that participants with healthy weight used semantic clustering to a greater extent with the non-food categories. It is possible that participants with healthy weight may have had more difficulty differentiating the two food categories. In the current study, the only time adults with OW/OB did not demonstrate less semantic clustering was related to recall of food words at the long delay phase. The four distinct categories are first explicitly revealed to participants following the short delay free recall, as part of short delay cued recall. Thus, one possible reason why there were no differences in use of semantic clustering for the food stimuli during the long delay recall could be that the adults with OW/OB better organized their retrieval for the food categories when given the next opportunity in long delay free recall, potentially due to some of the food words being more salient to adults with OW/OB.

Overall, this study suggested that adults with OW/OB are less likely to use efficient recall strategies in an episodic memory task which may impact overall memory performance. Strengths of this study include use of the coarsened exact method to match participants on demographic characteristics outside of BMI to minimize potential confounding variables (i.e., years of education) and utilizing a task with food and non-food stimuli which allows for an understanding of strategies used instead of just overall raw memory performance. Limitations include incorporating adults with both overweight and obesity which may have reduced our ability to detect differences between this group of participants and those with healthy weight. Relatedly, although age-matched, our study does not consider how long people may have experienced obesity or stage of life when obesity was experienced which can impact the effects on memory. Additionally, there are several types of memory processes that have not been assessed (e.g., spatial, relational, associative) which should be explored in future research studies. Future research should continue to evaluate the impact of food stimuli and memory and how poorer use of strategies may impact treatment performance. Research should explore whether stronger memory for food or food cues may contribute to overeating and weight gain representing a possible treatment target for weight loss. Further, given the differences in strategy usage on the task, future research should evaluate whether teaching of learning or memory strategies would help increase utilization of new skills in weight-loss treatment.

Acknowledgements

Thanks to the participants and staff at CHEAR who made this possible. Data summarized in this publication may be available in a deidentified format to investigators for research purposes with the approval of the principal investigators and the IRB as appropriate after publication of this article.

Funding

This study was supported by the National Institutes of Health under grants: R01DK103554, K23DK114480, and UL1TR001442. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

Data availability

Data will be made available on request.

References

Attuquayefio T, Stevenson RJ, Oaten MJ, & Francis HM (2017). A four-day Western-style dietary intervention causes reductions in hippocampal-dependent learning and memory and interoceptive sensitivity. PLoS One, 12(2), Article e0172645. 10.1371/journal.pone.0172645

Boutelle KN, Eichen DM, Peterson CB, Strong DR, Kang-Sim D-JE, Rock CL, et al. (2022). Effect of a novel intervention targeting appetitive traits on body mass index among adults with overweight or obesity: A randomized clinical trial. JAMA Network Open, 5(5). 10.1001/jamanetworkopen.2022.12354. e2212354–e2212354. [PubMed: 35583870]

Boutelle KN, Eichen DM, Peterson CB, Strong DR, Rock CL, & Marcus BH (2019). Design of the PACIFIC study: A randomized controlled trial evaluating a novel treatment for adults with overweight and obesity. Contemporary Clinical Trials, 84, Article 105824. 10.1016/j.cct.2019.105824

Bruehl H, Sweat V, Tirsi A, Shah B, & Convit A (2011). Obese adolescents with type 2 diabetes mellitus have hippocampal and frontal lobe volume reductions. Neuroscience & Medicine, 2(1), 34–42. 10.4236/nm.2011.21005 [PubMed: 21691448]

Brysbaert M, & New B (2009). Moving beyond Kučera and Francis: A critical evaluation of current word frequency norms and the introduction of a new and improved word frequency measure for American English. Behavior Research Methods, 41(4), 977–990. 10.3758/BRM.41.4.977 [PubMed: 19897807]

Castellanos EH, Charboneau E, Dietrich MS, Park S, Bradley BP, Mogg K, et al. (2009). Obese adults have visual attention bias for food cue images: Evidence for altered reward system function. International Journal of Obesity, 33(9), 1063–1073. [PubMed: 19621020]

Castro MG, Venutolo C, Yau PL, & Convit A (2016). Fitness, insulin sensitivity, and frontal lobe integrity in adults with overweight and obesity. Obesity, 24(6), 1283–1289. 10.1002/oby.21500 [PubMed: 27123868]

Cawley J, Biener A, Meyerhoefer C, Ding Y, Zvenyach T, Smolarz BG, et al. (2021). Direct medical costs of obesity in the United States and the most populous states. Journal of Managed Care & Specialty Pharmacy, 27(3), 354–366. 10.18553/jmcp.2021.20410 [PubMed: 33470881]

Cheke LG, Bonnici HM, Clayton NS, & Simons JS (2017). Obesity and insulin resistance are associated with reduced activity in core memory regions of the brain. Neuropsychologia, 96, 137–149. 10.1016/j.neuropsychologia.2017.01.013 [PubMed: 28093279]

Cheke LG, Simons JS, & Clayton NS (2016). Higher body mass index is associated with episodic memory deficits in young adults. Quarterly Journal of Experimental Psychology, 69(11), 2305–2316. 10.1080/17470218.2015.1099163

Chun MM, & Turk-Browne NB (2007). Interactions between attention and memory. Current Opinion in Neurobiology, 17(2), 177–184. 10.1016/j.conb.2007.03.005 [PubMed: 17379501]

Clifton P, Vickers S, & Somerville E (1998). Little and often: Ingestive behavior patterns following hippocampal lesions in rats. Behavioral Neuroscience, 112(3), 502–511. [PubMed: 9676968]

Collins R, & Stafford LD (2015). Feeling happy and thinking about food. Counteractive effects of mood and memory on food consumption. Appetite, 84, 107–112. 10.1016/j.appet.2014.09.021 [PubMed: 25280672]

Conforto RM, & Gershman L (1985). Cognitive processing differences between obese and nonobese subjects. Addictive Behaviors, 10(1), 83–85. 10.1016/0306-4603(85)90056-5 [PubMed: 4003140]

Cournot M, Marquié JC, Ansiau D, Martinaud C, Fonds H, Ferrières J, et al. (2006). Relation between body mass index and cognitive function in healthy middle-aged men and women. Neurology, 67(7), 1208–1214. 10.1212/01.wnl.0000238082.13860.50 [PubMed: 17030754]

Davidson T, Chan K, Jarrard L, Kanoski S, Clegg D, & Benoit S (2009). Contributions of the hippocampus and medial prefrontal cortex to energy and body weight regulation. Hippocampus, 19(3), 235–252. 10.1002/hipo.20499 [PubMed: 18831000]

Davidson T, & Jarrard L (1993). A role for hippocampus in the utilization of hunger signals. Behavioral and Neural Biology, 59(2), 167–171. 10.1016/0163-1047(93)90925-8 [PubMed: 8476385]

Davidson TL, Jones S, Roy M, & Stevenson RJ (2019). The cognitive control of eating and body weight: It's more than what you "think". Frontiers in Psychology, 10. 10.3389/fpsyg.2019.00062

Davidson T, Kanoski S, Walls E, & Jarrard L (2005). Memory inhibition and energy regulation. Physiology & Behavior, 86(5), 731–746. 10.1016/j.physbeh.2005.09.004 [PubMed: 16263144]

Davidson TL, Tracy AL, Schier LA, & Swithers SE (2014). A view of obesity as a learning and memory disorder. J Exp Psychol Anim Learn Cogn, 40(3), 261–279. 10.1037/xan0000029 [PubMed: 25453037]

Delis D, Kramer J, Kaplan E, & Ober B (2000). California verbal learning test. In Adult version (2nd ed.). San Antonio, TX: The Psychological Corporation. Manual.

Dixon J (2010). The effect of obesity on health outcomes. Molecular and Cellular Endocrinology, 316(2), 104–108. 10.1016/j.mce.2009.07.008 [PubMed: 19628019]

Duff MC, Covington NV, Hilverman C, & Cohen NJ (2020). Semantic memory and the Hippocampus: Revisiting, reaffirming, and extending the reach of their critical relationship. Frontiers in Human Neuroscience, 13. 10.3389/fnhum.2019.00471

Eichen DM, Pasquale EK, Twamley EW, & Boutelle KN (2021). Targeting executive function for weight loss in adults with overweight or obesity. Physiology & Behavior, 240, Article 113540. 10.1016/j.physbeh.2021.113540

Farruggia MC, & Small DM (2019). Effects of adiposity and metabolic dysfunction on cognition: A review. Physiology & Behavior, 208, Article 112578. 10.1016/j.physbeh.2019.112578

Flegal K, Kit B, & Graubard B (2013). Overweight, obesity, and all-cause mortality–reply. JAMA, 309(16), 1681–1682. 10.1001/jama.2013.3101

Francis HM, & Stevenson RJ (2011). Higher reported saturated fat and refined sugar intake is associated with reduced hippocampal-dependent memory and sensitivity to interoceptive signals. Behavioral Neuroscience, 125(6), 943–955. 10.1037/a0025998 [PubMed: 22023100]

Francis H, & Stevenson R (2013). The longer-term impacts of Western diet on human cognition and the brain. Appetite, 63, 119–128. 10.1016/j.appet.2012.12.018 [PubMed: 23291218]

Fryar C, Carroll M, & Afful J (2020). Prevalence of overweight, obesity, and severe obesity among adults aged 20 and over: United States, 1960–1962 through 2017–2018. National Center for Health Statistics E-Stats.

Gonzales MM, Tarumi T, Miles SC, Tanaka H, Shah F, & Haley AP (2010). Insulin sensitivity as a mediator of the relationship between BMI and working memory-related brain activation. Obesity, 18(11), 2131–2137. 10.1038/oby.2010.183 [PubMed: 20814415]

Gunstad J, Paul RH, Cohen RA, Tate DF, & Gordon E (2006). Obesity is associated with memory deficits in young and middle-aged adults. Eating and Weight Disorders, 11(1), e15–e19. 10.1007/bf03327747 [PubMed: 16801734]

Gunstad J, Sanborn V, & Hawkins M (2020). Cognitive dysfunction is a risk factor for overeating and obesity. American Psychologist, 75(2), 219. [PubMed: 32052996]

Higgs S (2002). Memory for recent eating and its influence on subsequent food intake. Appetite, 39(2), 159–166. 10.1006/appe.2002.0500 [PubMed: 12354684]

Higgs S, & Spetter MS (2018). Cognitive control of eating: The role of memory in appetite and weight gain. Current obesity reports, 7(1), 50–59. 10.1007/s13679-018-0296-9 [PubMed: 29430616]

Higgs S, Williamson AC, & Attwood AS (2008). Recall of recent lunch and its effect on subsequent snack intake. Physiology & Behavior, 94(3), 454–462. 10.1016/j.physbeh.2008.02.011 [PubMed: 18420236]

Ho D, Imai K, King G, & Stuart EA (2011). MatchIt: Nonparametric preprocessing for parametric causal inference. Journal of Statistical Software, 42(8), 1–28. 10.18637/jss.v042.i08

Hothorn T, Hornik K, van de Wiel MA, & Zeileis A (2008). Implementing a class of permutation tests: The coin package. Journal of Statistical Software, 28(8), 1–23. 10.18637/jss.v028.i08 [PubMed: 27774042]

Kang-Sim D-JE, Eichen DM, Appleton-Knapp SL, Strong DR, & Boutelle KN (In Preparation). Psychometric evaluation of a modified verbal list learning task with food words.

Kanoski S, & Davidson T (2010). Different patterns of memory impairments accompany short- and longer-term maintenance on a high-energy diet. Journal of Experimental Psychology: Animal Behavior Processes, 36, 313–319. 10.1037/a0017228 [PubMed: 20384410]

Leigh S-J, & Morris MJ (2020). Diet, inflammation and the gut microbiome: Mechanisms for obesity-associated cognitive impairment. Biochimica et Biophysica Acta - Molecular Basis of Disease, 1866(6), Article 165767. 10.1016/j.bbadis.2020.165767

Leng X, Xiao M, Bian Z, Zhang Y, Shi P, & Chen H (2021). Episodic memory for food and non-food cues in females with obesity. Eating Behaviors, 40, Article 101472. 10.1016/j.eatbeh.2020.101472

Loeber S, Grosshans M, Korucuoglu O, Vollmert C, Vollstädt-Klein S, Schneider S, … Kiefer F (2012). Impairment of inhibitory control in response to food-associated cues and attentional bias of obese participants and normal-weight controls. International Journal of Obesity, 36(10), 1334–1339. [PubMed: 21986703]

Martin AA, Davidson TL, & McCrory MA (2018). Deficits in episodic memory are related to uncontrolled eating in a sample of healthy adults. Appetite, 124, 33–42. 10.1016/j.appet.2017.05.011 [PubMed: 28479407]

Mestre ZL, Bischoff-Grethe A, Eichen DM, Wierenga CE, Strong D, & Boutelle KN (2017). Hippocampal atrophy and altered brain responses to pleasant tastes among obese compared with healthy weight children. International Journal of Obesity, 41(10), 1496–1502. 10.1038/ijo.2017.130 [PubMed: 28572588]

Mestre Z, Bischoff-Grethe A, Wierenga CE, Jernigan T, Eichen DM, Chang L, … Boutelle KN (2020). Associations between body weight, hippocampal volume, and tissue signal intensity in 12- to 18-year-olds. Obesity, 28(7), 1325–1331. 10.1002/oby.22841 [PubMed: 32501641]

Nijs IM, Muris P, Euser AS, & Franken IH (2010). Differences in attention to food and food intake between overweight/obese and normal-weight females under conditions of hunger and satiety. Appetite, 54(2), 243–254. [PubMed: 19922752]

Nilsson L-G, & Nilsson E (2009). Overweight and cognition. Scandinavian Journal of Psychology, 50(6), 660–667. 10.1111/j.1467-9450.2009.00777.x [PubMed: 19930267]

Parent MB, Higgs S, Cheke LG, & Kanoski SE (2022). Memory and eating: A bidirectional relationship implicated in obesity. Neuroscience & Biobehavioral Reviews, 132, 110–129. 10.1016/j.neubiorev.2021.10.051 [PubMed: 34813827]

Santangelo V (2015). Forced to remember: When memory is biased by salient information. Behavioural Brain Research, 283, 1–10. 10.1016/j.bbr.2015.01.013 [PubMed: 25595422]

Schmelzeis M, & Mittleman G (1996). The hippocampus and reward: Effects of hippocampal lesions on progressive-ratio responding. Behavioral Neuroscience, 110 (5), 1049–1066. [PubMed: 8919008]

Smith E, Hay P, Campbell L, & Trollor JN (2011). A review of the association between obesity and cognitive function across the lifespan: Implications for novel approaches to prevention and treatment. Obesity Reviews, 12(9), 740–755. 10.1111/j.1467-789X.2011.00920.x [PubMed: 21991597]

Stevenson RJ, Francis HM, Attuquayefio T, Gupta D, Yeomans MR, Oaten MJ, et al. (2020). Hippocampal-dependent appetitive control is impaired by experimental exposure to a Western-style diet. Royal Society Open Science, 7(2), Article 191338. 10.1098/rsos.191338

Szypula J, Ahern A, & Cheke L (2020). The role of memory ability, depth and mode of recall in the impact of memory on later consumption. Appetite, 149, Article 104628. 10.1016/j.appet.2020.104628

Vainik U, Baker TE, Dadar M, Zeighami Y, Michaud A, Zhang Y, … Dagher A (2018). Neurobehavioral correlates of obesity are largely heritable. Proceedings of the National Academy of Sciences, 115(37), 9312–9317. 10.1073/pnas.1718206115

Vartanian LR, Chen WH, Reily NM, & Castel AD (2016). The parallel impact of episodic memory and episodic future thinking on food intake. Appetite, 101, 31–36. 10.1016/j.appet.2016.02.149 [PubMed: 26923744]

Ward ZJ, Bleich SN, Long MW, & Gortmaker SL (2021). Association of body mass index with health care expenditures in the United States by age and sex. PLoS One, 16(3), Article e0247307. 10.1371/journal.pone.0247307

Werthmann J, Roefs A, Nederkoorn C, Mogg K, Bradley BP, & Jansen A (2011). Can (not) take my eyes off it: Attention bias for food in overweight participants. Health Psychology, 30(5), 561. [PubMed: 21767019]

Zhang Z, & Coppin G (2018). To what extent memory could contribute to impaired food valuation and choices in obesity? Frontiers in Psychology, 9. 10.3389/fpsyg.2018.02523

Table 1

Demographic characteristics of participants with healthy weight and with overweight/obesity.

	Healthy weight (n = 48)	OW/OB (n = 96)	p-value
Age in years; m(se)	44.44 (1.72)	45.30 (1.22)	0.661
% Female	81%	81%	1.00
% Hispanic	10%	10%	1.00
Non-Hispanic Non-White	21%	21%	1.00
Non-Hispanic White	69%	69%	1.00
Education in years; m (se)	17.06 (0.30)	16.79 (0.17)	0.425
BMI (kg/m^2); m(se)	21.66 (0.19)	34.60 (0.51)	<0.001

Note: OW/OB = Overweight/Obesity.

Table 2

Comparison of performance and strategy usage on the first five learning trials between participants with healthy weight and participants with overweight/obesity.

Standardized scores	Healthy weight (n = 48)	OW/OB (n = 96)	Cohen's d	p-value
T-score trials 1–5	57.04 (1.47)	53.92 (0.99)	0.32	0.095
Immediate Recall d'	0.62 (0.17)	0.29 (0.10)	0.30	0.098
Learning slope 1–5	0.27 (0.13)	−0.08 (0.09)	0.38	0.035
Recall consistency	0.65 (0.13)	0.33 (0.07)	0.41	0.034
Chance-Adjusted Semantic clustering	1.19 (0.19)	0.39 (0.13)	0.62	<0.001
Chance-Adjusted Serial clustering	0.80 (0.17)	0.19 (0.12)	0.51	0.003
Subjective Clustering	−1.00 (0.15)	−0.55 (0.12)	0.39	0.043

Note: OW/OB = Overweight/Obesity.

Table 3

Comparison of short and long delay recall between participants with healthy weight and participants with overweight/obesity.

Standardized scores	Healthy weight (n = 48)	OW/OB (n = 96)	Cohen's d	p-value
SD free recall d'	0.67 (0.18)	0.38 (0.10)	0.27	0.143
SD free recall semantic clustering	1.03 (0.20)	0.29 (0.12)	0.61	0.001
SD cued recall d'	0.48 (0.13)	0.19 (0.10)	0.30	0.084
LD free recall d'	0.44 (0.16)	0.20 (0.09)	0.26	0.144
LD free recall semantic clustering	0.78 (0.17)	0.29 (0.11)	0.44	0.019
LD cued recall d'	0.50 (0.14)	0.20 (0.09)	0.35	0.072
LD free recall as % of SD recall	103.38 (22.97)	104.9 (14.14)	0.09	0.491

Note: OW/OB = Overweight/Obesity; SD = Short Delay; LD = Long Delay.

Table 4

Comparison of semantic clustering use for food and non-food categories.

Raw scores	Healthy weight (n = 48)	OW/OB (n = 96)	Cohen's d	p-value
Immediate Recall Semantic Clustering for Food Stimuli	1.56 (0.17)	1.09 (0.11)	0.42	0.019
Immediate Recall Semantic Clustering for Non-Food Stimuli	2.05 (0.19)	1.09 (0.12)	0.78	<0.001
SD Semantic Clustering for Food Stimuli	2.57 (0.25)	1.82 (0.15)	0.47	0.009
SD Semantic Clustering for Non-Food Stimuli	3.00 (0.26)	1.85 (0.17)	0.67	<0.001
LD Semantic Clustering for Food Stimuli	2.61 (0.26)	2.21 (0.17)	0.24	0.213
LD Semantic Clustering for Non-Food Stimuli	3.12 (0.24)	2.19 (0.18)	0.55	0.001

Note: OW/OB = Overweight/Obesity; SD = Short Delay; LD = Long Delay.