HHS Public Access
Author manuscript
Int J Obes (Lond). Author manuscript; available in PMC 2022 July 19.

Published in final edited form as:
Int J Obes (Lond). 2022 April ; 46(4): 851–858. doi:10.1038/s41366-021-01036-5.

Retrieval-Induced Forgetting in Children and Adolescents with and without Obesity

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Registered at clinicaltrials.gov as NCT02390765

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Abstract

Background/objectives: Previous research indicates that youth with obesity exhibit deficits in executive functioning (EF), which often take the form of impaired response inhibition. One aspect of EF not previously studied in obesity is the adaptive process known as retrieval-induced forgetting (RIF), the suppression/inhibition of intrusive or non-target items by the retrieval of specific items from memory. The present study investigated if child or adolescent obesity disrupts the ability to inhibit retrieval of intrusive memories.

Subjects/methods: We compared the manifestation of RIF in children (ages 8–12) and adolescents (ages 13–18) as a function of their weight status and sex. We also evaluated the effects of these variables on simple recall of items from episodic memory under conditions where competition from intrusive items was reduced.

Results: Children with obesity did not demonstrate significant RIF, whereas RIF was exhibited by preteens without obesity and by teenage participants with- and without obesity (x Weight Status x Age Group interaction p = 0.028). This pattern of results did not differ as a function of sex for either age group. No differences in episodic memory were found. Additional analyses using Age as continuous covariate (and not as a nominal group) comparing participants who exhibited RIF with those who did not, found that the no RIF group consumed fast-food meals more frequently (p=.024) and had higher percentages of total body adiposity and android fat compared to the RIF group (p's<.05).

Conclusions: The findings expand what is known about the effects of childhood obesity on cognitive functioning, identify impaired RIF with specific behavioral and dietary factors and increased adiposity, and suggest the possibility that impairments in the ability to inhibit intrusive memories of food and eating may contribute to poor early-life weight control.

Keywords

self-regulation; self-control; executive functioning; memory; energy intake; adiposity; child

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In the most recent National Health and Nutrition Examination Survey reporting period (2017–2018), estimated obesity prevalence in U.S. children and adolescents, 2–19 years of age, reached an all-time high of 19.3%[1]. In addition to well-known sequalae that threaten physical health and psychosocial development[2–4], accumulating evidence also indicates that youth with obesity may be at higher risk for impairments in cognitive processes, especially those associated with executive functions (EFs). EFs are mental processes that underlie the self-regulation and the control of other cognitive processes such as decision-making, problem-solving, working memory, and the abilities to shift attention between different mental activities and delay gratification[5] Obesity has been linked to deficits in EFs. For example, a recent meta-analysis comparing individuals with and without obesity from age 6 through adulthood concluded that obesity was associated with poorer performance across all domains of EF, independent of age or sex[6]. Moreover, after reviewing 27 studies that focused solely on children and adolescents, Mamrot & Hanć[7] concluded that excess body mass is inversely related to executive functioning in both children and adolescents.

Prior studies[7,8] have also concluded that the that relationship between high weight and EF is driven by poor inhibitory control. Inhibitory control is considered a core executive function involved with the regulation of attention, thoughts, and emotional impulses[5]. Accordingly, inhibitory control involves the suppression of unwanted thoughts and intrusive memories or emotions that could direct attention away from, or interfere with, the retrieval of information that is needed to function adaptively in one's current situation[9,10]. Furthermore, several studies have reported developmental differences between pre-teenage children and older teenage adolescents in memory and executive function including inhibition[11–15].

The purpose of the present research was to evaluate the hypothesis that a specific type of inhibitory control, known as Retrieval-induced forgetting (RIF) is impaired in children and adolescents with obesity. RIF is an example of an adaptive process whereby attempts to retrieve certain target items from memory are facilitated by the inhibition of retrieval from memory of other potentially competing nontarget items[16]. For example, trying to learn (i.e., practicing) a subset of items from one category (e.g., apple, banana from the category "fruits") inhibits the ability to retrieve other non-practiced items from that same category (e.g., orange, cherry). RIF can be viewed as a mechanism of memory interference reduction. Previous studies found that RIF is robustly exhibited by school-age children, adolescents, and adults without obesity[17–19]. However, RIF has not been evaluated in individuals with obesity, and there appear to be no studies that examined if the effects of obesity on RIF differ between preteen children and teenage adolescents. In the present study, finding that RIF is reduced for youth with obesity, versus those without obesity, would provide new information about the nature of the inhibitory neurocognitive functions that are impacted by weight status. We also assessed whether participants who exhibited RIF differed from those who did not as a function of their age, adiposity, and dietary factors associated with the type and frequency of food and beverages they consumed.

Methods

Participants

Generally healthy males and females (8–18y) were recruited to participate in a 6-year nontreatment longitudinal study that recruited healthy children and adolescents to examine eating patterns and eating behavior endophenotypes to understand how they may lead to excessive weight gain and obesity-related comorbidities (Clinical Trials Identifier: NCT02390765). Exclusion criteria included: 1) history of major medical illness; 2) regular use of medication known to affect body weight; 3) current or previous pregnancy; 4) history of significant or recent brain injury; 5) current and regular use of illicit substances; 6) significant and recent weight loss (>5% of body weight); 7) current significant, full-threshold psychiatric disorder; 8) body mass index (BMI, kg/m2) < 5th percentile standard for age and sex for US children[20], and 9) full scale intelligent quotient score ≤ 70 according to the subtests that assess verbal comprehension and perceptual reasoning abilities of the Wechsler Abbreviated Scale of Intelligence, Second Edition (WASI-II;[21]). Children provided written assent and parents/guardians gave written consent. Families were informed that the purpose of the study was to better understand growth and health behaviors in children. The

Institutional Review Board of the National Institutes of Health approved all procedures. Participants were financially compensated for their time and inconvenience.

Procedure Overview.

Study procedures were conducted at outpatient clinics of the NIH Hatfield Clinical Research Center (Bethesda, MD). Participants came to the clinic after an overnight fast and underwent body composition assessment, completed questionnaires and computer tasks, and participated in a laboratory test meal as previously reported[22–27].

Body weight and body adiposity—Participants' weight and height were measured using calibrated instruments. BMI standardized deviation scores (BMIz) were calculated following Center of Disease Control and Prevention growth standards[28] to determine BMI percentiles. Obesity was defined as BMI ≥ 95th percentile for age and sex. Total adiposity (percentage fat mass) was measured by dual-energy x-ray absorptiometry (DXA) using an iDXA system (GE Healthcare, Madison WI). Gynoid and android fat percentages were calculated as previously reported[29,30].

Fast Food/Sugar Sweetened Beverage Intake—Items from the self-report version of the Dietary Screener Questionnaire (DSQ) were used to assess average frequency of fast food and sugar-sweetened beverage intake in the previous month with results expressed as frequency of consumption per month. The DSQ was developed by the Risk Factor Monitoring and Methods Branch of the National Cancer Institute and was included in the 2009–2010 National Health and Nutrition Examination Survey[31].

Laboratory test meal—Participants fasted overnight prior to their visit. At ~10:00am, youth were given a breakfast shake standardized to provide 21% of estimated energy needs, based on weight, height, age and average activity level in the previous week. Between 11:00am-12:00pm, participants were presented with a standardized buffet style test meal (>10,000 kcal) including a variety of food types and macronutrients (e.g., 54% energy from carbohydrate, 12% energy from protein, 33% energy from fat), were instructed to "let yourself go and eat as much as you want," and then were left alone to eat[32].

The Retrieval Practice Paradigm (RPP)[33]: We used a common version of the RPP task that was employed previously to demonstrate RIF in children and young adults[19]. This task required participants to study lists of six items in each of eight different categories (e.g., chair, table, lamp, couch, desk, bed in the category of FURNITURE). This was followed by a retrieval practice phase where the participants were cued to recall half of the items from half of the categories using a two- or three- character stem of an item (e.g., FURNITURE-ch__ with "ch" the cue for the item "chair"). None of the items in nonpracticed categories were cued (i.e., practiced) for recall. After performing a distractor task, the participants were asked to recall all the items within both the practiced and nonpracticed categories. During this final test, recall of the retrieval practiced items from the practiced categories (RP+ items) provides an index of episodic memory. RIF is demonstrated to the extent that nonpracticed items from the retrieval practiced categories (RP- items) are recalled less well compared to nonpracticed items from the retrieval nonpracticed categories (NRP- items). As noted previously, retrieval of the RP+ items is thought to automatically activate RIF which serves to inhibit retrieval of RP- items. Because no attempt is made to recall any NRP- items, none of those items would be subject to RIF, making them easier to recall compared to the RP- items in the final recall test. Therefore, weaker recall of RP- relative to NRP- items indicates stronger inhibitions of irrelevant items from memory, which is an adaptive function.

The RPP had three phases: 1) study phase; 2) practice phase (with cued recall); and 3) final recall test phase. During the study phase, participants viewed 48 category-exemplar pairs with eight categories and six exemplars per category on a computer screen (i.e., FRUIT – orange, FRUIT – pineapple, INSECT – beetle, INSECT – hornet, etc.). The words chosen were matched for strength of association with their category, concreteness, and frequency in the language and were age-appropriate for the youngest members of the preteen group. Participants were instructed to study each pair, specifically how the exemplar relates to the category, and were told that their memory for these pairs would be tested later. Each pair was viewed, one at a time, for five seconds each, in a random order. During the practice phase, participants practiced retrieving a subset of three exemplars each from a subset of four of the categories. These 12 category-exemplar pairs were practiced three times each in a random order and were counterbalanced across participants. During the retrieval practice phase, participants were given the category name and a two-letter stem of an exemplar. Participants were given eight seconds to identify the exemplar based on the stem. Participants were then given 5 different trail-making tasks to complete as distracters. Completion of all 5 tasks takes 15–20 minutes[19]. A final retention test was given immediately after the distracter task for which participants were given a category name and were asked to enter as many exemplars from that category as they could remember. This was repeated for all the categories that were presented during the initial study phase (i.e., both the practiced and nonpracticed categories from the practice phase). Participants were given thirty seconds for each category name to recall as many of the previously studied exemplars from the category as they could. In each phase of the study, the type and timing of the events presented were controlled by an automated program. In addition, an examiner provided the instructions for each phase, attempted to keep each of the participants on task and recorded the responses of each participant during the retrieval practice and final test phases.

Statistical Analyses: As this cross-sectional analysis was not prespecified in the longitudinal study protocol, there was no a priori power calculation performed for RIF. The RIF data obtained from each participant during the final test phase were converted into three proportions: (1) the proportion of practiced exemplars recalled from practiced categories (RP+ items) that were presented in the retrieval practice phase; (2) the proportion of nonpracticed exemplars recalled from the practiced categories (RP- items) presented in the retrieve practice phase; (3) the proportion of nonpracticed exemplars from the nonpracticed categories (NRP- items) that were not presented during the retrieval practice phase. Analysis of variance (ANOVA) compared these proportions as function of Age Group (preteen, 8–12y vs. teen, 13–18y), Weight Status (obesity vs. non-obesity) and Sex (male vs. female) of the participants. For a second analysis, a RIF score for each subject was calculated by dividing the proportion of NRP- items by the sum of the proportions of NRP- and RP-items. Scores >.50 were classified as evidence of RIF, whereas scores < .50 were classified as evidence of No RIF. We then conducted analysis of covariance (ANCOVA) using age as a continuous covariate (and not as a nominal group) to determine if participants classified as RIF differed from No RIF participants based on their percent body fat, in the frequency that they reported habitually consuming regular soda, fruit juices, other beverages with nutritive sweeteners added, and fast-foods and to examine differences in the percent of carbohydrate, fat and protein they consumed in their test meal. Post-hoc Least Significant Difference tests were used to evaluate interactions. We also reanalyzed of our memory data with the participants classified as having high adiposity for age and sex (≥75th percentile for percentage body fat) or lower adiposity based on percent total body adiposity according to the criteria developed by Centers for Disease Control investigators using National Health and Nutrition Examination Survey data[34,35]. For all analyses, the criterion for statistical significance was set at a p-value < .05. Partial eta squared (hp^2) was calculated as index of effect size for significant differences. Skew and kurtosis were calculated to assess normality of the distributions of RP-, NRP- and the ratio NRP/(NRP+RP-).

Results: A total of 198 participants were recruited. Of these, 19 had missing RIF data, or were otherwise unable to complete the task. The sociodemographic characteristics of participants with incomplete or missing RIF data were Sex (female = 11, male = 8); Age Group (preteen = 12, teen = 7); Race (Black or African American = 6. White = 10, Asian = 1, Multiple Races = 1, Unknown = 1); Mean BMI percentile = 66.1 ±2.11 (standard error of the mean (SEM). The remaining 179 participants were divided into preteen (8–12 years of age) and teen (13–18 years of age) age groups. Table 1 describes the characteristics of participants in these two age groups. On average, participants consumed 965.4±30.3 (SEM) kcal at the buffet meal, 44.3±1.5% of estimated total daily energy requirements. Participants with obesity consumed significantly more energy at the meal than those without obesity (1243.1±76.4 vs. 918.1±31.5 kcal, p=.0001, and had greater intake when it was expressed as the percentage of estimated total daily energy requirements consumed (49.3±3.8 vs. 43.6±1.6, but this difference was not significant, p=.1593.

For participants with obesity, mean BMI percentile was 97.71 ±4.50; for those without obesity, mean BMI percentile was 58.30 ±1.98 (p < .0001). Mean BMI percentile did not vary significantly with Age Group (preteen vs. teen) or Sex and there were no significant interactions involving these factors (largest F(1, 175) = 1.82, p > .17 for Sex).

Figure 1 shows that episodic memory performance, defined by the proportion of RP+ items recalled, was high and did not differ significantly based on Weight Status or Age Group. ANOVA yielded no main effects or interactions involving Weight Status, Age Group or Sex (the effects of Sex are not depicted in Figure 1). The largest F-value obtained was F(1,171) = 1.99, p. = .16 for the main effect of Weight Status.

Evidence for RIF takes the form of lower recall of RP- items compared to NRP- items. Figure 2 provides evidence of RIF in the teens and preteens without obesity and the teens with obesity in that the proportion of RP- items recalled was substantially lower than the proportion of NRP- items recalled for each of these groups. However, this pattern was not observed in preteens with obesity, who showed no significant difference in the proportion of RP- and NRP- items recalled. ANOVA obtained a significant RP- vs. NRP- x Weight Status x Age Group interaction, $F(1, 171) = 4.91$, $p = 0.028$, $hp^2 = .028$. Post-hoc tests confirmed that proportion of items recalled was significantly less for RP- items compared the NRP- items ($p < .05$) for all but the preteen participants with obesity ($p > .49$). This finding indicates that RIF was significantly impaired only among the preteens with obesity. Assessment of skew and kurtosis indicated that values of both RP- (skew = −0.12; kurtosis = −0.64) and NRP- (skew = −0.16; kurtosis = 0.29) were normally distributed[36,37].

Table 2 A–C depicts the results of additional analyses, using Age as a continuous covariate (and not as a nominal group), which compared participants classified as exhibiting RIF with those classified as exhibiting No RIF with respect to the estimated frequency of consuming several types of foods and beverages, the percentages of macronutrients that comprised their energy intake during the test meal, and the percent of body fat in total and in the respective gynoid and android regions. Considering the results of the DSQ, Table 2A shows that participants exhibiting No RIF reported a significantly higher frequency of eating fast-food meals compared to participants that exhibited RIF, $F(1, 176) = 4.70$, $p = .031$. No other DSQ measures yielded significant differences between RIF and No RIF participants. Table 2B shows the percentages of total test meal intake comprised of protein, fat, and carbohydrate as a function of RIF classification. The data revealed trends toward participants that exhibited No RIF consuming a higher percent of energy as fat, $F(1, 169)=3.23$, $p=.074$, and a lower percent as carbohydrate, $F(1, 169)=3.7967$, $p=.053$, compared to participants classified as RIF. Percent protein consumed did not differ based on RIF classification.

The results for body adiposity (Table 2C) revealed that the participants classified as No RIF also exhibited significantly higher mean percentage total tissue fat, $F(1, 175)=4.1201$, $p=.0438$ and android fat, $F(1, 175)=4.0284$, $p=.04628$, compared to participants who demonstrated RIF. However, for mean BMI percentile, while somewhat higher for No RIF participants (67.18, SEM = ±3.72) compared to those exhibiting RIF (64.37; SEM = ±2.73), this difference did not approach significance, $F(1, 157) < 1$. Skew (.751) and kurtosis (1.865) indicated that the RIF ratio scores used for the covariate analysis were normally distributed[35,35].

We also reanalyzed our memory recall data in which the participants were classified as high and low adiposity based on percent total body fat. As was found with the obesity classification based on BMI, there were no significant differences in recall of RP+ items in preteen or teens based for participants classified as high relative to low adiposity (Adiposity Status x Age Group interaction, $F(1,170) < 1$, $p > .97$; data not shown). indicating that episodic memory was not influenced by adiposity level in either the preteen or teen age groups. Figure 3 presents the results of our reanalysis of the RIF findings with participants classified as high and low adiposity based on percent total body fat. The pattern of RIF results obtained were like those reported above when the participants were classified as with obesity and without obesity based on BMI. That is, preteens with high adiposity failed to exhibit less recall of RP- items than NRP- items) (i.e., indicating impaired RIF) whereas low adiposity preteens and both high and low adiposity teens show weaker recall of RP- compared to NRP- items (indicating RIF). In contrast to our analysis of based on BMI, this reanalysis failed to yield a significant RP- vs. NRP- x Adiposity Status x Age Group interaction, $F(1, 170)=1.8312$, $p=.17779$). However, individual analyses comparing the difference in RP- and NRP- item recall separately for high adiposity preteens, low adiposity preteens, high adiposity preteens and low adiposity preteens indicated that significantly fewer RP- items than NRP- items were recalled for low adiposity preteens and low and high adiposity teens, respectively, (smallest $F(1, 55) = 9.012$, $p < .001$ for low adiposity preteens) whereas this difference was not significant for preteens with high adiposity, $F(1,55) < 1$, p >. 52). These results provide tentative support for the suggestion that, as was found with obesity based on BMI, only preteens with high adiposity exhibited impaired RIF.

Discussion

Based on BMI, RIF was impaired for preteens with obesity compared to preteens who did not have obesity. RIF performance did not vary significantly based on obesity status for teenage participants. No effect of Sex on RIF was found for either age group. Furthermore, episodic memory performance did not differ significantly based on Weight Status, Age Group, or Sex, nor did these factors interact with one another.

Inhibiting retrieval of some items from memory can be regarded as adaptive to the extent that such inhibition facilitates the retrieval of other items that may be more relevant to one’s current situation. The impairment in RIF observed in preteen children with obesity relative to those without obesity in our study suggests that children with obesity are less able to engage that inhibitory memory process compared to children without obesity. Previous studies have reported that childhood obesity is negatively associated with performance on tasks that assess the inhibition of behavioral responses, such as Go/No go (e.g.,[38], the Stop-signal task (e.g.,[39]) and the Stroop test (e.g.,[40]). A common feature of each of these tasks is the assessment of the ability to voluntarily suppress a prepotent behavioral response or tendency to respond that is elicited by a specific environmental cue. It has been proposed that impairments in behavioral inhibition may promote overeating and obesity by weakening the ability to withhold responses to food and food-related environmental stimuli[41–43]. Our current findings indicate that childhood obesity may also impair the ability to automatically inhibit retrieval of unwanted or irrelevant items from memory. It may be that this impairment in RIF contributes to obesity by weakening the ability to suppress the retrieval of memories of food and the pleasures of eating by environmental cues, when food intake is not needed (i.e., when those memories are irrelevant). Activation of such memories are associated with food cravings and overeating (e.g.,[44–46]) and could lead to excessive weight gain and obesity.

Although our study found significantly weaker RIF in preteens with obesity, this result was not obtained for teenage participants. Younger children tend to show weaker executive function, including inhibition, compared to adolescents (e.g.,[12–14]). It may be that overall inhibitory ability is lower for preteens making that ability more susceptible to disruption by obesity compared to teens. Lynch et al.,[47] investigated the influence of excess body weight on regional hippocampal surface morphology and memory performance in two cohorts, ages 8–13.9 years and 14–19.9 years, respectively. The authors reported that percent BMI was associated with reduced left hippocampal volume, which was localized to the anterior superior region and that this effect was strongest in the younger age group. This raises the possibility that the reduced RIF we observed in preteens with obesity may be based on greater sensitivity of RIF to alterations in hippocampal morphology, which may not have been as large in our teen compared to our preteen participants. It may be that obesity in preteens produces hippocampal changes and memory impairments that are not manifested in teens. It is also possible that hippocampal and memory dysfunction in teens with obesity require the emergence of these conditions during the pre-teenage years. Growth chart data to determine the actual age when all participants with obesity first manifested high BMI were not available.

Several studies have provided evidence that the hippocampus is part of the neural circuitry for RIF and for inhibitory memory control processes that may mediate RIF (see 38 for review). For example, Wimber et al., ([48]; but also see[49]), reported increased BOLD responses in the posterior temporal and parietal association cortices, in the bilateral hippocampus, and in the dorsolateral prefrontal cortex of humans when selective retrieval produced significant forgetting of the non-retrieved items in RIF. Koolschjjn et al.,[50] also suggested that protecting memories from interference in humans depends on the ability of the hippocampus to use contextual information to separate overlapping memories, with neocortex reducing interference by inhibiting the co-activation of those memories. The results of other studies, which involve human participants voluntarily suppressing intrusive memories, suggest that such memory inhibition is primarily a hippocampal-dependent function (e.g.[51]).

The present study found no significant effect of weight status on episodic memory. Pearce et al.,[52] reported no impairment in adolescents, aged 14–18 years, with and without obesity although a trend toward impaired episodic recall was reported in adolescents with severe obesity (BMI > 120% above the 95th percentile). Despite limited effects on episodic memory, fMRI revealed differential engagement of the hippocampus and other medial temporal lobe structures in the group with severe obesity. Furthermore, a study of children ages 7–9 years found that abdominal tissue mass was not associated with recognition memory (which includes an episodic memory component) of previously studied visual items in children with overweight and obesity, but was significantly associated with a hippocampal-dependent ability to remember relationships among visual cues[53]. Thus, it may be that the effects of obesity on hippocampal structure and function are particularly strong in younger children.

Adjusting for age, the participants who exhibited RIF and no RIF did not differ with respect to percent BMI, but RIF was associated with significantly lower percent android and total body fat. These findings are consistent with earlier reports indicating that cognitive deficits are more closely associated with measures of body adiposity than with measures of BMI, perhaps because high adiposity is more proximally linked to the development of obesity's complications[54,55] than high BMI, which represents both lean mass and fat mass. However, the present results found significant detrimental effects on RIF performance when BMI was used to classify participants as with and without obesity.

Furthermore, studies investigating associations of fast-food accessibility and frequency of intake with childhood and adolescent obesity (indexed primarily by BMI measures) have yielded mixed results. For example, recent systematic reviews and meta-analyses concluded that frequency of fast-food consumption was either not associated[56] or only weakly associated[57] with body weight. Similarly, the results of the current study failed to reveal a significant connection between obesity and reported frequency of eating fast-food meals. However, we did find that frequency of fast-food meals was significantly higher for participants that failed to show evidence of RIF compared to those that did show RIF. This result is consistent with the hypothesis that frequency of fast-food meals contributes to impaired RIF.

Our results are suggestive that differences in dietary macronutrient selection could be a contributor to impaired RIF. For participants classified as exhibiting RIF and no RIF, differences in the percent intake of the fat and carbohydrate narrowly missed attaining statistical significance, with percent fat intake higher for participants with no RIF compared to those exhibiting RIF whereas participants exhibiting No RIF had lower intake of carbohydrates compared to those exhibiting RIF. Because these two percentage measures are reciprocally related, it is not possible to discern whether impaired RIF is most closely associated with increased fat intake or decreased intake of carbohydrate. However, while it has often been reported in both human and nonhuman animal models that cognitive impairments are associated with elevated intakes of one or both of these macronutrients[58–62], short of starvation conditions, there seem to be no reports that attribute such impairments to reductions in carbohydrate intake.

Strengths of this investigation include the use of a computerized RPP paradigm that was suitable for preteens and teens, measurement of body composition by dual-energy x-ray absorptiometry in addition to determination of BMI, and the use of a controlled laboratory test meal to study energy intake. Limitations include the cross-sectional nature of the data, which precludes making causal inferences. The questions from the DSQ used in this study assessed only the frequency and not the quantity of fast food and sugar-sweetened beverage intake; future analyses should evaluate both to improve our understanding of such intake. Some of the words in the RIF task involved foods, and it is possible that responses might differ according to the specific words of the task. Future studies will be needed to examine this possibility. The relatively small sample sizes of the teen and preteen subgroups may also have reduced our ability to observe differences related to obesity as defined by BMI percentile. Studies with larger samples, particularly if followed longitudinally, would allow a better understanding of the complex relationships between diet, obesity, and hippocampal function. Lastly, the data were a secondary analysis of an ongoing trial; thus, no a priori power calculations were generated and no corrections for multiple comparisons were applied; thus, results should be considered hypothesis generating.

In conclusion, a specific type of inhibitory control, namely hippocampal-dependent retrieval induced forgetting, is impaired in preteens with obesity compared to their counterparts with lower BMI. A reduction in the ability to inhibit intrusive memories of food and eating may contribute to a “vicious cycle” of obesity and memory impairment in which weakened inhibitory control leads to overeating of a high-fat, high-sugar diet and weight gain that could result in further weakening of memory inhibition (e.g.,[63,64]), leading to additional weight gain, obesity, and perhaps more serious cognitive dysfunction later in life. Accordingly, the results of this study join other reports[63,65] that highlight the need for studying early interventions that can prevent or ameliorate the disruption of RIF, "break" the vicious cycle and, through translational research in both schools and community settings, improve health and academic outcomes for children.

Acknowledgements:

We thank the participants and their parents for their involvement in this trial. TLD, NRK, MTK and JAY designed the study; all authors (TLD, ER, EAK,KGD, LMF, MNP, SBY, AZ, NRK, LMS, MTK, AS, SIB, AH, KYC, and JAY) contributed to data collection; TLD conducted data analysis and interpretation, completed the literature search, and with JAY wrote the first draft of the manuscript and generated the figures. All authors (TLD, ER, EAK,KGD, LMF, MNP, SBY, AZ, NRK, LMS, MTK, AS, SIB, AH, KYC, and JAY) contributed to writing the paper and had final approval of the submitted versions. Dr. Sabrina Jones and Dr. Lauren McGrath were consulted about data analysis and the distractor task used in the study. This work was supported by Intramural Research Program (NICHD grant number ZIA-HD00641; Yanovski).

Conflict of Interest Statement:

The authors report no conflicts of interest for the present work. J.A.Y. reports grant support for unrelated projects examining pharmacological treatments of rare syndromes causing obesity from Rhythm Pharmaceuticals Inc. and Soleno Therapeutics, Inc.

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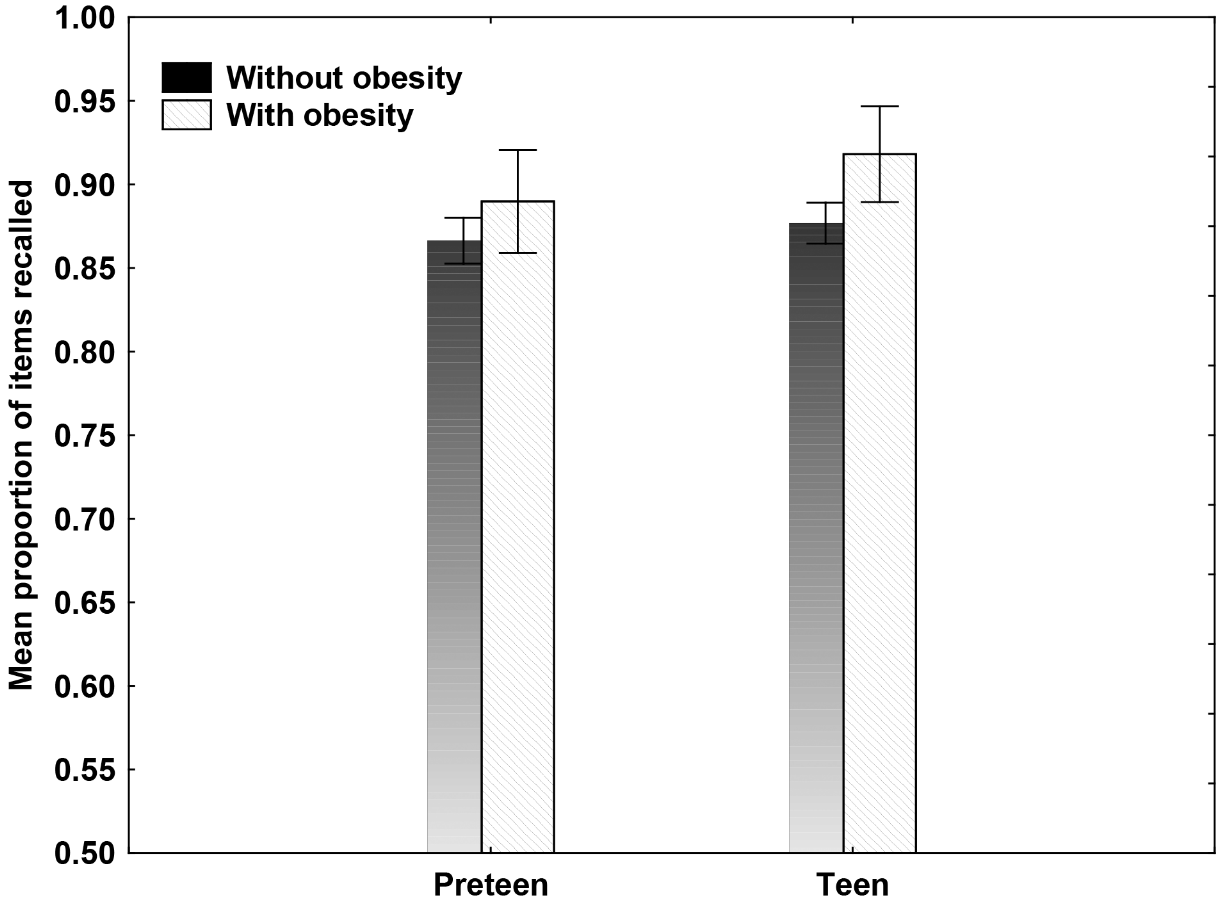

Figure 1:

Mean proportion of RP+ items (retrieval-practiced items from practiced categories) that were recalled during the test phase by preteens without (n = 65) and with (n = 13) obesity and by teens without (n = 85) and with (n = 16) obesity. Error bars indicate standard errors of the mean.

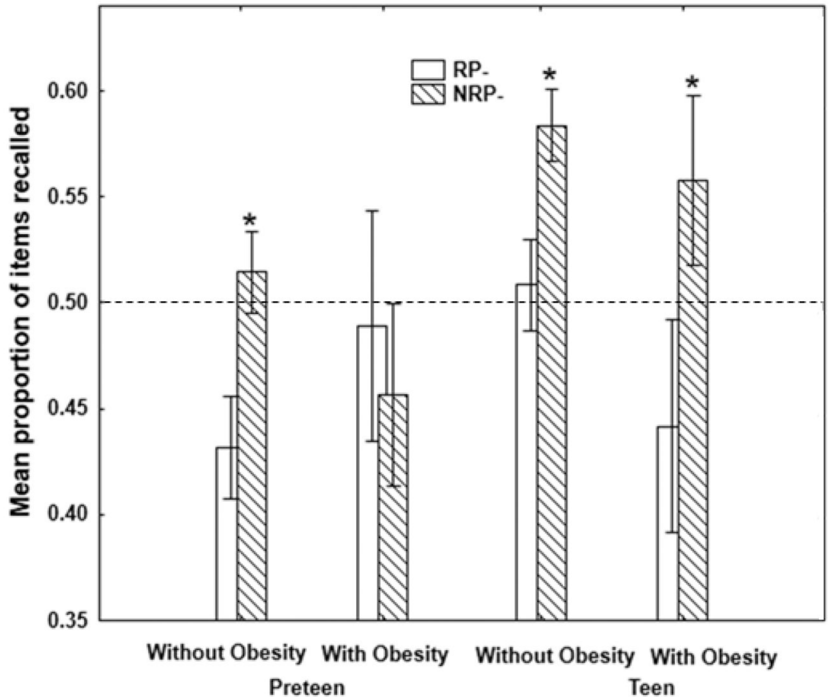

Figure 2:

Mean proportion of RP- item (nonpracticed items from retrieval practiced categories) and NRP- items (nonpracticed items from retrieval nonpracticed categories) that were retrieved during the test phase by preteens without (n = 65) and with (n = 13) obesity and by teens without (n = 85) and with (n = 16) obesity. Error bars indicate standard errors of the mean. Asterisks* indicate that the difference between RP- and NRP- items is statistically significant at $p < .05$.

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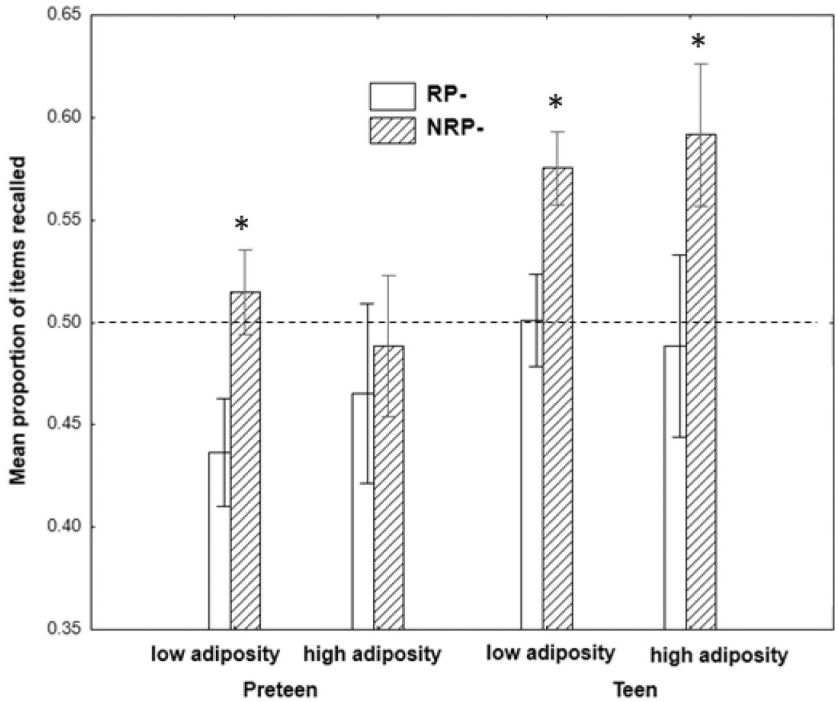

Figure 3:

Mean proportion of RP- item (nonpracticed items from retrieval practiced categories) and NRP- items (nonpracticed items from retrieval nonpracticed categories) that were retrieved during the test phase by preteens with low (n = 57) and high (n = 21) adiposity and by teens with low (n = 79) and high (n = 21) adiposity. Error bars indicate standard errors of the mean. Asterisks* indicate that the difference between RP- and NRP- items is statistically significant at $p < .05$ based on individual comparisons of RP- and NRP- items at each age group and adiposity classification. Note that adiposity data was not available for one participant in the preteen group.

Table 1:

Participant Characteristics

Category	Preteen (N=78)		Teen (N=101)		Total Sample (N=179)
	Obesity (N=13)	No Obesity (N=65)	Obesity (N=16)	No Obesity (N=85)	
Sex (% female)	53.8	49.2	62.5	58.8	55.5
Race (%)					
White	7	31	4	47	89
Black	2	14	12	18	46
Asian	0	10	0	12	22
Multiple/Not reported	4	10	0	8	22
Age (y)†	10.77±1.54	10.54±1.32	15.69±1.54	14.91±1.36	13.09±2.61
BMI Percentile†	97.16±1.64	59.78±25.55	98.15±1.16	57.17±27.14	64.69±28.21
Body Fat (%)†	42.03±7.80	27.46±7.31	40.27±7.72	25.09±8.02	28.47±9.48
Energy Intake at buffet meal (kcal)†	1015.9±408.1	828.4±367.6	1421.6±419.0	964.0±359.4	962.9±399.2
Energy Intake at buffet meal relative to total daily estimated energy requirements (%)†	50.0±24.3	43.5±20.3	50.2±19.4	42.9±17.3	44.3±19.3
RIF*†	0.47±0.08	0.56±0.13	0.59±0.11	0.54±0.10	0.54±0.11

*Mean RIF = NRP- /(RP- + NRP-)

†Mean ± Standard Deviation (SD)

Table 2A:

Dietary Screener Questionnaire reported consumption

Frequency per Month	**RIF**	**No RIF**	**P-value**	$\eta_p 2$
Regular Soda or Pop	9.03 ± 1.85	5.28 ± 2.34	0.211	
100% Pure Fruit Juice	11.14 ± 2.10	8.44 ± 2.78	0.448	
Coffee/Tea with Added Sugar or Honey	4.87 ± 1.16	3.24 ± 1.46	0.386	
Sweetened Fruit, Sport, Energy Drinks	6.32 ± 1.81	8.21 ± 2.29	0.520	
Fast Food Meals	4.91 ± 1.64	10.64 ± 2.07	***0.031*** *	***0.026***

Asterisks * and bold-face font indicate significant p-values. Mean ± SEM shown for RIF and No RIF classification.

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Table 2B:

Energy Intake during the Buffet Meal

Macronutrient Intake (% of total)	RIF	No RIF	P-value
Energy from Protein (%)	14.16 ± 0.36	14.64 ± 0.45	0.401
Energy from Fat (%)	35.56 ± 0.73	37.67 ± 0.92	0.074
Energy from Carbohydrate (%)	50.28 ± 0.83	47.68 ± 1.04	0.053

Table 2C:

DXA Percentage Fat

Fat depot (% of region)	RIF	No RIF	P-value	
Total tissue (%)	27.33 ± 0.90	30.28 ± 1.14	**0.044** *	**0.023**
Gynoid (%)	31.06 ± 1.00	34.19 ± 1.26	**0.052**	
Android (%)	23.97 ± 1.30	28.17 ± 1.63	**0.046** *	**0.023**

Asterisks * and bold-face font indicate significant p-values. Mean ± SEM shown for RIF and No RIF classification.