Eating Behaviors 35 (2019) 101338

Contents lists available at ScienceDirect

Eating Behaviors

journal homepage: www.elsevier.com/locate/eatbeh

Obesity is associated with poor working memory in women, not men: Findings from a nationally representative dataset of U.S. adults

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ARTICLE INFO

Keywords:
Obesity
Working memory
Sex differences

ABSTRACT

A growing body of research has linked obesity to lower working memory performance. However, sex differences are often found in associations between obesity and cognition, and little work has examined potential sex differences in the association between obesity and working memory. To address this issue, the present research uses data from Wave IV of The National Longitudinal Study of Adolescent to Adult Health (*N* = 4,769, mean age = 29) to examine whether sex moderated the association between excess weight and working memory. As expected, we found that obesity was associated with poorer working memory, but—importantly—this association was exclusively seen in women, not men. These results held when treating BMI as a continuous or categorical variable (e.g., normal weight, obese), as well as with and without controlling for covariates. The present results therefore indicate that the association between obesity and poorer working memory performance may be sex-dependent. These results suggest that interventions targeted at reducing obesity should be tailored to an individual's sex, as adherence to these interventions often requires working memory.

1. Introduction

The prevalence of obesity is problematic and rising in both developed and developing nations (Ng et al., 2014). This fact has far-reaching and costly implications, because obesity contributes to the development of numerous illnesses (e.g., heart disease) (Poirier et al., 2006), and psychiatric disorders (e.g., depression, anxiety) (Gariepy, Nitka, & Schmitz, 2010; Quek, Tam, Zhang, & Ho, 2017). Recently, attention has been paid to negative associations between obesity and cognitive functions—particularly executive functions (Liang, Matheson, Kaye, & Boutelle, 2014; Nederkoorn, Smulders, Havermans, Roefs, & Jansen, 2006; Rotge, Poitou, Fossati, Aron-Wisnewsky, & Oppert, 2017; Vainik, Dagher, Dubé, & Fellows, 2013, 2018; Wirt, Hundsdörfer, Schreiber, Kesztyüs, & Steinacker, 2014). For example, a recent meta-analysis found that obesity predicted broad deficits in executive functions, including poorer cognitive flexibility, inhibition, and working memory (Yang, Shields, Guo, & Liu, 2018).

Working memory refers to the ability to monitor the relevance of incoming stimuli and update information held in mind as required. As one of the main executive functions, working memory plays an important role in the successful self-regulation of eating behavior and body weight (Dohle, Diel, & Hofmann, 2017; Hofmann, Friese, & Roefs, 2009). Indeed, poor working memory is associated with more consumption of fatty foods (Wyckoff, Evans, Manasse, Butryn, & Forman, 2017), less consumption of fruits and vegetables (Allom & Mullan, 2014), and poor treatment outcomes during weight-loss interventions (Dassen, Houben, Allom, & Jansen, 2018). Therefore, poor working memory could contribute to the development and maintenance of obesity.

The relationship between obesity and working memory may be bi-directional, with obesity also contributing to poor working memory. That is, obesity upregulates inflammatory activity (Guillemot-Legris & Muccioli, 2017), and heightened inflammatory activity appears to worsen working memory (Lasselin et al., 2016; Shields, Moons, & Slavich, 2017; Sweat et al., 2008). Therefore, obesity may worsen working memory.

Regardless of directionality, obesity is clearly related to worse working memory performance. Importantly, though, there may be sex differences in this association, given that there are sex differences in associations between obesity and other cognitive processes and outcomes (Azurmendi et al., 2005; Elias, Elias, Sullivan, Wolf, & D'Agostino, 2005; Lu et al., 2014; Mond, Stich, Hay, Kraemer, & Baune, 2007; Schwartz et al., 2013). For example, there is a sex difference in the association between obesity and educational attainment (He, Chen, Fan, Cai, & Huang, 2019; Hill, Lopez, & Caterson, 2019). In particular, there is a negative association between obesity and academic

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https://doi.org/10.1016/j.eatbeh.2019.101338
Received 8 January 2019; Received in revised form 9 October 2019; Accepted 10 October 2019
Available online 31 October 2019
1471-0153/

achievement in girls, but that association is attenuated in boys (Martin et al., 2017). Similarly, women show an obesity-related decision-making deficit (i.e., a higher rate of delay discounting), but men do not (Weller, Cook, Avsar, & Cox, 2008).

There are additional reasons to expect a sex difference in the association between obesity and working memory. For example, relative to obese men, obese women may experience more weight-related stigmatization and stress (Wellman, Araiza, Solano, & Berru, 2019), and stress impairs working memory (Shields, Sazma, & Yonelinas, 2016). Alternatively, obese women evidence greater inflammatory activity than do men (Shanahan et al., 2013), and inflammatory activity appears to worsen executive functions—such as working memory (Shields et al., 2017). Indeed, both weight-related stigmatization and inflammatory activity have been linked to poorer cognitive performance in obese individuals (Sutin, Stephan, Robinson, Daly, & Terracciano, 2019; Sweat et al., 2008). Because of this, we tested whether sex moderates the association between obesity and working memory in a large, nationally representative sample of young adults in the United States.

2. Methods

2.1. Participants and procedure

Publicly available cross-sectional data from Wave IV of The National Longitudinal Study of Adolescent to Adult Health (Add Health) were used in this study (Harris, 2009). Of the 5,114 participants interviewed in Wave IV, individuals who were not pregnant and had a body mass index (BMI) of normal weight (18.5 to 24.9), overweight (25 to 29.9), and obese weight (above 29.9) were selected for analysis. The final sample consisted of the 4,769 participants (2,480 females, M_{age} = 29.02, SD_{age} = 1.78, age range = 25–34) with complete BMI, sex, and working memory data, though only 4,393 participants had complete data for all covariates considered in this study (Table 1).

2.2. Measures

2.2.1. Demographics

Approximate current age was calculated by subtracting the respondent's birth year from the year in which their Wave IV data were collected. Sex was self-reported. Race was identified by the interviewer.

2.2.2. Body mass index

BMI was calculated using the standard formula: weight (kilograms) divided by height (meters) squared (BMI = weight/height^2). Weight and height were measured by the interviewer using a digital scale.

2.2.3. Working memory

Working memory was measured using the digit span backward task. In this task, the interviewer read some strings of numbers and asked the participant to repeat them in reverse (e.g., If the interviewer said "5-1-7-4-2″, the correct response would be "2-4-7-1-5″). The task began with a two-number string. Respondents had two trials to recall the number series at each level, up to a total of seven possible levels. If the respondent answered correctly on the first trial of a given level, the second trial at that level was not administered and the task moved up to the next level. When the respondents could not repeat a number series in reverse in either trial at a given level, the task ended. The highest level a participant successfully passed was used as the dependent variable, with higher scores indicating better working memory. Scores can therefore range from 0 to 7; a score of 4 or 5 is typical, and 3 is borderline to impaired (Botwinick & Storandt, 1974; Weinberg, Diller, Gerstman, & Schulman, 1972). Prior work has found that the test-retest reliability of the digit span backward in adult groups was r = .83 (Wechsler, 1981). The digit span backward is a standardized working memory task used in the Wechsler Adult Intelligence Scale (WAIS-IV) IQ test; it shows good concurrent validity, as it is significantly correlated with other well-established working memory tasks (e.g., the N-back task) (Gevins & Smith, 2000).

Table 1
Baseline characteristics of the study sample.

Variables	Total population (n = 4769)	Males (n = 2289)	Females (n = 2480)	p	Missing values
Age, years (M ± SD)	29.0 ± 1.8	29.1 ± 1.8	28.9 ± 1.8	< .001[a]	0 %
Weight category (%)				< .001[b]	0 %
Normal weight	32.0 %	28.6 %	35.1 %		
Overweight	30.0 %	35.3 %	25.2 %		
Obese	38.0 %	36.1 %	39.8 %		
BMI (M ± SD)	29.3 ± 7.4	29.1 ± 6.5	29.6 ± 8.2	< .05[a]	0 %
Working memory (M ± SD)	4.19 ± 1.54	4.25 ± 1.56	4.13 ± 1.52	< .01[a]	0 %
Race (%)				< .01[b]	0.1 %
White	71.7 %	73.5 %	70.1 %		
Black	24.4 %	22.4 %	26.3 %		
American Indian	0.8 %	0.7 %	0.8 %		
Asian	3.1 %	3.4 %	2.7 %		
Household income (%)				< .001[b]	7.1 %
< $50.000	46.2 %	43.1 %	49.1 %		
$50.000–$100.000	38.6 %	39.9 %	37.5 %		
> $100.000	15.2 %	17 %	13.5 %		
Educational level (%)				< .001[b]	0.02 %
High school or less	22.3 %	29.5 %	19.4 %		
More than high school	77.7 %	70.5 %	80.6 %		
Smoke status (%)				< .001[b]	1.1 %
Smoker	37.3 %	42.0 %	33.1 %		
Non-smoker	62.7 %	58.0 %	66.9 %		
Alcohol (M ± SD)	2.3 ± 1.8	2.61 ± 1.90	1.95 ± 1.67	< .001[a]	0.2 %
Physical activity (M ± SD)	1.6 ± 2.6	2.08 ± 2.94	1.22 ± 2.21	< .001[a]	0.06 %
Illness (M ± SD)	0.2 ± 0.4	0.15 ± 0.39	0.15 ± 0.39	0.82[a]	0.04 %

Note: Normal-weight, BMI 18.5–24.9 kg/m^2; Overweight, BMI 25–29.9 kg/m^2; Obese, BMI ≥ 30 kg/m^2. [a] Independent samples *t-test*; [b] Chi-square test.

2.2.4. Covariates

Demographic variables, socioeconomic status, and behavioral factors were considered as covariates because these variables have been previously associated with either or both BMI and working memory (Claassen, Klein, Bratanova, Claes, & Corneille, 2018). Demographic variables consisted of participant age and race. Socioeconomic status included the following: (a) total household income (categorized as [0] less than $50,000 per year, [1] $50,000 − $99,999 per year, and [2] more than $100,000 per year), and (b) self-reported education level (categorized as [0] high school or less, or [1] more than high school—similar to other large population-based studies in young adults; Nagata et al., 2018). Behavioral factors included as covariates were smoking, alcohol use, physical exercise, and illnesses. For the coding of smoking, participants were asked, "During the past 30 days, on how many days did you smoke cigarettes?" Those who smoked on one or more days were considered current smokers (Stanton et al., 2016). Alcohol use during the past year was assessed on a scale coded as follows: 0 = never, 1 = 1 or 2 days in the past 12 months, 2 = once a month or less, 3 = 2 or 3 days a month, 4 = 1 or 2 days a week, 5 = 3–5 days a week, and 6 = almost every day. Physical activity was calculated as the sum of two items ("In the past 7 days, how many times did you participate in individual sports such as running, wrestling, swimming, cross-country skiing, cycle racing, or martial arts?" and "In the past 7 days, how many times did you participate in gymnastics, weight lifting, or strength training?") that were coded as 0 = not at all, 1 = 1 time, 2 = 2 times, 3 = 3 times, 4 = 4 times, 5 = 5 times, 6 = 6 times, and 7 = 7 or more times. The sum of the two items could thus range from 0 to 14. Finally, illnesses were counted as self-reported diagnoses of high blood pressure or hypertension, diabetes/high blood sugar, and heart disease. Count of illnesses could thus range from 0 to 3.

2.3. Analytic strategy

BMI is a continuous variable, but there are often categorical differences between obesity, overweight, and normal weight (Yang et al., 2018). Because of this, we analyzed these data in two ways. First, we examined the moderating effect of sex on the link between excess weight and working memory in an ANOVA, with Sex (male, female) and Weight Status (normal weight, overweight, obese) as factors. Reported means and standard errors are estimated marginal means and standard errors derived from the model. To facilitate future meta-analyses, each Cohen's *d* was calculated from the raw values in the data. Second, we conducted a series of separate nested regression model analyses to examine the moderating effect of sex on the link between BMI and obesity, with BMI as a continuous predictor. In these analyses, Model 1 included only BMI as a predictor of working memory. Model 2 added sex as a categorical predictor, with male as the reference group. Model 3 added the interaction between sex and BMI, which tested whether BMI–working memory associations differed between males and females. In these continuous analyses, we standardized working memory but used raw BMI scores so that the regression coefficient represents either the standard deviation difference in working memory for every one unit change in BMI or the standardized difference between males and females in working memory.

3. Results

3.1. Sex, weight status, and working memory

We first examined the moderating role of sex on the link between excess weight and working memory in an ANOVA, with Sex (male, female) and Weight Status (normal weight, overweight, obese) as factors. We found a main effect of Weight Status, $F(2, 4763) = 12.53$, $p < .001$, a main effect of Sex, $F(1, 4763) = 4.58$, $p = .032$, and the hypothesized Sex × Weight Status interaction, $F(2, 4763) = 9.78$, $p < .001$ (Fig. 1). Decomposing this interaction, we found that obese women ($M = 3.88$, $SE = 0.05$) showed worse working memory than overweight women ($M = 4.23$, $SE = 0.06$), $t(4763) = 4.56$, $p < .001$, $d = 0.24$, and normal weight women ($M = 4.35$, $SE = 0.05$), $t(4763) = 6.70$, $p < .001$, $d = 0.32$. Overweight women, however, did not significantly differ in working memory from normal weight women, $t(4763) = 1.50$, $p = .134$. In contrast, there were no differences in working memory among obese men ($M = 4.22$, $SE = 0.05$), overweight men ($M = 4.29$, $SE = 0.05$) and normal weight men ($M = 4.24$, $SE = 0.06$), $ps > .382$, $|d|s < 0.04$. Controlling for covariates did not alter these effects: The Sex × Weight Status interaction remained significant, $p = .017$; obese women showed worse working memory than overweight women, $p < .001$, and normal weight women, $p = .001$; overweight women did not differ from normal weight women, $p = .486$; and there were no differences in working memory among men by weight status, $ps > .781$.

Decomposing the interaction in a different way, obese women showed worse working memory than obese men, $t(4763) = 4.82$, $p < .001$, $d = 0.23$. Overweight and normal weight women, however, did not significantly differ in working memory from overweight and normal weight men, respectively, $ps > .137$, $|d|s < 0.08$. Controlling for covariates did not alter these results: in these analyses, obese women showed worse working memory than obese men, $p < .001$, whereas overweight and normal weight women did not significantly differ in working memory from overweight and normal weight men, respectively, $ps > .870$.

3.2. Examining moderating effects of sex with BMI as continuous

When BMI was treated as a continuous variable, Model 1 revealed that across all participants, every one unit increase in BMI predicted a decrease of .012 standard deviations in working memory performance, $B = -0.012$, 95 % CI [−0.016, −0.008]. Model 2 revealed that, across all participants, female sex predicted a decrease of .070 standard deviations in working memory performance, $B = -0.070$, 95% CI [−0.127, −0.014]. In Model 3, the test for moderation effect, the hypothesized BMI × Sex interaction was significant, $B = -0.014$, 95 % CI [−0.022, −0.006], $p < .001$, indicating the association between obesity and working memory was significantly more negative in females than in males. In this model, the association between BMI and standardized working memory scores for males was $B = -0.004$, 95 % CI [−0.010, 0.003], $p = .268$, and the association between BMI and standardized working memory scores for females was $B = -0.017$, 95 % CI [−0.022, −0.012], $p < .001$. Controlling for covariates did not alter these results: The BMI × Sex interaction remained significant, $p = .028$, with men showing no association between BMI and working memory, $p = .772$, and women showing a significant negative association between BMI and working memory, $p < .001$.

In short, excess weight was associated with worse working memory in women, but not men. This moderating effect was present when weight was analyzed categorically or continuously, and it held with and without covariates included in the models.

4. Discussion

In this study, we examined cross-sectional associations between working memory and weight in a sample of 4,769 individuals from the Add Health study, and whether sex moderated these associations. We replicated prior findings (e.g., Coppin, Nolan-Poupart, Jones-Gotman, & Small, 2014), showing that obese individuals have worse working memory than normal-weight individuals. Moreover, we found that this association was moderated by sex: women, not men, showed an association between obesity and poorer working memory. It should be noted that there were differences between males and females in some covariates (e.g., race, education; see Table 1). However, the results held when adjusting for covariates. Notably, however, in our categorical analyses, being overweight was not associated with significant

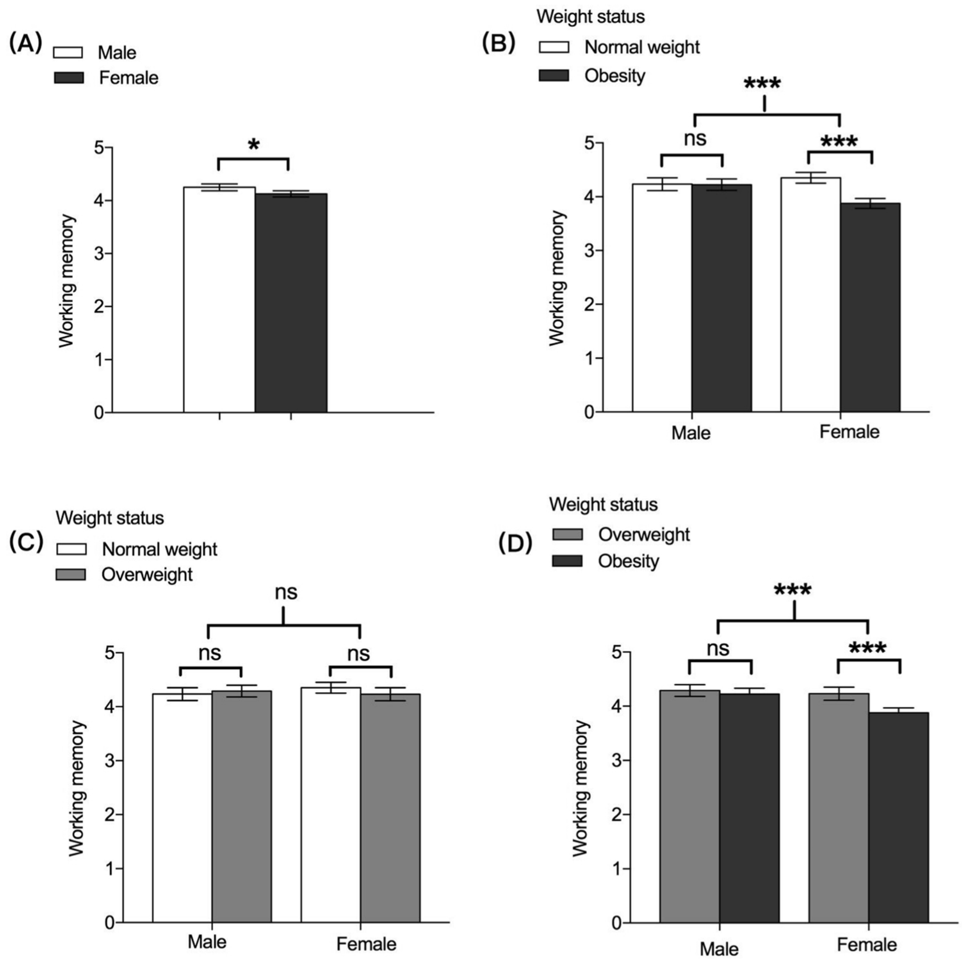

Fig. 1. Working memory performance by sex and weight status. (A) Women showed significantly lower working memory performance than men, $p < .05$. (B) Obese women showed significantly lower working memory performance than normal weight women, $p < .001$. In contrast, obese and normal weight men did not significantly differ in working memory performance. (C) Overweight women did not differ in working memory performance from normal weight women. Similarly, overweight men did not differ in working memory performance from normal weight men. (D) Obese women showed significantly lower working memory performance than overweight women, $p < .001$. In contrast, obese and overweight men did not significantly differ in working memory performance. Error bar represents 95 % confidence intervals of the mean.

differences in working memory in either sex.

We found that, relative to normal weight individuals, obese individuals showed worse working memory—albeit with working memory scores in a normal range for healthy adults. This finding is in agreement with prior work. In a recent meta-analysis, Yang and colleagues found that executive functions—including working memory—were worse in obese individuals relative to those with normal weight, although moderators such as sex or socioeconomic status could not sufficiently be examined (Yang et al., 2018). However, contrary to the findings of that meta-analysis, overweight individuals did not show a relative working memory deficit when compared to normal weight individuals in current study. One possible explanation for this difference is that the task used to assess working memory in our study (i.e., the backward digit span) differed from the tasks most commonly used to assess working memory in studies included in the meta-analysis (e.g., the *n*-back), and task characteristics play a role in the effects of weight on executive functions (e.g., Yang et al., 2018). Also, it should be noted that relatively few studies have examined whether being overweight (not obese) is associated with working memory deficits, suggesting that more research is needed before firm conclusions can be drawn.

In the current study, we found that obesity was associated with a relative working memory deficit in women, not men, though this deficit was small and within a normal range for working memory performance. Similar to this, prior studies have reported stronger negative associations between obesity and cognition in females (Lu et al., 2014; Mond et al., 2007; Schwartz et al., 2013; Weller et al., 2008). For example, the negative association between obesity and academic achievement is robust in girls, not boys (Martin et al., 2017). Moreover, two studies (Lu et al., 2014; Schwartz et al., 2013) have reported that body fat (e.g., visceral fat) is related to reduced executive function performance in females, not males. However, using The Framingham Heart sample, Elias et al. (2005) only found a negative association between BMI and cognition (including working memory) in males. A critical difference between our work and the Framingham Heart study is sample age (29 versus 67). Indeed, in contrast to our findings and those in children or young adult samples mentioned above, studies using elderly samples have reported that obesity or high adiposity were associated with cognitive decline in men but not in women (e.g., Kanaya et al., 2009). Overall, age seems to be an important factor contributing to sex differences in the association between obesity and cognition, and future studies should address the roles of age, sex, and their interaction in the relationship between obesity and executive functions.

Although our study was not able to examine mechanisms, it is worth speculating on differences between obese women and non-obese women, obese men, and non-obese men that might explain our observed results. At the psychological level, at least three factors may account for this result. First, obese women may experience more incidents of weight-related stigmatization than obese men (Wellman et al., 2019), and weight-related stigma has been linked to lower cognition (Sutin et al., 2019), including lower working memory (Guardabassi & Tomasetto, 2018). Second, women may experience more adverse childhood experiences—such as sexual abuse—than men (Anda et al., 1999; Schilling, Aseltine, & Gore, 2007), and greater childhood adversity has been linked to both obesity (Davis, Barnes, Gross, Ryder, & Shlafer, 2019) and poorer working memory (Goodman, Freeman, & Chalmers, 2018). Third, compared to men, women engage in more non-adaptive eating behaviors such as dietary restraint (i.e., controlling food intake in an effort to manage weight) and disinhibition (i.e., the tendency to overeat in response to various stimuli), and there are strong positive associations between these eating behaviors and weight gain or high BMI (Hays & Roberts, 2008; van Strien, Herman, & Verheijden, 2014). Critically, women who display more non-adaptive eating behaviors perform worse on working memory tasks (Green & Rogers, 1998; Whitelock, Nouwen, van den Akker, & Higgs, 2018). In total, at the psychological level, both obesity- and gender-related differences in weight-related stigmatization, adverse childhood experiences, and/or non-adaptive eating behaviors may account for the working memory deficit exhibited by obese women in this study.

The female-specific association between obesity and relatively poorer working memory performance may also be explained on the physiological level. In particular, the deleterious effect of adiposity on cognition appear to be mediated by obesity-induced activation of innate immunity, which produces sustained low-grade inflammation. Importantly, epidemiological evidence suggests that obese women show higher levels of inflammatory activity (e.g., C-reactive protein) than obese men (Shanahan et al., 2013). Moreover, a recent review proposed that women are more vulnerable to the detrimental effects of inflammation (Lasselin, Lekander, Axelsson, & Karshikoff, 2018). Indeed, inflammatory cytokines have been negatively associated with executive functions (including working memory) in obese women, not men (Gimeno, Marmot, & Singh-Manoux, 2008; Sweat et al., 2008). It should be noted, however, that other potential physiological pathways may explain these links, since many of these potential pathways (e.g., glucoregulatory function, anorexigenic or orexigenic peptides) have not been studied within the context of sex, obesity, and working memory. Thus, future work should also attempt to elucidate the biological mechanism(s) underpinning sex-specific associations between obesity and executive functions.

Overall, these findings may have important implications for both basic and applied research. For example, working memory is a core executive function, and executive functions are essential in daily life (e.g., for problem solving, behavioral control, numerical processing). Therefore, the sex-specific association between obesity and poor working memory may be one of the mechanisms underlying sex differences in previously reported associations between obesity and educational attainment. It should be noted, however, that it is unclear whether the relatively small difference between obese and non-obese women observed here could explain any differences in educational attainment. Similarly, these findings may help explain inconsistencies in previous studies (e.g., Smith, Hay, Campbell, & Trollor, 2011) that examined the executive function deficits associated with obesity. In particular, a different percentage of obese female participants may have led to these inconsistencies. Thus, we need to move beyond simply adjusting for sex and examine whether the association between obesity and executive function is modified by sex. On an applied level, because of the importance of self-regulation in adherence to weight-loss interventions (Dassen et al., 2018; Yang et al., 2019) and the critical role of working memory in self-regulation (Galioto et al., 2018), our findings suggest that interventions aimed at reducing obesity may need to differ between males and females for optimal success rates.

This study has several limitations worth noting. Because of the cross-sectional data used in this study, it is not possible to make causal interpretations. Future studies should use longitudinal data (e.g., future data of Add Health) to address the reciprocal relations of obesity and working memory and how sex moderate these associations. Another limitation of the current investigation is that we were only able to assess associations with a single measure of working memory. Future research should replicate these findings using other measures of working memory. Additionally, the current study examines only one aspect of executive function. As such, it would be interesting to consider sex differences in the association between obesity and other executive functions (e.g., inhibition) (Vainik et al., 2019). In addition, we used BMI as a proxy for adiposity, but BMI is a relatively coarse measure of body density and it does not consider relevant physical characteristics, such as muscle mass and anthropometric features (Bergman et al., 2011). Future research should replicate and extend this work using more direct measures of adiposity. Finally, although obese women showed poorer working memory than other individuals (e.g., normal weight women), obese women's working memory scores were still within a normal range, and the differences in working memory between obese women and other individuals were very small. Future studies should examine whether these very small but statistically significant findings have any clinical or real-world significance.

In conclusion, we found that obese women but not men had worse working memory than normal-weight individuals. Importantly, these results were robust, remaining constant whether or not covariates were included. Future research should be careful to consider sex as an important factor in the association between obesity and executive function.

Author contributions

Yingkai Yang and Cheng Guo developed the concept for this article and wrote the manuscript, Grant S. Shields, Qian Wu and Yanling Liu provided critical revisions to the paper, and all authors read and approved the final version.

Funding

This research was supported by Fundamental Research Funds for the Central Universities, SWU1909106.

Declaration of Competing Interest

The authors declare that they had no conflicts of interest with respect to their authorship or the publication of this article.

Acknowledgments

This research uses data from Add Health, a program project directed by Kathleen Mullan Harris and designed by J. Richard Udry, Peter S. Bearman, and Kathleen Mullan Harris at the University of North Carolina at Chapel Hill, and funded by grant P01- HD31921 from the Eunice Kennedy Shriver National Institute of Child Health and Human Development, with cooperative funding from 23 other federal agencies and foundations. Acknowledgement is due Ronald R. Rindfuss and Barbara Entwisle for assistance in the original design. Information on how to obtain the Add Health data files is available on the Add Health website (http://www.cpc.unc.edu/addhealth). No direct support was received from grant P01-HD31921 for this analysis.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.eatbeh.2019.101338.

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