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The association between reduced inflammation and cognitive gains after bariatric surgery

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Abstract

Objective—Bariatric surgery is associated with improved cognitive function, though the mechanisms are unclear. Elevated inflammation is common in obesity and associated with impaired cognition. Inflammation decreases after bariatric surgery, implicating it as a possible mechanism for cognitive improvement. The objective of this study was to examine whether reduced inflammation is a possible mechanism for post-operative cognitive improvement in bariatric surgery patients.

Methods—Participants were 77 bariatric surgery patients who completed cognitive testing before surgery and one year post-surgery. Cognitive domains assessed were attention/executive function, language, and memory. High-sensitivity C-reactive protein (hs-CRP) was assessed at both time points.

Results—Patients exhibited pre-operative cognitive impairment, though attention/executive ($M \pm SD_{baseline}$= 53.57 ± 8.68 vs.$M \pm SD_{follow\text{-}up}$= 60.32 ± 8.19) and memory ($M \pm SD_{baseline}$= 44.96 ± 7.98 vs.$M \pm SD_{follow\text{-}up}$= 51.55 ± 8.25) improved one year post-surgery. CRP was elevated at baseline and fell into the normative range post-surgery ($M \pm SD_{baseline}$= 0.9 ± 0.7vs.$M \pm SD_{follow\text{-}up}$= 0.2 ± 0.3 mg/dL). Pre-operative CRP was not associated with baseline cognitive function (β-values = -0.10 to 0.02) and changes in CRP also did not correspond to changes in cognition post-surgery (β-values = 0.02 to β = 0.11; *p*s>0.05 for all domains). A trend was detected for smaller improvements in memory among participants with elevated baseline CRP (>0.30 mg/dL) versus those with normal levels (Group x Time: *p*=0.083).

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Conflicts of Interest : None declared.

Conclusions—Improvements in hs-CRP were not associated with post-operative cognitive benefits. Future studies are needed to explore other inflammatory markers and potential mechanisms of cognitive improvement after bariatric surgery, including improved glycemic control and neurohormone changes.

Keywords

Obesity; bariatric surgery; cognitive function; inflammation; C-reactive protein; prospective study

Introduction

Obesity rates in the U.S. and across the globe have more than doubled over the past three decades(1–3), and obesity has been named a global epidemic by the World Health Organization(4). Obesity is associated with elevated morbidity(5), greater disability(6), and higher mortality risk(7). More recently, obesity has also been associated with poorer neurocognitive functioning across the lifespan(8) and in both healthy(9,10) and patient populations(11).

The cognitive sequelae of obesity include reduced performance on tasks of attention, executive function, and processing speed(8–10,12)as well as increased risk for neurodegenerative disorders, such as Alzheimer's disease(13).In addition to these functional changes, obesity has also been associated with changes in brain structure (e.g., reduced whole brain volume) even among healthy adults(14). Importantly, recent studies suggest that the poorer neurocognitive functioning associated with obesity may be partially reversible through bariatric surgery(15,16). Indeed, post-operative cognitive improvements have been robust, lasting up to two years after bariatric surgery(15). However, the mechanisms by which bariatric surgery contributes to these cognitive benefits are unclear. Previous studies indicate that the substantial weight loss and the resolution of medical comorbidities (including hypertension, diabetes, and sleep apnea)following surgery do not fully account for the observed cognitive improvements(15).

A possible mechanism for the cognitive gains found after bariatric surgery might involve changes in inflammatory levels. High inflammation levels are associated with weight gain(17,18) and obesity(19–23). Elevated inflammation is also related to cognitive decline and dementia(24–28) and has been proposed as a mechanism for the elevated risk of such conditions in obese persons(29). Importantly, inflammation levels have been shown to decrease after bariatric surgery(30,31), indicating that post-operative reduction in inflammation may be one mechanism by which bariatric surgery leads to improved cognitive function. Unfortunately, no study has yet examined the relationship between inflammation and cognition before and after bariatric surgery. Thus, the goal of this prospective cohort study was to examine the relationship between the inflammatory marker, C-reactive protein, and cognitive functioning at baseline and 1-year follow-up in a sample of bariatric surgery patients. We hypothesized that baseline inflammation will be negatively correlated with baseline cognitive function and that reductions ininflammation will predict 1-year improvements in cognitive function.

Methods

Participants

A total of 77 participants were recruited from the larger Longitudinal Assessment of Bariatric Surgery (LABS) parent project, a multi-site NIH prospective cohort study examining multiple risks and benefits of bariatric surgery(32). Data collection began November 2006 and ended November 2012. The present study focused on a cohort of LABs participants in which the impact of bariatric surgery on cognitive function was examined and blood specimens were collected to detect inflammation (32).In contrast to our previous study (15), we were not able to include a control group or two-year follow-up data, given that blood specimens were not available for the controls or at two-year follow-up. All patients were enrolled and recruited from existing LABS sites (Columbia, Cornell, and Neuropsychiatric Research Institute) that had institutional review board approval and obtained participants' informed consent(32).

Inclusion criteria included the following: (1) enrollment in LABS,(2) between 20–70 years of age, and (3)English-speaking. Exclusion criteria were as follows:(1) history of neurological disorder or injury (e.g., dementia, seizures), (2) moderate or severe head injury (defined as >10 minutes loss of consciousness), (3) past or current history of severe psychiatric illness (e.g. schizophrenia, bipolar disorder), (4) past or current history of substance abuse (defined by the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV) criteria), (5) history of a learning disorder or developmental disability (defined by DSM-IV criteria), or (6) impaired sensory function. All but one patient who had gastric banding underwent Roux-en-Y gastric bypass (RYGB) as the bariatric surgical procedure. The present sample represents all individuals with complete baseline and 1-year follow-up blood work and cognitive testing. Demographic and clinical characteristics of the sample are presented (Table 1).

Materials and Measures

Inflammation—High-sensitivity C-reactive protein (hs-CRP) was determined from participants' fasting blood specimens. hs-CRP values (mg/dL) were quantified by the LABS Central Laboratory(Northwest Lipid Metabolism and Diabetes Research Laboratories; Seattle, Washington) using standardized assay procedures. We examined hs-CRP as a continuous variable in the primary analyses. For exploratory analyses, we also calculated a dichotomous variable using the Cardiovascular Risk Assessment (AHA/CDC) Recommendations (33) for elevated CRP levels: > 0.30 mg/dL for elevated CRP vs. < 0.30 mg/dL for average CRP.

Cognitive Function—The Integneuro cognitive test battery was administered to operationalize cognitive function in multiple domains. The Integneuro is a computerized battery that can be completed in 45–60 minutes and demonstrates excellent validity and reliability(34,35). The cognitive domains and associated tests were as follows:

Attention/Executive Function

Digit Span Total: This task tests participants' attention and working memory. Participants are presented with a series of digits on the touch-screen, separated by a one-second interval. The subject is then immediately asked to enter the digits on a numeric keypad on the touch-screen. The number of digits in each sequence is gradually increased from 3 to 9, with two sequences at each level. The participants complete these same procedures in a backward sequence. Total digit span for both forwards and backwards served as the dependent variable.

Switching of Attention: This task is a computerized adaptation of the Trail Making Test A and B(36).Participants are first asked to touch a series of 25 numbers in ascending order as quickly as possible. This is followed by the presentation of 13 numbers (1–13) and 12 letters (AL) that participants alternately touch in ascending order. These tests assess attention and psychomotor speed as well as executive function. Time to completion served as the outcome measure in the current study.

Verbal Interference: This task taps into the ability to inhibit automatic and irrelevant responses and mimics the Stroop Color Word Test(37). Participants are presented with colored words one at a time. Below each colored word is a response pad with the four possible words displayed in black and in fixed format. The subject is required to name the color of each word as quickly as possible, assessing executive functioning. Total number of words correctly identified was used in the current analyses.

Memory

Verbal List-learning: Participants are read a list of 12 words a total of 4 times and asked to recall as many words as possible after each trial. Following presentation and recall of a distraction list, participants are then asked to recall words from the original list. After a 20-minute filled delay, participants are asked to freely recall the learned list and perform a recognition trial comprised of target words and non-target words. Total long delayed free recall and recognition of these verbal list items were indicators of memory function.

Language

Letter Fluency: Participants are asked to generate words beginning with a given letter of the alphabet for 60 seconds. A different letter is used for each of the three trials. Total number of correct words generated across the three trials served as the dependent variable.

Animal Fluency: In this task, participants generate as many animal names as possible in 60 seconds. Total correct served as the dependent variable.

Procedure

The Institutional Review Board approved all procedures, and participants provided written informed consent prior to study involvement. Consented participants underwent a blood draw after fasting for eight hours and completed a computerized cognitive test battery within 30 days prior to their bariatric surgery. The same procedures were performed one year following the surgery. Participant's height and weight were measured at each time point and used to calculate body mass index (BMI; kg/m^2). Medical and demographic characteristics were ascertained via self-report and corroborated by a medical record review performed by trained research staff.

Statistical Analysis

All raw scores of neuropsychological measures were converted to T-scores using normative data that accounts for age, gender, and estimated intelligence. T-scores are a type of standard score commonly used for neuropsychological testing and have a mean of 50 and a standard deviation of 10(38). Thus, a T-score of 35 is equivalent to cognitive performance that is 1.5 SDs below the mean and at the 7th percentile and is indicative of meaningful cognitive impairment(38). Baseline and 1-year follow-up composite scores for attention/executive function, memory, and language were computed that consisted of the mean of T-scores of the cognitive tasks that comprise each domain. Change in BMI from baseline to 1-year post-surgery was also calculated and included as a covariate in the current analyses.

To examine the baseline effects of CRP on baseline cognitive function, three separate regression analyses were conducted that consisted of age (years), sex (1 = males; 2 = females), and baseline BMI(kg/m^2) entered in block 1 and baseline CRP in block 2. Baseline attention/executive function, memory, or language served as the dependent variable for each regression model. An additional series of separate regression models were then performed to determine the effects of post-operative changes in CRP on each cognitive domain at the 1-year follow-up. Specifically, block 1 included age, sex, change in BMI, baseline performance of the respective cognitive domain, and baseline CRP levels. Block 2 included CRP at 1-year follow-up to determine its incremental predictive validity on cognitive function at 1-year follow-up.

Of note, we adjusted for baseline values in our models in order to adjust for the variance in the outcome variable that was due to the baseline scores and leaving the unique variance in the outcomes variable that was due to change. However, follow-up analyses were also conducted to determine whether change scores might better capture the association between change in CRP and cognition. Specifically, a difference score (i.e., 12-month – baseline) was computed for CRP and each cognitive domain, and the above regression models were repeated without baseline values entered in block 1. Block 2 included the CRP difference composite, and the dependent variables were the cognitive function difference scores.

Results

Sample Characteristics

The sample was severely obese at baseline with patients, on average, categorized as having Class III obesity(4) (Table 1). At 1-year post-surgery, average BMI decreased by 35%($F(1, 76) = 1145.34$, $p < .001$)and patients were categorized as having Class I obesity(Table 1). Diagnostic status of hypertension, type 2 diabetes mellitus (T2DM), and sleep apnea were also prevalent at baseline, but participants exhibited fewer medical comorbidities at the 1-year follow-up (Table 1).

CRP at Baseline and Follow-up

The sample demonstrated high levels of CRP at baseline (Table 1) with approximately 26% of participants exhibiting a CRP > 1.0 mg/dL. However, at 1-year post-surgery participants had CRP levels that fell within the normative range and represented a significant decrease (F(1,76) = 84.06, p< .001); of note, only 2 persons at 1-year follow-up exhibited CRP levels greater than 1.0 mg/dL (Table 1).

Bivariate correlations and independent samples *t*-tests were used to examine the association between CRP levels and sample characteristics. Baseline CRP was not associated with age (r(75) = −0.14, p = 0.23), sex (t(75) = −1.59, p = 0.12), baseline BMI (r(75) = −0.03, p = 0.82), or baseline diagnostic status of hypertension (t(75) = 1.75, p = 0.085), T2DM (t(75) = −0.09, p = 0.93), or sleep apnea (t(75) = 0.16, p = 0.88). One year after surgery, higher levels of CRP were associated with increased BMI (r(75) = 0.32, p = 0.005); however, this pattern did not emerge for hypertension (t(71) = −1.02, p = 0.31), T2DM (t(71) = −0.61, p = 0.54), or sleep apnea (t(12.95) = 0.56, p = 0.59) at the 1-year follow-up.

Cognitive Function at Baseline and Follow-up

Rates of baseline cognitive impairment (T-scores < 35) ranged from 2.6 to 16.9% (Table 2). The highest rates of impairment were in language (i.e., letter fluency) and memory (i.e., long delayed free recall and recognition tasks). Impairments on tasks of attention/executive function were observed but less prevalent. Repeated measures ANOVA showed significant improvements in cognitive function over the 1-year post-surgery in attention/executive function (F(1,76) = 91.80, p< .001) and memory (F(1,76) = 48.31, p< .001). There were no significant pre- to postoperative changes in language abilities(F(1,76) = 0.51, p = 0.48). Relative to pre-operative performance, rates of cognitive impairment were less prevalent one year following surgery on the majority of attention/executive function, memory, and language measures (Table 2).

Effects of CRP on Cognitive Function at Baseline and Follow-up

Regression analyses controlling for age, sex, and baseline BMI showed no baseline effects of CRP levels on any of the baseline cognitive domains (β = −0.10 to 0.02 and p> 0.05 for all). Consistent with this pattern, regressions also indicated that 1-year follow-up CRP levels did not predict follow-up cognitive function in any of the domains after controlling for age, sex, change in BMI, and baseline factors (see Table 3).Zero-order correlations also revealed no association between CRP levels and attention/executive function (r(75) = 0.08, p = 0.48), memory (r(75) = 0.06, p = 0.61) or language abilities (r(75) = −0.06, p = 0.61) at the 1-year follow-up. Likewise, regression analyses that used difference scores continued to show no longitudinal association between CRP levels and cognitive function in any of the domains (p> 0.10 for all).

Sensitivity Analyses

We also conducted a set of exploratory sensitivity analyses to examine whether the effects of post-operative changes in CRP on cognition at 1-year follow-up differed among the following groups: (1) individuals aged >50 years, (2) individuals with elevated baseline CRP

(> 0.30 mg/dL), and (3) individuals who experienced relatively less post-operative weight loss.

First, past work suggests that the sensitivity of inflammatory processes on cognitive outcomes increases with age (25–27). Accordingly, we restricted the sample to participants aged >50 years (N = 23) and then re-ran the models which included age, sex, change in BMI, baseline cognitive performance, and baseline CRP levels on Block 1 and CRP at 1-year follow-up on Block 2. These exploratory analyses continued to show no effects of post-operative changes in CRP levels on attention/executive function (p = 0.72), memory (p = 0.71), or language (p = 0.52) following bariatric surgery.

Second, we also examined whether those participants that exhibited elevated CRP levels at baseline (e.g., CRP > 0.30 mg/dL) demonstrated smaller cognitive improvements over the year following surgery. Participants were categorized into two baseline CRP groups: Elevated CRP (e.g.,> 0.30 mg/dL) and average CRP (e.g., < 0.30 mg/dL). Repeated measures ANOVA then examined changes in each cognitive domain with CRP entered as a grouping variable. A strong trend emerged for a CRP X Time effect on memory ($F(1,75)$ = 3.08, p = 0.083). Participants with elevated baseline CRP levels exhibited smaller improvements in memory one year after surgery (Table 4). No such pattern emerged for attention/executive function(p = 0.60) or language abilities (p = 0.64).

Finally, we examined whether the effects of follow-up CRP levels on cognitive function at follow-up differed among those participants with relatively less post-operative weight loss. All participants exhibited significant decreases in BMI at 1-year follow-up, so a median split was used to categorize participants into relatively high vs. low weight loss groups as based on the magnitude of BMI decrease. The median split (BMI decrease of 16.6 points) allowed us to maximize the sample size of the low weight loss group (n = 38). Among the low weight loss group, regression analyses controlling for age, sex, BMI change, baseline CRP, and baseline cognitive function showed that 1-year follow-up CRP levels were not predictive of attention/executive function (p = 0.19), memory (p = 0.54), or language (p = 0.71) at follow-up.

Discussion

This prospective study examined whether reduced inflammation is a possible mechanism for improvements in cognition following bariatric surgery. Although inflammation and cognition improved post-operatively, inflammation was not related to cognitive function at baseline and reductions in inflammation did not predict improvements in cognitive function at 1-year follow-up. Interestingly, participants classified as having elevated baseline inflammation showed a trend for smaller improvements in memory compared to those with average levels, but this effect was not observed for other domains and should not be over-interpreted. Of note, despite the use of two analytic methods (i.e., adjusting for baseline values vs. calculating difference scores), our pattern of null results remained the same.

The results of this study are consistent with evidence that reduced inflammation and improved cognition follow bariatric surgery (15,16,31). However, the lack of an association between these changes is somewhat surprising given past work that elevated systemic inflammation is associated with greater cognitive impairment, cognitive decline, and dementia(24–28)and has been shown to accelerate neurodegenerative disease progression(39). There are several possible explanations for this lack of association. First, many past studies that have detected an inflammation-cognitive decline relationship have focused on older adult samples(25–28), and findings in middle-aged adults are much more variable(40–42).However, even when limiting the current sample to patients 50 years and older, no association between changes in hs-CRP and cognitive function emerged. Similarly, the reliance on hs-CRP as a marker of inflammation may have contributed to our findings, as obesity is associated with elevations in many inflammatory markers(21–23), including some that may be more closely associated with cognitive function(28,43). For example, in persons with a trial fibrillation, reductions in markers such as interleukin (IL)-2, IL-9, and IL-12 predicted improved cognitive function but CRP did not(44). Additional work is much needed to clarify the possible contribution of inflammation to cognitive function in obese persons, especially given the recent findings that reduced inflammation following bariatric surgery was associated with reduced expression of Alzheimer’s disease-related genes(31).

In addition to examining additional inflammatory markers, other possible mechanisms for the cognitive benefits of bariatric surgery should be examined. For example, metabolic dysfunction, such as poor glycemic control and altered brain glucose metabolism, have been shown to improve after bariatric surgery and weight loss(45,46). Because these abnormalities have been implicated in cognitive impairment(47), changes in insulin regulation and glucose metabolism are likely contributors to post-operative gains. Similarly, bariatric surgery provides many cardiovascular and cardiorespiratory benefits(48,49) and improvements in processes such as endothelial function may lead to better cognitive function(50,51). Finally, novel markers such as members of the polypeptide Y family that are potent an orexigenic and orexigenic compounds with weight regulation effects(52) have been implicated in cognitive function (53,54), and are altered after bariatric surgery(55).Clearly, future work is needed to elucidate the most important contributors to cognitive improvement as change in such markers may ultimately reduce the risk of Alzheimer’s disease in obese individuals(56).

Several limitations of the current study should be noted. First, our sample was modestly sized and comprised largely of patients that underwent RYGB. Future investigations with a larger and more diverse sample are needed as it is possible that other surgical procedures may produce differential cognitive effects. For example, gastric sleeve gastrectomy produces different post-operative outcomes than RYGB (e.g., less nutritional deficiencies(57) and greater reductions in ghrelin levels(58)), and such differences might lead to differences in neurocognitive outcomes. Second, our study was predominately middle-aged adults and research on the possible neurocognitive effects of bariatric surgery in older adults is much needed. Although there has been a dramatic increase in the number of bariatric surgery procedures in older adults(59), little is known about the possible neurocognitive outcomes in this population. Similarly, studies involving longer surgical follow-up intervals (e.g., 10+ years) may help to clarify whether changes in inflammation and other possible mechanisms following bariatric surgery can ultimately reduce risk of conditions like Alzheimer’s disease. Next, our study did not include measures of physical activity and/or cardiorespiratory fitness. Given the consistently documented relationship of these fitness variables with cognitive function (49,60,61)and inflammation (62,63), future studies should include activity and fitness indicators as other potential mechanisms of post-surgery cognitive improvement or confounders of inflammation-cognition relationships. Lastly, we were not able to adjust for patients' medication use in this study. Given the potential influence of commonly prescribed medications on cognitive function (64–66), future investigations should examine whether baseline medication use and/or post-surgery medication changes are associated with cognitive changes.

In brief conclusion, reduced inflammation(as measured by CRP) was not associated with improved cognitive function in persons who underwent bariatric surgery. Future studies are needed to explore other inflammatory markers (e.g., α_1-antichymotrypsin or interleukin-6) and to clarify other potential mechanisms by which bariatric surgery results in cognitive improvement. Similarly, extended follow-up periods are needed to elucidate whether effective bariatric surgery and weight loss can ultimately reduce risk of conditions like stroke or Alzheimer's disease.

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Abbreviations

DSM-IV	Diagnostic and Statistical Manual of Mental Disorders
hs-CRP	high sensitivity C-reactive protein
LABS	Longitudinal Assessment of Bariatric Surgery
RYGB	Roux-en-Y gastric bypass

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Table 1

Characteristics of Participants (N = 77)

Characteristics	**Baseline**	**1-Year Follow-up**	***F/Chi-Square* (p-value)**
Age, mean(*SD*)	43.4(10.6)	--	--
Women, %	83.1	--	--
Body Mass Index (kg/m^2), mean(*SD*)	46.7(5.3)	30.5(5.4)	1145.34 (<0.001)*
Hypertension (% yes)	44.2	39.0	2.9 (0.089)
Type 2 diabetes (% yes)	23.4	18.2	1.1 (0.29)
Sleep Apnea (% yes)	35.1	16.9	2.2 (0.14)
CRP (mg/dL), mean(*SD*)	0.9(0.7)	0.2(0.3)	84.1 (<0.001)*

Note. CRP = C-reactive protein. Sample size varies for baseline and 1-year follow-up hypertension, type 2 diabetes, and sleep apnea; statistics for differences in the variables is based on complete data for each time point. Repeated measures analysis of variance and chi-square tests were used to examine changes in variables over time.

*$p < 0.01$

Table 2

Neuropsychological Test Performance among Bariatric Surgery Patients ($N = 77$)

	Baseline M(SD)	**1-year Follow-up M(SD)**	**ANOVA *p* value**	**Baseline % with T-score < 35[a]**	**1-year Follow-up % with T-score < 35[a]**
Attention/Executive Function					
Composite Score	53.57(8.68)	60.32(8.19)	<0.001*	2.6	0.0
Digit Span Total	50.67(9.01)	54.43(10.86)	0.005*	2.6	0.0
SOA-A	55.78(13.59)	64.18(12.13)	<0.001*	7.8	1.3
SOA-B	53.81(14.40)	60.72(11.88)	<0.001*	6.5	6.5
Verbal Interference	54.02(13.42)	61.96(11.85)	<0.001*	7.8	1.3
Memory					
Composite Score	44.96(7.98)	51.55(8.25)	<0.001*	6.5	1.3
LDFR	46.95(10.81)	54.17(9.25)	<0.001*	13.0	1.3
Recognition	42.96(9.31)	48.92(9.79)	<0.001*	15.6	6.5
Language					
Composite Score	48.81(10.04)	49.37(9.43)	0.48	7.8	3.9
Verbal Fluency	46.92(11.41)	47.40(10.53)	0.59	16.9	11.7
Animals	50.69(10.81)	51.35(10.86)	0.53	5.2	5.2

Note. SOA = Switching of Attention. LDFR = Long Delay Free Recall. Repeated measures analyses of variance were conducted to examine changes in cognitive test performance over time.

[a] T-scores < 35 are equal to 1.5 standard deviations below the mean and indicate cognitive impairment (38)

* $p < 0.01$

Table 3

Predictive Validity of Post-Surgery CRP Changes on Cognitive Function

	Attention/Executive Function			Memory			Language		
	β	SE b	*p*	*β*	SE b	*p*	*β*	SE b	*p*
Block 1									
Age	0.30	0.07	0.73	−0.15	0.09	0.17	−0.09	0.08	0.32
Sex	0.10	1.83	0.25	0.04	2.39	0.71	−0.01	2.05	0.95
BMI Change	−0.04	0.16	0.65	−0.08	0.21	0.47	0.03	0.19	0.70
Baseline CRP	0.00	0.93	0.99	0.00	1.19	0.99	0.02	1.05	0.82
Baseline Cognition†	0.72	0.08	<0.001*	0.44	0.11	<0.001*	0.76	0.08	<0.001*
R^2		0.55			0.26			0.56	
F		17.18			5.11			18.28	
p-value		<0.001*			<0.001*			<0.001*	
Block 2									
Follow-up CRP	0.11	2.76	0.31	0.11	3.60	0.42	0.02	3.14	0.84
R^2		0.55			0.27			0.56	
F for ΔR^2		1.07			0.66			0.04	
p-value		0.31			0.42			0.84	

Note.

†Each 1-year follow-up cognitive function variable was adjusted for its corresponding baseline cognitive function variable. Hierarchical regression analyses were conducted to examine whether post-bariatric surgery changes in CRP predicted cognitive test performance at the one-year follow-up.

*$p < 0.01$

Table 4

Cognitive Improvements 1-year Post-Bariatric Surgery for Individuals with Elevated vs. Normal Baseline CRP

	Individuals with Elevated Baseline CRP (*n* = 60)[a]			**Individuals with Normal Baseline CRP (*n* = 17)[b]**				
	Baseline	**Follow-up**	**Average Change**	**Baseline**	**Follow-up**	**Average Change**	**Group X Time**	***p*-value**
Attention/EF	53.36(9.00)	59.92(8.75)	+6.56	54.29(7.65)	61.75(5.79)	+7.46	0.28	.60
Memory	45.09(8.44)	50.81(8.08)	+5.72	44.49(6.27)	54.16(8.53)	+9.67	3.08	.083
Language	48.65(10.23)	49.01(9.51)	+0.36	49.37(9.62)	50.65(9.30)	+1.64	0.23	.64

Note. EF = executive function. Average change represents group-level changes from baseline to follow-up. Positive values indicate improvement in cognitive performance at follow-up. Repeated measure analyses of variance were conducted to examine cognitive changes one year after bariatric surgery in participants with elevated and normal baseline CRP.

[a]Elevated CRP values are CRP value ≥ 0.30 mg/dL.

[b]Normal CRP values are CRP values < 0.30 mg/dL.