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Short-term improvements in cognitive function following vertical sleeve gastrectomy and Roux-en Y gastric bypass: a direct comparison study

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Abstract

Background—Cognitive deficits are observed in individuals with obesity. While bariatric surgery can reverse these deficits, it remains unclear whether surgery type differentially influences cognitive outcome. We compared the extent to which vertical sleeve gastrectomy (VSG) and Roux-en Y gastric bypass (RYGB) ameliorated cognitive impairments associated with obesity.

Methods—Female participants approved for VSG ($N = 18$) or RYGB ($N = 18$) were administered cognitive measures spanning the domains of attention [Hopkins Verbal Learning Test (HVLT) Trial 1 and Letter Number Sequencing], processing speed [Stroop Color Trial, Symbol Digit Modalities Test, and Trail Making Part A], memory [HVLT Retained and HVLT Discrimination Index], and executive functioning (Stroop Color Word Trials and Trail Making Part B–A) prior to surgery and at 2 weeks and 3 months following surgery. Scores for each cognitive domain were calculated and compared between surgical cohorts using repeated measures analyses of variance.

Results—Significant weight loss was observed 2 weeks and 3 months following RYGB and VSG and was accompanied by improvements in processing speed and executive functioning. Patients who received RYGB also experienced improved attention as early as 2 weeks, which persisted at 3 months. This was not observed in individuals who underwent VSG. No changes in memory were observed from baseline measures in either group.

Conclusions—This is the first report of cognitive improvements following VSG and the first direct comparison of cognitive improvements following RYGB and VSG. Short-term improvements in specific domains of cognitive function are observed at the beginning of the active

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weight loss phase following bariatric surgery that persisted to 3 months. The anatomical distinction between the two surgeries and resulting differential metabolic profiles may be responsible for the improvements in attention observed following RYGB but not following VSG.

Keywords

Bariatric surgery; Vertical sleeve gastrectomy; Roux-en Y gastric bypass; Cognition

Obesity is a risk factor for cognitive deficits and body mass index (BMI) is positively associated with widespread cognitive impairment (e.g., [1–5]; see [6, 7] for review). Bariatric surgery is the most effective treatment to date for obesity and obesity-related comorbidities with the two most common bariatric procedures being the Roux-en Y gastric bypass (RYGB) and the vertical sleeve gastrectomy (VSG) [8]. Deficits in cognitive performance associated with obesity are ameliorated as early as 12 weeks following RYGB with improvements in some cognitive domains persisting out to 3 years post-operation (see [9] for review; [10–13]). Despite VSG currently being the most common bariatric procedure performed, there are no reports documenting the effects of VSG on cognition.

In both the RYGB and VSG procedures, the stomach is reduced to a fraction of its original size. However, in RYGB the proximal jejunum is transected approximately 40–60 cm from the ligament of Treitz, and the distal portion of the jejunum, known as the Roux limb (approximately 80–150 cm in length), is attached to the gastric pouch. The remainder of the stomach, the gastric remnant, along with the duodenum and proximal jejunum are reattached to the distal jejunum. As a result of their anatomical distinction, RYGB and VSG result in differential metabolic profiles and gastrointestinal hormonal milieu that is independent of weight loss ([14, 15]; see [16] for review). Recent evidence from animal models suggests that gut hormones may influence critical brain regions involved in cognitive performance [17–21]. Ghrelin, an orexigenic peptide hormone produced in the gastrointestinal tract primarily in the gastric fundus, was shown to induce hippocampal neurogenesis [18, 21] and stimulate learning [17, 20] in rodents. Similarly, administration of the anorexigenic hormone glucagon-like peptide-1 (GLP-1), which is produced in the gastrointestinal tract and released in response to nutrient ingestion, to the hippocampus of rats improved learning and memory performance [19]. The degree of biological changes in the levels of these hormones is bariatric surgery-dependent [14, 15]. Thus, one surgery may yield greater or earlier cognitive improvements relative to the other.

Therefore, we aimed to determine whether bariatric surgery type, specifically VSG and RYGB, differentially influences short-term cognitive outcomes and if improvements in cognitive performance are detectable as early as 2 weeks post-surgery during the initial phase of active weight loss. The domains of cognitive function assessed here were attention, processing speed, memory, and executive functioning.

Materials and methods

Participants

Males and females were recruited from an existing study investigating the neural correlates of taste changes following bariatric surgery. Adults between 18 and 55 years of age with a BMI ≥ 35 who were approved for bariatric surgery at the Johns Hopkins Center for Bariatric Surgery met inclusion criteria for participation. Exclusion criteria were the following: presence of an active DSM-IV Axis 1 diagnosis within the past 3 months with the exception of binge eating disorder; presence of a DSM-IV diagnosed substance dependent disorder; drug use within the past 6 months (by self-report or toxicity screen); cigarette use > 2 packs/day; alcohol consumption > 14 beverages/week or 5 beverages/day; use of psychoactive medications; pregnant or lactating (if female); reading comprehension below a 5th grade level; history or presence of head injury, central nervous system disorders, neurosurgical procedures, syncope, or lactose intolerance; recent (≥ 3 months) treatment for ≥ 2 weeks with antidepressants, neuroleptics, sedatives, hypnotic medications, isoniazids, glucocorticoids, psychostimulants, appetite suppressants, opiates or opiate antagonists; contraindications to undergoing MRI; exposure to an investigational drug within 30 days of the study; altered taste acuity. Male participants (VSG: $N = 5$; RYGB: $N = 0$) were later excluded from analyses due to insufficient enrollment numbers. Two subjects (1 RYGB, 1 VSG) did not complete all visits and therefore were excluded from the dataset. Final participant sample sizes for each group were RYGB: $N = 18$ and VSG: $N = 18$.

The study received institutional review board approval at the Johns Hopkins University and all eligible individuals provided written informed consent prior to participation in the study. Participants completed the oral and written cognitive test battery in a fasted state (at least 4 h) at three time points: prior to surgery and at 2 weeks and 3 months following surgery. Demographic and anthropometric information were collected at each visit prior to cognitive testing. Participants were compensated with gift cards upon completion of each visit.

Cognitive tests

Participants were administered a brief cognitive battery of five tests—the Letter Number Sequencing Test (LNS) [22], Hopkins Verbal Learning Test (HVLT) [23], Stroop Color and Word Test (SCWT) [24], oral Symbol Digit Modalities Test (SDMT) [25], and the Trail Making Test (TMT) [26]—spanning the four cognitive domains of attention, processing speed, executive functioning, and memory. The LNS is a measure of auditory attention in which individuals are read a series of numbers and letters in a randomized order and are asked to recall the numbers and letters in ascending order. The HVLT is a measure of auditory-verbal learning, memory retrieval, and recognition. The task requires participants to recall a list of 12 words over three learning trials. Following a 25-min delay, individuals are asked to freely recall as many words as they can remember. Participants are then presented with a 24-item list containing words from the original list along with semantically related and unrelated words. The HVLT recognition discrimination index was calculated as the number of hits minus false alarms. The SDMT is a measure of processing speed in which participants are asked to pair symbols and numbers as rapidly as possible. The TMT is a measure of focal attention and visual set-shifting. First, subjects are asked to connect a series

of 25 numbered dots as quickly and as accurately as possible. Next, for the set-shifting portion of the task, the dots are labeled with numbers and letters; subjects are instructed to alternate connections between numbers and letters in alphabetical and numerical order (e.g., 1–A–2–B–3–C). The SCWT is a measure of oral processing speed and response inhibition. During the first two trials, participants are instructed to read a list of color words (e.g., “red”) and colors (e.g., “XXXX” printed in red ink), respectively, as quickly as possible. During the third trial, the list consists of color names printed in a color inconsistent with the name (e.g., the word ‘red’ printed in blue ink). Participants are asked to relay the color of the ink in which the words are printed as quickly as possible. Measures were administered and scored according to standard instructions. Indices from these tasks were then assigned to the following domains: (1) Auditory attention [LNS total score and the first learning trial (Trial 1) of the HVLTL], (2) Processing speed [Color Trial of the SCWT, SDMT, and TMT Part A], (3) Memory for auditory-verbal information (HVLTL percent retained, HVLTL Recognition Discrimination Index). Executive functioning was assessed using the Color Word Trial of the SCWT [24] and the difference score of the TMT [26] (Part B–Part A).

Statistical analyses

Data were analyzed using SPSS Statistic Software v.24. The alpha level was established at $p = 0.05$ and Bonferroni correction was used to control for multiple comparisons when applicable. The Greenhouse–Geisser correction was used to produce a more valid critical F value if sphericity was violated.

Participant demographics

Independent samples t tests were conducted on age and education and Chi-square analyses were conducted on race to assess differences between groups in patient demographics.

Anthropometrics

Percent total weight loss (%TWL) was calculated by $[(\text{Pre-surgical or Baseline Weight}) - (\text{Post-surgical Weight})] / [(\text{Pre-surgical or Baseline Weight})] \times 100$. Percent excess weight loss (%EWL) was calculated by $[(\text{Pre-surgical or Baseline Weight}) - (\text{Post-surgical Weight})] / [(\text{Pre-surgical or Baseline Weight}) - (\text{Ideal Weight})] \times 100$ with ideal weight being defined as the weight equivalent to a BMI of 25 kg/m². BMI point loss and total pound loss (TPL) were calculated by subtracting the weight value at each post-surgical time point from the respective value prior to surgery. Effectiveness of bariatric procedures was assessed via repeated measures ANOVAs (surgery group $\times$ time) on body weight, BMI, BMI point loss, TPL, %TWL, and %EWL. A one-sample t test was performed on BMI point loss, TPL, %EWL and %TWL (test value = 0) to identify significant changes in weight metrics from baseline.

Cognitive tests

Repeated measures ANOVAs (surgery group $\times$ time) were run on raw scores for each cognitive test to determine changes in cognitive domains as a function of surgery type across time. When a main effect of time was identified, t tests were performed within each group comparing 2-week and 3-month data with baseline to determine the pattern of cognitive

change across time for RYGB and VSG. For an overall cognitive measure, composite scores were generated by averaging the individual z-scores calculated for each test score at each time point. Repeated measures ANOVAs (surgery group x time) were then conducted on the composite scores to identify the impact of bariatric surgery type on general cognition.

Results

Subject demographics

There was no difference in age [$t_{(39)} = 0.119$, $p = 0.906$] or education [$t_{(39)} = -0.019$, $p = 0.985$] between surgical groups. More African Americans received VSG than RYGB in this cohort [$\chi^2(1) = 6.067$, $p = 0.048$]. See Table 1 for a complete depiction of participant demographics.

Anthropometrics

Both surgical groups had similar preoperative weight and BMI. Similar significant weight loss from baseline, as measured by TPL, BMI point loss, %TWL, and %EWL, at 2 weeks and 3 months following surgery was observed for both surgery groups (See Table 2; Fig. 1).

Cognitive tests

Short-term changes in performance in 4 cognitive domains were assessed in patients from baseline at 2 weeks and 3 months following bariatric surgery—attention, processing speed, memory, and executive functioning. The repeated measures ANOVAs revealed a main effect of time for tests assessing attention, processing speed, and executive functioning (see Table 3). No main effect of group or group $\times$ time interaction was found for any cognitive measure. Further t tests indicated that attention improved as early as 2 weeks and persisted at 3 months following RYGB, but VSG resulted in no improvement in attention (Table 4, Fig. 2). Processing speed increased as early as 2 weeks and persisted at 3 months following both RYGB and VSG (Table 4, Fig. 3). Of note, performance on TMT, Part A in participants who received RYGB did not survive Bonferroni correction. Executive functioning increased as early as 2 weeks, although this did not survive Bonferroni correction, and persisted at 3 months following both RYGB and VSG (Table 4, Fig. 4). Memory scores did not change at either the 2 week or 3 month time point following RYGB or VSG (Fig. 5). Overall cognitive performance, represented by the composite score created from each participant's standardized data across all tests, did not change following bariatric surgery (Fig. 6).

Discussion

Our data complement the literature demonstrating improved cognitive performance following RYGB at 3 months, [2, 11, 27] and enhance these findings by showing that cognitive improvements occur as early as 2 weeks post-operation. We also show for the first time improvements in cognitive function following VSG, specifically in the domains of executive function and processing speed, which paralleled those observed in RYGB. Weight loss results in improved cognition (see [28] for review) and may be a factor in the enhanced cognitive performance following bariatric surgery observed in our study. Additionally, reductions in inflammation associated with weight loss [29–32] rather than weight loss itself

may be responsible for these short-term cognitive changes. The cognitive improvements observed following RYGB in previous studies have persisted out to 3 years, which is outside the dynamic weight loss phase and encompasses the period where many individuals show significant weight regain (e.g., [33–36]; see [37] for review). While improvements in cognitive performance observed in our study occurred during the active weight loss phase, other surgery-related, weight loss-independent factors may be responsible for the amelioration of cognitive impairments. For example, bariatric surgery results in alterations in the gut hormone milieu including ghrelin and GLP-1 [14, 15, 38] that have been linked to cognitive improvements in animal models [17–21].

Another possibility for the immediate and persistent cognitive improvements observed following bariatric surgery may be the recovery of structural brain abnormalities associated with obesity. Obesity is correlated with decreased fractional anisotropy in white matter tracts [39–44], which tracks with reduced executive functioning and processing speed [45]. Increased BMI has been shown to be associated with hippocampal atrophy [46]. Bariatric surgery ameliorates such obesity-induced structural abnormalities in cognition-related brain regions including the hippocampus at 1 month [47, 48] and 1 year [49]. These weight loss-dependent or weight loss-independent mechanisms resulting from bariatric surgery may be responsible for the short-term improvements in cognition. These mechanisms are not mutually exclusive.

In addition to driving within-group changes in cognitive performance, the dramatic rise in gut hormones following bariatric surgery may also explain the improved attention observed in RYGB but not VSG. For example, postprandial GLP-1 is markedly increased following RYGB and enhanced to a lesser extent following VSG [14, 15]. In rodent models, administration of GLP-1 and GLP-1 agonists, analogous to a rise in GLP-1 following bariatric surgery, results in hippocampal neurogenesis and improves cognitive function [19]. Ghrelin is significantly reduced following VSG due to the removal of the gastric fundus where ghrelin cells are primarily located [14, 50, 51]. Acute decreases in circulating ghrelin are observed following RYGB that increase above pre-surgical levels with time ([14, 50–54]; see [55] for review). Ghrelin administration enhances cognitive function and hippocampal neurogenesis in a rodent model [17, 18, 20, 21]. Thus, the opposing changes in ghrelin secretion following VSG and RYGB may be a mechanism for the differential improvements in attention observed between the two surgery groups here. However, the cognition-enhancing effects of ghrelin may not translate from a rodent model to humans [56, 57]. Whether cognitive improvements track with changes in gut hormones following bariatric surgery across time should be explored.

The immediate improvements within the cognitive domains of attention and processing speed observed at 2 weeks post-surgery may not be related to the bariatric intervention. Practice effects and/or familiarity with the tests may be possible drivers of improved cognitive performance observed here, at least at the 2 week post-surgical test. If this were the case, however, both groups would be expected to show similar performance, yet only participants who received RYGB demonstrated improved attention as assessed by the LNS measure.

In our study, there was no improvement in memory out to 3 months following surgery. This was surprising given that previously published data from the Longitudinal Assessment of Bariatric Surgery (LABS) study revealed improvements in memory at 3 months in their cohort of RYGB recipients [10]. One possibility for the conflicting results is that our study was restricted to females, whereas the population tested in Alosco et al., 2014 included both males and females. Alternatively, 3 months may be a critical window for changes in memory performance following bariatric surgery; future testing in our participants may reveal improvements in memory.

The cognition composite score revealed no change from baseline to 3 months following surgery. This may be due to scores on cognitive assessments where no improvements were observed neutralizing scores on assessments that improved following surgery. Alternatively, the relatively small sample size, although matched between groups, may account for the lack of significant changes in overall cognition. These data suggest that an overall composite score may not be an appropriate metric for assessing changes in cognition following bariatric surgery; the cognitive domain and rate of improvement may be surgery-type dependent, and combining the data may conceal these changes.

Limitations

While females comprise 80% of individuals receiving bariatric surgery, a limitation of this study was its restriction to females. Males were recruited and participated, but there were too few to permit analysis. Thus, males were excluded, and sex as a biological variable was not addressed. Another limitation is our relatively small sample size. However, there were equal numbers of patients in each surgery group, and their characteristics were similar.

Strengths

To our knowledge, this is the first study aimed at identifying and comparing the short-term effects of the two most popular bariatric procedures, RYGB and VSG, when similar weight loss is observed. Divergence in weight alone cannot account for changes observed here, as we have shown that both surgeries result in similar short-term weight loss.

In conclusion, we have demonstrated that bariatric surgery not only results in significant weight loss, but also improves short-term (2 weeks and 3 months post-surgery) cognitive performance in individuals with obesity. Studies assessing long-term cognitive performance measures and the underlying mechanisms are needed. Improvements in cognition across a range of domains may be independent of its weight loss benefits. Furthermore, the rate at which cognitive improvements are observed and the cognitive domains impacted by bariatric surgery appear to depend upon the type of surgery received. Future studies assessing the association of gut hormones and inflammatory markers with cognition, and the postoperative structural changes in the brain as a function of surgery type are warranted.

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Fig. 1. Similar significant changes in weight are observed at 2 weeks and 3 months following RYGB (red, mean $\pm$ SE) and VSG (blue mean $\pm$ SE) as measured by **a** total pounds lost, **b** BMI point loss, **c** percent total weight loss, and **d** percent excess weight loss (Color figure online)

Fig. 2.

Mean $\pm$ SE performance in the cognitive domain of attention, as assessed by the **a** Hopkins Verbal Learning Test (HVLT) Trial 1 and **b** Letter Number Sequencing (LNS), significantly improved with time in participants who received RYGB (red solid line), but not VSG (blue dashed line) (Color figure online)

Fig. 3. Mean $\pm$ SE performance in the cognitive domain of processing speed, as assessed by the **a** Color Trial of the Stroop Color and Word Test (SCWT), **b** Symbol Digit Modalities Test (SDMT), and **c** Trail Making Test (TMT) Part A, significantly improved with time following RYGB (red solid line) and VSG (blue dashed line) (Color figure online)

Fig. 4.

Mean $\pm$ SE performance in the cognitive domain of executive functioning, as assessed by the **a** Color Word Trial of the Stroop Color and Word Test (SCWT) and **b** Trail Making Test (TMT) Part B-Part A, significantly improved with time following RYGB (red solid line) and VSG (blue dashed line) (Color figure online)

Fig. 5.

Mean $\pm$ SE performance in the cognitive domain of memory, as assessed by the **a** Hopkins Verbal Learning Test (HVLT) retained and **b** HVLT discrimination index, did not change following RYGB (red solid line) or VSG (blue dashed line) (Color figure online)

Fig. 6.

Mean $\pm$ SE overall cognitive performance at 2 weeks and 3 months following RYGB (red solid line) and VSG (blue dashed line) did not change (Color figure online)

Table 1Mean $\pm$ SE of participant demographics and weight metrics

Demographics	RYGB (N = 18)	VSG (N = 18)
Age	39.8 $\pm$ 2.0	37.7 $\pm$ 1.8
Race	C = 13, AA = 4, O = 1	C = 7, AA = 11
Education (years)	15.7 $\pm$ 0.7	15.4 $\pm$ 0.6
Baseline weight	273.8 $\pm$ 8.4	268.0 $\pm$ 7.8
Weight, 2 weeks post-surgery (lbs)	253.6 $\pm$ 8.5	250.6 $\pm$ 7.6
Weight, 3 months post-surgery (lbs)	225.6 $\pm$ 8.8	225.7 $\pm$ 7.5
Baseline BMI	44.5 $\pm$ 1.2	43.9 $\pm$ 1.3
BMI, 2 weeks post-surgery	41.2 $\pm$ 1.2	41.0 $\pm$ 1.3
BMI, 3 months post-surgery	36.7 $\pm$ 1.3	36.9 $\pm$ 1.3
TPL, 2 weeks post-surgery	20.2 $\pm$ 0.9	17.4 $\pm$ 1.3
TPL, 3 months post-surgery	48.1 $\pm$ 1.8	42.3 $\pm$ 2.6
BMI point loss, 2 weeks post-surgery	3.3 $\pm$ 0.1	2.9 $\pm$ 0.2
BMI point loss, 3 months post-surgery	7.8 $\pm$ 0.3	6.9 $\pm$ 0.4
%TWL, 2 weeks post-surgery	7.5 $\pm$ 0.4	6.6 $\pm$ 0.5
%TWL, 3 months post-surgery	17.9 $\pm$ 0.9	15.9 $\pm$ 0.9
%EWL, 2 weeks post-surgery	17.7 $\pm$ 1.3	15.9 $\pm$ 1.4
%EWL, 3 months post-surgery	42.4 $\pm$ 3.2	38.7 $\pm$ 2.8

M Male, *F* Female, *C* Caucasian, *AA* African American, *O* Other

Table 2

Results from repeated measures ANOVAs (surgery type x time) performed on body weight measures

Body weight metric	Group	Time	Group × Time
Weight (lbs)	$F_{(1,39)} = 0.808, p = 0.374$	$F_{(1,3,51,4)} = 489.603, p < 0.001$	$F_{(1,4,54,0)} = 0.216, p = 0.806$
BMI	$F_{(1,39)} = 0.021, p = 0.886$	$F_{(1,4,54,0)} = 609.360, p < 0.001$	$F_{(1,4,54,0)} = 1.010, p = 0.345$
TPL	$F_{(1,39)} = 0.067, p = 0.797$	$F_{(1,39)} = 388.296, p < 0.001$	$F_{(1,39)} = 0.430, p = 0.516$
BMI point loss	$F_{(1,39)} = 0.835, p = 0.366$	$F_{(1,39)} = 429.432, p < 0.001$	$F_{(1,39)} = 1.222, p = 0.276$
%TWL	$F_{(1,39)} = 1.277, p = 0.265$	$F_{(1,39)} = 380.888, p < 0.001$	$F_{(1,39)} = 1.373, p = 0.248$
%EWL	$F_{(1,39)} = 0.941, p = 0.338$	$F_{(1,39)} = 265.347, p < 0.001$	$F_{(1,39)} = 1.041, p = 0.314$

Bold indicates significant statistic

Table 3
Results from repeated measures ANOVAs conducted on scores for each cognitive assessment

Cognitive domain	Cognitive test	Group	Time	Group × Time
Attention	HVLT trial 1	$F_{(1,34)} = 0.369, p = 0.547$	$F_{(2,68)} = 3.162, p = 0.049$	$F_{(2,68)} = 0.590, p = 0.557$
	Letter number sequencing	$F_{(1,34)} = 2.191, p = 0.148$	$F_{(1,7,57,4)} = 10.533, p = 0.001$	$F_{(1,7,57,4)} = 1.528, p = 0.224$
Processing speed	Stroop: color	$F_{(1,34)} = 0.008, p = 0.928$	$F_{(2,68)} = 20.448, p < 0.001$	$F_{(2,68)} = 2.214, p = 0.117$
	Symbol digit modalities	$F_{(1,34)} = 1.113, p = 0.299$	$F_{(2,68)} = 10.842, p < 0.001$	$F_{(2,68)} = 0.225, p = 0.799$
	Trails making test part A	$F_{(1,34)} = 1.395, p = 0.246$	$F_{(1,7,56,8)} = 8.460, p = 0.001$	$F_{(1,7,56,8)} = 0.706, p = 0.497$
Memory	HVLT percent retained	$F_{(1,34)} = 0.241, p = 0.626$	$F_{(1,6,53,8)} = 0.685, p = 0.508$	$F_{(1,6,53,8)} = 0.228, p = 0.797$
	HVLT discrimination index *	$F_{(1,34)} = 1.244, p = 0.273$	$F_{(2,64)} = 0.517, p = 0.599$	$F_{(2,64)} = 0.0320, p = 0.727$
Executive functioning	Stroop: color word	$F_{(1,34)} = 0.418, p = 0.522$	$F_{(2,68)} = 13.099, p < 0.001$	$F_{(2,68)} = 0.017, p = 0.983$
	Trails B-A	$F_{(1,34)} = 0.767, p = 0.387$	$F_{(2,68)} = 2.428, p = 0.096$	$F_{(2,68)} = 1.280, p = 0.285$
Composite score		$F_{(1,34)} = 0.003, p = 0.955$	$F_{(2,68)} = 0.004, p = 0.996$	$F_{(2,68)} = 0.584, p = 0.561$

Bold indicates significant statistic

* RYGB: $N = 18$, VSG: $N = 16$

Table 4

Results from t tests conducted on data of which a main effect of time was revealed

Cognitive domain	Cognitive test	Pre-intervention versus 2 weeks post- intervention		Pre-intervention versus 3 months post-intervention	
		RYGB	VSG	RYGB	VSG
Attention	HVLT: trial 1	$t_{(17)} = -0.907$, $p = 0.377$	$t_{(17)} = -0.732$, $p = 0.474$	$t_{(17)} = -2.781$, $p = 0.013^{\#}$	$t_{(17)} = -0.908$, $p = 0.376$
	Letter number sequence	$t_{(17)} = -2.959$, $p = 0.009^{\#}$	$t_{(17)} = -0.809$, $p = 0.430$	$t_{(17)} = -3.259$, $p = 0.005^{\#}$	$t_{(17)} = -2.046$, $p = 0.057$
Psychomotor speed	Stroop: color	$t_{(17)} = -3.330$, $p = 0.004^{\#}$	$t_{(17)} = -2.738$, $p = 0.014^{\#}$	$t_{(17)} = -4.510$, $p < 0.001^{\#}$	$t_{(17)} = -3.204$, $p = 0.005^{\#}$
	Symbol digit modality	$t_{(17)} = -0.922$, $p = 0.369$	$t_{(17)} = -1.811$, $p = 0.088$	$t_{(17)} = -3.037$, $p = 0.007^{\#}$	$t_{(17)} = -4.085$, $p = 0.001^{\#}$
Executive functioning	Trails A	$t_{(17)} = -1.252$, $p = 0.227$	$t_{(17)} = -1.265$, $p = 0.223$	$t_{(17)} = -2.278$, $p = 0.036$	$t_{(17)} = -2.914$, $p = 0.010$
	Stroop: color word	$t_{(17)} = -2.153$, $p = 0.046$	$t_{(17)} = -2.251$, $p = 0.038$	$t_{(17)} = -3.477$, $p = 0.003^{\#}$	$t_{(17)} = -4.004$, $p = 0.001^{\#}$

Bold indicates significant statistic

[#] p values that survived Bonferroni correction