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Executive functioning and dietary intake: Neurocognitive correlates of fruit, vegetable, and saturated fat intake in adults with obesity

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Abstract

Obesity is a significant public health issue, and is associated with poor diet. Evidence suggests that eating behavior is related to individual differences in executive functioning. Poor executive functioning is associated with poorer diet (few fruits and vegetables and high saturated fat) in normal weight samples; however, the relationship between these specific dietary behaviors and executive functioning have not been investigated in adults with obesity. The current study examined the association between executive functioning and intake of saturated fat, fruits, and vegetables in an overweight/obese sample using behavioral measures of executive function and dietary recall. One-hundred-ninety overweight and obese adults completed neuropsychological assessments measuring intelligence, planning ability, and inhibitory control followed by three dietary recall assessments within a month prior to beginning a behavioral weight loss treatment program. Inhibitory control and two of the three indices of planning each independently significantly predicted fruit and vegetable consumption such that those with better inhibition and planning ability consumed more fruits and vegetables. No relationship was found between executive functioning and saturated fat intake. Results increase understanding of how executive functioning influences eating behavior in overweight and obese adults, and suggest the importance of including executive functioning training components in dietary interventions for those with obesity. Further research is needed to determine causality as diet and executive functioning may bidirectionally influence each other.

Keywords

executive functioning; diet; fruits and vegetables; obesity

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Two-thirds of Americans are overweight or obese (Go et al., 2014), and global rates of obesity are rising (Ng et al., 2014). Poor diet and sedentary lifestyle are two factors contributing to the spread of the obesity epidemic (Gable, Chang, & Krull, 2007; Lee et al., 2011). Conversely, a healthy diet can help maintain a healthy weight, and reduce the risk of chronic diseases, including cancer, diabetes, and coronary heart disease (Epstein et al., 2001; Mente, de Koning, Shannon, & Anand, 2009; Rolls, Ello-Martin, & Tohill, 2004). The United States Department of Agriculture (USDA) recommends eating approximately five servings of fruits and vegetables daily and consuming less than 10% of calories from saturated fat in order to reach and maintain a healthy weight (United States Department of Agriculture, 2010). Despite awareness of such recommendations, individuals are often unable to successfully implement dietary changes in accordance with the above-stated guidelines (Guenther, Dodd, Reedy, & Krebs-Smith, 2006), as evidenced by the high rates of overweight and obesity (Ng et al., 2014).

Emerging evidence has indicated that the ability to make healthy eating choices in the face of biological drives is heavily dependent on executive function (i.e., cognitive control processes that contribute to one's ability to self-regulate and successfully carry out goal-directed behavior; Gazzaley & D'Esposito, 2007; Hofmann, Schmeichel, & Baddeley, 2012). As metabolic control processes and the obesogenic environment encourage overconsumption of highly palatable foods, executive function processes are required to maintain an equal or negative energy balance and make healthy food choices. Specifically, inhibitory control (i.e., one's ability to regulate automatic behavioral responses) is important for limiting engagement in prepotent and rewarding behaviors, such as consuming highly palatable food (Hofmann, Friese, & Roefs, 2009; Houben, Nederkoorn, & Jansen, 2014). Other executive functioning processes, such as set shifting (i.e., flexibly altering goals and behaviors in light of new information), updating (monitoring and updating goals), and planning ability (i.e., generating mental representations of steps to achieve an intention) play a role in initiating and carrying out health behaviors, including healthy eating habits (Allan, Johnston, & Campbell, 2011; Allan, Snihotta, & Johnston, 2013; Limbers & Young, 2015; Wong & Mullan, 2009; Zhou et al., 2015). Several studies have examined the association between executive functioning and intake of food groups (e.g., fruits and vegetables) and nutrients (e.g., saturated fat; Allom & Mullan, 2014; Limbers & Young, 2015; Zhou et al., 2015). For instance, Allom & Mullan (2014) demonstrated that inhibitory control negatively predicted reported consumption of foods high in saturated fat and updating was positively associated with fruit and vegetable consumption.

Studies demonstrating that poor executive functioning is associated with higher consumption of unhealthy foods and lesser consumption of healthy foods in a naturalistic setting have primarily been conducted among healthy weight populations (Allom & Mullan, 2014; Hall, 2012; Hall, Lowe, & Vincent, 2014; Houben, 2011; Jasinska et al., 2012). Especially considering the large literature base showing executive function deficits in obese compared to healthy weight individuals (Fitzpatrick, Gilbert, & Serpell, 2013; Gunstad, 2007; Lavagnino, Arnone, Cao, Soares, & Selvaraj, 2016), there is a need to study executive functioning and nutrient intake in adults with obesity. Understanding how executive functioning and dietary intake relate among obese individuals could also inform the development of weight loss interventions. Further, a major limitation of the literature on

sizes, allowing for detailed analysis of specific food items and nutrients consumed. The ASA24 uses an automated multiple pass method, in which users are prompted multiple times to provide details and additions to meals and snacks, and has been found to accurately estimate intake compared to interviewer administered recalls and biomarkers (Kipnis et al., 2003; Moshfegh et al.; Schatzkin et al., 2003; Subar et al., 2012). Participants completed the ASA24 on three separate, nonconsecutive days during a one-week period, including one weekend day, prior to beginning BWL treatment. Fruit and vegetable consumption was measured in one cup serving equivalents. Saturated fat intake was measured in grams. Total energy consumption was measured in kilocalories (Kcals). Daily averages of fruit/vegetable consumption and saturated fat intake were calculated.

Neuropsychological Assessment

Intelligence—The Wechsler Test of Adult Reading (WTAR) is a reading recognition test used to measure estimated verbal intelligence. WTAR scores can be converted to Full Scale IQ (FSIQ) estimates using normative data from the co-norming sample. The WTAR is strongly correlated (.70–.80) with WAIS-III FSIQ scores for a wide age range of WTAR scores (Wechsler, 2001).

Inhibitory Control—Inhibitory control was measured using the D-KEFS Color-Word Interference task (Delis, Kaplan, & Kramer, 2001). This measure is a Stroop task presented on flash card. Participants are first shown blocks of colors and are asked to name the colors. Next, participants are shown words and asked to read the words. The third trial uses color names written in dissonant color ink, and participants are asked to name the color of the ink (not the word). In this study, the difference in time between trial 1 (color naming) and trial 3 (inhibition) was used to measure response inhibition, with higher scores indicating poorer inhibitory control. Subtraction of trial 1 time from trial 3 time is a means of accounting for deficits in naming speed. This measure is widely used in both clinical practice and research, and Stroop tasks, such as the color word interference task, been utilized in examination of the relationship between inhibitory control and eating behavior and weight outcome in prior studies (Allom & Mullan, 2014; Cohen, Yates, Duong, & Convit, 2011; Mobbs, Iglesias, Golay, & Van der Linden, 2011; Reyes, Peirano, Peigneux, Lozoff, & Algarin, 2015; Verdejo - García et al., 2010).

Planning—Planning and task monitoring abilities were assessed using the D-KEFS tower task (Delis, Kaplan, & Kramer, 2001). The task requires participants to build a series of nine towers using five disks that vary in size. Participants are shown images of various towers to build with the disks, and instructed to use as few moves as possible when building. The task becomes progressively more difficult and all trials are timed. Participants must adhere to two rules: move only one piece at a time using one hand, and never place a larger disk on top of a smaller disk. In addition to a total achievement score, mean amount of time before making the initial move and the mean number of rule violations per trial were recorded. Higher achievement scores, greater first move time, and fewer rule violations indicate better planning. This task was chosen as it is a well validated and normed test that provides a fairly holistic view of executive functioning. While achievement score on this task gives a global score, first move time measures rash action, as participants who do not plan their strategy

tend to make their first move quickly, despite the complexity of the task requiring advanced planning (including placement of the first disk). Number of rule violations measures task monitoring and updating—the ability to keep engaged in goal directed behavior (building the tower) while attending to set parameters (rules).

Statistical Analyses

Skewed variables (all macronutrient and executive functioning measures) were corrected using square root and natural log transformations (Tabachnick & Fidell, 2007). As analyses using transformed variables yielded the same results as when using original variables, analyses are presented with original values for ease of interpretation.

As a preliminary analysis, we examined correlations between BMI, inhibitory control, planning, saturated fat intake, calories, and fruit and vegetable consumption. Using servings of fruits and vegetables and grams of saturated fat as dependent variables, hierarchical regression analyses were conducted to assess the association between executive functioning and fruit, vegetable, and saturated fat intake. In the first hierarchical regression analysis (examining predictors of fruit and vegetable consumption), age, gender, IQ, and BMI were controlled for in step 1, calories were included in step 2, and executive functioning variables comprised step 3. Consistent with Tabachnick & Fidell's (2007) recommendations, due to the high correlation of calories and saturated fat intake, total calories were not included as a covariate in the hierarchical regression with saturated fat as the outcome variable.

Results

Descriptives and correlations between included variables are presented in Table 1.

Fruit and Vegetable Intake

As can be seen in Table 2, demographic variables (BMI, IQ, gender, age) accounted for 2.8% of the variance of fruit and vegetable intake. The addition of calories in step 2 accounted for an additional 6.7% of variance of fruit and vegetable intake. Executive functioning measures accounted for an additional 7.5% of variance. It was hypothesized that planning, but not inhibitory control, would be predictive of fruit and vegetable intake. Partially consistent with our prediction, inhibitory control and two of the three indices of planning (tower task rule violations per item ratio, and tower task mean first move time) each independently significantly predicted fruit and vegetable consumption such that those with better inhibition and planning ability consumed more fruits and vegetables.

Saturated Fat Intake

As shown in Table 3, demographic variables accounted for 5.3% of variance in saturated fat intake. Adding executive functioning variables in step two accounted for an additional 2.7% of variance in saturated fat intake. Neither the model nor any included variables reached significance.

Discussion

The aim of the current study was to evaluate whether inhibitory control and planning ability were related to saturated fat and fruit and vegetable intake in overweight and obese adults while controlling for total calories consumed. As hypothesized, those who performed better on a behavioral task of planning ability consumed more fruits and vegetables. These findings are consistent with previous research in healthy weight samples (Allom & Mullan, 2014; Limbers & Young), and suggest that planning ability is associated with greater fruit and vegetable intake in overweight and obese adults. On a broader level, this finding further supports the rationale for including planning strategies as a major component in health behavior interventions, perhaps especially for those with deficits in planning ability. In fact, those with poorer planning (measured through the same behavioral task used in the current study) have been found to benefit (i.e., increase fruit and vegetable intake) most from using implementation intentions (Allan et al., 2013), suggesting that use of behavioral strategies (i.e., action planning and implementation intentions) can compensate for deficits in planning ability.

Our findings also indicated that those with better ability to withhold prepotent responses (i.e., superior inhibitory control) eat more fruits and vegetables. It is possible that in overweight and obese samples, inhibitory control contributes to increased consumption of fruits and vegetables via withholding a response to a more palatable option (e.g., high-fat, high-sugar foods) resulting in higher consumption of fruits and vegetables. Given that weight gain and greater BMI are associated with greater hedonic drive (Blundell & Finlayson, 2004; Lowe & Butryn, 2007), findings could reflect a need to exercise inhibitory control to make healthy food choices, in the face of a constant draw towards highly palatable foods. Perhaps overweight and obese individuals (known to have inhibitory control deficits compared to healthy weight individuals) must execute increased inhibitory control (relative to healthy weight individuals) over hedonic response to highly palatable food in order to choose a healthier option, whereas healthy weight individuals do not need to utilize increased inhibitory control to make these choices. Future research with both an overweight and healthy weight sample is necessary to test this hypothesis. Our findings contrast with previous findings (Allan et al., 2011; Allom & Mullan, 2014; Wong & Mullan, 2009) that did not detect a relation between inhibitory control and fruit and vegetable intake, and more generally literature on self-regulation of health behaviors conceptualizing inhibitory control as most vital to resisting a behavior (i.e., inhibitory self-control) and planning as more important for engaging in health behaviors; (i.e., initiatory self-control; de Boer, van Hooft, & Bakker, 2011; de Ridder, de Boer, Lugtig, Bakker, & van Hooft, 2011; de Ridder, Lensvelt-Mulders, Finkenauer, Stok, & Baumeister, 2012).

These findings begin to bridge the gap between literature on excess weight and executive functioning and research on how executive functioning influences dietary choices of specific nutrients or food groups. The current study is unique in that it included total caloric intake in the statistical model for predicting fruit and vegetable intake. Contrary to previous findings of lack of association between calorie intake and quantity of fruits and vegetables consumed (Mytton, Nnoaham, Eyles, Scarborough, & Mhurchu, 2014), results of the current investigation found that greater caloric consumption was associated with *greater* fruit and

vegetable intake. As the sample in this study was weight-loss treatment seeking adults, prior to starting any intervention, it is possible that this relation emerged as a result of pre-treatment attempts to lose weight by increasing fruit and vegetable intake without decreasing total caloric intake.

The hypothesized relationship between saturated fat intake and inhibitory control was not supported by the results, and, in fact, trended towards a relationship in which poorer inhibitory control was associated with less saturated fat intake. Given the difference in measurement of saturated fat between this study (grams saturated fat calculated from dietary recall) and other studies examining executive functioning and saturated fat intake (i.e., Limbers & Young, 2015 and Allom & Millan, 2014 who both used self-reported weekly frequency) it is not wholly surprising that results were not consistent. Given the discrepant findings, further research is needed to clarify the relationship between inhibitory control and fat intake in overweight and obese adults.

The lack of association between inhibitory control and saturated fat is also inconsistent with the relationship between increased food intake in a laboratory setting and lower inhibitory control, as well as observed deficits in those with excess weight (Fitzpatrick et al., 2013; Guerrieri et al., 2007; Gunstad, 2007; Houben, 2011). Literature linking inhibitory control and diet/weight is most robust using measures of late-stage motor inhibition, such as go/no-go or stop signal tasks (Bartholdy, Dalton, O'Daly, Campbell, & Schmidt, 2016; Lavagnino et al., 2016). Perhaps late-stage inhibition may be a better measure of one's ability to resist highly palatable fatty foods, while processes measured in the Stroop task such as conflict monitoring (i.e., processing and monitoring incoming stimuli for changes that signal recruitment of top-down attentional control) may be predictive of the ability to make healthy choices such as eating fruits and vegetables.

Further, inhibitory control in response to food stimuli is poorer than in response to neutral stimuli, and this may be especially pronounced in obese individuals (Loeber et al., 2012; Mobbs et al., 2011; Nijs, Franken, & Muris, 2010; Price, Lee, & Higgs, 2016). It is possible that inhibitory control deficits that influence diet are food-specific rather than general. Several studies have examined food-related moderators (e.g., hunger, attention bias to food, and dietary restraint) of the effect of inhibitory control on dietary and weight outcomes (Jansen et al., 2009; Nederkoorn, Guerrieri, Havermans, Roefs, & Jansen, 2009; Nederkoorn, Houben, Hofmann, Roefs, & Jansen, 2010). Perhaps, in this study, unmeasured variables obscured the relationship between inhibitory control and saturated fat intake. Future studies examining inhibitory control and specific dietary choices (i.e., saturated fat) should use both food and non-food stimuli in measuring inhibitory control and account for variables such as dietary restraint and hedonic drive.

One of the greatest strengths of this investigation was the use of dietary recall to calculate fruit, vegetable, saturated fat, and total caloric intake. Most studies investigating executive functioning and dietary outcomes for a particular food group have used frequency recalls or laboratory taste tests (Allom & Mullan, 2012; Collins & Mullan, 2011; Hall, 2012; Hofmann et al., 2009; Jasinska et al., 2012; Wong & Mullan, 2009; Zhou et al., 2015) which are subject to desirability bias, have been found to be less accurate and ecologically valid than

study furthers previous findings on executive functioning and diet by examining a treatment-seeking overweight and obese adult population and by using a rigorous and ecologically valid measure of dietary intake.

As overweight and obese individuals are perhaps in the greatest need of dietary intervention, it is important to understand how individual factors, such as executive functioning, influence eating behavior and treatment outcomes. Behavioral interventions targeting planning using implementation intention/action planning are effective in changing eating habits and are often a core component of behavioral weight loss interventions (Adriaanse, Vinkers, De Ridde, Hox, & De Wit; Michie et al., 2011). The current findings underscore the importance of these well-established interventions, as well as the need to further study the influence of executive functioning on outcomes in behavioral weight loss interventions and continued development of treatments with an executive functioning training component.

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Table 1

Means, standard deviations and Pearson correlations of BMI, age, IQ, executive functioning measures, and dietary intake.

	1	2	3	4	5	6	7	8	9	10
1. BMI	1	-.020	-.109	.044	.004	.056	.050	.094	.156*	-.073
2. Age		1	.137*	.098	.172*	-.050	.278**	-.178	-.119	.081
3. IQ			1	-.083	-.124	.135*	-.171*	.024	-.006	-.069
4. Planning (1 st Move Time)				1	.059	-.008	.109	.017	-.004	.112
5. Planning (rule violations)					1	-.409**	.210**	-.033	-.043	.191*
6. Planning (Achievement Score)						1	-.242**	.069	.089	-.059
7. Inhibitory Control							1	-.177*	-.140	-.122
8. Calories								1	.843**	.083
9. Saturated Fat									1	-.103
10. Fruits & Vegetables										1
Mean	36.5	51.7	112.9	5.61	1.1	17.0	24.7	2166	29.9	1.2
SD	5.7	10.1	10.6	3.0	2.5	4.0	9.5	679.9	14.7	1.0

Table 2

Hierarchical regression analysis for prediction of fruit and vegetable intake.

	Step 1				Step 2				Step 3			
	β	R ²	F	p	β	R ²	F	p	β	R ²	F	p
		.028	1.17	.326		.067	11.96	.001		.075	3.56	.008
BMI	-.063			.421	-.087			.255	-.080			.282
Gender	-.140			.078	-.088			.261	-.079			.299
Age	.054			.499	.114			.151	.106			.189
IQ	.003			.967	-.017			.826	.000			.995
Calories					.271			.001	.242			.002
Inhibitory Control									-.167			.040
Planning (Achievement Score)									-.031			.704
Planning (Rule Violations)									.178			.030
Planning (First Move Time)									.167			.025

Table 3

Hierarchical regression analysis for prediction of saturated fat intake.

	Step 1				Step 2			
	β	R ²	F	p	β	R ²	F	p
BMI	.147	.053	2.266	.064	.148	.027	1.152	.334
Gender	-.123			.058	.130			.057
Age	-.142			.118	-.092			.099
IQ	.108			.073	-.004			.269
Color-Word				.687	-.160			.959
Tower Task Achievement Score					.041			.057
Tower Task Rule Violations					.001			.634
Tower Task First Move					.002			.993
								.978