FASTING COGNITION AND WEIGHT STATUS IN COLLEGE STUDENTS

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by

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Introduction

A growing body of literature suggests that breakfast really is “the most important meal of the day.” Breakfast has increasingly become recognized as an important meal: the 2010 Dietary Guidelines for Americans (DGA, 2010) include a recommendation to eat a nutrient-dense breakfast. Unfortunately, the frequency of breakfast consumption has declined over the past several decades (Giovanni et al., 2008). Individuals report several reasons for skipping breakfast, including not having enough time to eat in the morning or simply not being hungry early in the day (Rampersaud, Pereira, Girard, Adams, & Metzl, 2005). However, breakfast consumption is associated with several health benefits (Berg-Kelly, 1995), such as better dietary quality, healthier levels of physical activity, and more successful weight loss and weight loss maintenance.

Breakfast Skipping, Diet, and Physical Activity

Observational work demonstrates several positive links between breakfast and health markers. For example, studies capturing eating habits via diet history questionnaires show that habitually skipping breakfast is associated with lower overall dietary quality (Morgan, Zabik, & Stampley, 1986; Nicklas, Myers, Reger, Beech, & Berenson, 1998) and a lower likelihood of meeting nutrient intake recommendations in children, adolescents, and adults (Preziosi et al., 1999). A cross-sectional correlational study by Sjoberg, Hallberg, Höglund, & Hulthén (2003) demonstrates that omitting breakfast is associated with a less healthy lifestyle, poorer food
choices, and poorer nutrient intake. Individuals who skip breakfast are also more likely to consume excessive calorie-dense foods later in the day (Morgan et al., 1986) and to have higher levels of cholesterol than breakfast consumers (Resnicow, 1991). Overall, research suggests that skipping breakfast is related to dietary patterns that are not conducive to a healthy diet.

Moreover, correlational studies demonstrate that skipping breakfast is associated with lower levels of physical activity in adolescents and adults (Keski-Rahkonen, Kaprio, Rissanen, Virkkunen, & Rose, 2003) as well as school-aged children (Sandercock, Voss, & Dye, 2010). In dieting adults who achieved at least a 30-pound weight loss, those who did not regularly consume breakfast reported engaging in less physical activity than breakfast eaters (Wyatt et al., 2002). Similarly, in a 5-year longitudinal study (Timlin, Pereira, Story, & Neumark-Sztainer, 2008), teens and adolescents who did not eat breakfast daily were less likely to engage in physical activity. Additionally, youth involved in sports report eating breakfast more frequently than their non-sport-involved counterparts (Croll et al., 2006). Such findings lead Wyatt and colleagues (2002) to propose that nutrients consumed at breakfast may leave individuals with greater ability and energy to perform physical activity. Although the directionality of this relationship has not been fully established, skipping breakfast is clearly related to lower levels of physical activity. In conjunction with an increased risk for poor diet patterns, a likelihood of a sedentary lifestyle may place breakfast skippers at a higher risk for overweight/obesity and weight-related issues.

**Breakfast Skipping and Obesity**

Given the relationships between breakfast consumption, diet quality, and physical activity, it is not surprising that skipping breakfast is associated with poorer ability to maintain a healthy weight (DGA, 2010; Wyatt et al., 2002). A 5-year longitudinal study by Ma and colleagues
(2003) found that skipping breakfast was associated with a significant increase in the risk for becoming obese in adults aged 20-70 years. In children, greater weekly frequency of breakfast intake is associated with 30% lower odds of being obese in boys and girls (Boutelle, Neumark-Sztainer, Story, & Resnick, 2002). Adolescents who routinely skip breakfast have been shown to have a higher body mass index (BMI) compared to adolescents who frequently eat breakfast (Rampersaud et al., 2005). Breakfast skippers are not only more likely to become overweight or obese, they are also more unlikely to have success losing and maintaining any weight loss.

Skipping breakfast could hinder the weight loss process, including weight loss maintenance, an important outcome achieved by only a small percentage of individuals who lose weight (Wing & Hill, 2001). Work by Wyatt and colleagues (2002) shows that behaviors that are common to successful weight-loss maintainers include eating breakfast on a regular basis; specifically, 78% of individuals surveyed in this study who maintained their weight-loss reported eating breakfast every day of the week. Further, surveys from the Nationwide Food Consumption Survey of 1996 show that skipping breakfast seems to be less prevalent among successful weight-loss maintainers than among the general public (Haines, Guilkey, & Popkin, 1996). Taken together, these studies suggest that skipping breakfast may represent a barrier to achieving and maintaining a healthy weight.

Despite the positive associations of eating breakfast in the morning (i.e., healthier diet, higher levels of physical activity, and greater success with weight loss), research shows that approximately 10% to 30% of individuals skip breakfast every day (Rampersaud et al 2005). In particular, observational studies have found that relative to lean children, breakfast skipping is more common in overweight and obese children (Serra et al., 2003; Veugelers & Fitzgerald, 2005) and that obese individuals are more likely to fast in the morning in attempt to lose weight.
than lean (Chapman, Melton, & Hammond 2007). Although individuals may skip breakfast as a way to restrict caloric intake to maximize weight loss (Chapman, Melton, & Hammond, 2007), a review of the literature suggests that breakfast consumption is independently correlated with having a lower BMI (Timlin & Pereira, 2007). As such, individuals who regularly skip breakfast in effort to keep their weight lower may unknowingly be working against themselves. Indeed, it is possible that it would be especially important for this group to habitually eat breakfast, given the negative weight and health-related associations with lower frequency of breakfast consumption.

In sum, there are several negative health factors associated with regularly skipping breakfast. Overweight and obese individuals in particular are more likely to habitually fast in the morning in order to lose weight, but could potentially benefit the most from the health behaviors associated with regularly eating breakfast (i.e., better dietary quality, physical activity, weight management). These physical factors are each important to maintaining a healthy lifestyle and ultimately a higher overall quality of life. However, while physical health is vital, the effects of eating breakfast appear to extend beyond external/physical health: a growing body of literature also suggests a positive relationship between consuming breakfast and cognitive functioning.

**Cognitive Repercussions of Skipping Breakfast**

Evidence suggests that breakfast is both acutely and cumulatively beneficial for cognition. In an internet-based observational study, Wesnes and colleagues found habitual breakfast consumption was related to better cognitive performance on tasks of attention (Wesnes, Pincock, Richardson, Helm, & Hails, 2012). Studies show that children who routinely eat breakfast have greater academic performance in mathematics (Murphy et al., 1998, Kleinman et al., 2002) and English (Gajre, Fernandez, Balakrishna, & Vazir, 2008). Correlational studies have also shown
that habitually eating breakfast is associated with higher academic performance in adolescents (Lien, 2006; Boschloo et al., 2012). These findings collectively show a clear relationship between cognitive performance and acute breakfast consumption, though causation is not clear from these observational studies.

To address causation, several studies have been undertaken to experimentally manipulate breakfast consumption (i.e., comparisons of fasted and breakfast-fed conditions). These studies demonstrate that skipping breakfast is acutely associated with poorer performance on tasks of executive functioning, including attention, working memory, and processing speed, as well tasks that require the retention of new information (Conners & Blouin, 1992/3; Mahoney, Taylor, Kanarek, & Samuel, 2005; Martin & Benton, 1999; Wesnes et al., 2003; Widenhorn-Muller, Hille, Klenk, & Weiland, 2008; Defeyter & Russo, 2013). For example, randomized cross-over trials examining fasted and non-fasted states show that children perform significantly worse on tasks of attention (Conners & Blouin, 1983; Wesnes et al., 2003), and exhibit decreased attention and concentration throughout the morning (Defeyter & Russo, 2013) when they do not receive breakfast. Cooper, Bandelow, & Nevill (2011) randomly assigned adolescents to a breakfast eating condition or breakfast skipping condition and found that those who did not eat breakfast had lower accuracy of response on tasks of visual search and inhibitory control. This study suggests that extension of the overnight fast is particularly detrimental on tasks with very high cognitive load. Though a larger sample size was used for this study relative to other similar work, participants chose their breakfast intake ad libitum (i.e., individuals ate as much as they pleased), which may confound effects versus using a meal with a fixed quantity for all participants.

Taken together, these findings suggest that skipping breakfast may negatively impact several important cognitive domains. Studying attention and executive function appears to be
key to understanding the cognitive effects of skipping breakfast. Because executive functioning underlies planning and regulating behavior (Lezak, Howieson, Bigler, & Tranel, 2012), even mild impairments in this domain can have substantial impact on everyday life (Gurd, Kischka, & Marshall, 2010) and important health consequences, specifically in the context of eating patterns (Calvo, Galioto, Gunstad, & Spitznagel, 2014; Galioto, Gunstad, Heinberg, & Spitznagel, 2014). Executive function performance positively predicts making health-conscious choices such as regularly consuming breakfast (Wong & Mullan, 2009). Additionally, Adolphus, Lawton, & Dye (2013) posit that complex attention is an important part of academic and occupational performance; a prerequisite of academic learning is the ability to attend to information learned in class. As such, optimal attention and executive functioning may be important both for better performance at school or work, and also for making better food and weight/health related choices, and thus ultimately for maintaining a healthy lifestyle.

In sum, a pattern of studies show that failing to eat breakfast is related to negative acute and long-term effects on cognitive performance, particularly in domains that have important health and academic implications, such as executive functioning and attention. However, the work done to date regarding the mechanisms of cognitive dysfunction from skipping breakfast has been primarily in healthy, lean individuals. Although obese people are at high risk for skipping breakfast (Serra et al., 2003; Veugelers & Fitzgerald, 2005), the cognitive effects of extending the morning fast in obese individuals has never previously been compared to the effects in lean controls. This area of research warrants further investigation, particularly given the cognitive differences between lean and obese individuals.

**Obesity and Cognition**

Obesity is associated with many negative health consequences, including cardiovascular
disease, type 2 diabetes, sleep apnea, and cancer (Bray, 2004). Evidence suggests that obesity also plays an independent role in cognitive functioning. Overweight and obese individuals exhibit poorer cognitive functioning when compared to lean in a number of cross-sectional studies (Cserjési, Molnar, Luminet, & Lenard, 2007; Elias et al., 2003; Gunstad et al., 2007; Gunstad et al., 2010; Waldstein et al., 2005).

In particular, obese individuals consistently demonstrate poorer performance in domains of attention and executive functioning, cognitive skills that are particularly important in everyday life and that demonstrate significant response to eating versus skipping breakfast. Lean versus obese differences are noted both in self-report and performance-based measures of cognition. For example, obese individuals report more difficulty with focusing attention relative to lean (Braet, Claus, Verbeken, & Vlierberghe, 2007). Similarly, obese individuals demonstrate poorer executive functioning, which underlies planning, organizing, and impulsivity (Lezak, Howieson, Bigler, & Tranel, 2012). These deficits are consistently noted on tests of inhibition, or self-control (Lezak, Howieson, Bigler, & Tranel, 2012) and working memory performance (Gunstad et al., 2007; Gunstad et al., 2010; Waldstein & Katz, 2005), an aspect of executive function and complex attention responsible for storage and manipulation of information (Baddeley, 1992). Elias and colleagues (2002) found that obesity was independently associated with poorer performance on tests of working memory and verbal fluency (tasks often considered to represent attention and executive function; Lezak, Howieson, Bigler, & Tranel, 2012) in middle-aged and elderly men with hypertension. Moreover, Wirt, Hundsdörfer, Schreiber, Keszyus, & Steinacker (2014) showed that obese children displayed significantly lower inhibitory control (i.e., on a Go/No-Go task) compared to lean and overweight children. These studies collectively point to obesity as a potential risk factor for poorer attention and executive functioning. The
mechanism by which obesity may affect cognitive performance is not fully clear, although several factors have been proposed, such as vascular changes (e.g., hypertension, cardiovascular disease; Rahmouni, Correia, Haynes, & Mark, 2005), systemic inflammation (Teunissen et al., 2003), and reduced cardiovascular fitness (Colcombe & Kramer, 2003). One important possible mechanism warranting further investigation is metabolic functioning, particularly the regulation of glucose.

**Glucoregulation: A Potential Mechanism Underlying the Relationship between Obesity and Cognition**

Difficulty with regulating glucose (also known as glucoregulation) is common among obese individuals, even those who do not have type 2 diabetes (Golay & Felber, 1993; Mayega et al., 2013). Obese individuals exhibit greater glucose excursion in response to food (Rizza, 2010), as well as higher levels of fasting glucose (Sinha et al., 2002), a known sign of impaired glucoregulation (American Diabetes Association, 2008). Given that maintaining an optimal level of glucose is necessary for adequate cognitive functioning (Nilsson, Radeborg, & Bjorck, 2007), poor glucoregulation could underlie the cognitive difficulties noted in obese individuals. Even in healthy, middle-aged individuals, abnormalities in glucose tolerance (preceding type 2 diabetes, as measured by oral glucose tolerance tests and laboratory measures of insulin) have negative effects on cognitive functioning (Convit, Wolf, Tarshish, & De Leon, 2003; Espeland et al., 2011; Fontbonne, Berr, Ducimetiere, & Alperovitch, 2001; Lamport, Dye Mansfield, & Lawton, 2013; Messier, Desrochers, & Gangon, 1999). The exact manner by which glucose affects cognition is not entirely clear, though various hypotheses have been suggested; for example Lamport and colleagues (2013) postulate that the transfer of glucose and insulin across the blood brain barrier and between the intracellular and extracellular fluid in the brain are negatively affected by glucose tolerance abnormalities, thus leading to cognitive deficits.
To date, only one study has demonstrated a direct link between impaired glucoregulation and brain activation as well as cognition among non-diabetic obese adults (Gonzales et al., 2010). In this study, obese persons demonstrated lower fMRI blood-oxygen-level dependent (BOLD) response during a working memory task compared to normal weight controls. The relationship between BMI and BOLD response was mediated by insulin sensitivity, which directly affects the ability to regulate glucose. Poorer glucoregulation thus appears to be implicated in decreased cognitive performance. This relationship may be particularly important in obese individuals, who not only have fasting glucose abnormalities, but are also more likely to skip breakfast, and therefore potentially already more vulnerable to cognitive impairment relative to lean individuals.

The literature regarding the effects of blood glucose level on the brain is complex. Some studies show higher postprandial glucose is associated with better cognitive performance in young adults (Donohoe & Benton, 2010), while others show that the same response is related to decreased executive and attention functioning in older diabetics (Abbatecola et al., 2006). These different findings are likely due to the abnormal glucoregulation seen in diabetics, and possibly to failure to account for BMI in both studies, as higher postprandial glucose is evident within obese individuals relative to lean (Rizza, 2010). In contrast to postprandial glucose, fasting glucose is less well-studied. Although the literature is not fully consistent, it appears that poorer glucoregulation, regardless if in a fasted or fed state, is the main factor in the resulting impairment in cognitive performance, and that improving glucoregulation results in better cognitive performance (Gradman, Laws, Thompson, & Reaven, 1993; Meneilly, Cheung, Tessier, Yakura, & Tuokko, 1993; Ryan et al., 2006).

Given the disruptive effects on normal glucose regulation associated with chronic fasting (Smith et al., 2010), and the relationship between impaired glucoregulation and cognitive
functioning, extending the typical overnight fasting period by skipping breakfast could thus result in greater deficit of cognitive functioning in obese individuals relative to lean. Because breakfast skipping and cognition may have a common underlying factor in this group, (i.e., glucose) the relationship between obesity, skipping breakfast, and cognitive functioning, as well the contribution of glucoregulation, warrants further investigation.

The Current Study

In sum, skipping breakfast has been repeatedly linked to poorer health outcomes as well as poorer cognitive functioning. Obese individuals are at a higher risk of skipping breakfast relative to lean individuals. Additionally, obese individuals demonstrate greater cognitive difficulty than lean, especially in attention and executive function, as well as poorer glucoregulation. Taken together, the literature suggests that obese individuals may be at risk of exacerbating their cognitive vulnerability by skipping breakfast, particularly given the higher likelihood for poor glucoregulation in this group.

Understanding how specific cognitive domains (e.g., attention and executive function) are affected by extending a fast in the morning via skipping breakfast may be particularly important for academic and occupational success. There is a large body of work regarding the effects of skipping breakfast (Benton & Sargent, 1992; Conners & Blouin, 1982/3; Mahoney et al., 2005; Martin & Benton, 1999; Wesnes et al., 2003; Widenhorn-Muller et al., 2008) and the effects of obesity (Elias et al., 2003; Gunstad et al., 200; Gunstad et al., 2010, Waldstein & Katz, 2005) on cognitive functioning. However, despite the cognitive importance of eating breakfast and the fact that obese individuals are at risk both for greater cognitive difficulty and skipping breakfast, no study to date has determined if the cognitive effects of skipping breakfast are greater for this group relative to lean individuals. Further, if skipping breakfast affects
cognition differently in these two groups, understanding possible underlying mechanisms (e.g.,
gluco-regulation) will be important.

**Aims/Hypotheses**

The current study examines differences between obese versus lean college students on
neuropsychological tests of executive functioning and attention and fasting peripheral glucose,
and investigates the contribution of gluco-regulation as a possible mechanism for differences in
performance. Specific aims and hypotheses are as follows:

**Aim 1**: Demonstrate that obese and lean individuals differ significantly on measures of
attention and executive functioning.

**Hypothesis 1**: Obese individuals will demonstrate poorer performance relative to lean on
tasks of attention and executive functioning.

**Aim 2**: Demonstrate that cognitive performance on tasks of attention and executive
function change over time (i.e., in an extended fast) in the total sample.

**Hypothesis 2**: Performance on tasks of executive functioning and attention will decrease
over time (i.e., worse performance at 90 minutes than at baseline).

**Aim 3**: Determine if obese individuals will exhibit greater cognitive impairment relative
to lean individuals over time.

**Hypothesis 3**: Weight status (i.e., lean versus obese) and time (i.e., baseline versus 90
minutes) will interact to produce changes in cognitive performance (i.e., attention and
executive function). Specifically, obese individuals will exhibit a larger decrease in cognitive
performance over time compared to lean.

**Aim 4**: Demonstrate that lean and obese individuals differ on fasting glucose.
**Hypothesis 4:** Obese individuals will exhibit significantly higher levels of fasting glucose compared to lean.

**Aim 5:** Demonstrate that fasting glucose changes over time (i.e., in an extended fast) in the total sample.

**Hypothesis 5:** Glucose levels will decrease from baseline to 90 minutes in all participants.

**Aim 6:** Determine whether there will be group differences in fasting glucose changes over time in obese and lean individuals.

**Hypothesis 6:** Obese individuals will show a larger decrease in glucose over time compared to lean individuals.

**Aim 7:** In the event of significant main effects or an interaction in the above aims regarding cognition (Aims 1-3), determine if glucoregulation (i.e., baseline fasting glucose level; Nabb & Benton, 2006) moderates the relationship between cognitive performance and weight status and/or time.

**Hypothesis 7a:** Glucoregulation will moderate the relationship between cognitive performance (i.e., attention and executive function) and weight status; specifically, obese individuals will exhibit poorer glucoregulation, which will account for poorer cognitive performance compared to lean.

**Hypothesis 7b:** Glucoregulation will moderate the relationship between cognitive performance (i.e., attention and executive function) and time in the entire sample; specifically, poorer glucoregulation will account for changes in cognitive performance at 90 minutes compared to baseline.
Methods

Study Design and Participants

The current study is part of a larger trial examining multiple beverages (i.e., milk, juice, and water), which were counterbalanced to prevent order effects. Participants consisted of 70 (35 lean, 35 obese) undergraduate students at Kent State University (57.1% female; average age = 20.84, SD = 2.36). See Table 1 for participant demographics. Participants were recruited via flyers and student newspaper ads on campus. Telephone screening was conducted to exclude participants from the study for the following reasons: if there was past or present diagnosis of diabetes, neurological disorder (e.g. seizure disorder or epilepsy), moderate or severe head injury (defined as loss of consciousness lasting longer than 10 min), heart disease or heart failure, stroke, aneurysm, high blood pressure, bleeding/clotting disorders, severe psychiatric illness (e.g. schizophrenia, bipolar disorder) or current use of psychotropic medication, alcohol or drug dependence (defined by DSM-IV-TR criteria), learning disorder or developmental disability (defined by DSM-IV-TR criteria), diagnosis of Attention Deficit Hyperactivity Disorder (ADHD), or impaired sensory function (e.g. visual or auditory impairment) sufficient to impact testing. Participants were also excluded if they were lactose intolerant, actively attempting to lose weight, or if they experienced weight loss of greater than 20 pounds in the past six months. Lean individuals were classified as having a BMI ranging from 18.5 to 24.9; obese individuals were classified as having a BMI of over 29.9. Upon arrival, participants were excluded from continuing in the study if their BMI did not meet study criteria or if they exhibited fasting
glucose measurement above 126 mg/dL, as measurements higher than this would indicate either non-compliance with fasting restrictions or possible presence of pre-diabetes (American Diabetes Association, 2008).

**Instruments**

**Cognitive Function.** The Automated Neuropsychological Assessment Metrics-4 (ANAM4) is a battery of sensitive computer-based tests designed to assess multiple areas of cognition (www.vistalifesciences.com). The ANAM has good test-retest reliability (0.87; Cole et al, 2013); it has been validated in several studies and demonstrates consistent correlations with traditional neuropsychological measures of similar domains, suggesting adequate concurrent validity (Segalowitz, et al. 2007). Precise measurement of reaction time in these measures allows for detection of subtle changes in cognition (Roebuck-Spencer, Vincent, Gilliland, Johnson, & Cooper, 2013). These tasks utilize both practice sessions and alternate forms in effort to reduce practice effects (Beglinger et al., 2005). The following tests of cognitive function were utilized:

The ANAM4 Go/No-Go (GNG) measures rapid response inhibition (www.vistalifesciences.com) and is sensitive to executive dysfunction (Picton et al., 2007). Participants are continuously presented with a rapid succession of single characters (X or O) and asked to respond when a go stimulus (the letter “X”) is presented, and to withhold response when a no-go stimulus (the letter “O”) is presented. The task lasts approximately 3 minutes, including practice trial and the actual test. Inhibitory control is examined through speed and accuracy (i.e., quickly executing the correct response). The current study utilized GNG commission errors in order to assess failure to inhibit a response, and reaction time (milliseconds) for speed of response.
The ANAM4 Standard Continuous Performance (CPT) assesses sustained attention and vigilance (www.vistalifesciences.com). In this task, individual characters (including foil and target letters) are displayed sequentially. The participant is asked to respond only when the target letter (the letter “B”) is displayed. This task lasts approximately 7 minutes, including practice trial and actual test. The current study utilized CPT reaction time (milliseconds) to capture speeded accuracy on this measure, as well as omission errors (failing to respond when the target letter is displayed) in order to capture drift in attention.

**Medical, Psychosocial History, and Frequency of Breakfast Consumption.** A medical and psychiatric history questionnaire was used as a secondary check of any history not identified through telephone screening that might impact cognitive function (e.g., head injury, substance use disorders, learning disorders, and developmental disorders). Additionally, participants were asked to complete a brief questionnaire at each session to report regular eating patterns (including average frequency of breakfast consumption), past 24 hour sleep, alcohol consumption, and exercise, as well as when they last ate, to further ensure that they met inclusion criteria and followed the study protocol.

**Glucose Measurement.** Blood glucose was measured using the FreeStyle Lite blood glucose monitoring system (Abbot Laboratories, Abbott Park, Illinois, U.S.A.), which utilizes a coulometric electrochemical sensor assay method. Fresh capillary blood was taken via finger stick by a new safety lancet for each measurement. This method is able to detect results ranging from 20-500 mg/dL.
Results

An independent samples t-test revealed participants were approximately equal in age (lean M = 20.47, obese M = 21.15) gender (lean % female = 55.9, obese % female = 57.6), and average breakfast consumption (lean M = 4.54 days per week, obese M = 4.56 days per week); p > .05 for all. Chi square test revealed no significant differences in ethnicity across groups, though the obese group consisted of a higher percentage of Caucasian participants (72.7% versus 58.8% in the lean group; p > .05). An independent samples t-test revealed, by nature of the terms, groups differed significantly in weight and BMI (p < .01). See Table 1 for group demographic information.

Data from three participants were identified as multivariate outliers and removed from analyses. Of note, data were not normally distributed on GNG commission errors or CPT omission errors at baseline and 90 minutes. Transformations including logarithm, square root, and inverse were utilized, but these variables ultimately could not be transformed to reflect a normal distribution. As such, the variables were left as is and the following results reflect non-normally distributed data on those variables. These data are therefore interpreted with caution.
Table 1. *Participant Demographics (n= 67)*

<table>
<thead>
<tr>
<th></th>
<th>Lean (Mean/SD)</th>
<th>Obese (Mean/SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>20.47 (1.62)</td>
<td>21.15 (2.99)</td>
</tr>
<tr>
<td>Sex (% female)</td>
<td>55.9</td>
<td>57.6</td>
</tr>
<tr>
<td>Race/Ethnicity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(% Caucasian)</td>
<td>58.8</td>
<td>72.7</td>
</tr>
<tr>
<td>(% Hispanic)</td>
<td>2.9</td>
<td>0.0</td>
</tr>
<tr>
<td>(% Asian-American)</td>
<td>5.9</td>
<td>0.0</td>
</tr>
<tr>
<td>(% African-American)</td>
<td>23.5</td>
<td>24.2</td>
</tr>
<tr>
<td>(% Other)</td>
<td>8.8</td>
<td>3.0</td>
</tr>
<tr>
<td>Height (inches)</td>
<td>68.91 (3.52)</td>
<td>67.81 (3.69)</td>
</tr>
<tr>
<td>Weight (lbs)**</td>
<td>144.26 (17.39)</td>
<td>243.44 (54.55)</td>
</tr>
<tr>
<td>BMI**</td>
<td>21.62 (1.66)</td>
<td>36.33 (5.97)</td>
</tr>
<tr>
<td># Breakfast per Week</td>
<td>4.54 (1.87)</td>
<td>4.56 (1.81)</td>
</tr>
<tr>
<td>Time Since Last Meal (hrs)</td>
<td>10.90 (2.08)</td>
<td>11.12 (2.49)</td>
</tr>
</tbody>
</table>

*Note:* **p < .01
**Aim 1:** Determine whether obese and lean individuals differ significantly on measures of attention and executive functioning.

A repeated measures mixed MANOVA revealed no significant main effects for weight group status on GNG/CPT reaction time \([F(2,64), p = .156; \Lambda = 0.94; \eta^2 = 0.05]\) or errors \([F(2,64), p = .873; \Lambda = 0.99; \eta^2 = 0.004]\). See Table 2 for lean and obese group differences in cognitive performance.

**Aim 2:** Determine whether cognitive performance on tasks of attention and executive function change over time (i.e., in an extended fast) in the total sample.

A repeated measures mixed MANOVA revealed significant main effects emerged for time on reaction time \([F(2, 64) = 16.16, p = < .01; \Lambda = 0.66; \eta^2 = .33]\). Specifically, there were differences in GNG reaction time speed \([F(1, 65) = 5.916, p = < .05; \eta^2 = 0.08]\), such that reaction time was faster at 90 minutes (M = 317.83; SD = 34.43) compared to baseline (M = 323.10; SD = 33.94) on the GNG in the entire sample. Significant differences also emerged in reaction time on the CPT \([F(1, 65) = 22.03, p = < .01; \eta^2 = 0.25]\) in the opposite direction, such that reaction time was slower at 90 minutes (M = 471.29, SD = 51.61) compared to baseline (M = 450.21, SD = 50.96). No significant main effects for time emerged on for commission or omission errors, though there was a trend toward significance \([F(2, 64) = 2.63, p = .08; \eta^2 = 0.07]\). Further investigation of univariate variables revealed a significant difference on CPT omission errors over time \([F(1,65) = 5.14, p = .03; \eta^2 = 0.07]\) such that more omission errors were committed on the CPT at 90 minutes (M = 0.33, SD = 0.64) compared to baseline (M = 0.16, SD = 0.41) in the entire sample. Given that variables in this model were non-normal and the omnibus model was not significant, these data were interpreted with caution. See Table 2 and Figures 1, 2, and 3 for changes in cognitive performance over time.
Aim 3: Determine if obese individuals will exhibit greater cognitive impairment relative to lean individuals over time.

A repeated measures mixed MANOVA revealed no interaction effects between weight group and time on reaction time \( F(4,62) = 0.932, p = .45; \Lambda = 0.943; \eta^2 = 0.057 \) or errors \( F(2,64) = 0.626, p = .538; \Lambda = 0.02; \eta^2 = 0.02 \) on either task. See Table 2 for lean and obese group differences in cognitive performance.

Figure 1. Changes in GNG reaction time (msec) performance over time in lean versus obese individuals
Aim 4: Determine whether lean and obese individuals differ significantly on fasting glucose.

A repeated measures mixed MANOVA revealed main effects for weight group on fasting glucose \([F(1,65) = 7.67, p < .01; \eta^2 = 0.10]\). Specifically, obese individuals exhibited higher levels of fasting glucose (\(M = 90.27, \text{SD} = 11.83\)) than lean (\(M = 86.85, \text{SD} = 10.28\)) at baseline.
as well as at 90 minutes (obese M = 86.72, SD = 8.21), (lean M = 78.71, SD = 8.22). See Table 2 and Figure 4 for lean and obese group differences in fasting glucose.

**Aim 5**: Determine whether fasting glucose levels change over time (i.e., from baseline to 90 minutes) in all participants.

A repeated measures mixed MANOVA revealed main effects for time on fasting glucose levels \([F(1,65) = 23.20, p < .001; \Lambda = .263; \eta^2 = 0.26]\), such that glucose levels were lower at 90 minutes (M = 82.66, SD = 9.22) compared to baseline (M = 88.53, SD = 11.12). See Table 2 and Figure 4 for changes in fasting glucose over time.

**Aim 6**: Determine whether there will be group differences in fasting glucose changes over time in obese and lean individuals.

A repeated measures mixed MANOVA revealed no interaction effects between weight group and time on glucoregulation \([F(1,65) = 3.59, p = .62; \Lambda = 0.94; \eta^2 = .052]\).

**Figure 4. Changes in fasting glucose (mg/dL) over time in lean versus obese individuals**
### Table 2. Full sample and weight group differences and glucose variables (n=67)

<table>
<thead>
<tr>
<th></th>
<th>Lean (Mean/SD)</th>
<th>Obese (Mean/SD)</th>
<th>Full Sample (Mean/SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reaction Time (msec)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GNG Baseline</td>
<td>314.44(34.87)</td>
<td>332.03(32.08)</td>
<td>323.10(33.94)</td>
</tr>
<tr>
<td>GNG 90 Minutes</td>
<td>311.91(38.97)</td>
<td>323.93(27.09)</td>
<td>317.83(34.43)&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>CPT Baseline</td>
<td>444.79(53.94)</td>
<td>455.78(47.88)</td>
<td>450.21(50.96)</td>
</tr>
<tr>
<td>CPT 90 Minutes</td>
<td>470.91(58.56)</td>
<td>471.68(44.21)</td>
<td>471.29(51.61)&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Errors</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GNG Baseline</td>
<td>5.06(2.17)</td>
<td>5.67(3.36)</td>
<td>5.36(2.81)</td>
</tr>
<tr>
<td>GNG 90 minutes</td>
<td>5.58(3.99)</td>
<td>5.45(3.57)</td>
<td>5.56(3.76)</td>
</tr>
<tr>
<td>CPT Baseline</td>
<td>0.20(0.48)</td>
<td>0.12(0.33)</td>
<td>0.16(0.41)</td>
</tr>
<tr>
<td>CPT 90 Minutes</td>
<td>0.32(0.68)</td>
<td>0.33(0.59)</td>
<td>0.33(0.64)&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Glucose (mg/dL)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline&lt;sup&gt;a,c&lt;/sup&gt;</td>
<td>86.65(10.28)</td>
<td>90.27(11.83)</td>
<td>88.53(11.12)</td>
</tr>
<tr>
<td>90 Minutes&lt;sup&gt;a,c&lt;/sup&gt;</td>
<td>78.71(8.22)</td>
<td>86.72(8.21)</td>
<td>82.66(9.22)</td>
</tr>
</tbody>
</table>

*Note*: a <i>p < .01</i> between time; b <i>p < .05</i> between time; c <i>p < .01</i> between weight groups
Aim 7: In the event of significant main effects or interaction in the above aims regarding cognition (Aims 1-3), determine if glucoregulation moderates relationships between cognitive performance and weight status and/or time.

Aim 7a: Due to the lack of significant findings regarding cognition and weight groups, moderation models were not conducted to detect the role of glucoregulation in cognitive performance between groups.

Aim 7b: Three hierarchical multiple regression models were conducted for each significant finding in cognitive performance differences over time (i.e., GNG reaction time, CPT reaction time, CPT omission errors) to assess for moderation.

A hierarchical multiple regression analysis was run to assess the increase in variation explained by the addition of an interaction term between GNG reaction time at baseline and glucoregulation to a main effects model. Glucoregulation did not moderate the changes throughout the course of an extended fast from baseline to 90 minutes on GNG reaction time, ($b = .00, t(66) = .057, p > .05$).

A hierarchical multiple regression analysis was run to assess the increase in variation explained by the addition of an interaction term between CPT reaction time at baseline and glucoregulation to a main effects model. Glucoregulation did not moderate the changes throughout the course of an extended fast from baseline to 90 minutes on CPT reaction time, ($b = -.009, t(66) = -1.243, p > .05$).

A hierarchical multiple regression analysis was run to assess the increase in variation explained by the addition of an interaction term between CPT omission errors at baseline and glucoregulation to a main effects model. Glucoregulation did not moderate changes throughout
the course of an extended fast from baseline to 90 minutes on CPT omission errors, (b = .008, 
$t(66) = .451, p > .05$).
Discussion

Summary of Findings

The current study examined changes in cognitive performance, fasting differences in cognition and glucose between lean and obese college students, and the potential contribution of glucoregulation to these effects throughout the course of an extended fast. Although lean and obese groups did not significantly differ in cognition, obese individuals exhibited higher fasting glucose throughout the fast. Moreover, the entire sample showed an overall decrease in fasting glucose during the extended fast, during which reaction time became faster on a task of inhibitory control (GNG) and slower on a task of sustained attention (CPT), with a trend toward significance for more errors committed on the latter task. Finally, glucoregulation did not moderate the relationship between cognitive task performance and time for those tasks that did show change (i.e., GNG reaction time, CPT reaction time, and CPT errors). Several aspects of these findings warrant brief discussion.

Differences in GNG and CPT Performance

Examination of GNG and CPT performance in the extended fast produced results that, at first pass, appear to conflict with each other: while the entire sample performed more slowly on the CPT with a trend toward more errors during the course of the fast, performance on GNG was actually faster over time, though no change occurred in accuracy. Given that past research shows that fasting has detrimental effects on cognitive performance, the discrepancy in findings is
unexpected, though not inexplicable. Our findings could reflect greater vulnerability of sustained attention and vigilance compared to inhibitory control in an extended fast. With the exception of one study (Defeyter & Russo, 2013), fasting effects on inhibitory control has not been previously examined, though sustained attention has been frequently examined (Benau et al., 2014). The GNG and CPT inherently measure different constructs (i.e., inhibitory control versus sustained attention and vigilance, respectively; Lezak, Howieson, Bigler, & Tranel, 2012). Thus, differential findings across these measures may simply reflect that the constructs measured respond differently to fasting conditions. Moreover, previous work suggest the cognitive load of a task, or the load a task imposes on an individual’s cognitive system (Paas & Van Merriënboer, 1994), may play a role in the relationship between fasting and cognitive performance (Cooper, Bandelow, & Nevill, 2011), and that cognitive load may also be an important moderator of the relationship between glucose and cognitive performance (Meikle, Riby, & Stollery, 2005).

Although this past research suggests that GNG performance, with its greater working memory load, should potentially have shown greater impairment (rather than improvement) over time, it may be that the greater cognitive challenge of the GNG yielded a different behavioral response to the task. Participants may have perceived the GNG as more difficult, and responded by garnering cognitive resources to confront the challenge; in contrast, the CPT appears to be easier and is also longer, thus participants may have been more likely to experience attentional drift over time.

**Obese versus Lean Cognitive Performance**

In contrast to hypotheses, there were no main effects for weight group or significant interactions between weight group and time for either cognitive task. Our findings suggest that any cognitive difficulty noted in this specific population may be quite mild. Although cognitive
performance changed in the entire sample, the lack of difference between our lean and obese groups suggests that an extended fast does not result in poorer cognitive performance for young, obese individuals relative to lean. One potential reason for the lack of significant differences between groups could be the healthy nature of our sample. Participants were screened and excluded for medical conditions including insulin resistance, hyperlipidemia, and hypertension in an effort to optimally understand the independent contribution of obesity. However, in light of the known links between cognition and such variables (Cox et al., 2005; Waldstein et al., 1996; Zambon et al., 2010), this likely limited the cognitive variability within the current sample. The proposed mechanisms for cognitive changes associated with obesity are often based on disease models, such as microvascular disease and poor glycemic control (de Jongh, Serné, Ijzerman, de Vries, & Stehouwer, 2004; Olefsky, Kolterman, & Scarlett, 1982). These medical issues can undermine frontal systems integrity (Quinque et al., 2012), in turn affecting executive function and attention. Thus, by eliminating individuals with any medical condition potentially impacting cognition (other than obesity), our sample may have been too healthy to find effects. This potentially calls into question the role of obesity as an independent risk factor for cognitive vulnerability. Alternatively, it is possible that the specific cognitive tests used in this sample are simply less sensitive to cognitive effects of obesity than those used in previous studies. For example, results show slower raw score reaction times in obese compared to lean individuals (see Table 2, Figures 1 and 2). These differences were consistent, but not significant, suggesting that a reaction time test with slightly greater sensitivity to lean versus obese differences (e.g., a test of longer duration) might yield significant results.

Changes in Fasting Glucose
As expected, baseline glucose decreased in the entire sample during the course of the fast. Obese individuals exhibited poorer glucoregulation (i.e., higher fasting glucose) relative to lean individuals; this finding is consistent with past research, which shows that obese individuals generally have poorer glucoregulation, even in the absence of clinical glucose impairment. However, this study did not find that baseline glucoregulation moderated the relationship between changes in cognitive performance during the extended fast for either task. Prior work suggests that abnormalities in glucoregulation (e.g., such as in type 2 diabetes) have negative effects on postprandial executive functioning (Meneilly et al., 1993; Lamport, Dye, Mansfield, & Lawton, 2013) and attention (Fischer, Colombani, Langhans, & Wenk, 2001; Papanikolau, Palmer, Binns, Jenskins, & Greenwood, 2006; Nilsson, Radeborg, & Bjorck, 2009; Nilsson, Radeborg, & Bjorck, 2012), although these postprandial findings may not translate to an extended fasting paradigm, such as the one utilized in the current study.

**Limitations**

The current study is not without limitations. First, as described above, this sample was very young and healthy (see exclusionary criteria above), which may have precluded detection of lean and obese group cognitive differences typically observed in the literature (Gunstad et al., 2007; Verbeken, Braet, Claus, Nederkoorn, & Oosterlaan, 2009; Braet, Claus, Verbeken, & Vlierberghe, 2007). In addition, given that we excluded individuals with diabetes, participants were required to have normal fasting glucose levels: those with a fasting glucose of over 126 mg/dL (considered a sign of prediabetes) were excluded from participation. As such, glucoregulation in our sample had limited variability. Exclusion of health factors such as impaired fasting glucose allowed for the current study to address obesity as an independent contributor to cognitive impairment; however, it is possible that inclusion of individuals with
clinically impaired gluoregulation would have provided the variability needed in our sample to
detect differences in cognitive performance. Another potential limitation is the fact that the
current study utilized capillary blood measurements. More precise methods such as continuous
glucose monitoring or oral glucose tolerance testing may have served as more sensitive measures
of gluoregulation, though these methods are more burdensome for participants. Additionally,
the non-normal distribution on omission errors for the CPT may be a limiting factor and suggests
a potential ceiling effect: although most participants did not commit any errors on either the
GNG or CPT, those committing more than a few (i.e., four or five) errors were classified as
outliers. Again, our ability to detect differences may have been improved with greater variability.

Strengths

The current study also has important strengths. Although hypotheses regarding lean and
obese differences were not supported, our findings noting cognitive changes in the context of an
extended fast have more general implications for breakfast skippers. For example, the negative
effects of skipping breakfast on sustained attention in this sample suggest it may be important to
promote regular breakfast consumption, as attention is an important part of cognitive functioning
which contributes to several cognitive domains; as such, fasting-induced inattention may have
significant implications for academic and occupational success (Adolphus, Lawton, & Dye,
2013). Although past studies have examined postprandial cognitive differences in weight groups
and gluoregulation (Lamport, Chadwick, Dye, Mansfield, & Lawton, 2014), no work to date
has conducted this type of fasting comparison. Additionally, past work examining cognition in
lean and obese individuals in the context of gluoregulation has been conducted only in middle
aged and older adults (Lamport et al., 2014). The current study contributes to the literature by
examining this question in a college student sample, an important age group in understanding
breakfast consumption. College students are at increased risk of adopting unhealthy eating patterns (Nelson, Story, Larson, Neumark, Sztainer, & Lytle, 2008; Huang et al., 2003), and the likelihood of breakfast consumption decreases with age (Rampersaud et al., 2005); thus, college students are an important sample for future work.

**Future Directions**

The current study presents several other possible directions for future work. Given that significant differences were not found between weight groups in cognitive performance, future studies may wish to consider implementing a longer fasting period, as a longer duration may allow for better detection of impairment. However, the length of the fast in the current study was chosen in order to maintain ecological validity in examining effects of skipping breakfast. A longer fast might elicit significant group differences, but would not reflect “normal” fasting, as it is uncommon for individuals to skip both breakfast and lunch (Wells, Read, Idzikowski, & Jones, 1998). Further, because the current study excluded participants with clinically impaired glucoregulation, future studies may benefit from including these individuals (i.e., those with higher fasting glucose levels), as it would possibly allow for detection of cognitive impairment. Moreover, medical comorbidities that are likely to lead to both cognitive impairment and difficulty with glucoregulation (i.e., obesity, type 2 diabetes) increase with age, and older adults are more vulnerable to these deficits (Hassing et al., 2004; Yaffe et al., 2004; Walther, Birdsell, Glisky, & Ryan, 2010). As such, work similar in nature to the current study is necessary in an older population, though interventions in college students may help establish healthy habits early on. Moreover, future studies may consider utilizing measures that are more difficult and therefore more likely to elicit group differences in such a young, healthy sample. For example, working memory tasks (e.g., N-back tests) require individuals to manipulate information for
complex cognitive operations and involve an executive control mechanism that is recruited to focus attention and combat interference (Lezak et al., 2012); as such, inclusion of working memory tasks may require more cognitive resources and thus allow for greater detection of group differences. Additionally, although the literature primarily shows fasting effects in aspects of both attention and executive functioning, particularly in reaction time (Benau et al., 2014), postprandial work points to the potential role of glucoregulation in memory tasks (Messier, Desrochers, & Gagnon, 1999; Greenwood, Kaplan, Hebblethwaite, & Jenkins, 2003; Lamport et al., 2014). As such, future studies examining cognition in a fasted state may consider utilizing memory-related tasks in addition to executive function/attention tasks.

**Summary of Findings**

In summary, the current study examined the effects of an extended fast on cognitive performance, fasting differences in cognition between lean and obese college students, and the potential contribution of glucoregulation to these relationships. The entire sample showed an overall decrease in fasting glucose during the extended fast, during which reaction time became faster on a task of inhibitory control and slower on a task of sustained attention with a trend toward significance for more errors committed on this task. Lean and obese groups did not significantly differ in cognition, although obese individuals exhibited higher glucose throughout the fast. Glucoregulation did not moderate the relationship between changes in cognitive performance over time, possibly due to limited variability in glucoregulation in this sample. These findings suggest that a sustained attention task is vulnerable to the effects of an extended fast, though an inhibitory control task may be less so, and may elicit a performance pattern of “rising to the occasion” to meet a greater cognitive challenge. This study confirms prior work suggesting that healthy obese individuals have higher fasting glucose levels relative to lean, even
in the absence of clinically impaired glucoregulation (i.e., diabetes), though this did not produce significant group differences in cognition. Future studies should consider including participants with clinically impaired fasting glucose levels and extending the fast for longer than one night. Further, different cognitive measures that show greater variability in young, healthy adults may result in more successful detection of differences between lean and obese individuals on cognitive performance.
References


44. Lamport, D. J., Chadwick, H. K., Dye, L., Mansfield, M. W., & Lawton, C. L. (2014). A low glycaemic load breakfast can attenuate cognitive impairments observed in middle aged obese females with impaired glucose tolerance. *Nutrition, Metabolism and Cardiovascular Diseases*.


