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Meal skipping and cognition along a spectrum of restrictive eating

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ABSTRACT

Objective: Inadequate nutrition adversely impacts brain development and cognitive functioning (Pollitt et al., 1983). Studies examining the acute impact of eating regular meals on cognition have reported inconsistent findings, necessitating the exploration of individual differences in samples contributing to equivocal results. The present study examines the impact of skipping lunch on cognitive ability in college-aged students by including eating restraint as a moderator.
Methods: Participants were 99 college-aged students (M = 19.7 years, SD = 1.5) randomized to a blinded 'lunch' or 'lunch-omission' condition, and assessed on memory, attention, processing speed, set shifting, and eating disorder symptomology.
Results: Regressing long and short-term memory on the lunch manipulation, eating restraint scores, and their interaction revealed significant interactions: those who had lunch had superior memory performance, but only for those reporting lower levels of eating restraint. Regressing set shifting speed on the manipulation, those who had lunch had slower set shifting speed than those who skipped, but only for those reporting lower levels of eating restraint.
Conclusions: Results suggest that skipping lunch may have immediate consequences on cognition, however, cognitive enhancing effects may be diminished in the presence of even low levels of eating restraint. Findings highlight the significance of purported subclinical levels of eating restraint and may inform health education strategies.

1. Introduction

Eating breakfast has been reported to have positive benefits on executive functioning processes, including working memory (Galioto & Spitznagel, 2016; Pollitt, Lewis, Garza, & Shulman, 1983). Despite possible advantages of breakfast consumption on cognitive, and putatively, academic performance, 40–45% of college-aged students report skipping breakfast (Deshmukh-Taskar et al., 2010; Galioto & Spitznagel, 2016; Pendergast et al., 2016; Vereecken et al., 2009). While less is known about the cognitive consequences of skipping lunch, data from a sample of 17,361 adults from the National Health and Nutrition Examination Survey found that 26.5% of adults reported skipping lunch, and reported that lunch was the most commonly skipped meal across age groups, followed by breakfast (Krok-Schoen et al., 2019). Notwithstanding the critical synergy of nutrition and academic performance, existing literature indicates that in transitioning from high school to college, students are more susceptible to the development of poor nutritional choices and behaviors, including skipping meals, restricting intake, or relying on foods with low nutrient density (Ferrara, 2009; Gutierrez et al., 2013). With the current uptick in popularity of fasting methods in the general public, meal skipping over long periods of time is becoming increasingly common (Stockman et al., 2018). Understanding the acute and sustained consequences of skipping meals could provide essential information that may help inform the eating choices of young adults.

To date, effects of breakfast consumption are the most frequent focus of study, though studies on meal consumption generally provide inconsistent results around the subsequent impact on cognition. In a

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systematic review, Galioto and Spitznagel (2016) found null outcomes between breakfast consumption relative to no breakfast on tasks of attention, information processing, and executive functioning. Additionally, they report a small but robust improvement in working memory after breakfast. With respect to lunch, some evidence supports this mid-day meal benefiting cognitive functioning (specifically, reading speed and arithmetic reasoning) in adults (Kanarek & Swinney, 1990); however, studies have also found *decrements* in short-term cognitive performance after lunch (Muller et al., 2013). Failure to detect meaningful differences between lunch and no-lunch conditions was also reported in a series of earlier studies (Smith and Miles, 1986; Craig, 1986). Taken together, these results paint a complicated picture for subsequent interpretation. Given the lack of consistency across findings for both breakfast and lunch and the dearth of studies comparing differences in cognition after various meals, it is not yet clear whether or not skipping breakfast versus lunch would result in differential cognitive outcomes. The current paper focuses on lunch given it's prevalence of being skipped above other meals in adults (Ferrara, 2009).

Several limitations of prior work may explain discrepant findings. Sample sizes of meal skipping studies are typically small, with only one third of the studies reviewed randomizing individuals to conditions (Muller et al., 2013). In randomized studies, conditions are not blinded, allowing for the possibility of confounding factors (e.g., effort, motivation) impacting results (Muller et al., 2013). Finally, and potentially most critically, whether or not meal skipping is a one-time occurrence (acute) versus a more habitual behavior (sustained) may differentially impact cognitive functioning. If so, such findings would have important implications for better understanding initiating versus sustaining motivations for food restriction in the form of skipping meals.

Individuals engaging in prolonged, habitual restrictive eating behavior often cite reasons for intentional restriction of food type and amount to influence one's shape and weight (Elran-Barak et al., 2015). Greater endorsement of eating restraint has been shown to be associated with impaired cognitive functioning: Green et al. (1994) found that in 70 female university students and university staff (ages 18–40), those who scored higher on the eating restraint factor of the Dutch Eating Behavior Questionnaire showed poorer immediate memory and longer reaction times on cognitive tasks relative to those who scored lower. Similarly, Rogers and Green (1993) found that in a sample of 55 female adults, those reporting higher levels of restrictive eating performed more poorly on tests of sustained attention and reaction time as compared to individuals reporting lower levels of restrictive eating. Researchers hypothesize that for individuals participating in restrictive eating, impaired cognitive functioning may arise as a consequence of eating restriction on energy metabolism (Green et al., 1994; Rogers & Green, 1993). Relatedly, studies have demonstrated evidence of eating disorder thoughts compromising memory capacity in people with greater levels of eating disorder pathology (Green et al., 1996; Kemps et al., 2006; Kemps & Tiggemann, 2005). Preoccupation with food or body image may thus be another putative mechanism through which cognition is compromised in this population. During college, where cognitive ability is constantly assessed via academic examinations, it is important to consider the role of emerging eating disorder psychopathology on cognitive functioning.

Investigations of controlled dietary manipulation on cognition are rare, particularly in young adulthood. The effects of inadequate nutrition may differentially impact vulnerable youth, such as those who more chronically restrict their caloric intake. Unhealthy eating habits are frequently formed and maintained during college; those exercising restrictive patterns of eating may be at a higher risk for developing dangerous meal-skipping habits and eating disorders (Hoerr et al., 2002; Neumark-Sztainer et al., 1995). The current study attempts to build on prior work by 1) investigating the effects of lunch skipping via a standardized laboratory manipulation, 2) blinding individuals to conditions, and 3) examining the moderating effects of restrictive eating over the past month on cognitive variables (memory, inhibition, set shifting speed, processing speed). Using a sample of college-students allows for the potential identification of a particular threshold of restrictive eating behavior at which differences cognitive functioning may arise. The choice of the cognitive domains in the current study were informed by the existing literature on meal skipping and subsequent impact on cognition (Galioto & Spitznagel, 2016; Gutierrez et al., 2013).The unique attributes of blinding allow participants to respond to cognitive assessments without a subconscious bias about whether or not having a midday meal or skipping a midday meal may influence their performance. Based on previous research, we hypothesized that individuals who are randomized to receive lunch will demonstrate superior cognitive performance across domains relative to individuals who do not receive lunch, but that this association will only hold true for those reporting lower levels of habitual restrictive eating behavior. Given the literature on impaired cognition in individuals with eating disorders who chronically restrict their eating, short-term benefits of having lunch in the present study may not translate to improved performance on a cognitive battery thereafter.

2. Methods

Participants were recruited for a study that employed incomplete disclosure in advertising the study purpose. Eligibility criteria and recruitment are presented in Table 1. The study was framed as an investigation of the effectiveness of a meal replacement shake on food preoccupation. In fact, participants were blindly randomized to receive a ‘lunch’ shake, or a ‘lunch omission’ (Table 2). All study procedures were approved by the Duke University Campus Institutional Review Board (IRB), protocol number C0873. Caloric load for each shake was discussed with a registered dietician and head of the university nutrition services (Franca Alphin, MPH, RDN, LDN, CSSD, CEDRD) regarding comparability to a typical meal/no-meal condition. All shakes were prepared from scratch by the Refrectory Café, a supplier of Duke University nutrition options. Participants were told during the phone screen (and reminded via email the day before the visit) to not eat any food or have any caffeine 2 h prior to their appointment time.

Table 1
Eligibility criteria.[a]

Inclusion criteria
18–25 years old
Interested in trying out a meal replacement shake
Able to read and write in English
Willing to provide consent to be in the study
Able to commute to the Brightleaf lab location
Exclusion criteria
Lactose intolerant
Allergic to nuts

[a] Participants were primarily recruited using flyers and the undergraduate psychology pool, an online resource for participation in research studies in exchange for class credit. Participants could choose to complete the study for course credit or monetary compensation (twenty dollars per hour).

Table 2
Participant flow.[a]

Time	Task	Measure/assessment	Variables assessed
11:00 AM	Affect/Satiety/Energy Questionnaire	Three 1-item self-report	Affect/satiety/energy[b]
11:10 AM	Consume Shake	–	
	Demographic Questionnaire	Qualtrics force-choice questions	Age, Sex, BMI, Race, Class status, Major, GPA, Eating disorder history/current diagnosis
11:30 AM	2 hour wait period	Movie[c]	
1:30 PM	Affect/Satiety/Energy Questionnaire	Three 1-item self-report	Affect/satiety/energy
1:40 PM	Neuropsychological Battery	Wechsler Memory Scale (WMS) Spatial Addition, WMS Verbal Paired Associates Parts 1 & 2, Color Word Interference, Trail Making Test, Continuous Performance Task	Short-term, long-term, and working memory, processing speed, set shifting.
3:00 PM	Post-test Questionnaire[b]	Beck Depression Inventory, State/Trait Anxiety Inventory, Eating Disorder Examination Questionnaire, Manipulation Check	Depression, anxiety, and eating disorder symptomology
4:00 PM	Leave		

[a] Study design was identical in both conditions.
[b] Results from measures of affect/satiety/energy and depression/anxiety are reported in a separate paper.
[c] Movies were randomly assigned to participants; all movies were rated PG: Jaws (1975), My Girl (1991), Indiana Jones (1981), and Mary Poppins (1964).

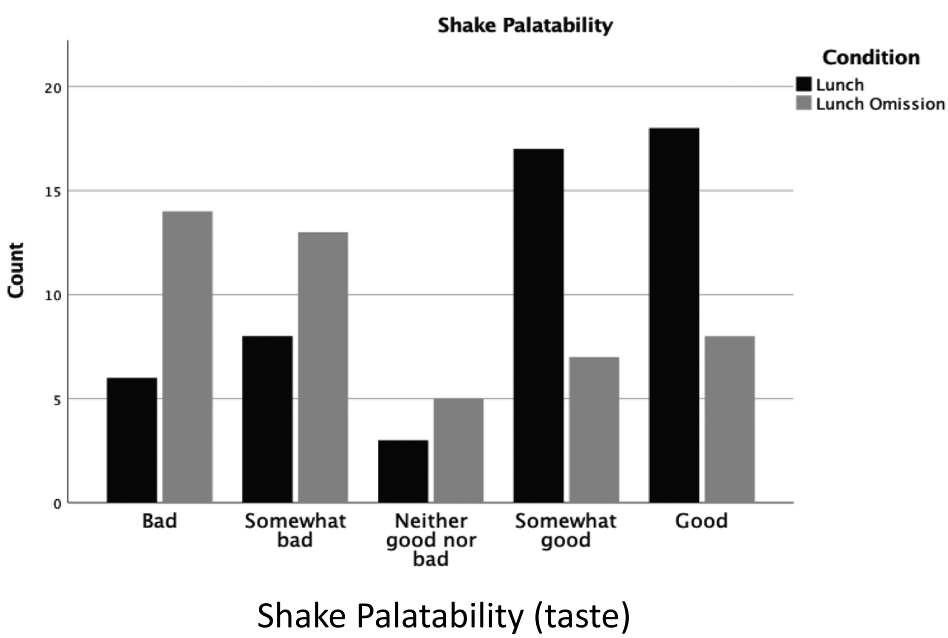

Fig. 1. Shake palatability by condition.

2.1. Randomized conditions

2.1.1. Lunch condition

In this condition, participants consumed a pink 638-calorie shake per 16-ounce serving. The ingredients were: Strawberries, coconut milk, banana, non-fat Greek yogurt, vanilla extract, and hemp protein powder. This shake had 35% of calories from carbohydrates, 6% from protein, and 59% from fat.

2.1.2. Lunch omission condition

In this condition, participants consumed a green 48-calorie shake per 16-ounce serving. The ingredients were: Spinach, water, xanthan gum, ground cinnamon, and natural peanut butter powder (allergies and dietary restrictions were assessed during screening). This shake had 50% of calories from carbohydrates, 33% from protein, and 17% from fat. While the shakes have different sensory properties, the use of xanthan gum helped create a similar consistency and texture between both shakes, despite the difference in hue and caloric properties. The palatability differences between shakes can be found in below in Fig. 1.

2.2. Measures

2.2.1. Sociodemographic characteristics

Participants were given a demographic questionnaire (Table 3).

2.2.2. Eating Disorders Examination-Questionnaire (EDE-Q) (Fairburn & Beglin, 1994)

The global EDE-Q score is comprised of 23 questions assessing the frequency of eating disordered behavior over the past 28 days. These items are rated on a 7-point forced choice scale, from 1 (“No days”) to 7 (“Every day”).[2] The EDE-Q comprised of the average of four subscales: eating restraint, eating concern, shape concern, and weight concern. For the purposes of this study, we exclusively looked at *eating restraint* based on aforementioned hypotheses that restrictive eating behavior

[2] The EDE-Q is typically scored on a 0–6 scale, however, the scoring program applied in this manuscript employed 1–7, thus the interpretation of a 2 (a 1 in the typical version) is 0–5 days.

Table 3
Sample demographics.[a]

Variable: Mean (standard deviation)	Lunch (n = 52)	No lunch (n = 47)
Age	19.60 (1.52)	19.78 (1.61)
BMI	23.04 (2.82)	23.00 (3.74)
GPA (out of 4.0)	3.81 (0.49)	3.75 (0.43)
Sex: # (%)		
Male	13 (13.13%)	20 (20.2%)
Female	39 (39.39%)	27 (27.27%)
Race: # (%)		
Caucasian	24 (24.24%)	21 (21.21%)
African American	7 (7.07%)	5 (5.05%)
Asian/Pacific Islander	17 (17.17%)	15 (15.15%)
Hispanic/Latino	1 (1.01%)	4 (4.04%)
Native American	0 (0%)	1 (1.01%)
Multiracial	1 (1.01%)	0 (0%)
Other	2 (2.02%)	1 (1.01%)
Class status: # (%)		
Freshman	23 (23.23%)	21 (21.21%)
Sophomore	9 (9.09%)	6 (6.06%)
Junior	9 (9.09%)	5 (5.05%)
Senior	6 (6.06%)	9 (9.09%)
Graduate student	2 (2.02%)	3 (3.03%)
Professional student	1 (1.01%)	1 (1.01%)
Other	2 (2.02%)	2 (2.02%)

[a] Of note, none of the sociodemographic variables differed significantly across conditions ($p > .05$) in all cases. Additionally, there were no students pursuing degrees in nutritions or dietetics.

may differentially impact the relationship between cognitive ability and meal skipping. In our sample, internal consistency for the eating restraint subscale score was (α = 0.75), comparable to prior studies where internal consistency has been reported to be (α = 0.70) for eating restraint (Peterson et al., 2007).

2.2.3. Manipulation check

The questionnaires ended with an assessment of participants' impression of the study (to check for efficacy of blinding). Participants were asked (1) whether they answered any questions randomly (yes/no); (2) how they were recruited (free text entry); (3) what they thought the study's purpose was (free text entry); (4) how many calories their shake was (0–800); (5) palatability of the shake (using a 1–5 Likert Scale and the option to provide open ended comments); (6) whether they would use their shake as a meal replacement (yes/no); and, (7) to explain why they would not, if they had selected no to the previous question (free text entry). Palatability data can be found reported in Fig. 1.

2.2.4. Working memory: Wechsler Memory Scale-IV Spatial Addition (Wechsler et al., 2009)

The spatial addition subtest assesses visual working memory ((Wechsler et al., 2009). Specifically, this subtest requires storage, manipulation, and the ability to ignore competing stimuli. From the WMS Technical Manual, normative data is based on a national sample representative of the U.S. population of 1400 adults, divided into 14 different age bands of 100 individuals per band (aged 16–69); in the normative sample for college-aged students, mean scores are (M = 9.9, SD = 2.8) (Wechsler et al., 2009). The spatial addition subtest demonstrates good test-retest reliability: 0.89–0.92 for the 18–24-year-olds age band, and content validity for spatial addition is moderately high (rs = 0.78) (Wechsler et al., 2009).

2.2.5. Short term and long-term memory: WMS-IV Verbal Paired Associates (2-parts) (Wechsler et al., 2009)

WMS Verbal Paired Associates Part 1 assesses short-term memory. Participants recall word pairs after prompted with the first word in the pair. For Part 2, participants recall the same word pairs after a 20-minute delay (long term memory recall). Additionally, participants are asked whether or not both words in a pair were on the original list (long term memory recognition). Verbal Paired Associates demonstrates high test re-test high reliability: 0.93 and 0.84 for the 18–19-year-old age band in Parts 1 and 2 respectively, and 0.94 and 0.84 for the 20–24-year-old age band; content validity for this sub-test is moderately high (rs = 0.76 Part 1; rs = 0.77 Part 2) (Wechsler et al., 2009).

2.2.6. Inhibition and set shifting speed: Delis-Kaplan Executive Function System (D-KEFS): Color Word Interference (Delis et al., 2001)

The Color Word Interference subtest measures both the ability to inhibit a dominant and automatic verbal response and set shifting speed. In condition 1, participants name color patches, and in condition 2, participants read the names of colors printed in black ink. In condition 3 (inhibition), participants inhibit reading words in order to name the ink color in which the words are printed. Condition 4 (set shifting speed) asks the participant to switch back and forth between naming dissonant ink colors and reading words. Taken from the D-KEFS Technical Manual (Delis et al., 2001), normative data was standardized on a nationally representative, stratified sample of 1750 non-clinical children, adolescents, and adults, ages 8–89 years old. Test re-test coefficients in this standardized sample are 0.62–0.76. Content validity is reported to be moderate-high (rs = 0.31–0.60).

2.2.7. Processing speed: D-KEFS: Trail Making Test (Delis et al., 2001)

The Trail Making subtest assesses visual attention and processing speed. Performance provides data regarding visual search speed, scanning, processing speed, and executive functioning, using completion time as the primary performance measure. Test re-test coefficients in the Trail Making Test were reported as high (0.77) (Delis et al., 2001).

2.3. Data analytic strategy

Data met assumptions of normality and no outliers were identified in the dataset using visual examination of skewness and kurtosis and assessment of scatterplots to confirm the use of a GLM model. After linear regression models were run, the Durbin-Watson statistic reflected that residuals were independent. A P-Plot was used to confirm the values of the residuals were normally distributed, and lastly, Cook's Distance statistics for each observation indicated no outliers in the data biasing the model. The pattern of missing data were assessed prior to analyses and identified to be missing completely at random (MCAR), Little's MCAR test was non-significant for the EDE-Q restraint (χ^2 = 4.78, p = .44) and for change in satiety (χ^2 = 4.20, p = .99). Thus, listwise deletion, or the removal of incomplete cases from data analyses, was used as the missing data approach used for scoring questionnaires and subsequent analyses (Peugh & Enders, 2004). This method was chosen as appropriate due to missing data in the current study being missing completely at random.

Multiple linear regression analyses were used to investigate the relationship between the dependent variables (short term memory, long term memory, working memory, set shifting, inhibition, and processing speed) and predictor variables (lunch/no lunch condition and level of eating restraint). Models included dummy variables to code group membership (Lunch/Pink Shake = 0, Lunch Omission/Green Shake = 1). Despite random assignment into group membership, the difference in the proportions of sex in each group approached statistical significance (p = .07). Since such differences between group may impact both eating restraint scores and cognitive outcomes, we entered sex a covariate in the model. Similarly, participants reported that the palatability (taste of their shake) different significantly by condition (F (1, 97) = 12.23, p = .001) with a medium effect size (Cohen's d = 0.7), see Fig. 1, below. To account for this difference between groups, palatability was also entered as a covariate in all the analyses reported below. Lastly, to account for variability in what participants may have eaten the 2 h prior to their study appointment, baseline levels of satiety were entered as a covariate into the analyses. Differences in baseline

Table 4
Distribution of eating restraint.

Average score	Interpretation	Frequency	Cumulative %	% endorsed
1	No days	22	22.22%	22.22%
2	1–5 days	39	61.62%	39.39%
3	6–12 days	17	78.79%	17.17%
4	13–15 days	8	86.87%	8.08%
5	16–22 days	11	97.98%	11.11%
6	23–27 days	1	98.99%	1.01%
7	Every day	1	100.00%	1.01%

satiety were not statistically significant between groups ($p = .40$).

The Johnson-Neyman Floodlight technique was used to highlight the entire range of EDE-Q Restraint scores where the simple effect is significant; the border between these regions is known as the "Johnson-Neyman point" (Spiller et al., 2013). Values on one side of this point yield significant differences between groups, values on the other side of the point do not. Thus, this statistical technique highlights the range of values on the continuous predictor for which group differences are statistically significant. All analyses were conducted using SPSS version 25, with an alpha level = 0.05. Figures were produced using JMP version 13. The data that support the findings of this study are available from the corresponding author upon reasonable request.

Of note, no mathematical corrections were made for multiple comparisons (Rothman, 1990). Given that these reported data are from a pilot study, interpretations of the results should be considered liberally and in light of the exploratory nature of this project. *p*-Values for the non-significant interaction terms were > 0.05 are reported in Results, Table 5.

3. Results

3.1. Manipulation check

When asked about the study's purpose, 80 participants (80.81%) reported reasons consistent with the purported intention ("To test the effectiveness of a meal replacement shake"); 12 (12.12%) incorporated eating disorders into the study purpose ("To evaluate anorexia/mental health associated with eating"); and 7 (7.07%) reported not knowing. These data of study intent did not interact with any of the findings reported below.

Participants' estimated calorie content differed significantly by condition ($F(1, 97) = 5.64, p < .05$) with a small effect size (Cohen's $d = 0.27, r = 0.13$). Individuals in the lunch condition estimated their shake to be ($M = 354$, $SD = 139.56$) calories, while individuals in the no-lunch condition estimated their shake to be ($M = 315.12$, $SD = 139.31$) calories. Despite this approximately 39-calorie difference, individuals in the no lunch condition believed their shake was 267 cal more than its actual value. This, in conjunction with participant's beliefs on the study purpose, suggests that incomplete disclosure was successful.

3.2. Moderation for cognition/condition

Multiple linear regressions were conducted to assess whether degree of endorsement of eating restraint moderated the relationship between cognitive outcome variables and the lunch manipulation. The dependent variable of the regression was entered as the cognitive domain assessed, and the predictor variables were entered as condition, continuous EDE-Q restraint scores, and the interaction between EDE-Q restraint scores and condition type. The distribution of EDE-Q restraint scores in this sample can be found modeled in Table 4.

3.2.1. Short term memory

Short-term verbal recall was measured by the WMS Verbal Paired Associates 1. Analyses revealed a significant interaction between condition and eating restraint ($F(4, 98) = 1.93, p = .04$), with a medium effect size, Cohen's $f^2 = 0.10$ (Table 5, Fig. 2). The Johnson-Neyman Floodlight technique identified ranges of EDE-Q restraint scores for which the simple effect of the manipulation was significant (Spiller et al., 2013). Individuals in the lunch condition had superior short-term recall relative to individuals in the lunch omission condition, only when EDE-Q restraint scores were less than or equal to 2.32. 66.32% of the

Table 5
Regression output with Johnson Neyman (JN) points.

Construct	DV (n)	Predictor	Coefficient [95% CI]	*p*	JN	Cohens f
Short term memory	WMS Verbal Paired Associates Part 1 ($n = 99$)	Intercept	50.19 [38.38, 62.00]	.00		
		Sex (Male)	−0.01 [−3.54, 3.52]	.99		
		Palatability	−0.46 [−1.64, 0.73]	.45		
		Satiety	−0.62 [−2.57, 1.34]	.53		
		Condition (Lunch Omission)	−9.87 [−16.67, −3.07]	.01		
		EDE Restraint Subscale	−1.24 [−2.92, 0.45]	.15		
		Condition (lunch omission) × EDE Restraint Subscale	2.75 [0.12, 5.38]	.04**	≤2.32	0.1
Long term memory (recall)	WMS Verbal Paired Associates Part 2 ($n = 99$)	Intercept	12.92 [10.57, 15.27]	.00		
		Sex (Male)	0.22 [−0.48, 0.92]	.54		
		Palatability	−0.04 [−0.28, 0.19]	.72		
		Satiety	0.15 [−0.24, 0.54]	.44		
		Condition (Lunch Omission)	−1.42 [−2.77, −0.07]	.04*		
		EDE Restraint Subscale	−0.22 [−0.55, 0.12]	.20		
		Condition (Lunch Omission) × EDE Restraint Subscale	0.45 [−0.08, 0.97]	.09		
Working memory	WMS Verbal Spatial Addition ($n = 99$)	Intercept	21.16 [16.78, 25.54]	.00		
		Sex (Male)	−1.71 [−3.02, −0.40]	.01*		
		Palatability	0.39 [−0.04, 0.83]	.08		
		Satiety	0.13 [−0.60, 0.85]	.73		
		Condition (Lunch Omission)	−0.75 [−3.27, 1.78]	.56		
		EDE Restraint Subscale	−0.55 [−1.17, 0.08]	.09		
		Condition (Lunch Omission) × EDE Restraint Subscale	0.37 [−0.61, 1.34]	.46		

(*continued on next page*)

Table 5 (*continued*)

Construct	DV (n)	Predictor	Coefficient [95% CI]	*p*	JN	Cohens f
Long term memory (recognition)	WMS Verbal Paired Associates Recognition (*n* = 98)	Intercept	39.57 [38.47, 40.67]	.00		
		Sex (Male)	0.15 [−0.18, 0.48]	.37		
		Palatability	0.01 [−0.10, 0.12]	.90		
		Satiety	0.03 [−0.15, 0.21]	.76		
		Condition (Lunch Omission)	−0.71 [−1.35, −0.08]	.03*		
		EDE Restraint Subscale	−0.09 [−0.25, 0.07]	.25		
		Condition (Lunch Omission) × EDE Restraint Subscale	0.26 [0.01, 0.50]	.04**	≤1.14	0.07
Inhibition	DKEFS Color Word Interference Condition 3 (n = 99)	Intercept	35.42 [21.75, 49.08]	.00		
		Sex (Male)	−0.38 [−4.47, 3.70]	.85		
		Palatability	0.48 [−0.89, 1.84]	.49		
		Satiety	1.06 [−1.20, 3.32]	.36		
		Condition (Lunch Omission)	−2.59 [−10.45, 5.27]	.52		
		EDE Restraint Subscale	−0.33 [−2.28, 1.62]	.73		
		Condition (Lunch Omission) × EDE Restraint Subscale	1.31 [−1.73, 4.35]	.39		
Set shifting speed	DKEFS Color Word Interference Condition 4 (n = 99)	Intercept	48.55 [35.04, 62.05]	.00		
		Sex (Male)	−1.20 [−5.23, 2.84]	.56		
		Palatability	0.76 [−0.59, 2.12]	.27		
		Satiety	0.19 [−2.04, 2.43]	.87		
		Condition (Lunch Omission)	−9.46 [−17.23, −1.69]	.02*		
		EDE Restraint Subscale	−0.93 [−2.86, 0.99]	.34		
		Condition (Lunch Omission) × EDE Restraint Subscale	3.49 [0.49, 6.50]	.02**	≤1.36	0.10
Processing speed	DKEFS Trail Making Test Condition 4 (*n* = 97)	Intercept	58.01 [33.19, 82.83]	.00		
		Sex (Male)	−2.24 [−9.67, 5.20]	.55		
		Palatability	−0.39 [−2.89, 2.10]	.75		
		Satiety	−0.14 [−4.26, 3.98]	.95		
		Condition (Lunch Omission)	−3.63 [−17.92, 10.66]	.62		
		EDE Restraint Subscale	−0.66 [−4.20, 2.88]	.71		
		Condition (Lunch Omission) × EDE Restraint Subscale	3.15 [−2.37, 8.67]	.26		

* Significant main effect.
** Significant interaction.

sample had EDE-Q Restraint scores below this cut off, and 33.67% of the sample had scores above this cut-off.

The dashed line indicates the specific level (2.32) of EDE-Q restraint scores at which short-term memory loses significance between conditions. The area of significance is to the left of the dashed line; the area to the right of the dashed line is non-significant. A small jitter was applied to data points for visual clarity.

3.2.2. Long term memory

Long-term memory was measured by the WMS Verbal Paired

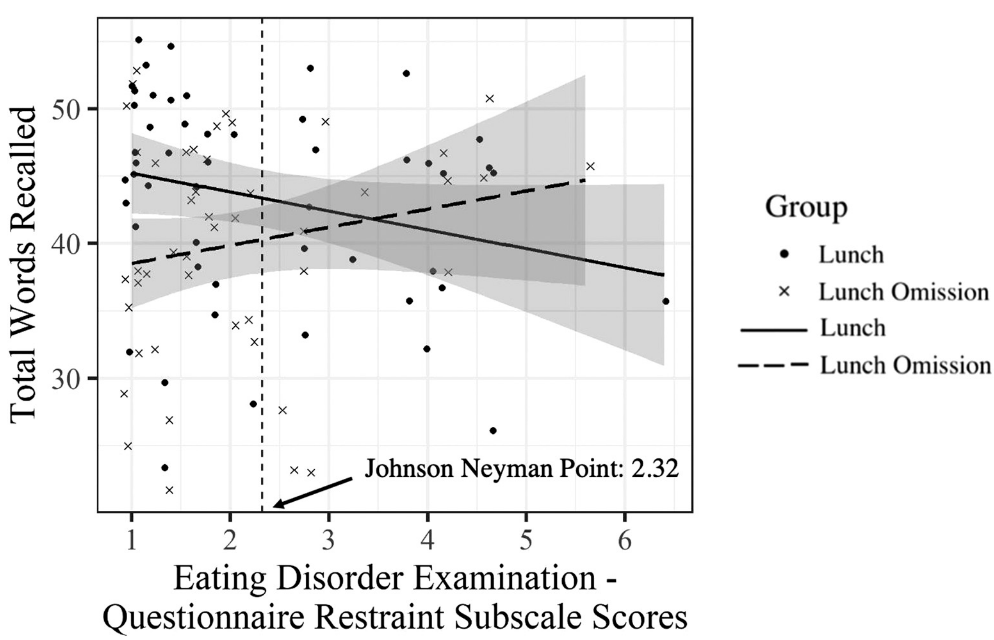

Fig. 2. Short term memory interaction plot.

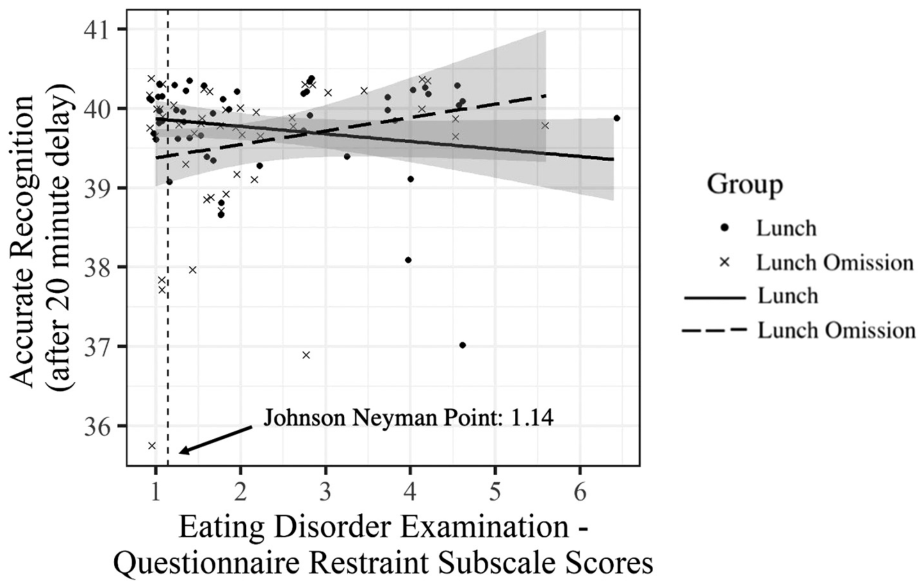

Fig. 3. Long term memory interaction plot.

Associates Part 2 (recall) and WMS Recognition. The simple effect of condition on WMS recognition was moderated by differences in EDE-Q restraint, F (4, 98) = 1.40, p = .04, with a medium effect size, Cohen's f^2 = 0.10 (Table 5, Fig. 3). Individuals in the lunch condition had superior long-term recognition ability relative to individuals in the lunch omission condition, when EDE-Q restraint scores were less than or equal to 1.14. 22.7% of the sample had EDE-Q Restraint scores below this cut off, and 77.32% of the sample had scores above this cut-off.

The dashed line indicates the specific level (1.14) of EDE-Q restraint scores at which long-term memory loses significance between conditions. The area of significance is to the left of the dashed line; the area to the right of the dashed line is non-significant. A small jitter was applied to data points for visual clarity.

3.2.3. Set shifting speed

Set shifting speed was measured by the DKEFS Color Word Interference condition 4. Analyses revealed that the simple effect of condition on set shifting speed was moderated by differences in EDE-Q restraint (F (4,98) = 2.02, p = .02), with a medium effect size, Cohen's f^2 = 0.10 (Table 5, Fig. 4). Individuals in the lunch omission condition had significantly faster set shifting times than individuals in the lunch condition, only when EDE-Q restraint scores were less or equal to than 1.36. 29.6% of the sample had EDE-Q Restraint scores below this cut off, and 70.4% of the sample had scores above this cut-off.

The dashed line indicates the specific level (1.36) of EDE-Q restraint scores at which set-shifting speed loses significance between conditions. The area of significance is to the left of the dashed line; the area to the right of the dashed line is non-significant. The y-axis represents time; thus, greater scores on the y-axis indicate poorer performance.

3.2.4. Inhibition, processing speed, working memory

There were no significant interactions between condition and EDE-Q restraint for working memory (p = .47), inhibition (p = .43), and processing speed (p = .25) (Table 5).

4. Discussion

Previous investigations of cognitive functioning and meal skipping

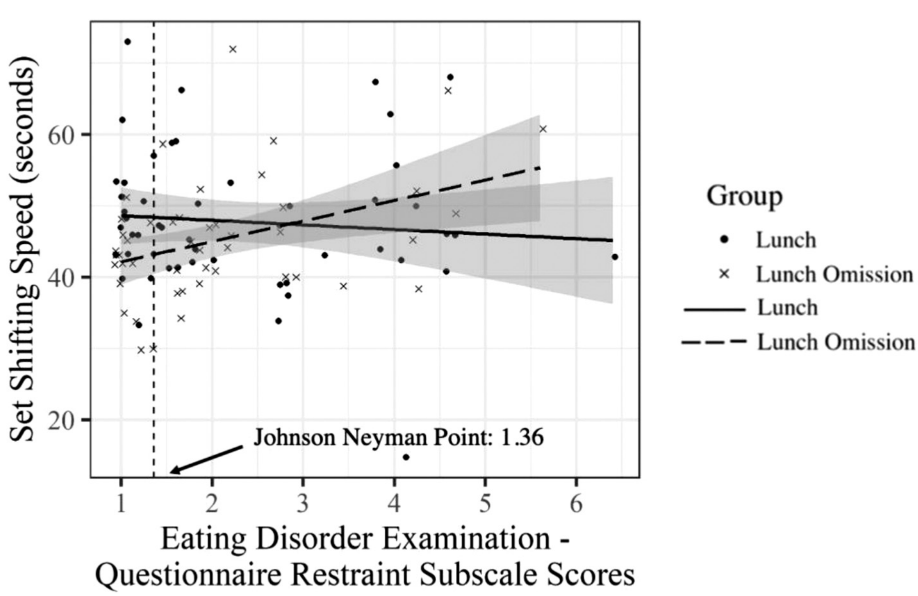

Fig. 4. Set shifting interaction plot.

behavior have produced equivocal findings; one logical moderator previously suggested in research has been individual differences in eating disorder behaviors, such as restrictive eating or skipping essential meals (Muller et al., 2013).The present study included eating restraint as a moderator to clarify the relationship between skipping a meal and the short-term effects of such eating behavior on cognition. Of note, eating restraint was measured by the EDE-Q restraint subscale, and captures both cognitive restraint (e.g., thoughts and efforts to try to reduce intake) and dietary restriction (the number of days a person has gone 8 or more waking hours with deliberately not eating to influence shape/weight). In brief, findings demonstrate that consuming a lunch (of 638 cal) enhances some aspects of cognition: improving short and long-term memory; but diminishes set shifting speed. However, the positive effects of lunch consumption are reduced in the context of higher scores on the EDE-Q Restraint subscale, over the prior 28 days. The current data reflect that not only do cognitive deficits accompany subclinical levels of self-reported restriction in our sample, but also that people restricting or thinking about restricting their eating miss out on experiencing the acute rewarding properties of consuming a meal (such as cognitive enhancements), a factor that may diminish the perception of food as necessary for optimal brain function. This is aligned with existing literature on cognitive deficits accompanying subclinical eating disorder symptomology (Green et al., 1994; Green et al., 1995).

4.1. Implications

4.1.1. Memory

Including eating restraint as a moderating variable revealed that those randomized to the lunch condition had superior short and long-term memory performance, but *only* when eating restraint scores were below a specific threshold. It is possible that after engaging in cognitive/dietary restriction for a week or more, one's ability to learn and encode new information may be impaired as a consequence of preoccupying thoughts and behaviors (e.g., about restrictive eating), irrespective of a short-term change in nutrition. Fairly consistently, research has reported cognitive consequences of prolonged dietary restriction, including impaired memory (Shaw & Tiggemann, 2004). Indeed, Shaw and Tiggemann (2004) suggest that eating disorder cognitions interfere with both immediate and delayed recall in a sample of individuals engaging in long-term dietary restriction. In earlier research, Green et al. (1995) found that those regularly dieting demonstrated poorer immediate free-recall for verbal information relative to non-dieting individuals. They conducted both within and between-subjects designs, suggesting that the impairment was likely attributable to the dieting behavior rather than pre-existing differences. In those meeting diagnostic criteria for anorexia nervosa, similar cognitive impairment is evident (Elran-Barak et al., 2015).

Even at subthreshold levels, cognitive restraint and dietary restriction has been shown to be associated with impaired cognitive functioning (Green et al., 1994; Green et al., 1995; Rogers & Green, 1993). The present study's findings are consistent with current research in eating disorders: higher levels of eating disorder psychopathology, specifically, higher scores on the EDE-Q Restraint subscale, are associated with impaired recall regardless of lunch consumption (Green et al., 1994; Rogers & Green, 1993). Findings also capture a group of subclinical individuals who may be missed by current diagnostic criteria. Additionally, individuals eating regular meals exhibit memory benefits from the consumption of lunch relative to skipping lunch. Consideration of these individual differences in cognitive/dietary restraint may explain prior conflicting evidence reviewed around the cognitive advantages of having meals.

4.1.2. Set shifting

The current study's results present a curious finding contradictory to our prior hypothesis: For individuals with eating restraint scores below a specific threshold, skipping lunch appears to benefit set shifting speed. Keys (1950) survey of seminal animal studies of hunger drive and goal directed activity lends some insight into this finding; reporting "starvation induced hyperactivity", or spurts of activity during acute phases of caloric deprivation related to the periodicity of hunger contractions in the stomach wall (Jenkins et al., 1926; Richter, 1928; Shirley, 1928a, 1928b). This boost in activity is also seen in human models and has been highlighted as a benefit for acute fasting as a weight loss strategy.

Intermittent fasting is a relatively new dieting technique that can involve taking periodic breaks from eating (Collier, 2013). There are various eating patterns involved in intermittent fasting, which do not always involve meal skipping. Of the studies that have investigated implications of cognition after meal skipping patterns of intermittent fasting, Solianik et al. (2016) looked at the impact of a 48-hour fast on working memory, spatial orientation, and set shifting, finding that fasting was associated with significantly faster set shifting times. This is consistent with the present study's findings, for participants with lower levels of eating restraint. However, people endorsing more frequent thoughts of and actual restrictive eating behavior may not experience the aforementioned cognitive benefit.

Indeed, while initial stages of fasting are associated with heightened levels of activity and faster set shifting (Heilbronn et al., 2005; Solianik et al., 2016), sustained caloric deprivation compromises executive functioning, thereby decreasing the initial efficacy of intermittent fasting (Lang et al., 2014). Individuals vulnerable to eating disorders, for whom perfectionism and hyper-sensitivity are prominent, may notice and find "starvation-induced hyperactivity" particularly reinforcing, driving the desire to engage in restrictive eating behaviors (Bastiani et al., 1995; Halmi et al., 2005; Kaye, 2008). However, over a prolonged period of time, caloric deprivation impairs executive functioning, reducing the initial "boost" felt by fasting (Lang et al., 2014).

The present study's results highlight a possible subclinical cutoff at which benefits from cognitive/dietary restraint on set shifting speed in a high-achieving, college aged sample lose efficacy. Data reflect that if participants in our sample are restricting their eating or attempting to restrict their eating for a quarter of the past month or more, implementation of a short-term fast dampens set shifting speed. This data stands to reinforce regular eating habits in college students.

4.2. Limitations

Despite the novel methodology and implications of the present study, results should be considered in light of limiting factors. Insufficient statistical power due to the sample size may have limited the significance of analyses; for current interaction effects the power is ($1 - \beta = 0.74$). Additionally, we did not conduct a pre-lunch assessment of cognitive functioning to avoid carry over effects given our particular neurocognitive battery and possible impact on post-meal assessment performance; instead, participant GPA's were recorded. Future studies may benefit from use of a randomized crossover design to strengthen the methodological approach and eliminate confounds. Additionally, the inclusion of a clinical group for comparison to healthy individuals would be helpful in clarifying differences between conditions across a full range of eating psychopathology.

Additionally, future studies should include a measurement of consumption prior to the lab visit; participants in the present study were informed to not eat/drink 2 h prior to their visit. The present study would have benefited from assessment of adherence to these parameters to control for any deviations from these guidelines. Baseline satiety was not significantly different between groups.

The macronutrient composition and palatability of the two shakes were different; in creating the shakes authors prioritized matching on consistency and adherence to a calorie dense versus a very low calorie shake. The distribution of nutrients has been shown to impact cognition thereafter; thus, future studies should keep the ratio of macronutrients or glycemic index in each shake as consistent as possible to minimize confounds. While palatability was controlled for in the analyses reported, future studies may benefit from adherence to more standard measures of palatability assessment (e.g., 100 mm VAS or 1–9 hedonic rating scale). The current study was more focused on assessment of palatability to determine success in deception.

Additionally, the characteristics of the present study's sample should be considered. All participants were students enrolled at an academically rigorous university. Scaled means on cognitive measures were generally 0.66–2.43 standard deviations above the age-matched normed mean (M = 10, SD = 3). This ceiling is not attributed to inaccurate assessments used; more likely, it is attributed to the particularly high-functioning sample.

4.3. Conclusions

The present study used a novel paradigm to clarify the relationship between meal skipping and cognitive functioning by including variability in scores of cognitive and dietary restraint as a moderator. This study offers new, unbiased associations between meal skipping and cognition in college students, a population for whom data on healthy eating habits could be particularly valuable. Results and implications inform the current literature on meal skipping by beginning to clarify prior equivocal findings. Results may help frame health communication messages: skipping meals may have acute cognitive consequences, highlighting impaired cognitive performance at levels of cognitive and dietary restraint lower than normative clinical cut-offs. Future studies can use the current preliminary findings as a foundation to further investigate the impact of meal skipping on cognition across a spectrum of dietary restriction and cognitive restraint.

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CRediT authorship contribution statement

Nandini Datta: Conceptualization, Methodology, Formal analysis, Investigation, Writing (original draft preparation), Visualization, funding acquisition (NSF Grant) and Project administration; **Tatyana Bidopia:** Investigation, Writing (review and editing); **Samir Datta:** Formal analysis, Writing (review and editing); **Gauri Mittal:** Investigation, Writing (review and editing); **Franca Alphin:** Resources, Writing (review and editing); **Elizabeth Marsh:** Supervision, Writing (review and editing); **Gavan Fitzsimons:** Supervision, Formal analysis, Funding acquisition, Writing (review and editing); **Timothy Strauman:** Supervision, Writing (review and editing); **Nancy Zucker:** Supervision, Conceptualization, Methodology, Funding acquisition, Writing (help in original draft preparation and review/editing). All authors have approved the final manuscript and contributed to the preparation of the manuscript.

Declaration of competing interest

All authors declare that they have no conflict of interest.

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