Habitual Consumption of a High-Fat-Sugar Diet: Disruptions on Hippocampal Memory and Executive Functioning

by

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Table of Contents

List of Tables

List of Figures

List of Appendices

Abstract

There is growing evidence for the role of higher reported saturated fat and refined sugar diet (HFS) in impairing hippocampal-dependent memory. In consonance with animal research, human research showed that overconsumption of a HFS diet may impede the performance on supposedly hippocampal-dependent memory tasks and lead to reduced hippocampal volume. This study examines whether habitual consumption of a HFS diet disrupts performance on well-established hippocampal-dependent tasks and whether the disruption effect is partially mediated by diet's effects on executive functions after adjusting for confounding factors. A total of 349 healthy young adults completed the hippocampal-dependent Pattern Separation and the Associative Memory task, measuring the ability to differentiate among similar memory representations and to form associations between previously unrelated items of information, respectively. Participants also completed a verbal memory task, assessing their word recall and word recognition ability, along with the Everyday Memory Questionnaire (EMQ-R) assessing subjective memory complaints. Furthermore, participants completed two executive functioning tasks: Trail Making and Stroop Task which assesses attention/ cognitive flexibility and the ability to inhibit cognitive interference, respectively. After adjusting for several potential confounding variables, we found that HFS diet predicted worse pattern separation scores and recognition memory accuracy. HFS intake was also significantly associated with poorer TMT task performance. Importantly, TMT task performance partially mediated the relationship between HFS diet and memory performance on the pattern separation task. Taken together, our findings suggest that HFS diet impairs not

only hippocampus-dependent memory processing but also affects executive functioning, which can also indirectly impair memory. The findings are consistent with animal studies and call for further investigations on the psychological and neural mechanisms underlying the dietary effects on cognitive processes.

Keywords: hippocampus, Western diet, memory, pattern separation, executive functioning

Chapter 1

Introduction

Consumption of high saturated fat and refined sugar diets (HFS) has become very prevalent in Western societies in the 21st century (Davidson, 2013). This type of diet, also referred to as the Western-style diet, is characterized by low price, high-energy content, high palatability (Taylor et al., 2021). The diet contributes both to weight gain (Kopp, 2019) as well as to potential memory disturbance. This disturbance has been hypothesized to occur in the hippocampus (Yeomans, 2017), a brain structure that plays a key role in learning, episodic memory, and spatial navigation (Burgess et al., 2002). Animal studies showed that overconsumption of a HFS diet impaired cognitive processes dependent upon the hippocampus (Abbott, 2019; Davidson et al., 2005), as evidenced by rats that were maintained on a HFS diet showing deficits in learning spatial information, accompanied by poorer neural plasticity within the hippocampus (Molteni et al., 2002). Other studies also reported impaired hippocampal-dependent place recognition but not object recognition in rats within only one week of exposure to HFS diet (Beilharz et al., 2014; Tran & Westbrook, 2015).

Despite the preliminary evidence from animal research, only limited literature provided some evidence that HFS diets may adversely impact hippocampus-dependent memory in humans as well (Taylor et al., 2021). According to the Vicious Cycle of obesity model (VCM) proposed by Davidson et al. (2005), regular consumption of a HFS diet leads to hippocampus dysfunction, resulting in impaired inhibitory control mechanisms, and thus further overconsumption of a HFS diet, leading to cumulative hippocampal disruption.

1

In line with the VCM model, several studies indicated that appetitive control declined after exposure to a Western-diet, which correlated with performance declines on potentially hippocampal-dependent memory tasks (Attuquayefio et al. 2016; Stevenson et al., 2020). For example, studies reported that HFS interfered with performance on Hopkins Verbal Learning Test (Attuquayefio et al., 2017), California Verbal Learning Test (Ashby-Mitchell et al., 2015), as well as verbal pair associates (VPA) and logical memory (LM) subsets from the Weschler Memory Scale (Attuquayefio et al. 2016; Brannigan et al., 2015; Francis & Stevenson, 2011), that could all be sensitive to hippocampal damage (Aslaksen et al., 2018; Bonner-Jackson, 2015; Clark et al., 2018; Saling et al., 1993). Similarly, neuroimaging studies reported that HFS consumption was associated with decreased left hippocampal volume, suggesting that this type of diet specifically impacts the hippocampal function (Jacka et al.,2015; Stadterman et al., 2020).

However, previous studies relied mainly on verbal memory tasks to test the disruption effect of diet on hippocampal function. Neuroscience research has shown that the hippocampus and its anatomical wiring and neural firing properties are crucial for supporting relational binding of the individual elements together and forming coherent representations (Davachi, 2006). It is also critical for successful discrimination among similar experiences (Yassa & Stark, 2011). Therefore, other neuropsychological tests that rely on these hippocampal processes are necessary to make more robust inferences about the diet-induced effects on the hippocampus.

First, the hippocampus is involved when creating memory links between individual components and contextual information (Mayes et al., 2007), tested by administering an associative memory task. This task involves instructing participants to memorize item pairs, such as face-name pairs, and testing their recall of these pairs. Sperling and colleagues (2003) indicated that the ability to form associations between previously unrelated items of

information, such as names and faces, is an essential aspect of episodic memory function and that anterior regions of the hippocampal formation are crucial for successful associative encoding. To date, only a couple of studies used an associative memory task (e.g., using creature-scene pairings) in testing prepubescent children and found a negative correlation between intake of saturated fat acids intake and task accuracy (Baym et al., 2014). It was also reported that intake of added sugar was negatively correlated with eye movement measures of relational memory (Baym et al., 2014).

Another process that relies on the hippocampus is pattern separation, which assesses the ability to avoid confusion between similar memories (Yassa & Stark, 2011). In tasks that examine pattern separation, participants are usually instructed to learn different stimuli (e.g., everyday objects) and after a delay, instructed to identify the items (Stark et al., 2013) that not only include the learned and new items, as in regular memory tasks, but also unlearned items that are very similar to the learned items (i.e., similar lures). Pattern separation rate is then calculated and used to represent participants' ability to avoid memory interference, i.e., correctly identifying similar items by differentiating them from the new ones. Studies have determined pattern separation to be a fundamental hippocampal process (Kassab & Alexandre, 2018 Stark et al, 2013; Yassa & Stark, 2011) and a crucial part of the episodic memory in which similar experiences are stored and retrieved as distinct memories (Zotow et al., 2020). Both human and animal studies have argued that the dentate gyrus of hippocampus (Stark et al., 2013; Yassa & Stark, 2011) and its projections to the CA3 subregion play a key role in pattern separation (Bakker et al., 2008). Therefore, given the hippocampal involvement in these processes, in order to provide converging evidence for the role of HFS in disrupting hippocampus function, we need to examine participants' performance on the aforementioned well-established associative memory and pattern separation tasks in relation to diet, in addition to verbal memory (Bonner-Jackson et al., 2015).

Furthermore, there is possibility that HFS diet may also impact executive functions, besides the hippocampal memory. Allom and Mullan (2014) demonstrated that slower executive functioning, specifically involving the disruption of inhibitory control, is associated with greater intake of fatty foods. Nyaradi et al. (2014) also reported that performance on the Groton Maze Learning test, assessing spatial working memory performance and processing speed (Pietrzak et al., 2008), was associated with the level of consumption of the Western diet at age 14. A meta-analysis also reported that obese participants have broad impairments on executive functioning and that overweight participants display deficits on inhibition and working memory performances (Yang et al., 2018). Considering that executive attention and episodic memory are also strongly related (McCabe et al., 2010) and that attention has a significant impact on encoding and subsequent retrieval (Duff et al., 2005), if diet disrupts executive functioning, it may also indirectly impact memory performance. Although a few studies reported that the association between diet and hippocampal function was not mediated by attention or general cognitive function (Francis and Stevenson, 2011), it is still unknown whether poorer memory performance in HFS consumers is due to dietary effects on the hippocampus or other brain regions that support different executive functions such as the prefrontal cortex.

To address these unanswered questions, in the current study, in addition to dietary assessment, we gave participants two hippocampal memory tasks, Associative Memory and Pattern Separation. Associative memory task allowed us to measure participants' ability to remember face-name associations whereas the pattern separation task allowed us to measure the ability to differentiate between memory representations with similar features. We also gave participants two executive functioning tasks, Trail Making Task, and Stroop task, to measure attention/ cognitive flexibility (Bowie & Harvey, 2006) and ability to inhibit cognitive interference (Scarpina & Tagini, 2017), respectively. We also included a verbal

memory task to see if consistent results with the literature showing a negative relationship between HFS diet and verbal memory would emerge. Furthermore, in order to explore the association between diet and subjective memory complaints, we gave a self-assessment memory measure.

In order to make inferences about the association between diet and memory, it is crucial to consider many factors that may affect or covary with diet and cognitive function. These factors may impact the relationship between diet and cognitive performance, through either altering consistency of food intake and performance on cognitive tasks. For example, stress and sleep deprivation can lead to increased appetite and energy intake of highly palatable foods (Berg Schmidt et al., 2018; Shlisky et al., 2012) and impair performance on hippocampal memory tasks (Alzoubi et al., 2013; Kim et al., 2015), which can be ameliorated by increased levels of physical exercise (Hueston et al., 2017). In addition, eating behaviors such as eating disinhibition, restraint, and hunger levels (Stunkard & Messick, 1985) may alter the consistency of food intake (Francis & Stevenson, 2011) and increased BMI can impact memory recall performance (De Wit et al., 2017). Memory recall is also affected by increased age (Danckert & Craik, 2013) and gender (Koss & Frick, 2017). In order to control for these effects and detect the unique effect of HFS on cognition, we included questions of demographic information, Body Mass Index (BMI), mood/general distress, physical activity, sleep, and dietary behaviors.

Utilizing two different non-verbal hippocampal-dependent memory and executive functioning tasks, a different verbal memory measure, and controlling for key confounding factors allowed us to address the unanswered questions. We hypothesize that higher HFS intake will predict poorer performance on the associative memory and the pattern separation task, in addition to verbal memory and self-report of daily memory failures, even after controlling for confounding factors. We also hypothesize that higher HFS diet will predict

poorer performance on executive functioning tasks. Given the association between executive functioning and memory, we anticipated that the diet effects on memory would be reduced but remain significant after controlling for executive functioning performance., i.e., HFS diet's effect on memory can be partially mediated by its effect on executive functioning.

Chapter 2

Methods

Participants

A total of 349 (180 males, 158 females, two others, i.e., not identify as male or female) participants took part in the study. Nine participants were excluded due to not meeting the age criteria. This resulted in a final sample of 340 participants. The amended sample's age range varied from 18 to 35 (M= 29.51, SD= 3.88). Detailed demographic information is presented in Table 1.

All participants were recruited via Amazon Mechanical Turk (MTURK) using Cloudresearch (formerly TurkPrime; see Litman et al., 2017). We only used Cloudresearch-approved sample to ensure the quality of the online data. This involved blocking participants with duplicated IP addresses; blocking participants with suspicious geocode; and only including participants with a verified USA location.

Research has shown that MTURK provides a viable and generalizable sampling technique (Gerlich et al., 2018). In addition, MTURK participants' attentiveness on online attention checks was shown to be better than subject pool participants' (Hauser & Schwarz, 2016). We included a total of nine attention check questions and found that 95.13% of the participants answered all correctly. Given that no participants got more than one attention check question incorrect, we did not exclude them from our analyses.

Based on self-report, all participants reported to be non-diabetic, having no history of eating disorders, and were not on a weight loss diet. They were not using prescription medication (excluding contraceptive pills).

This study was presented using Qualtrics software. At the beginning of the study, participants were made aware of their right to withdraw at any time throughout the study. Informed consent was obtained electronically from all participants in accordance with the Institutional Review Board's guidelines (Appendix A). Total completion time of the study was 30-40 minutes long. Participants were debriefed at the end of the study through an online post- debrief document that they can download to their computer (Appendix B). Participants received compensation of $5 upon successful completion of the study. This study was determined to be exempt from ongoing review by Health Science and Behavioral Sciences Institutional Review Board.

Psychopy software was used for programming memory and executive functioning tasks and presented online using Pavlovia platform (Peirce et al., 2019). Qualtrics software was used for presentation of all questionnaires, including the DFS questionnaire that measures participants' HFS intake, as well as confounding measures of sleep, physical activity, diet-related behaviors, depression, anxiety, and stress level. We also used Qualtrics software to present the verbal memory task. Participants' responses to cognitive tasks and questionnaires were recorded through both platforms.

Dietary Assessment

Dietary Fat and Sugar Short Questionnaire (DFS-SQ) was administered to measure participants' HFS intake level (Appendix C). The Dietary Fat Sugar Questionnaire (DFS-SQ; Francis & Stevenson, 2013a) asks participants to recall the frequency of their consumption of 24 food and drink items over the past year which are either high in saturated fat or refined sugar, or both (such as red meat, pork, fried chicken, salami, sausage, bacon, high-fat salad dressing, butter, eggs, pizza, cheese, French fries, potato chips, doughnuts, cakes, cookies, ice cream, pancakes, chocolate, lollies, spreads, sports drinks, soft drinks, full-fat milk, sweetened beverages, white bread). This questionnaire also assesses the frequency of added

sugar (in beverages, cereal, and food) and restaurant-prepared food consumption (McDonald's, KFC, Mexican, etc.). Higher scores on the scale indicate a greater intake of saturated fat and refined sugars. Research has shown that the measure is valid and reliable for assessing saturated fat and sugar intake (Francis & Stevenson, 2013a). Reliability analysis conducted with our sample of 340 participants also confirmed good internal consistencies of the scale, Cronbach's α=.85.

Memory Measures

Three different memory tasks were used to measure hippocampal memory performance: pattern separation task, associative memory task, and verbal memory task. In addition, subjective memory complaints were assessed using the Everyday Memory Questionnaire-revised (EMQ).

The Pattern Separation Task. The pattern separation task had encoding and delayed retrieval phases. All instructions and stimuli were based on Stark et al. (2013) and were derived from: https://github.com/celstark/MST/tree/master/InstructionalVideos and https://github.com/celstark/MST/tree/master/Set%204 from Set 4.

First, participants were instructed to study 24 different object images, each presented for 3 seconds on the screen. Between the presentation of pictures, there was a fixation cross presented for 0.5 seconds. Participants were instructed to respond to the images as either "indoor" or "outdoor" objects by pressing keys (i) or (o) on their keyboard, respectively.

A retrieval task was given after a short delay (*M*= 158.2 seconds, *SD*=11.52) in which participants completed the TMT (See Figure 1). At the retrieval stage, participants were presented with a total of 72 images and instructed to judge whether the image is "old", "similar", or "new". Among the 72 images, "old" images were identical to the initial 24 images that have been studied. "Similar" images consisted of similar yet non-identical images that have been studied. "New" images consisted of completely novel pictures. Participants

were instructed to judge the 72 images as old, similar, or new by pressing the keys v (old), b (similar), and n (new) on their keyboard (See Figure 2). The images were presented for 3 seconds maximum on the screen and terminated when a response was made. The order of the pictures in the encoding and retrieval phase was randomized across participants.

Two scores were obtained from the pattern separation task. The first score, called the "pattern separation score (PS score)", was obtained by calculating the ratio of correct identification of similar items minus the ratio of "similar" responses given to new items (Stark et al., 2013). We also calculated the "Old-item hit rate" score, derived from the correct identification ratio of old items. This score represented participants' recognition memory accuracy as it assessed the ability to distinguish among similar representations when attempting to correctly identify the previously presented items.

Associative Memory Task. Participants were instructed to study 18 face images paired with a name for the associative memory task. The face images were taken from an open-source face database, Face Research Lab's London set (Debruine & Jones, 2017). All faces were Caucasian with neutral facial expressions. Face images included only the face area (see Figure 3 for example fact stimuli). A common English first name (e.g., Emily or David) was presented along with the face image. The names all had 5 letters and were chosen from the Social Security Administration website (https://www.ssa.gov/oact/babynames/decades/names1990s.html). Each pair was presented for 3 seconds on the screen. In every trial, participants were instructed to respond to the question: "Would the face and name fit together?" Participants were instructed to press "1" if they thought the face and name fit together and "2" if they thought the face and name did not fit together.

After a short delay (M=51.61 seconds, SD=14.84) in which participants completed the Stroop task (see Figure 1), a retrieval task was given. In each trial, participants were

presented with face images along with three name options. All three names in each retrieval trial were the names that had been paired with faces in the encoding phase. Each name option had a number assigned to them (1, 2, 3). All 18 names appeared at locations 1, 2, or 3 equal number of times. Participants were instructed to press the number key for the correct name paired with the face shown on the screen. In each trial, participants were given maximum four seconds to make the response (See Figure 1). The trial was terminated after a response was made. The order of the face-name encoding and retrieval trails was randomized across participants.

Associative memory accuracy score was obtained through calculating the ratio of correct identification of face-name pairs for 18 trials.

Verbal Memory Task. The verbal memory task consisted of encoding, delayed free recall, and recognition phases. This task was embedded in the Qualtrics survey. First, participants were instructed to study 12 neutral words during the encoding stage, each presented visually (not verbally) for 2.5 second on the screen. The words were taken from Potter and Keeling's word list 1 (2005). After a delay (M=118 seconds, SD=54), participants completed the free recall task where they were instructed to type as many words as they can remember. Participants were given one minute to complete the free recall task. The first score, named "Word Recall" was calculated from this phase of the task, corresponding to the ratio of the number of correct reproduction of words from memory out of the 12 words previously presented. Minor typos and plurals were counted as corrected responses.

After the free recall stage, participants completed the recognition task. In this phase, participants were presented with 18 words (12 learned and 6 unlearned "lure" words) and were asked if they had previously studied the words. 6 unlearned words were taken from Potter and Keeling's word list 2 (2005). Participants responded as either "yes" or "no" to the 18 words presented. Hit rate was derived the ratio of correctly identifying learned words.

False alarm rate was derived from the ratio of incorrectly identifying a lure (unlearned) word as learned. Then, to derive the "Word Recognition score", false alarm rate was subtracted from the hit rate.

Subjective Memory Impairment Assessment. The Everyday Memory Questionnaire-revised (EMQ-R; Royle & Lincoln, 2008) was administered to assess subjective memory impairment in daily life (Appendix D). EMQ-R asks participants to recall the frequency of their memory failure with 13 items. Higher scores indicate greater memory impairment complaints. Previous studies showed that this measure is a valid and reliable for assessing memory impairment complaints (Royle & Lincoln, 2008). Reliability analysis conducted with our sample of 340 participants also confirmed good internal consistencies of the scale, Cronbach's α=.93.

Executive Functioning Measures

Two different tasks were used to measure executive functioning performance (EF): Trail Making Task (TMT) and Stroop task. EF measures allow to assess attention alternating ability/sequencing and cognitive flexibility as measured by TMT (Bowie & Harvey, 2006); and the ability to inhibit cognitive interference as measured by Stroop (Scarpina & Tagini, 2017).

TMT task. During the initial four task trials, named "unmixed trials", participants were presented with either numbers or letters, but not both, on the screen. For the first two trials, participants were instructed to connect, i.e., using a mouse cursor to touch, a series of letters in alphabetical order (A, B, C...H). When letters were connected correctly by the cursor, a line would be drawn between the connected letters. Participants had to connect the letters correctly in order to complete the trial. Participants were instructed to complete the task as fast as they can. Thus, the reaction times were used to measure their performance. For

the following two trials, participants were instructed to connect numbers in numerical order (1,2,3...8). The four unmixed trials were used to provide a baseline measure.

Later, participants were instructed to alternate between numbers and letters and connect them in ascending and alphabetical order (1, A, 2, B, 3, C, and so on…) with their cursor until they match eight numbers and eight letters together (… 8, H). This step named the "mixed trial", was completed in a total of four trials.

Before calculating TMT task performance, first, we excluded trials with unreasonably long reaction times (trials larger than 3 standard deviations of all trails from all participants). Only 42 out of 2720 trials were excluded. After this exclusion, we calculated the TMT reaction time difference (TMT-RT differences)" between the mixed and unmixed trials to reflect the attention switching cost in the mixed trials while controlling for basic cognitive processes involved in both trails (e.g., motor speed, letter/number identification, etc.). To do so, we first multiplied the unmixed trials reaction time by two and subtracted this reaction time from mixed trials. We multiplied the unmixed trial's reaction time by two because these trials consisted of 8 sequences, while mixed trials consisted of 16 sequences.

Stroop Task. Participants were instructed to name the color of the ink used to print the color word on the screen. Three color words were presented in either a congruent (e.g. word RED presented in red ink) or an incongruent (e.g. word RED presented in blue ink) condition. Participants were asked to respond as quickly and as accurately as possible. This task required overcoming interference between the word meaning and the word color perception and participants should base answers solely on the color of the ink of the word, ignoring the word meaning. Participants were presented with a total of 60 trials and were instructed to respond to the color of the word by pressing the keys r (red), g (green), and b (blue) on their keyboard. If participants did not respond to a trial within 3 seconds, the next trial would start.

Two scores, one reflecting reaction time and the other accuracy, were obtained for the Stroop task. We calculated the Stroop reaction time difference (Stroop RT differences) score, by subtracting the average reaction time of the congruent trials from that of the incongruent trials. The second score called the "Stroop Accuracy" was obtained by calculating the ratio of correct identification of word colors for all 60 trials.

Confounding Factors

In addition to obtaining demographic information, participants completed several questionnaires to obtain the following control measures: Body Mass Index (BMI), eating behaviors, stress, anxiety, depression, sleep, and physical activity. All questionnaires were presented using Qualtrics software.

Demographics. Participants were instructed to complete a demographic questionnaire regarding age, gender, education level, and ethnicity.

BMI. Participants were asked to provide their height (in foot and inches), and weight (in pounds) to calculate Body Mass Index (BMI), using the formula: $(weight/height^2) \times 703$.

Three-Factor Eating Questionnaire (TFEQ) was included as a confounding predictor, given that cognitive aspects of eating may alter the consistency of food intake (Francis & Stevenson, 2011). TFEQ (Stunkard & Messick, 1985) consists of 51 items, measuring 3 dimensions of eating behavior, i.e., cognitive restraint, disinhibition, and hunger. For example, the cognitive restraint factor asks participants to judge, as true or false, a statement like : "I consciously hold back at meals in order not to gain weight.". Similarly, the disinhibition scale asks to judge the statement: "When I feel lonely, I console myself by eating" and hunger scale asks to judge: "I am so hungry that I eat more than three times a day." The reliability and validity of the TFEQ subscales have been shown to be strong in previous studies (Stunkard & Messick, 1985). Reliability analysis conducted with our sample of 340 participants also confirmed good internal consistencies, overall Cronbach's α=.87.

Cronbach's alpha values were .85, .84 and .88 for separate factors of cognitive restraint, disinhibition, and hunger.

The Depression Anxiety Stress Scales—21 *(*DASS-21; Lovibond & Lovibond, 1995) was administered as another confounding variable. DASS-21 is a self-report questionnaire designed to measure general distress, by assessing the severity of symptoms common to depression, anxiety, and stress over the preceding 7 days (Appendix F). For example, the depression scale asks participants to rate the statement: "I felt that life was meaningless". Similarly, the anxiety scale asks to rate the statement: "I felt I was close to panic" and the stress scale asks to rate: "I found it difficult to relax". The scale shows acceptable reliability, convergent, and discriminant validity (Lovibond & Lovibond, 1995). Reliability analysis conducted with our sample of 340 participants also confirmed excellent internal consistencies of the scale, Cronbach's α=.96

PROMIS—Level 2 Sleep Disturbance—Short Form (American Psychiatric Association, 2013), consists of eight items and is used to measure the severity of sleep disturbance (Appendix G). PROMIS scales were found to have good measurement precision to assess sleep quality and sleep dissatisfaction (Yu et al., 2012). Higher scores on the scale indicate greater sleep disturbance. Reliability analysis conducted with our sample of 340 participants also confirmed excellent internal consistencies of the scale, Cronbach's α=.94.

Physical Activity Habits were assessed using three questions asking participants to estimate the frequency, duration, and intensity of their exercise routines (Francis & Stevenson, 2011). Three scores were highly correlated with one another (r=.53-.68, p<.001) and were summed to give a total physical activity score (Appendix H).

Procedure

A schematic flowchart for the whole study is presented in Figure 1.

The study was first posted on MTurk.com using Cloudresearch Mturk Toolbox. A basic description of the study and the exclusion criteria were also posted. Once participants chose to participate, they were directed to a consent form on Qualtrics.com. After the informed consent was obtained, participants were automatically directed to Pavlovia and instructed to complete the computerized cognitive tasks in the following order: the encoding stage of the pattern separation task, the TMT task, the testing phase of the pattern separation task, the encoding phase of the associative memory task, the Stroop task, and the testing phase of the associative memory task. The completion of the cognitive tasks lasted approximately 15 to 20 minutes.

Next, participants were redirected to Qualtrics where they were presented with demographic questions regarding age, gender, ethnicity, and education level. Participants were also asked to provide their height and weight to calculate BMI. Next, participants completed the encoding stage of the word memory task, the Dietary Fat-Sugar-Short-Questionnaire (DFS-SQ) questionnaire, then the free recall and recognition stage of the verbal memory task. Subsequently, all other questionnaires were presented in the order as follows: Three-Factor Eating Questionnaire, physical activity, Everyday Memory, sleep, and the depression, anxiety, and stress Scale. Participants had to complete a total of nine attention check questions dispersed in the survey. After the participants completed the survey, they were provided with a random ID to input into MTurk to receive compensation. At the final stage, participants were also presented with a debrief document that they can download to their computers. The completion of the questionnaires lasted approximately 15 to 20 minutes. Completion of the entire study was approximately 30-40 minutes.

Statistical Analyses

Data was first checked for missing items, outliers, and wrong data entries. Out of 349 participants who completed the study, 9 cases were excluded due not meeting the age criteria. Another 9 cases had errors entering their height and weight and were not included in the BMI analysis. For TMT, 42 trials with unreasonably long durations ($> 3SD$) were excluded.

For the initial analysis, we first explored the relationship between the different memory measures and how they were associated with executive function measures using Pearson correlation analyses. We also explored the relationship between HFS diet and covariates using Pearson correlations. Then, we explored the relationship between the HFS diet and memory and executive functioning measures using regression analyses.

Next, to test our hypothesis that higher HFS intake will predict poorer performance on the memory tasks and executive functioning, we conducted separate multiple regression analyses. We entered all covariates (age, gender, education, BMI, sleep, physical activity, TFEQ-disinhibition score, TFEQ-hunger score, TFEQ-restraint score, DASS-anxiety score, DASS-stress score, and DASS-depression score) and the DFS measure as predictors. We then entered the following memory and executive functioning measures as outcome variables: Pattern Separation score, Old Item Hit rate, Associative Memory score, Word free recall, Word recognition score, EMQ score, Stroop Accuracy, Stroop RT difference, and TMT RT difference.

Next, to examine whether higher HFS diet predicted poorer performance on the memory tasks after controlling for its effects on executive functioning, executive function measures were entered as covariates to the regression analysis along with the DFS measure for outcome variables. In order to assess whether DFS intake partially affects memory through its effects on executive functioning, we also conducted mediation analyses using PROCESS macro version 4.1 model 4 (Hayes, 2017).

To ensure potential violations of normality did not impact the results, we also bootstrapped the regression and mediation analyses (with 1000 resampling) to obtain bootstrapped significance level using the bias-corrected and accelerated (BCa) method in SPSS version 28.

Chapter 3

Results

Descriptive information for predictor and outcome variables is presented in Table 2.

Correlations Among Different Memory Measures

All memory measures were significantly correlated with one another (See Table 3) (p= .016 - <.001). Participants who performed better on one memory task also performed better on other memory tasks. Participants who reported more subjective memory complaints also performed significantly worse on each of the memory tasks.

Correlations Between Memory Measures and Executive Function Measures

There were also significant correlations between most of the memory task performances and executive functioning performances, except for between Stroop and EMQ (See Table 4) (p= .047 - <.001). Thus, participants who performed worse on most EF tasks also performed worse in most memory tasks.

DFS Correlations with Covariates

There were some significant negative correlations between covariates and task performances as well as the DFS score (See Table 5). Participants who had higher BMI scores also reported higher DFS intake. In terms of eating habits, participants who reported higher hunger levels and disinhibition as well as lower restraint also had higher DFS scores. In addition, participants who reported more anxiety, depression, and stress had higher DFS scores. Correlations among covariates can be found in Table 6.

DFS Predicting Memory and Executive Functioning: Individual Models

We conducted regression analyses to examine how DFS predicts memory and executive functioning measures. Regression analyses showed that DFS negatively predicted PS score, Old-item hit rate, Associative memory accuracy, Word free recall, and EMQ scores. Participants who reported more DFS intake performed worse on most memory tasks except for the word recognition task.

In addition, DFS positively predicted TMT RT difference scores. Participants who reported a higher DFS intake had larger differences in the amount of time it took them to complete the mixed vs. unmixed trials of TMT task. However, DFS did not significantly predict Stroop scores. Scatter plots in Figure 4 illustrate how DFS predicts memory and executive function measures.

Prediction of Diet on Memory Tasks: Controlling for confounding variables

To analyze the prediction of diet on memory performance, we conducted multiple regression analyses for the memory task performances as outcome measures. We entered all covariates (age, gender, education, BMI, sleep, physical activity, TFEQ disinhibition score, TFEQ hunger score, TFEQ restraint score, DASS anxiety score, DASS stress score, DASS depression score) and the main predictor of interest, DFS z-score, to our model. We used the standardized DFS z-score for all regression analyses. All of the analyses were bootstrapped using the bias-corrected and accelerated (BCa) method.

PS Score

We first entered the PS score as the dependent variable. The results showed that DFS significantly predicted PS score after controlling for all covariates, $b=-.058$, $\beta = -.215$, $t=-4.02$, $p<.001$, which was also confirmed by bootstrapped coefficients, 95% Confidence Interval (CI) for b [-085, -.033], $p <.001$ (See Table 7 for detailed results). Semi-partial correlations indicated that DFS uniquely explained 4% of the variance in PS scores ($sr=-.20$).

Among the covariates, anxiety emerged as a unique predictor for PS score, b=-.029, β= -.449, p<.001. Participants who reported higher HFS intake or anxiety had lower PS scores.

Old-Item Hit Rate

A similar analysis was conducted by entering Old-Item Hit Rate score (signifying recognition memory accuracy) as the dependent variable. Results showed that DFS emerged as a significant unique contributor of Old-item hit rate after controlling for all covariates, b= -.029, β = -.163, t=-2.91, p=.004, confirmed by bootstrapped coefficients, 95% CI for b [-.053, -.007], p =.017 (See Table 8 for detailed results). Semi-partial correlations indicated that DFS explained 2.3% of the variance in Old-item hit rate (sr=-.151). In addition, anxiety emerged as a significant predictor for Old-item hit rate, b=-.012, β= -.282, p=.004. Participants who reported higher HFS intake and anxiety had lower Old-item hit rate scores.

Associative Memory

DFS did not significantly contribute to the prediction of associative memory scores after controlling all covariates, β = -.077, t=-1.35, p=.178 (See Table 9 for detailed results). We found that anxiety scores emerged as a significant predictor of associative memory, β = -.35, p <.001. In addition, depression scores emerged as a marginally significant predictor of associative memory performances, β = .17, p =.061. Participants who reported less anxiety performed better on the associative memory task.

EMQ

DFS did not significantly contribute to the prediction of subjective memory complaints after controlling all covariates, β = .064, p =.142 (See Table 9 for detailed results). Only anxiety and sleep scores emerged as a significant contributors to the prediction of subjective memory complaints, β = .404, p< .001; β = .116, p= .018, respectively. Participants who reported more anxiety and sleep problems reported more subjective memory complaints.

Word Recall

DFS did not significantly contribute to the prediction of free recall performance after controlling all covariates, β= -.028, p=.614 (See Table 10 for detailed results). However, hunger and physical activity scores emerged as significant contributors to the prediction of word recall, β= -.255, p=.003; β= .114, p= .048, respectively. Participants who reported less hunger and more physical activity had better free recall scores.

Word Recognition

DFS did not significantly contribute to the prediction of word recognition after controlling all covariates, β= -.005, p= .924 (See Table 10 for detailed results). Only hunger scores emerged as a significant contributor to the prediction of word recognition, β= -.257, p=.003. Participants who reported less hunger also performed better on the word recognition task.

Prediction of Diet on Executive Functioning Tasks

Stroop Accuracy

We conducted similar analyses for executive functioning task scores as we did for memory task scores. The results showed that DFS did not significantly contribute to the prediction of Stroop Accuracy scores after controlling all covariates, β= -.055, p=.337. (See Table 11 for detailed results). Only gender and anxiety emerged as a significant contributors to the prediction of Stroop Accuracy scores. Participants who were male and reported more anxiety had worse Stroop accuracy scores, β= -.133, p= .021; β= -.282, p=.005, respectively.

Stroop RT Difference

The results showed that DFS did not significantly contribute to the prediction of Stroop RT difference scores after controlling all covariates, β= -.045, p=.434 (See Table 12 for detailed results). We found that hunger and disinhibition scores emerged as a significant

contributors to the prediction of Stroop RT difference scores, β= .270, p=.002; β= -.227, p=.012. Participants who reported more hunger but less disinhibition in their eating had larger differences in their reaction times to incongruent vs. congruent trials of the Stroop task.

TMT RT Difference

DFS was a significant unique predictor of TMT RT differences after controlling for all covariates, b=2.19, β= .157, t=2.78, p=.006, which was also confirmed by marginally significant bootstrapped coefficients, 95% CI for b [.476; 4.203], p=.078 (See Table 12 for detailed results). Semi-partial correlations indicated that DFS uniquely explained 2.1% of the variance in TMT RT differences (sr=.146)

Anxiety scores also emerged as a significant predictor of TMT RT differences, b=1.34, β= .397, p<.001. Participants who reported consuming a higher HFS diet and having higher anxiety had larger differences in their reaction time to mixed vs. unmixed trials of the TMT task.

Prediction of Diet on Memory after controlling for Executive Functioning

Initial analyses showed that diet significantly predicted performance on two scores: PS score and Old-item hit rate, after controlling for several potential confounding variables. We conducted further analyses on these results to see whether diet still predicts pattern separation scores and Old-item hit rate after controlling for executive functioning performances. Previous analyses also showed that DFS was a significant unique predictor of TMT RT differences. Therefore, we entered TMT RT difference score as a covariate to our analysis for PS score and Old-item hit rate.

Results showed that diet significantly predicted PS scores even after controlling for all covariates and TMT RT difference performance, b=-.052, β= -.192, t=-3.58, p<.001, which was also confirmed by bootstrapped coefficients, 95% CI for b [-.082; -.021], p<.001 (See Table 7 for detailed results). Semi-partial correlations indicated that DFS explained 3% of

the variance in PS scores after controlling for all covariates and TMT RT differences (*sr*=.176).

We also found that DFS intake significantly predicted Old-item hit rate above and beyond the prediction of all covariates and executive functioning performances, *b*=-.024, *β*= -.131, *t*=-2.36, *p*=.019, which was also confirmed by bootstrapped coefficients, 95% CI for *b* [-.046; -.002], *p*=.032 (See Table 8 for detailed results). Semi-partial correlations indicated that DFS uniquely explained 1.5% of the variance in Old-item hit rate scores after controlling for all covariates and EF performances (*sr*=-.121).

Mediation Analysis

Ps Score

The mediation analysis showed that the indirect pathway from HFS diet to TMT RT differences to PS scores was significant as the bootstrap confidence interval did not include zero, indirect effect= -.0063, 95% CI for *b* [-.0157, -.0010], which was confirmed by Sobel test, *z*= -2.23, *p*= .03. As reported earlier, the direct effect from HFS to PS scores after controlling for TMT RT difference was still significant. Therefore, results indicate that TMT partially mediated the effect of HFS on PS score (See Figure 5).

Old-item Hit Rate

The mediation analysis showed that the indirect pathway from HFS diet to TMT RT differences to Old-item hit rate score was significant as the bootstrap confidence interval did not include zero, indirect effect= -.0057, 95% CI for *b* [-.0136, -.0005], which was confirmed by Sobel test, *z*=-2.01, *p*= .04. As reported earlier, the direct effect from HFS to Old-item hit rate scores after controlling for TMT RT difference was still significant. Therefore, results indicate that TMT partially mediated the effect of HFS on the Old-item hit rate score (See Figure 6).

Chapter 4

Discussion

In this study, we assessed whether habitual consumption of high fat and sugar disrupts hippocampal memory, as evaluated by the ability to separate among similar memory representations (i.e., pattern separation task) and the ability to form associations between items (i.e., associative memory task). In addition, we examined whether that disruption effect is, to some extent, mediated by diet's effects on executive functions after adjusting for confounding factors. First, before controlling for confounds, we found that higher HFS intake was associated with poorer pattern separation score, recognition memory accuracy (i.e., old-item hit rate), associative memory accuracy, word recall score, as well as higher subjective memory complaints. In addition, HFS diet was associated with poorer executive functioning scores, including the TMT RT difference score and Stroop accuracy. Notably, higher HFS intake was still significantly associated with worse pattern separation scores and recognition memory accuracy after adjusting for confounds. HFS intake was also still significantly associated with poorer TMT task performance, indicating worse attention switching ability. Importantly, TMT task performance partially mediated the relationship between HFS diet and pattern separation score and recognition memory accuracy. This suggests that through its partial effects on attention switching ability, a HFS diet may indirectly disrupt the ability to discriminate among similar experiences as well as recognition memory. These findings support previous research showing that consumption of a HFS dietary pattern may disrupt performance on hippocampal-dependent memory tasks (Attuquayefio et al., 2016; Attuquayefio et al., 2017; Brannigan et al., 2015; Francis & Stevenson, 2011;

Stevenson et al., 2020) and executive functioning (Nyaradi et al. 2014; Ramey, 2020).

Habitual HFS consumers also self-reported more instances of memory failures in their daily life, in consonance with their poorer objective memory performance, thereby supporting the association between subjective memory complaints and objective cognitive functions. This finding was also consistent with neuroimaging studies that reported reduced gray matter density and hippocampal volumes in healthy older individuals with subjective memory complaints compared to those without (Weber & Maki, 2016).

Impact of HFS Diet on Pattern Separation, Recognition Memory, and Attention Switching

We included key confounding factors to control for variables that may impact the relationship between HFS diet and cognitive performance. After controlling for confounds, HFS diet expectedly remained a significant unique predictor of pattern separation score and recognition memory accuracy. Findings likely suggest that HFS diets disrupt the ability to discriminate between similar representations, a hippocampal-dependent process, in line with animal findings that transgenerational administration of a Western diet in rats can impair their pattern separation ability (Lange et al., 2018) and human findings showing that habitual HFS diet intake may worsen hippocampal-dependent memory functioning (Attuquayefio et al., 2016; Attuquayefio et al., 2017; Brannigan et al., 2015; Francis & Stevenson, 2011; Stevenson et al., 2020), potentially attributable to disruption in adult hippocampal neurogenesis (Gandy et al., 2017). According to previous studies, reduced hippocampal levels of brain-derived neurotrophic factor (BDNF) levels in response to HFS diets represents one potential mechanism impacting neurogenesis in the hippocampus (Kanoski et al., 2007; Molteni et al., 2002; Pérez-García et al., 2016; Stranahan et al., 2008). This in turn, leads to increased neurodegeneration, and impairments in learning and memory (Lange et al., 2018). Bekinschtein et al. (2013) suggested that BDNF in the dentate gyrus is required to

successfully encode similar representations in humans. It could be that HFS diet impacted the BDNF levels in the dentate gyrus, leading to significantly poorer encoding of similar representations in our pattern separation task. Besides BDNF, other mechanisms involved may be the degradation of the blood-brain barrier (BBB; Hargrave et al., 2016a; Hsu & Kanoski, 2014), production of oxidative stress, insulin resistance (Stranahan et al., 2008), and low-grade inflammation (Więckowska-Gacek et al., 2021).

Findings also revealed that habitual consumption of a HFS diet was associated with poorer recognition memory accuracy (as assessed by old-item hit rate). In our study, recognition memory measure required correctly recognizing the previously presented items (old items) by differentiating them from their similar lures, thus further relying upon pattern separation processes. Therefore, our memory recognition score reflected participants' memory performance through the hippocampus-dependent processes, specifically through their ability to distinguish among similar representations when identifying previously presented items. Previous studies argued that recall of what was recently eaten is part of episodic memory and that hippocampal impairments could result in loosening of this food intake regulation system (Stevenson & Francis, 2017). Given that memory for recent eating bears significance for modulating subsequent food regulation and intake, reduced memory of recent intake may increase future eating (Higgs, 2002; Higgs et al., 2008; Seitz et al., 2021). VCM explains that intake of HFS dietary intake leads to hippocampal dysfunction, resulting in impaired memory of recent intake and poorer inhibition of eating behavior, thus leading to further intake of HFS diet. Therefore, HFS participants' poorer recognition memory in our study may indicate poorer recall of their recent meals (what and how much was eaten) and poorer ability to differentiate between similar eating experiences (what was eaten a moment ago versus earlier in the day). This may then disrupt the regulation of food intake (Kanoski & Davidson, 2011), and result in further hippocampal dysfunction and cognitive disruptions

(Hargrave et al., 2016b), such as overeating, excess weight gain, and more severe forms of cognitive impairment (Davidson & Martin, 2014).

We also found that HFS diet significantly impacted TMT RT difference scores (although not Stroop RT difference scores). This finding suggests that the HFS effect was explicitly related to attention/ task switching ability and cognitive flexibility rather than the ability to inhibit cognitive interference, supporting findings that diet quality was associated with TMT task performance (Wright et al., 2016). Animal research indicated that high-fat diets could lead to impaired task performance through reduced brain-derived neurotrophic factor (BDNF) in both the prefrontal cortex and ventral hippocampus (Kanoski et al., 2007). Therefore, HFS diets could potentially impact other brain regions, such as the prefrontal cortex, supporting executive functions of attention and cognitive flexibility. It should be noted that in an experimental design study conducted by Francis and Stevenson (2011) with a total sample size of 32, TMT task performance was not different across HFS and Low-Fat Sugar consumers. Given that we detected a relationship between HFS intake and TMT task performance with a sample size of 349, it could be that the effects of a HFS diet on TMT is not large and cannot be detected with a small sample size.

Studies have also argued that alternations in executive functioning are linked to engagement in healthy versus unhealthy behaviors, such that greater cognitive flexibility may help adjust behavior in line with weight loss goals rather than engaging in unhealthy choices (Allom et al., 2018; Allom & Mullan, 2014). If HFS disrupts aspects of executive functioning such as cognitive flexibility, it may also exacerbate further engagement in habitual consumption of an unhealthy HFS diet and cause additional cognitive disturbances, thus indicating a reciprocal relationship between executive function and dietary behavior (Allan et al., 2016). However, it should be noted that behavioral inhibitory control was not specifically measured in our study. If future studies demonstrate that HFS diet disrupts performance on a

behavioral inhibitory control task such as the Go/No-Go task, it will clarify the potential relationship between HFS intake and engagement in unhealthy dietary choices.

The finding that word recognition was not inversely associated with HFS intake may suggest that word recognition memory was less sensitive to diet-induced hippocampal changes. Previous studies have asserted that recognition memory relies upon both familiarity and recollection (Merkow et al., 2015). While the hippocampus is critical for recollection (Eichenbaum et al., 2007), the familiarity component may be related to a different set of brain regions other than the hippocampus, such as the perirhinal cortex (Brandt et al., 2016; Squire et al., 2007; Yonelinas et al., 2002; Yonelinas et al., 2005). Therefore, it could be that our word recognition task, which relied strongly upon familiarity, was less sensitive to diet-induced changes compared to the word free recall task. Our results are congruent with animal studies that showed how exposure to a HFS diet impaired place recognition but not object-recognition memory, which relies upon the hippocampus and perirhinal cortex, respectively (Beilharz et al., 2014).

Similarly, after adjusting for confounds, HFS diet was not significantly associated with associative memory. Previous studies have argued that the hippocampus plays a key role when learning new associations, such as when linking arbitrary stimuli together in memory (Brasted et al., 2003; Mayes et al., 2007; Suzuki, 2007). For this reason, we expected to find HFS consumption to have linkage with poorer performance on the associative memory task. In this task, however, we gave participants three name choices (previously matched with a unique face) and instructed them to match the previously studied face with the correct name option. Participants may have relied more on familiarity, dependent more upon the perirhinal activity rather than the hippocampus (Brandt et al., 2016; Squire et al., 2007; Yonelinas et al., 2002; Yonelinas et al., 2005), which, in turn, may have limited task's power to measure hippocampal-related memory. Therefore, it would be premature to conclude that HFS does

not impact associative memory. Instead of giving choices of previously presented answers, future studies could utilize associative memory tasks that require participants to judge item pairs as either intact or reshuffled (Sperling et al., 2003).

Taken together, findings provide evidence that HFS diet may disrupt both hippocampal memory and executive functioning, which may, in turn, impede ability to engage in a healthy lifestyle needed to reverse the consequences (Yeomans, 2017). Given that we controlled for BMI, our findings indicate that diet can impact brain regions in the absence of obesity, disrupting normal-weight young adults' cognitive processing, lending credence to the notion that diet-induced cognitive deficits may precede weight gain rather than vice-versa (Davidson et al., 2013).

HFS diet and Pattern Separation: Attention Switching as a Mediator

According to prior literature, attention and memory are strongly associated, and attentional control mechanisms affect episodic encoding (Chun & Turk-Browne, 2007). This supports the notion that hippocampal-dependent memory function cannot be separated from other cognitive functions supported by prefrontal regions (Francis & Stevenson, 2013b). Therefore, if HFS diets impair executive functions such as attention switching, it may also indirectly impair memory. Our findings likely provide indirect support for recent findings showing that executive functions accounted for the association between a plant-based diet (as opposed to a Western diet) and memory recall in older adults (Ramey et al., 2020), wherein a word learning task was used to assess memory, and animal fluency/ digit symbol task to evaluate executive functioning.

Impact of Confounding Factors

Although not our primary focus, we also found that anxiety levels predicted several performances related to memory and executive functioning. After controlling for anxiety, we found that the prediction of HFS diet on associative memory, subjective memory complaints,

word recall, and Stroop Accuracy was lost. These findings suggest that self-reports of anxiety severity significantly impacted the relationship between diet and certain measures of memory (both objective and subjective) as well as diet and executive functioning. These findings are in line with previous studies which suggest that the emotional state of the participant, including anxiety can affect cognitive performance (Lukasik et al., 2019; Matsumoto & Kawaguchi, 2020), and how anxiety disorders can lead to significant impairments in episodic memory (Airaksinen et al., 2005). Animal research has indicated that chronic stress reduces dendritic branching of the hippocampus and impairs cognitive processes (Cameron & Schoenfeld, 2018, as cited in Albrecht et al., 2020). Furthermore, even short periods of acute stress during juvenility may have a long-lasting impact on anxiety-like behavior and coping in adulthood, accompanied by alterations in core regions critical to stress processing such as the amygdala, prefrontal cortex, as well as hippocampus (Albrecht et al., 2017). Long-term exposure to Western Diet induces hypothalamic-pituitary-adrenal (HPA) axis dysregulation, implicated in anxiety, and has detrimental effects on brain regions such as the hippocampus and amygdala (López-Taboada et al., 2020). According to the findings of one study, HFS impaired spatial learning, increased anxiety, and decreased neurogenesis in the dentate gyrus (Ferreira et al., 2018), a structure particularly crucial for pattern separation (Stark et al., 2013). Therefore, decreased neurogenesis in the dentate gyrus may result in poorer pattern separation abilities, leading to misperception and confusion of stimuli, using inappropriate responses for the actual stimuli, and impairing psychological flexibility, which could then indirectly impact emotional wellbeing (Gandy et al., 2017). Poorer pattern separation may result in overgeneralization of threat expectancies and contribute to clinical anxiety (Bernstein & McNally, 2018; Lange et al., 2017; Leal & Yassa, 2018). However, causality cannot be established within these processes as it is unclear whether HFS diet predicts or is predicted by anxiety level. Future studies could explore how the cumulative effects of HFS

diet and poor pattern separation ability could be related to anxiety disorders, which could then further disrupt pattern separation performance.

Furthermore, we found that physical activity and hunger level were better predictors of word recall performance than diet, coinciding with findings that physical activity can improve learning and encoding of words (Ruscheweyh et al., 2011) and ameliorate stress-induced changes to hippocampal function by attenuating the negative impacts on neurogenesis on cognition (Hueston, 2017). We also found that higher hunger levels were associated with larger RT differences between the congruent and incongruent trials of the Stroop Task. According to Francis and Stevenson (2011), lower hunger scores were linked to better retention on the logical memory task, consistent with our findings. However, it should be noted that the hunger scale from the TFEQ could be influenced by the acute hunger state at the time of testing rather than sensitivity to hunger state (Yeomans & McCrickerd, 2017), suggesting that lower word recall or poorer Stroop RT scores may have been influenced by hunger at the time of testing. Thus, it remains unknown whether HFS diet, sensitivity to hunger, poorer appetite control, or solely the current state of hunger caused impaired word recall and Stroop RT scores in our study.

Limitations

One limitation is the study's correlational nature, as the direction of causality is not entirely clear, i.e., whether HFS diet caused poorer executive functioning, pattern separation, anxiety, or vice-versa. However, experimental design studies support the causal pathway of excessive HFS diet intake leading to disrupted hippocampus functioning (Francis & Stevenson, 2011; Kanoski et al., 2007; Molteni et al., 2002).

Second, this study utilized an online sample of young adults between the ages of 18 to 35 and relied on their self-reported dietary intake. Therefore, there is no clarity on whether more prolonged periods of HFS diet consumption can lead to even poorer cognitive performances in older adults or whether other lifestyle factors will camouflage the effects.

The dietary retrospective self-report is also an indirect measure of dietary intake, usually impacted by socially desirable responses, thus leading to under-reporting (Taylor et al., 2021).

Furthermore, we utilized two different executive functioning measures, focusing mainly on cognitive flexibility and the ability to inhibit cognitive interference. However, it is argued that executive functioning is an umbrella term used for a wide range of cognitive processes and that a single ability measure is incapable of capturing the conceptual scope of executive functioning (Delis, 2012, cited in Goldstein et al., 2014). Hence, future studies would do well to explore whether a HFS diet impacts a wide collection or a limited set of higher-level abilities.

Conclusion and Future Directions

In this study, we have shown that HFS dietary intake is not only associated with poorer hippocampal-dependent pattern separation ability and recognition memory, but also with the poorer executive function of attention alternating ability. More specifically, we demonstrated that poorer attention alternating ability partially mediates the relationship between HFS diet and the ability to separate similar stimuli as well as HFS diet and recognition memory accuracy. Given the lack of human research, our findings are valuable and claim evidence for the role of diet in impairing critical cognitive functioning, which may impede engagement in a healthy lifestyle and contribute to obesity. Future studies could explore this issue by investigating the psychological and neural mechanisms underlying this dietary effect and inform dietary interventions which, in turn, may play a significant role in countering diet-induced cognitive impairment.

Table 1

Demographic Data

Variables		Male	Female	Other
Age	Mean (SD)	29.5 (3.6)	29.6 (4.2)	27.5 (4.9)
Ethnicity	White	122	111	2
	African-American	22	16	0
	Asian	17	16	0
	Arab/Middle-Eastern	0	1	0
	Indigenous	1	0	0
	Latin/ Hispanic	8	6	0
	Other or Mixed	10	8	0
Education	Middle School	1	0	0
	High School	28	20	0
	Technical School	5	7	0
	Some College	37	37	0
	Bachelor's Degree	94	66	2
	Graduate Degree	15	28	0

Table 2

Descriptive Statistics

Variables	N	Mean Score	SD
BMI	331	26.26	5.97
DFS Score	340	58.94	13.12
PS Score	340	52.50%	.27
Old-Item Hit Rate	340	72.46%	.18
Associative Memory Score	340	55.60%	.20
EMQ score	340	12.96	10.71
Word Free Recall	340	35.93%	.24
Word Recognition	340	59.73%	.31
Trail Making Task RT (non-mixed trials total)	340	9.18 seconds	5.90
Trail Making Task RT (mixed trials total)	340	29.65 seconds	21.51
Stroop Accuracy	340	90.01%	15.57
Stroop Congruent RT	340	.80 seconds	.22
Stroop Incongruent RT	340	.93 seconds	.27

Note. DFS Score=Dietary Fat Sugar Score; PS Score=Pattern Separation Score; RT=Reaction Time; EMQ Score=Everyday Memory Questionnaire Score

Table 3

Correlations Among Memory Measures

Memory Measures	1	2	3	4	5	6
1. PS Score						
2. Old Item Hit Rate	.43***					
3. Associative Memory	.40***	.29***				
4. Word Free Recall	.36***	.24***	.34***			
5. Word Recognition	.38***	.33***	.33***	.66***		
6. EMQ	-.24***	-.18**	-.15**	-.13*	-.15**	

* p <.05. ** p<.01. *** p< .001
Note. PS Score= Pattern Separation Score; EMQ Score= Everyday Memory Questionnaire Score

Table 4

Correlations Between Memory Measures and Executive Function Measures

	PS Score	Old-Item Hit Rate	Associative Memory	Word Free Recall	Word Recognition	EMQ
TMT RT Difference	-.26***	-.28***	-.20***	-.15**	-.14**	.13*
Stroop RT Difference	-.18**	-.11*	-.11*	-.21***	-.16**	.07
Stroop Accuracy	.28***	.22***	.34***	.25***	.18***	-.08

* *p* <.05. ** *p*<.01. *** *p*< .001
Note. PS Score= Pattern Separation Score; TMT=Trail Making Task; EMQ= Everyday Memory Questionnaire; RT= Reaction Time.

Table 5

DFS Z-Score and Task Performance Correlations with Covariates

	Age	Gender	Edu	BMI	TFEQ-H	TFEQ-R	TFEQ-D	Depr	Anx	Stress	PA	Sleep
HFS z-score	-.08	-.01	-.05	.11	.28***	-.13*	.26***	.11*	.24***	.16**	-.10+	.09+
PS Score	.16**	-.05	.03	.01	-.13*	-.09	-.12*	-.10+	-.31***	-.15**	.03	.00
Old-Item Hit Rate	.02	.00	-.07	.03	-.15**	-.05	-.12*	-.10+	-.25***	-.17**	.10+	-.07
Associative	.11*	-.02	-.02	-.06	-.07	-.05	-.11*	-.01	-.18***	-.06	.06	.03
Word Free	.11+	-.01	.02	-.04	-.23***	.05	-.14**	-.17**	-.24***	-.19***	.17**	-.12*
Word Recog	.14*	-.01	.02	.01	-.19***	-.01	-.11+	-.18***	-.23***	-.17**	.14**	-.06
EMQ	-.15**	-.10+	-.06	.05	.35***	.10	.36**	.51***	.65***	.60***	-.15**	.41***
Stroop Acc	.03	-.13*	.08	-.03	-.00	-.01	-.03	-.07	-.16**	-.06	.10+	-.04
Stroop RT diff	-.01	-.07	.09+	.05	.15**	.02	.04	.10+	.11*	.10+	-.03	.11*
TMT RT diff	-.03	.03	.04	-.03	.08	.01	.08	.09+	.23***	.10+	-.08	-.01

+ p between .05 and .09 * p <.05. ** p<.01. *** p< .001

Note. PS Score=Pattern Separation Score; Acc=Accuracy; Recog=Recognition; EMQ=Everyday Memory Questionnaire; TMT= Trail Making Task; RT=Reaction Time; Edu= Education; TFEQ-H= Hunger; TFEQ-R= Restraint; TFEQ-D= Disinhibition; Depr= Depression; Anx=Anxiety; PA= Physical Activity

Table 6

Correlations Among Covariates

	1	2	3	4	5	6	7	8	9	10	11	12
1. Age	-											
2. Gender	-.02	-										
3. Education	.13*	-.05	-									
4. BMI	.04	.08	-.08	-								
5. Hunger	-.00	-.11*	.02	.22***	-							
6. Restraint	-.04	-.11*	.10+	-.01	-.12*	-						
7. Disinhibition	-.04	-.14*	.03	.31***	.77***	.01	-					
8. Depression	-.13*	.00	-.06	.11+	.31***	.08	.33***	-				
9. Anxiety	-.22***	-.03	-.08	.07	.35***	.12*	.36***	.71***	-			
10. Stress	-.14*	-.11*	-.01	.09	.34***	.11*	.38***	.79***	.81***	-		
11. Physical Activity	.08	.14**	.07	-.17**	-.20***	.19***	-.23***	-.19***	-.21***	-.15**	-	
12. Sleep	.07	-.15**	-.02	.12*	.26***	.08	.27***	.46***	.42***	.52***	-.10+	-

+ p between .05 and .09 * p <.05. ** p<.01. *** p< .001

Table 7

Regression Analysis Details for PS score

PS Score	b	β	t		b	β	t
First Analysis				*Second Analysis*			
Age	.005	.07	1.36	Age	.005	.08	1.50
Gender	-.024	-.05	-.83	Gender	-.022	-.04	-.81
Education	.000	-.00	-.03	Education	.002	.01	.16
BMI	.001	.04	.68	BMI	.001	.03	.57
Sleep	.003	.09	1.49	Sleep	.003	.08	1.29
Physical Activity	-.002	-.02	-.34	Physical Activity	-.003	-.02	-.44
Hunger	-.003	-.05	-.57	Hunger	-.003	-.05	-.62
Restraint	-.005	-.09	-1.72	Restraint	-.005	-.09	-.1.72+
Disinhibition	.000	.00	.05	Disinhibition	.000	.01	.09
Depression	.007	.13	1.57	Depression	.007	.13	1.59
Anxiety	-.029	-.45	-4.84***	Anxiety	-.025	-.39	-4.15***
Stress	.007	.12	1.13	Stress	.005	.09	.86
DFS z-score	-.058	-.22	-4.02***	DFS z-score	-.052	-.15	-2.84**
				TMT RT difference	-.003	-.19	-3.58***

^{+}p between .05 and .09. * p <.05. ** p<.01. *** p< .001.

Note. Analysis 1 includes all covariates and DFS z-score as predictors for outcome variable PS score. Second analysis includes all covariates, DFS z-score, and TMT RT difference as predictors for outcome variable PS score.

Table 8

Regression Analysis Details for Old-item hit rate

Old-Item Hit Rate	b	β	t		b	β	t
First Analysis				*Second Analysis*			
Age	-.002	-.04	-.74	Age	-.001	-.03	-.58
Gender	-.013	-.04	-.66	Gender	-.012	-.03	-.62
Education	-.013	-.08	-1.57	Education	-.011	-.07	-1.34
BMI	.002	.06	1.18	BMI	.001	.06	1.04
Sleep	.001	.02	.37	Sleep	.000	.01	.09
Physical Activity	.006	.08	1.42	Physical Activity	.005	.08	1.33
Hunger	-.004	-.08	-.98	Hunger	-.004	-.09	-1.06
Restraint	-.002	-.07	-.1.18	Restraint	-.002	-.07	-1.18
Disinhibition	.001	.03	.38	Disinhibition	.002	.04	.42
Depression	.005	.14	1.61	Depression	.005	.14	1.64
Anxiety	-.012	-.28	-2.90**	Anxiety	-.009	-.20	-2.06*
Stress	-.001	-.02	-.17	Stress	-.002	-.06	-.53
DFS z-score	-.029	-.13	-2.36*	DFS z-score	-.024	-.13	-2.36*
				TMT RT difference	-.003	-.20	-3.74***

* p <.05. ** p<.01. *** p< .001.

Note. Analysis 1 includes all covariates and DFS z-score as predictors for outcome variable Old-item hit rate. Second analysis includes all covariates, DFS z-score, and TMT RT difference as predictors for outcome variable Old-item hit rate.

Table 9

Regression Analysis Details for Associative Memory and EMQ

Associative Memory	β	t	EMQ	β	t
Age	.05	.97	Age	-.03	-.72
Gender	-.02	-.34	Gender	-.03	-.72
Education	-.05	-.83	Education	-.03	-.69
BMI	-.04	-.72	BMI	-.05	-1.24
Sleep	.07	1.11	Sleep	.12	2.38*
Physical Activity	.02	.37	Physical Activity	.00	-.00
Hunger	.05	.57	Hunger	.07	1.12
Restraint	-.04	-.73	Restraint	.03	.75
Disinhibition	-.10	-1.06	Disinhibition	.06	.90
Depression	.17	1.88[+]	Depression	.00	.02
Anxiety	-.36	-3.59**	Anxiety	.40	5.37***
Stress	.10	.90	Stress	.15	1.74[+]
DFS z-score	-.07	-1.35	DFS z-score	.06	1.47

[+] p between .05 and .09. * $p <.05$. ** $p<.01$. *** $p< .001$.

Table 10

Regression Analysis Details for Word Free Recall and Word Recognition

Word Free Recall	β	t	Word Recognition	β	t
Age	.07	1.32	Age	.09	1.62
Gender	-.04	-.76	Gender	-.03	-.50
Education	-.01	-.27	Education	-.01	-.11
BMI	.00	.15	BMI	.05	.80
Sleep	-.03	-.53	Sleep	.03	.45
Physical Activity	.11	1.98*	Physical Activity	.10	1.76[+]
Hunger	-.26	-2.97**	Hunger	-.26	-3.00**
Restraint	.01	.19	Restraint	-.04	-.69
Disinhibition	.14	1.63	Disinhibition	.16	1.79[+]
Depression	.05	.52	Depression	-.05	-.60
Anxiety	-.15	-1.54	Anxiety	-.18	-1.82[+]
Stress	-.03	-.30	Stress	.06	.51
DFS z-score	-.03	-.51	DFS z-score	-.01	-.10

[+] p between .05 and .09. * $p < .05$. ** $p < .01$. *** $p < .001$.

Table 11

Regression Analysis Details for Stroop Accuracy and Stroop RT difference

Stroop Accuracy	β	t	Stroop RT Difference	β	t
Age	-.03	-.48	Age	-.02	-.37
Gender	-.13	-2.32*	Gender	-.06	-1.03
Education	.05	.89	Education	.10	1.88^{+}
BMI	.01	.20	BMI	.07	1.19
Sleep	-.03	-.42	Sleep	.06	1.01
Physical Activity	.09	1.50	Physical Activity	.01	.07
Hunger	.00	1.07	Hunger	.27	3.07**
Restraint	-.02	-.37	Restraint	.02	.26
Disinhibition	-.05	-.58	Disinhibition	-.23	-2.52*
Depression	.06	.62	Depression	.02	.16
Anxiety	-.36	-2.83**	Anxiety	.11	1.08
Stress	.10	1.15	Stress	-.05	-.43
DFS z-score	-.06	-.96	DFS z-score	.05	.78

$^{+}$ p between .05 and .09. * p <.05. ** p<.01. *** p< .001.

Table 12

Regression Analysis Details for TMT RT difference

TMT RT Difference	b	β	t
Age	.16	.05	.84
Gender	.36	.01	.24
Education	.79	.07	1.26
BMI	-.08	-.05	-.79
Sleep	-.15	-.09	-1.36
Physical Activity	-.20	-.04	-.61
Hunger	-.09	-.03	-.31
Restraint	.02	.01	.11
Disinhibition	.06	.02	.19
Depression	-.00	.00	-.00
Anxiety	1.34***	.40	4.07***
Stress	-.56	-.20	-1.77[+]
DFS z-score	2.19**	.16	2.78**

[+] *p* between .05 and .09. * *p* <.05. ** *p*<.01. *** *p*< .001.
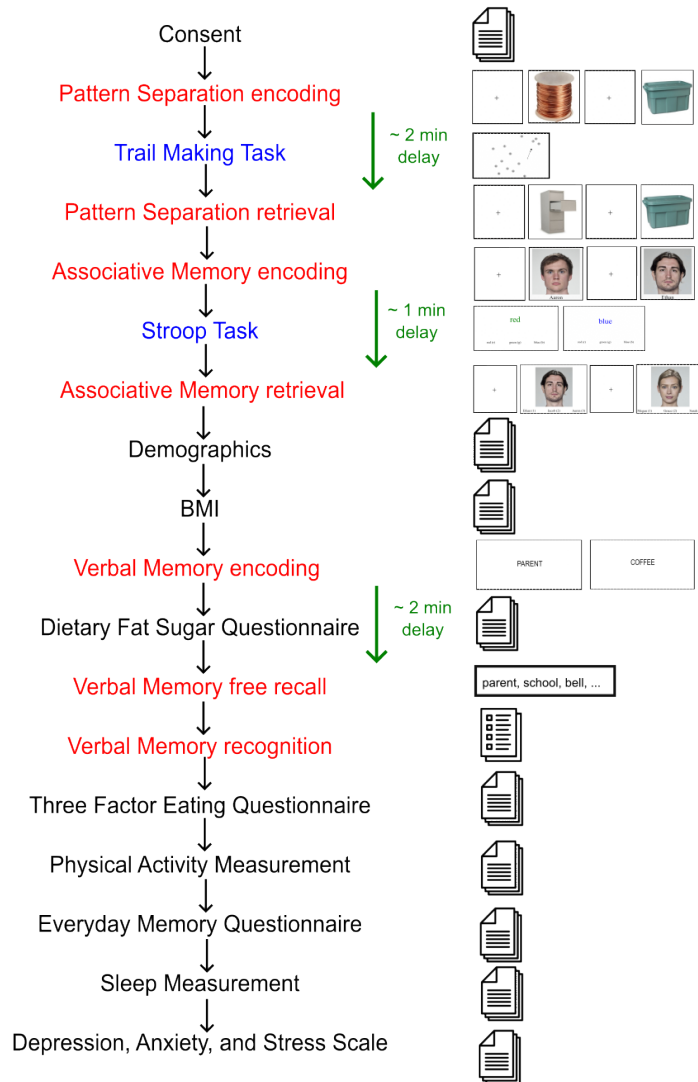
Figure 1. Figure illustrates the study procedure flowchart
Note. Red represents memory tasks and blue represents EF tasks.
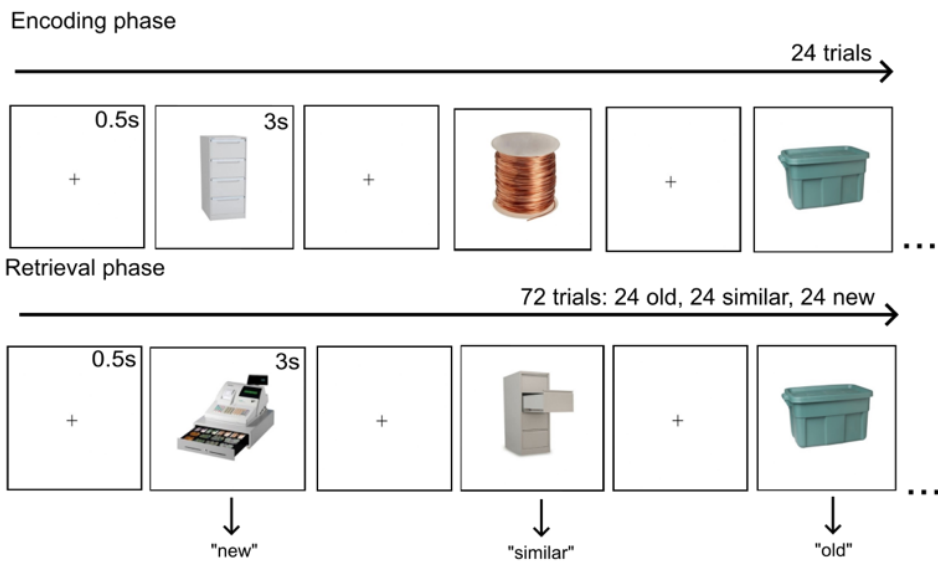
Figure 2. Illustration of the Pattern Separation Task encoding and retrieval phases. Stimuli derived from https://github.com/celstark/MST/tree/master/Set%204
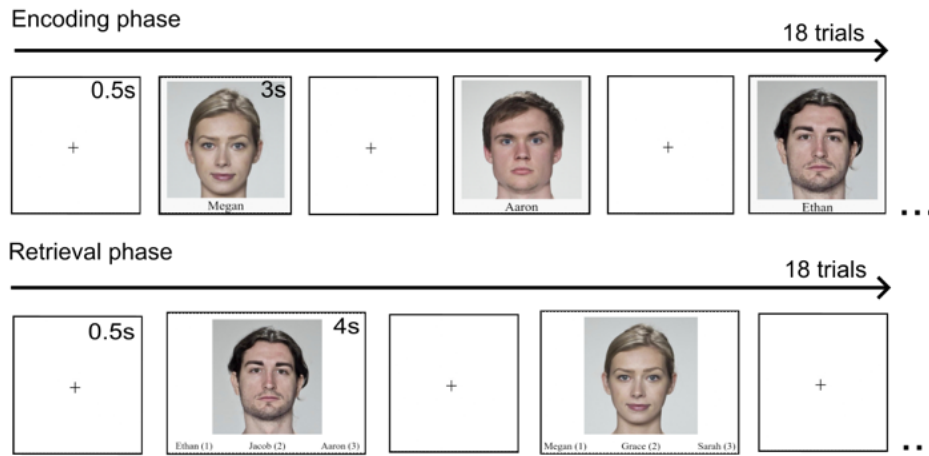
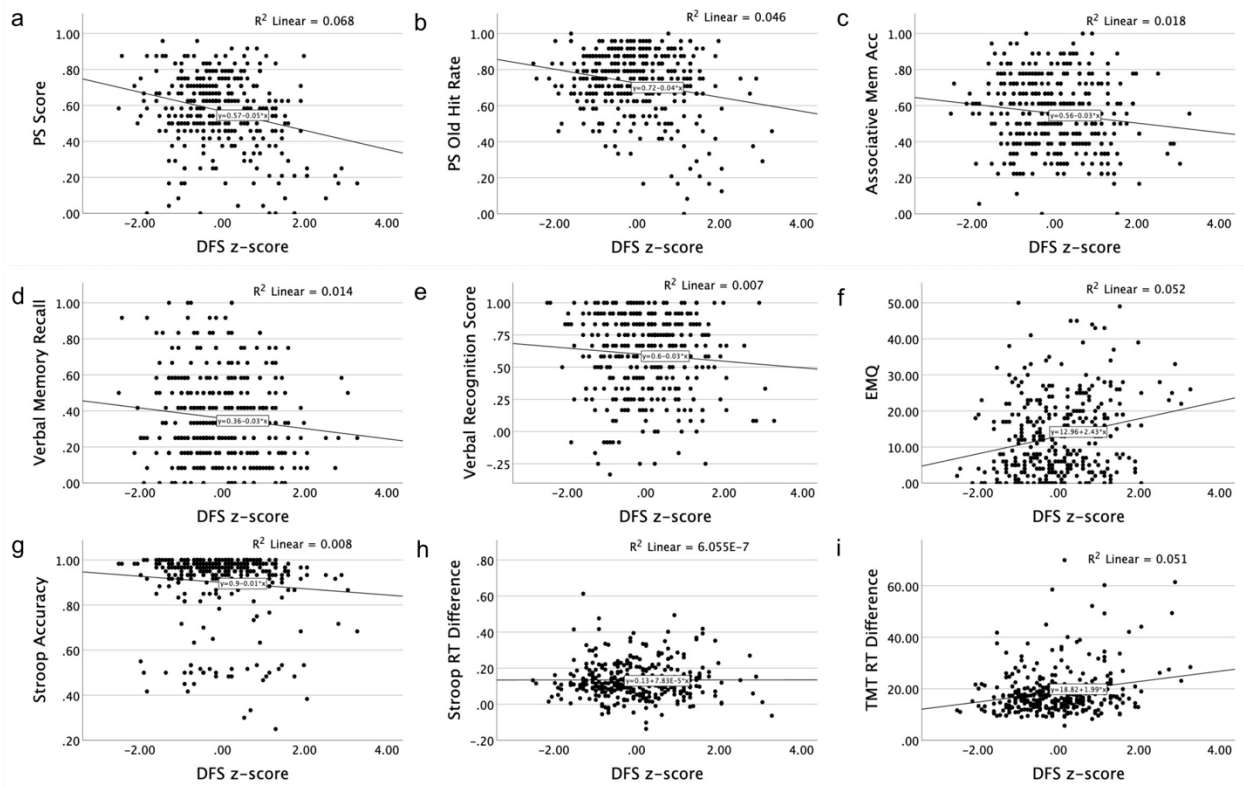**Figure 3.** Illustration of the Associative Memory Task encoding and retrieval phases. Face images derived from Face Research Lab London Set (Version 5, figshare) by L. DeBruine and B. Jones, 2017, https://doi.org/10.6084/m9.figshare.5047666.v5

Figure 4. Figure showing the relationship between DFS, memory, and executive function measures
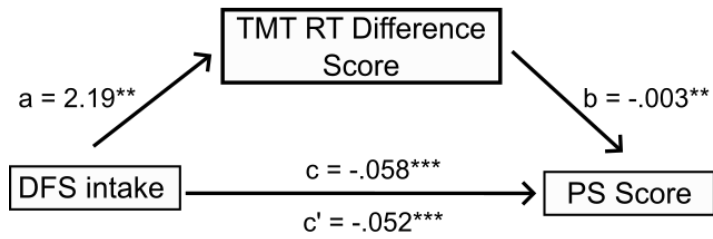
Figure 5. The model showing the direct and indirect effects of DFS intake on PS Score and TMT RT difference score.

Note. The c path represents the total effect of the DFS intake on PS score performance. a x b represents the mediation (i.e. indirect) effect of TMT RT difference on the prediction of DFS on PS score. The c' path represents the direct effect of DFS intake on PS score performance after controlling for the mediator. a, b, c and c' are unstandardized regression coefficients. *p*<.05. ** *p*<.01. ***p*<.001.
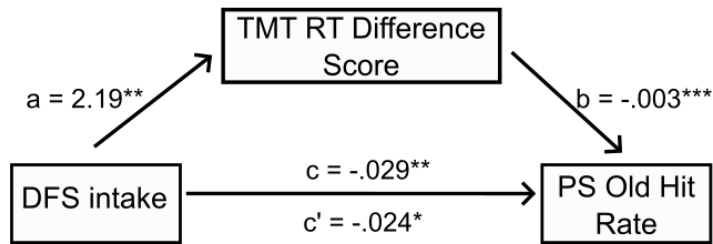
Figure 6. The model showing the direct and indirect effects of DFS intake on Old-Item Hit rate and TMT RT difference score.

Note. The c path represents the total effect of the DFS intake on Old-item hit rate score performance. a x b represents the mediation (i.e., indirect) effect of TMT RT difference on the prediction of DFS on Old-Item Hit Rate. The c' path represents the direct effect of DFS intake on Old-item hit rate performance after controlling for the mediator. a, b, c and c' are unstandardized regression coefficients.

*p<.05. ** p<.01. ***p<.001.

Appendix A: Consent Form

UNIVERSITY OF MICHIGAN
CONSENT TO BE PART OF A RESEARCH STUDY

Study title: Diet and Cognitions
Principal Investigator: Selen Atak
Co-Investigator: Alyssa Boye
Faculty Advisor: Zhong Xu Liu, Ph.D., Susana Peciña, Ph.D.

You are invited to take part in a research study to further our understanding of the relationship between dietary habits and cognitive functions. This form contains information that will help you decide whether to join the study.

Disclaimer: To receive payment for participation, completion of the entire study is required.

1. **Who can take part in this study?**

You can take part in this study if you are aged between 18-35 and do not have the following conditions: diabetes, history of eating disorders, currently on a weight-loss diet, and using prescription medication besides contraceptive medication.

2. **What will happen to me in this study?**

If you choose to participate, you will be asked to complete a questionnaire about mood, physical activity, sleep, and dietary behaviors. You will also be asked to complete a series of cognitive tasks. Some tasks will involve remembering pictures of objects, faces, and words. Others will involve following patterns of numbers and letters, and making judgments about colors. Completion of the study will take approximately 40-50 minutes.

3. **Are there any risks and benefits to taking part?**

This study contains minimal risk to the participants. You will be asked to answer questions about information regarding health and eating habits. This may discomfort some participants. Please remember that you do not have to answer any questions you do not want to answer.

One other potential risk of participating is the breach of confidentiality. However, we will protect the confidentiality of your research records by assigning you a verification code, which will be the only identifying information linked to the data we are collecting from you. Your MTurk worker ID will only be used for the detection of repeat participation.

Please note that even though you may not receive any personal benefits from being in this study, others may benefit from the knowledge gained from this study.

4. **If I want to stop participating in the study, what should I do?**

You are free to leave the study at any time. If you decide to leave the study before it is finished, your data will be deleted.

5. What will happen to the information collected in this study?

The results of this research may be written for publication. The data may also be stored for future research. However, we will protect your confidentiality by not collecting and including any information that can identify you directly.

6. Who will have access to my research records?

It is possible that other people may need to see the information we collect in this project. These people work for the University of Michigan, government offices, and/or Institutional Review Board (IRB) that are responsible for making sure the research is done safely and properly.

7. Will I be paid or given anything for taking part in this study?

You will receive $5 through MTurk for your participation in the study. It is important to note compensation requires the completion of the entire questionnaire. Upon completion, you will receive a validation code that will need to be entered into Mturk. Satisfactory completion of the work is evaluated in numerous ways, including several attention checks placed throughout this study and the time taken to complete the study. In order to receive payment, you must respond appropriately to these attention checks. You will not be paid if you fail these questions. Only proceed if you agree to these terms.

Who can I contact about this study?

Please contact the researchers listed below if you have any questions or concerns;

> **Principal Investigator:** Selen Atak
> **Email:** seatak@umich.edu
>
> **Faculty Advisor:** Zhong Xu Liu
> **Email:** zhongxu@umich.edu
>
> **Faculty Advisor:** Susana Peciña
> **Email:** pesu@umich.edu
>
> **Study Coordinator:** Alyssa Boye
> **Email:** aboye@umich.edu

In the survey, you will be asked questions related to your mood and feelings. If you wish to speak to someone about any upsetting feelings you have, provided below is a resource list that includes hotlines you can contact.

National Suicide Prevention Lifeline: 800-273-8255
Confidential emotional support hotline for people in suicidal crisis or emotional distress

Crisis Text Line: Text HELLO to 741741

24-hour crisis center for people in emotional distress

American Psychological Association: https://www.apa.org/helpcenter/crisis
A resource to connect to psychologists near you for longer-term help

If you have questions about your rights as a research participant, or wish to obtain information, ask questions or discuss any concerns about this study with someone other than the researcher(s), please contact the following:
> University of Michigan
> Health Sciences and Behavioral Sciences Institutional Review Board (IRB-HSBS)
> 2800 Plymouth Road
> Building 520, Room 1169Ann Arbor, MI 48109-2800
> Telephone: 734-936-0933 or toll free (866) 936-0933
> Fax: 734-936-1852
> E-mail: irbhsbs@umich.edu

You can also contact the University of Michigan Compliance Hotline at 1-866-990-0111.

YOUR CONSENT

Consent/Assent to Participate in the Research Study
By signing this document, you are agreeing to be in this study. Make sure you understand what the study is about before you sign. I/We will give you a copy of this document for your records and I/we will keep a copy with the study records. If you have any questions about the study after you sign this document, you can contact the study team using the information provided above.

You are enrolling in this research study through the Amazon Mechanical Turk (MTurk) site. Information gathered through Amazon MTurk is not completely anonymous. Any work performed on Amazon MTurk can potentially be linked to information about you on your Amazon public profile page, depending on the settings you have for your Amazon profile. We are using CloudResearch to assist in survey administration. Compensation is provided via MTurk. A verification code provided at the end of the survey will allow for your work to be approved and compensated. We will have access to your MTurk worker ID for the sole purpose of detecting repeat participants. Amazon Mechanical Turk has privacy policies of its own outlined for you in Amazon's privacy agreement. If you have concerns about how your information will be used by Amazon, you should consult them directly.

I understand what the study is about and my questions so far have been answered. I agree to take part in this study.

Appendix B: Participant Debriefing Form

The task that you just completed involved answering questions based on your diet, eating habits, sleep, physical activity, and mood. The goal of this questionnaire was to determine your diet and control for other factors. You also completed a series of cognitive tasks that measured short-term memory, associative memory, attention, and visual attention. The goal of these tasks was to determine your performance on pattern separation, associative memory, attention, and word recall tasks. Your participation was important in helping researchers understand the relationship between diet and memory.

Final results will be available from the investigator, Selen Atak, by 1/1/2024. You may contact me at seatak@umich.edu to receive an email copy of the final report. All results will be grouped together; therefore individual results are not available. Your participation, including your name and answers, will remain absolutely confidential, even if the report is published. If you are uncomfortable with this you can request that your results be withdrawn from the study at any time before its publication. If you have any additional questions regarding this research, please contact at seatak@umich.edu.

You are able to talk to a counselor about any stress or negative feeling brought on by your participation. If you wish to speak to someone about any upsetting feelings you have, provided is a resource list that includes hotlines you can contact:

National Suicide Prevention Lifeline: 800-273-8255
Confidential emotional support hotline for people in suicidal crisis or emotional distress
Crisis Text Line: Text HELLO to 741741
24-hour crisis center for people in emotional distress
American Psychological Association: https://www.apa.org/helpcenter/crisis
A resource to connect to psychologists near you for longer-term help

If you are interested in the topic, you can learn more about the research area by reading the articles listed below:

Attuquayefio, T., Stevenson, R. J., Boakes, R. A., Oaten, M. J., Yeomans, M. R., Mahmut, M., & Francis, H. M. (2016). A high-fat high-sugar diet predicts poorer hippocampal-related memory and a reduced ability to suppress wanting under satiety. Journal of Experimental Psychology: *Animal Learning and Cognition, 42*(4), 415.

Francis, H. M., & Stevenson, R. J. (2011). Higher reported saturated fat and refined sugar intake is associated with reduced hippocampal-dependent memory and sensitivity to interoceptive signals. *Behavioral Neuroscience, 125*(6), 943.

Thank you for participating. We ask that you refrain from speaking to others about the study until it is completed, in order to receive unbiased results from other participants.

Thank you once again for your time!

Appendix C: Dietary Fat and Sugar –Short Questionnaire

Think about the food you've eaten over the past year. Remember breakfast, lunch, dinner and eating out. Please select the option that best describes how often you have consumed each of the following food or drink items.

		Less than 1 per month	2–3 per month	1–2 per week	3–4 per week	5+ per week
1	Mince, beef or lamb, for example, in hamburgers, nachos or bolognaise					
2	Beef or pork such as steak, ribs, roasts or in sandwiches					
3	Fried chicken or chicken burgers					
4	Sausages, frankfurts or salami					
5	Bacon					
6	Salad dressings (not low fat)					
7	Margarine, butter or oil in cooking					
8	Eggs (not egg whites alone)					
9	Pizza					
10	Cheese or cheese spread (not low fat)					
11	French fries, fried potatoes					
12	Corn chips, potato chips, popcorn with butter					
13	Doughnuts, pastries, croissants					
14	Cakes, cookies					
15	Ice cream (not sorbet or low fat)					
16	Chocolate					
17	Lollies					
18	Spreads incl. peanut butter, jam, honey					
19	Pancakes or French toast					
20	Sports drinks (e.g. Gatorade) or energy drinks (e.g. Red Bull)					
21	Soft drink (not including diet)					
22	Milk (full fat only). Include milk drunk by itself or in cappuccinos, milkshakes, hot chocolates etc.					
23	Other sweetened beverages (e.g. juice with added sugar, cordial, sweetened teas)					
24	White bread (white bread only)					
25	In the past year, how many times have you eaten food from a takeaway or fast food restaurant for example McDonalds, KFC, Mexican, Chinese, Thai, Italian (pizza or pasta)?					

		None	1–2	3–4	5–6	7+
26	In the past week, how many teaspoons of sugar have you added to your beverages, cereal or food?					

Appendix D: Everyday Memory Questionnaire

Everyday Memory Questionnaire – Revised

Instructions

Below are listed some examples of things that happen to people in everyday life. Some of them may happen frequently and some may happen very rarely. We should like to know how often on average you think each one has happened to you over the past month. Write the appropriate letter in the box beside the item.

A. **Once or less in the last month.**
B. **More than once a month but less than once a week.**
C. **About once a week.**
D. **More that once a week or less than once a day.**
E. **Once or more in a day.**

1. Having to check whether you have done something that you should have done.
2. Forgetting when it was that something happened; for example, whether it was yesterday or last week.
3. Forgetting that you were told something yesterday or a few days ago, and maybe having to be reminded about it.
4. Starting to read something (a book or an article in a newspaper, or a magazine) without realizing you have already read it before.
5. Finding that a word is 'on the tip of your tongue'. You know what it is but cannot quite find it.
6. Completely forgetting to do things you said you would do, and things you planned to do.
7. Forgetting important details of what you did or what happened to you the day before.
8. When talking to someone, forgetting what you have just said. Maybe saying 'what was I talking about?'
9. When reading a newspaper or magazine, being unable to follow the thread of a story; losing track of what it is about.
10. Forgetting to tell somebody something important, perhaps forgetting to pass on a message or remind someone of something.
11. Getting the details of what someone was told you mixed up and confused.
12. Forgetting where things are normally kept or looking for them in the wrong place.
13. Repeating to someone what you have just told them or asking someone the same question twice.

Please check that you have put a letter in EVERY box. THANK YOU.

Appendix E: Three Factor Eating Questionnaire

ID [   ]

Three Factor Eating Questionnaire (TFEQ)

The following questions all relate to various aspects of your eating habits. Please answer all questions as accurately as possible.

Please answer the following questions by circling the response (True or False) which best describes your behavior. [Computerized Version: *Please answer the following questions by selecting the response (True or False) which best describes your behavior.*]

1. When I smell a sizzling steak or see a juicy piece of meat, I find it very difficult to keep from eating, even if I have just finished a meal.	**True / False**
2. I usually eat too much at social occasions like parties and picnics.	**True / False**
3. I am usually so hungry that I eat more than three times a day.	**True / False**
4. When I have eaten my quota of calories, I am usually good about not eating any more.	**True / False**
5. Dieting is so hard for me because I just get too hungry.	**True / False**
6. I deliberately take small helpings as a means of controlling my weight.	**True / False**
7. Sometimes things just taste so good that I keep on eating even when I am no longer hungry.	**True / False**
8. Since I am often hungry, I sometimes wish that while I am eating, an expert would tell me that I have had enough or that I can have something more to eat.	**True / False**
9. When I feel anxious, I find myself eating.	**True / False**
10. Life is too short to worry about dieting.	**True / False**
11. Since my weight goes up and down, I have gone on reducing diets more than once.	**True / False**
12. I often feel so hungry that I just have to eat something.	**True / False**
13. When I am with someone who is overeating, I usually overeat too.	**True / False**
14. I have a pretty good idea of the number of calories in common food.	**True / False**
15. Sometimes when I start eating, I just can't seem to stop.	**True / False**
16. It is not difficult for me to leave something on my plate.	**True / False**
17. At certain times of the day, I get hungry because I have gotten used to eating then.	**True / False**

Three Factor Eating Questionnaire (TFEQ)

18. While on a diet, if I eat food that is not allowed, I consciously eat less for a period of time to make up for it.	**True / False**
19. Being with someone who is eating often makes me hungry enough to eat also.	**True / False**
20. When I feel blue, I often overeat.	**True / False**
21. I enjoy eating too much to spoil it by counting calories or watching my weight.	**True / False**
22. When I see a real delicacy, I often get so hungry that I have to eat right away.	**True / False**
23. I often stop eating when I am not really full as a conscious means of limiting the amount that I eat.	**True / False**
24. I get so hungry that my stomach often seems like a bottomless pit.	**True / False**
25. My weight has hardly changed at all in the last ten years.	**True / False**
26. I am always hungry so it is hard for me to stop eating before I finish the food on my plate.	**True / False**
27. When I feel lonely, I console myself by eating.	**True / False**
28. I consciously hold back at meals in order not to gain weight.	**True / False**
29. I sometimes get very hungry late in the evening or at night.	**True / False**
30. I eat anything I want, any time I want.	**True / False**
31. Without even thinking about it, I take a long time to eat.	**True / False**
32. I count calories as a conscious means of controlling my weight.	**True / False**
33. I do not eat some foods because they make me fat.	**True / False**
34. I am always hungry enough to eat at any time.	**True / False**
35. I pay a great deal of attention to changes in my figure.	**True / False**
36. While on a diet, if I eat a food that is not allowed, I often then splurge and eat other high calorie foods.	**True / False**

Three Factor Eating Questionnaire (TFEQ)

Please answer the following questions by circling the number above the response that best describes your behavior. *(Computerized Version: Please answer the following questions by selecting the response that best describes your behavior.)*

37. How often are you dieting in a conscious effort to control your weight?

1	2	3	4
Rarely	Sometimes	Usually	Always

38. Would a weight fluctuation of 5 lbs affect the way you live your life?

1	2	3	4
Not at all	Slightly	Moderately	Very much

39. How often do you feel hungry?

1	2	3	4
Only at mealtimes	Sometimes between meals	Often between meals	Almost always

40. Do your feelings of guilt about overeating help you to control your food intake?

1	2	3	4
Never	Rarely	Often	Always

41. How difficult would it be for you to stop eating halfway through dinner and not eat for the next four hours?

1	2	3	4
Easy	Slightly difficult	Moderately difficult	Very difficult

42. How conscious are you of what you are eating?

1	2	3	4
Not at all	Slightly	Moderately	Extremely

43. How frequently do you avoid 'stocking up' on tempting foods?

1	2	3	4
Almost never	Seldom	Usually	Almost always

Three Factor Eating Questionnaire (TFEQ)

44. How likely are you to shop for low calorie foods?

1	2	3	4
Unlikely	Slightly unlikely	Moderately likely	Very likely

45. Do you eat sensibly in front of others and splurge alone?

1	2	3	4
Never	Rarely	Often	Always

46. How likely are you to consciously eat slowly in order to cut down on how much you eat?

1	2	3	4
Unlikely	Slightly unlikely	Moderately likely	Very likely

47. How frequently do you skip dessert because you are no longer hungry?

1	2	3	4
Almost never	Seldom	At least once a week	Almost every day

48. How likely are you to consciously eat less than you want?

1	2	3	4
Unlikely	Slightly unlikely	Moderately likely	Very likely

49. Do you go on eating binges though you are not hungry?

1	2	3	4
Never	Rarely	Sometimes	At least once a week

50. On a scale of 0 to 5, where 0 means no restraint in eating (eating whatever you want, whenever you want it) and 5 means total restraint (constantly limiting food intake and never 'giving in'), what number would you give yourself? (Please circle/select ONE number)

0. Eat whatever you want, whenever you want it

1. Usually eat whatever you want, whenever you want it

2. Often eat whatever you want, whenever you want it

3. Often limit food intake, but often 'give in'

4. Usually limit food intake, rarely 'give in'

5. Constantly limiting food intake, never 'giving in'

---

51. To what extent does this statement describe your eating behavior?

"I start dieting in the morning, but because of any number of things that happen during the day, by evening I have given up and eat what I want, promising myself to start dieting again tomorrow."

1	2	3	4
Not like me	Little like me	Pretty good description of me	Describes me perfectly

---

This is the end of the questionnaire, thank you for your time.

Appendix F: The Depression Anxiety Stress Scales—21

| **DASS**21 | Name: | | | Date: | | | |

Please read each statement and circle a number 0, 1, 2 or 3 which indicates how much the statement applied to you *over the past week*. There are no right or wrong answers. Do not spend too much time on any statement.

The rating scale is as follows:

0 Did not apply to me at all
1 Applied to me to some degree, or some of the time
2 Applied to me to a considerable degree, or a good part of time
3 Applied to me very much, or most of the time

1	I found it hard to wind down	0	1	2	3
2	I was aware of dryness of my mouth	0	1	2	3
3	I couldn't seem to experience any positive feeling at all	0	1	2	3
4	I experienced breathing difficulty (eg, excessively rapid breathing, breathlessness in the absence of physical exertion)	0	1	2	3
5	I found it difficult to work up the initiative to do things	0	1	2	3
6	I tended to over-react to situations	0	1	2	3
7	I experienced trembling (eg, in the hands)	0	1	2	3
8	I felt that I was using a lot of nervous energy	0	1	2	3
9	I was worried about situations in which I might panic and make a fool of myself	0	1	2	3
10	I felt that I had nothing to look forward to	0	1	2	3
11	I found myself getting agitated	0	1	2	3
12	I found it difficult to relax	0	1	2	3
13	I felt down-hearted and blue	0	1	2	3
14	I was intolerant of anything that kept me from getting on with what I was doing	0	1	2	3
15	I felt I was close to panic	0	1	2	3
16	I was unable to become enthusiastic about anything	0	1	2	3
17	I felt I wasn't worth much as a person	0	1	2	3
18	I felt that I was rather touchy	0	1	2	3
19	I was aware of the action of my heart in the absence of physical exertion (eg, sense of heart rate increase, heart missing a beat)	0	1	2	3
20	I felt scared without any good reason	0	1	2	3
21	I felt that life was meaningless	0	1	2	3

Appendix G: PROMIS—Level 2 Sleep Disturbance

LEVEL 2—Sleep Disturbance—Adult[*]

*PROMIS—Sleep Disturbance—Short Form

Name: _____   Age: _____   Sex: ❑ Male ❑ Female   Date: _____

If the measure is being completed by an informant, what is your relationship with the individual receiving care? _____

In a typical week, approximately how much time do you spend with the individual receiving care? _____ hours/week

Instructions to patient: On the DSM-5 Level 1 cross-cutting questionnaire that you just completed, you indicated that *during the past 2 weeks* you (the individual receiving care) have been bothered by "problems with sleep that affected your sleep quality over all" at a mild or greater level of severity. The questions below ask about these feelings in more detail and especially how often you (the individual receiving care) have been bothered by a list of symptoms **during the past 7 days.** Please respond to each item by marking (✓ or x) one box per row.

In the past SEVEN (7) DAYS….						Clinician Use
	Not at all	A little bit	Somewhat	Quite a bit	Very much	
1. My sleep was restless.	❑ 1	❑ 2	❑ 3	❑ 4	❑ 5	
2. I was satisfied with my sleep.	❑ 5	❑ 4	❑ 3	❑ 2	❑ 1	
3. My sleep was refreshing.	❑ 5	❑ 4	❑ 3	❑ 2	❑ 1	
4. I had difficulty falling asleep.	❑ 1	❑ 2	❑ 3	❑ 4	❑ 5	
In the past SEVEN (7) DAYS….						
	Never	Rarely	Sometimes	Often	Always	
5. I had trouble staying asleep.	❑ 1	❑ 2	❑ 3	❑ 4	❑ 5	
6. I had trouble sleeping.	❑ 1	❑ 2	❑ 3	❑ 4	❑ 5	
7. I got enough sleep.	❑ 5	❑ 4	❑ 3	❑ 2	❑ 1	
In the past SEVEN (7) DAYS….						
	Very Poor	Poor	Fair	Good	Very good	
8. My sleep quality was…	❑ 5	❑ 4	❑ 3	❑ 2	❑ 1	
					Total/Partial Raw Score:	
					Prorated Total Raw Score:	
					T-Score:	

Appendix H: Physical Activity Measurement

We are aiming to measure your level of physical activity. Please answer the following questions to the best of your ability.

1. How often do you engage in physical activity?

Never
Less than 1 per month
2-3 per month
3-4 per week
5+ times per week

2. How long do you engage in a physical activity session?

I don't exercise
10-25 minutes
25-40 minutes
40-60 minutes
60+ minutes

3. How would you rate the intensity of your physical activity session?

I don't exercise
Light
Moderate
Heavy
Very heavy

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