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Food Anticipation Enhances Cognitive Ability of Overweight and Obese in the Presence of Hunger

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Abstract

By randomizing the order in which participants perform a cognitive test and a food choice task in a controlled experiment, we show that overweight and obese participants exhibit an anticipatory food reward effect. Eye tracking data revealed that temptation, in the form of visual attention, and emotional arousal was higher under low cognitive resources. The anticipation of food reward helped enhance the mental resources of overweight and obese individuals and improve their performance in a cognitive test. However, there was no anticipation reward among normal weight participants. Our results support the notion that rewarding processes underlying food intake present similar patterns to those behind other forms of addiction.

Keywords: anticipation, biometrics, cognitive function, hunger, obesity

One Sentence Summary:

An anticipatory food reward effect under a state of hunger — present only among overweight and obese individuals — potentially places food as a form of addiction.

Main Text:

Resource scarcity in the form of financial constraints, time pressure, sleep deprivation, and high cognitive load can severely impede cognitive capacity, resulting in suboptimal behavior (*1-5*). Diminished resource capacity affects behavior in various ways. For instance, low-income individuals often take high-interest loans (*6*), purchase lottery tickets (*7*), fail to enroll in welfare assistance programs (*8*), and make shortsighted economic decisions (*9, 10*). Restrained eaters focus more on food-related cues (*11*), are more impatient (*12*), and overeat under high cognitive load (*13*). Likewise, overloaded individuals often rely on deadline extensions that can buy them more time (*14*), while the sleep deprived make more risky choices in gambling tasks (*15*).

Motivated by a new, but emerging literature in the field of neuroscience, we investigate a different kind of resource scarcity, namely "food deprivation". To date, only two studies have shed some light on whether hunger influences non-hunger-related decisions. The first study finds that the percentage of favorable judicial rulings fluctuates in relation to the time in which judges take a food break. They attribute this effect to cognitive depletion (*16*), but are unable to separate the effects of eating and resting on the said fluctuations. The second study experimentally manipulates the hunger level of participants and demonstrates that hunger increases monetary impatience and affects time preferences (*12*). We further investigate the effect of food deprivation on non-hunger related decisions by examining whether the cognitive capacity of hungry people can be enhanced by the simple act of anticipating food intake. This was done by conducting a controlled experiment where subjects fasted for several hours before arriving to the laboratory.

Recent neuroscience evidence suggests that food consumption can be classified as a form of addiction for obese individuals (*17*). A key feature in addiction "conditions" relates to the dopamine reward system, which intensifies the "reward" in anticipation of the addictive action and not necessarily in the action itself (*18, 19*). In this context, it has been shown that obese individuals are prone to a phenomenon known as the "anticipatory food reward", in which they exhibit greater activity in somatosensory and gustatory brain regions in response to anticipated food intake (*20-22*). These brain regions are responsible for encoding the sensory and hedonic aspects of food palatability (*21*), meaning that the obese derive more pleasure from the desire to eat food than from the actual act of eating (*23*).

We test for the presence of an "anticipatory food reward" effect by randomizing the order in which subjects performed a cognitive test and a food choice task. Our main hypothesis is that subjects who perform the food choice task prior to the cognitive test will experience an anticipatory effect since they are aware that they will imminently consume a food snack at the end of the experiment. We show that overweight and obese subjects experience an anticipatory effect, which enhanced their cognitive capacity after merely choosing a food snack that would be readily available for them to eat after the experiment. The overweight and obese subjects who completed the cognitive test first before the food choice task performed significantly worse in the cognitive ability test than those who completed the food choice task first. This finding can help answer a very important question: How does the interaction between hunger and an anticipatory reward system affect the food choices of overweight and obese individuals? We show that the cognitive impairment induced by hunger only affected the food choices of obese individuals, who were more likely to make unhealthy food choices.

Moreover, the results we present place food as a form of addiction, but only among overweight and obese individuals. While there is an ongoing debate as to whether addictions constitute a form of disease (*24*) – which may be treatable and perhaps even, covered by healthcare programs – our findings suggest that food consumption should be included in this conversation as a potential form of addiction.

Experimental Design

The experiment took place at the Human Behavior Lab (HBL) at Texas A&M University. The experimental sessions were conducted individually at different times of the day (from 8:00 am to 8:00 pm) in order to control for time-of-the-day effects. Each session lasted around 60 minutes. To qualify for the study, subjects had to be at least 18 years old and must not have a history of any psychiatric or eating disorders. Participants were instructed to eat regularly during the day, but to refrain from eating for at least 3 hours prior to their experimental session.[1] This food deprivation period was selected to mimic the hunger state that most individuals experience between meals, thus allowing for the assessment of the effect of food deprivation on cognitive function and the examination of differences in anticipation of a food reward.

Participants completed a cognitive performance test and a food choice task in randomized order. This generated the two conditions needed to test for the presence of an

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[1] This fasting requirement has been previously used as a manipulation of hunger to examine the effect of hunger on economic decision-making (*12*).

anticipatory food reward effect. Specifically, subjects who completed the food choice task first will anticipate food intake prior to the cognitive test. On the other hand, subjects who performed the cognitive test first, cannot anticipate food consumption and serve as the control. The cognitive performance task included 24 problems from the Raven's Progressive Matrices test, which is a computer-based test that has been validated as a measure of fluid intelligence independent of acquired knowledge (*2*, *25*). The test consists of a sequence of geometric patterns with one missing shape. Subjects were asked to choose which of eight alternatives best fit in the missing shape (*26*).

The food task presented subjects with 20 snacks choice sets, each consisting of a fixation point shown for 2 seconds (s), followed by a stimulus (food product images) (8s), a choice decision (no time restriction), and an inter-stimulus (0.75s). For each choice set, subjects were asked to choose between a healthy and an unhealthy version of the same snack (e.g. original vs. light Yoplait vanilla yogurt). The healthy and unhealthy snacks were ready-to-eat items selected to be similar in every aspect, except the number of calories (they were similar in terms of price, brand, packaging, and flavor). However, the food choices gave participants a menu of options to choose from in order to appeal to a variety of food snacks. In order to incentivize the food choice task, subjects were told that one of the twenty choice sets will be randomly chosen at the end of the session as binding. Subjects then had to eat the product they chose in the binding choice set at the end of the experiment, after which they received their payment and were escorted out of the lab. The binding decision was randomly determined using a bingo cage that contained 20 balls numbered 1-20. At the end of the experiment, subjects drew a ball from the bingo cage to determine the binding choice set.

After completing the two tasks, participants filled out a demographic and behavioral survey. Since participants were required to fast for three hours prior to the experiment, they were asked to report the time at which they last ate that day. Moreover, they reported their level of hunger on a scale from 1 to 9 (1 = Not at all, and 9 = Extremely hungry). Finally, the weight and height of each participant were collected using a calibrated digital scale and measuring tape.

During the food choice task, subjects' visual attention to the food products was recorded using a non-invasive Tobii TX300 eye tracker (Tobii 2014). The eye tracking device was embedded in the computer screen and tracked gaze position at a sampling rate of 120 Hz. Two eye tracking metrics, total visit duration and pupil dilation, were used to assess objective visual attention (temptation) and emotional arousal experienced by participants while performing the food choice task. Visual stimuli were presented using iMotions software (iMotions 2014).

Results and Discussion

A total of 182 students participated in the experiment in exchange for a $20 compensation fee. Around half the sample was male (49.4%), and the average age was 23.4 years. Moreover, 34.8% identified themselves as White, 19.3% as Hispanic, and 45.9 % as non-White and non-Hispanic. Participants were classified according to their weight status using body mass index (BMI).[2] The average BMI of the sample was 24.7, which is indicative of normal-weight. Of the 182 participants, 116 were normal weight, 41 were overweight, and 25 subjects were obese. Recall that subjects were asked to fast for at least 3 hours prior to the experimental session (*Mean* = 4.91; SD = 3.20). Self-

[2] Normal weight is defined as a BMI between 18.5 and 24.9 kg/m^2, overweight is defined as a BMI between 25 and 29.9 kg/m^2, and obese is defined as a BMI of 30 kg/m^2 or more (WHO 2000).

reported hunger levels were collected in the demographic/behavioral survey. There were no differences in the reported level of hunger across all weight categories, which indicates that they experienced a similar state of hunger upon arrival to the lab (μ = 5.119; p = 0.593).

Our main hypothesis states that anticipating food intake can significantly offset the cognitive cost associated with hunger. If this is the case, we expect a significant increase in cognitive performance (as measured by the Raven's test) when hungry subjects anticipate food consumption. The cognitive performance in the Raven's test is plotted in Fig. 1. The results show that overweight and obese subjects who completed the cognitive test prior to the food choice task performed significantly worse than those who completed the tasks in the opposite order (P=0.005; P= 0.021, respectively). This provides a clear indication of the presence of an anticipatory food reward effect: when hungry overweight and obese individuals were informed that they would be consuming food at the end of the experiment, it seems that the expectation of the imminent food consumption helped enhance their mental resources and performance in the test. This conforms to biological evidence suggesting that digestive and metabolic responses are initiated when individuals are exposed to food-related cues or anticipate food intake (*27*). What is interesting however is that we find this to be true only for the overweight and obese. As shown in Fig. 1, it is clear that the anticipatory effect was not present for normal weight individuals, who performed similarly in cognitive ability task regardless of the order in which the cognitive test and food choice task were presented (P= 0.324). The results of our controlled experiment provide support to previous neurobiological evidence suggesting that obese individuals may anticipate more reward from food intake compared to lean individuals and experience greater sensory pleasure when eating (*22*).

A primary function of scarcity is drawing attentional focus to the task at hand. For example, food deprived individuals pay more attention to food-related cues on a computer screen compared to individuals who were not food deprived (*11, 28*), while thirsty individuals attend more readily to water-related cues (*29*). Similarly, alcoholics and restrained eaters are more likely to detect alcohol and food-related signals, respectively (*30*). We use two eye tracking metrics – namely pupil dilation and total visit duration – to examine the effects of an anticipatory food reward on visual attention (temptation) towards food snacks under a state of hunger.

The average pupil size, which represents changes in pupillary dilation, is indicative of emotional arousal exhibited by participants while looking at the snacks in the food choice task. Pupil dilation has been linked to higher emotional engagement or arousal (*31*), where an increase in pupil size is related to higher approach towards the stimuli, regardless of hedonic valence (*32*). Fig. 2 shows the results by BMI category. The average pupil size is significantly lower for obese subjects who performed the cognitive test after the food choice task (P= 0.026). That is, when the obese anticipate food intake, they exhibit lower engagement or arousal towards the food snacks. Conversely, under no anticipatory effect, the obese exhibit higher levels of arousal towards the snacks. No significant effects were found regarding the emotional engagement exhibited by normal weight and overweight individuals. These results are further supported by the total time subjects spent looking at the snacks during the food choice task.

We use the time difference in the visual attention of subjects between the healthy versus the unhealthy food products as the degree of temptation (Fig. 3). That is, a negative value indicates higher attention towards the unhealthy snacks, while a positive value implies the opposite. Overweight and obese participants spent more time looking at the unhealthy snacks compared to normal weight individuals. This indicates that obese individuals do not only exhibit more arousal towards food but also pay more attention or are more tempted towards unhealthy rather than healthy food products. We show below how this temptation towards unhealthy food products exhibited by the obese translated to their final food choices.

The percentage of healthy food choices by BMI category is displayed in Fig. 4. The hunger-induced impairment in the cognitive capacity of overweight and obese individuals had a clear and significant effect only on the food choices of the obese. That is, when the obese are cognitively impaired, they make more unhealthy choices. This finding can be explained by the fact that the obese individuals who performed the cognitive test prior to the food task (no anticipatory reward effect) demonstrated lower cognitive capacity. That is, their mental resources were depleted due likely to the state of hunger they were facing which left them with fewer resources to make optimal food choices. Moreover, they drew more attention towards the unhealthy food snacks, meaning that they were unable to override their temptation towards unhealthy food. Interestingly, while overweight individuals exhibited the same pattern of temptation, they were able to override temptation and their food choices did not change.

Conclusion

We examine the role of anticipatory food reward in offsetting the cognitive cost associated with hunger. Our data support the neurobiological view that the obese derive more pleasure from anticipating food intake than from actual consumption (*20*). In our context, the anticipation of food reward helped enhance the mental resource of overweight and obese individuals, enabling them to improve their cognitive performance. Although alternative methods have proven useful in restoring mental resources – such as glucose supplementation, rest, and positive mood (*16, 33 – 36*) – we found that the simple act of anticipating food consumption is also effective in this regard. Given that enhancement of mental resources has been linked to improved food choices (cite studies here… if any), future research should also test whether anticipation of food reward would subsequently enhance not just cognitive ability but also choice or consumption of healthier food among obese individuals.

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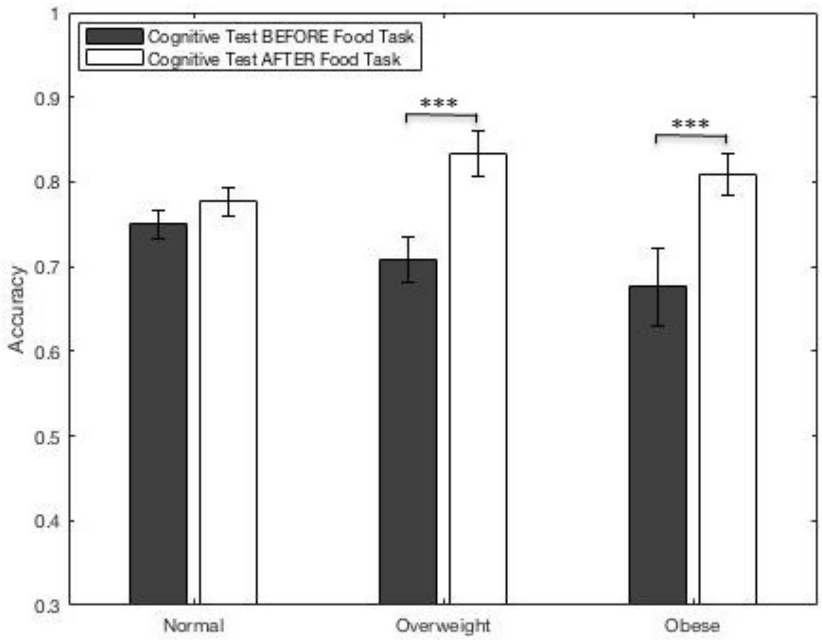
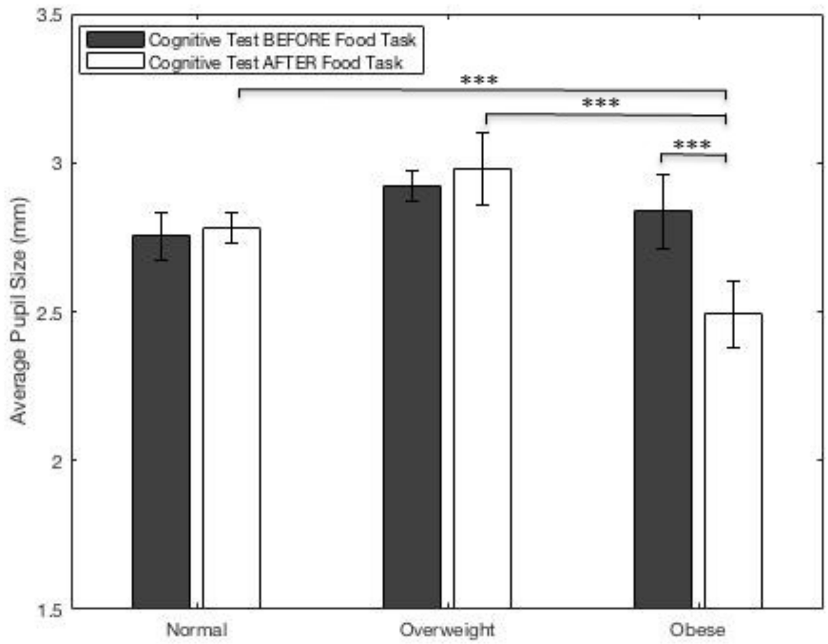
Figures

Figure 1. Accuracy on Raven's test by BMI category



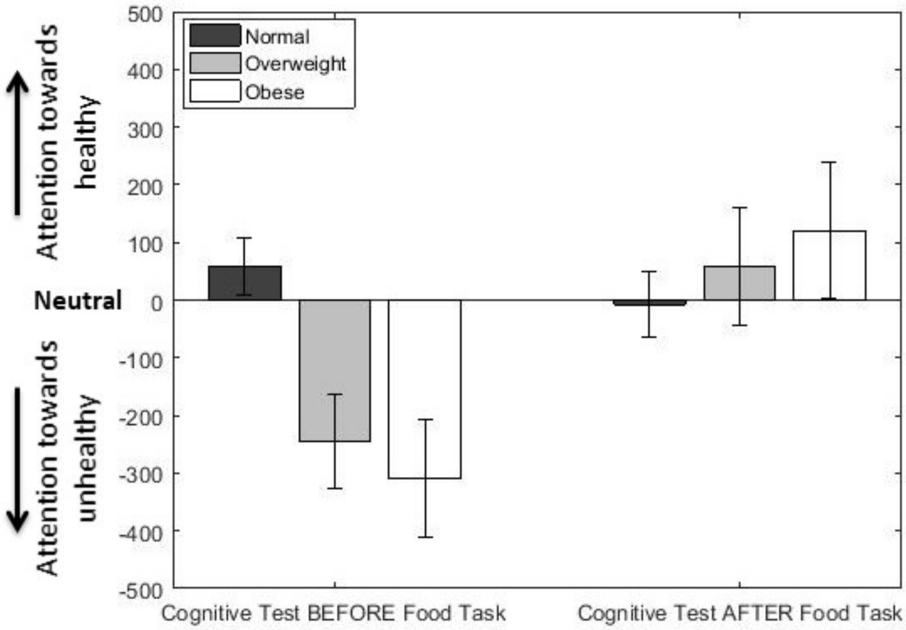
Notes: Accuracy represents the percentage of correct answers in the Raven's test. The order in which the cognitive test and the food choice task were presented was randomized across subjects; i.e. half subjects performed the cognitive test prior to the food choice task (dark bars) and half subjects did the opposite (white bars). *P<0.1, **P<0.05, ***P<0.01

Figure 2. Average pupil size during food choice task by BMI category and condition



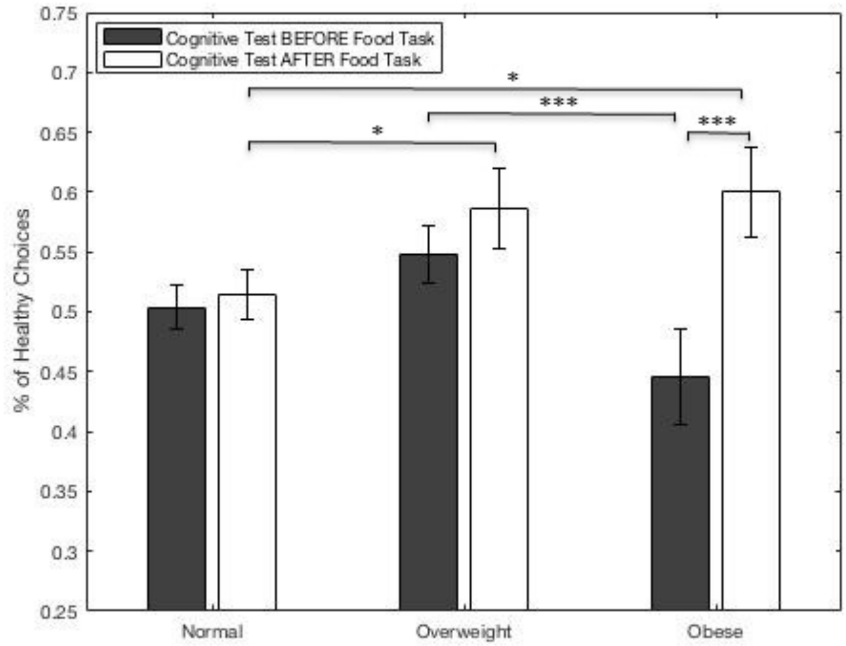
Notes: The average pupil size is used as a measure of the emotional arousal subjects exhibited during the food choice task. The order in which the cognitive test and the food choice task were presented was randomized across subjects; i.e. half subjects performed the cognitive test prior to the food choice task (dark bars) and half subjects did the opposite (white bars). **P*<0.1, ***P*<0.05, ****P*<0.01 **P*<0.1

Figure 3. Attention level (temptation) towards food products by BMI category



Notes: The estimates represent the average difference in the amount of time subjects spent looking at the healthy versus the unhealthy food products.

Figure 4. Healthy food choices by BMI category



Notes: Percentage of healthy food choices during food choice task by BMI category. **P*<0.1, ***P*<0.05, ****P*<0.01 **P*<0.1