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Working memory and attentional bias on reinforcing efficacy of food

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ABSTRACT

Reinforcing efficacy of food, or the relationship between food prices and purchasing, is related to obesity status and energy intake in adults. Determining how to allocate resources for food is a decision making process influenced by executive functions. Attention to appetitive cues, as well as working memory capacity, or the ability to flexibly control attention while mentally retaining information, may be important executive functions involved in food purchasing decisions. In two studies, we examined how attention bias to food and working memory capacity are related to reinforcing efficacy of both high energy-dense and low energy-dense foods. The first study examined 48 women of varying body mass index (BMI) and found that the relationship between attentional processes and reinforcing efficacy was moderated by working memory capacity. Those who avoid food cues and had high working memory capacity had the lowest reinforcing efficacy, as compared to those with low working memory capacity. Study 2 systematically replicated the methods of study 1 with assessment of maintained attention in a sample of 48 overweight/obese adults. Results showed the relationship between maintained attention to food cues and reinforcing efficacy was moderated by working memory capacity. Those with a maintained attention to food and high working memory capacity had higher reinforcing efficacy than low working memory capacity individuals. These studies suggest working memory capacity moderated the relationship between different aspects of attention and food reinforcement. Understanding how decision making process are involved in reinforcing efficacy may help to identify future intervention targets.

1. Introduction

Food reinforcement is an important predictor of energy intake (Epstein, Carr, Lin, Fletcher, & Roemmich, 2012), weight status (Saelens & Epstein, 1996) and weight gain (Carr, Lin, Fletcher, & Epstein, 2014) in children (Hill, Saxton, Webber, Blundell, & Wardle, 2009), adolescents (Epstein, Yokum, Feda, & Stice, 2014) and adults (Epstein, Leddy, Temple, & Faith, 2007a). Those with higher food reinforcement consume more calories, are more likely to be obese, and gain more weight over time (Epstein et al., 2007a). Food reinforcement is assessed by asking individuals to either respond for food (value) or determine how much money they would spend on portions of food (efficacy) (Epstein et al., 2007a). Decisions about how much time or money should be spend on food involves choices about how valuable food is compared to other goods and activities.

Decision making is guided by environmental cues and involves executive function processes that compare and contrast options (Diamond, 2013). Two executive processes can be identified as likely candidates for decision making involving food choices; attentional control and working memory capacity. Food is a primary reinforcer, meaning that no learning is required for food to effectively motivate behavior (Epstein et al., 2007a). Primary reinforcers automatically capture attention and the magnitude of reinforcing efficacy of food may be related to individual differences in these attentional processes (Tapper, Pothos, & Lawrence, 2010). Attentional control involves both bottom-up and top-down cognitive processes (Sarter, Givens, & Bruno, 2001; Uncapher, Hutchinson, & Wagner, 2011). Bottom-up control likely involves the initial orientation towards food, and then a conscious choice about maintaining attention towards food occurs (Sarter et al., 2001), that can be moderated by working memory processes (Higgs, Rutters, Thomas, Naish, & Humphreys, 2012). The second candidate process is working memory capacity. Working memory capacity is an executive function, describing how well one can store information while alternating between task relevant and task irrelevant stimuli (Engle, 2002). Those with increased working

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memory capacity may be better able to compare the costs and benefits of responding for different types of food.

Theories on reward-driven behaviors, including the competing neurobehavioral decisions system (Bickel & Yi, 2008), the hot/cool system theory (Metcalfe & Mischel, 1999) and the dual-systems theory (Hofmann, Friese, & Strack, 2009), hypothesize a competing activation between the reward or "hot" system and the rational executive or "cold" system. The relative activation between these systems is theorized to predict behavior, i.e. if the executive system has few resources or low functionality, than the reward system can drive behavior that offers immediate gratification. Previous research has characterized the ability to delay gratification as an important component of the executive system that allows for healthier choices (Carr, Daniel, Lin, & Epstein, 2011; Epstein, Salvy, Carr, Dearing, & Bickel, 2010b), but has not examined how executive functions influence the reward system, or food reinforcement.

In two studies we examined how working memory capacity may moderate the relationship between initial attention bias (study 1) and maintained attention bias (study 2) on the reinforcing efficacy of both high energy-dense (HED) and low energy-dense (LED) foods. Reinforcing efficacy of food assesses the relationship between food prices and food purchases. Those who find food more reinforcing should be less responsive to price changes, as they will continue to purchase their favorite food even as the price increases, which is assessed by the elasticity of demand for food. In addition, people who find food more reinforcing should have a higher breakpoint for food, or the maximal price they will spend for food. It is also possible that those who find food more reinforcing will consume more when it is free, as assessed by intensity of demand.

We hypothesized that working memory capacity would moderate the relationship between initial or maintained attention and food reinforcing efficacy. For both measures of attention, we hypothesized that those with high levels of attention towards food cues and low working memory capacity would have the highest level of food reinforcement, and those with low levels of attention and high working memory capacity would have the lowest level of food reinforcement.

2. Study 1

2.1. Methods

2.1.1. Participants

Participants were 48 females (25 lean, 23 overweight/obese) recruited from posted flyers and web-based advertisements, for a one session study examining hypothetical food choices and computer tasks. Participants must like the study foods at least a 5 on a 9 point scale and ranked a high energy-dense food as their favorite. Exclusionary criteria included medications that affect appetite, smell or taste (e.g. insulin, anti-depressants), current/recent diagnoses with eating or psychological disorders, dietary restrictions, allergies to study foods, current use of tobacco, nicotine or other controlled substances and excessive alcohol consumption (>21 drinks per week), as assessed by a prescreening phone or web survey. Participants were stratified by obesity status, lean (BMI<25) versus overweight/obese (BMI $\geq$ 25), to ensure proportionate numbers of weight status within the sample.

2.1.2. Measurement

2.1.2.1. Demographics. Race/ethnicity, household income, educational level and race/ethnicity were assessed using a standard questionnaire.

2.1.2.2. Anthropometrics. Participant's height and weight were measured without shoes using a Digi-kit™ stadiometer (North Bend, WA), calibrated daily, and a Tanita™ BWB-800P digital weight scale (Arlington Heights, IL). Body mass index was calculated (BMI = kg/m^2) for each participant.

2.1.2.3. Hunger, fullness and food liking. Subjective ratings for hunger and fullness were measured before and after the tasks during each session and the food liking for their favorite HED and LED foods. The scales used a five point Likert scale anchored by "Extremely Hungry" and "Not hungry at all," "Extremely Full" and "Not full at all" and "Do not like" and "like very much." Participants were asked to complete hunger and fullness scales at both the beginning and end of session to ensure that hunger ratings did not change as a potential alternative explanation.

2.1.2.4. Three factor eating questionnaire. Dietary restraint was measured with the Three Factor Eating Questionnaire(Stunkard & Messick, 1985), a validated instrument to detect dietary restriction (Allison, Kalinsky, & Gorman, 1992; Laessle, Tuschl, Kotthaus, & Pirke, 1989) and measures dietary restraint, dietary disinhibition, and hunger (Laessle et al., 1989). All measures were included in the questionnaire. Dietary restraint has been related to attention bias for food (Ahern, Field, Yokum, Bohon, & Stice, 2010; Tapper, Pothos, Fadardi, & Ziori, 2008; Werthmann et al., 2013).

2.1.2.5. Reinforcing efficacy. Reinforcing efficacy was measured using the Food Purchasing questionnaire, a modification of the cigarette purchasing task (MacKillop et al., 2008). This asks one to indicate how many portions of food one would consume at various price points. Hypothetical consumption is used rather than purchasing to prevent over-inflated numbers at very low price points (i.e. free, $0.01). Participants were first asked to rank four high energy-dense (HED) foods (cookies, potato chips, nachos, donuts) from 1 (favorite) to 4 (least favorite) and four low energy-dense (LED) foods (carrots, yogurt, apples, bananas). Participants completed two separate questionnaires, for their highest ranked HED food and their highest ranked LED food. They were instructed to imagine that they were deciding on their snack foods for a one day period and were asked to indicate how many portions they would consume at the following prices ($0.01, $0.05, $0.13, $0.25, $0.50, $1, $2, $3, $4, $5, $6, $11). A picture of the snack food in its packaging were displayed on the screen, while the participants were making choices. Three outcome measures were calculated from the questionnaire; breakpoint, intensity of demand and elasticity of demand. Breakpoint is defined as the price at which people stop purchasing food. Intensity of demand is defined as the number of portions chosen when the price is $0 and elasticity of demand is the slope of the relationship between food portions chosen and price on a log-log scale (Bickel, Marsch, & Carroll, 2000; Hursh, 1980). Larger values on breakpoint and intensity indicate higher reinforcing efficacy and more positive elasticity values indicate a less elastic (more inelastic) value, or higher reinforcing efficacy.

2.1.2.6. Operational span task. The operational span task is a computerized version of the OPSAN, the GOSPAN (De Neys, d'Ydewalle, Schaeken, & Vos, 2002), and consisted of 15 word list trials with alternating math problems. A set of 60 operation (math) problems and 60 words are presented on the screen in an alternating fashion. Participants were required to respond on a keyboard if the math equation (such as $(4/2)+1=9$) is true or false and then shown a word (such as BALL). A series of 3–6 operation-word pairs are presented in a random order and after each trial participants are required to recall the previous set of words in order. Participants first completed a practice trial of a two-word set. Working memory capacity was calculated as the longest individual