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Habituation and recovery of salivation and motivated responding for food in children

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Abstract

Salivary responses habituate to repeated presentations of food cues, and these responses recover when new food stimuli are presented. Research suggests that within-session changes in motivated responding for food may also habituate, and motivated responding may, therefore, recover when new foods are presented. The purpose of this study was to evaluate similarities in the pattern of salivation and motivated responding for a cheeseburger stimulus in children, followed by either a novel stimulus (French fries) or another cheeseburger trial. The order of the task (salivation or motivation) was counterbalanced over days. Salivation and motivated responding for cheeseburger were reliably reduced over seven trials, and responses recovered after presentation of French fries on trial 8. Random regression models showed a significant relationship between the rate of change in motivated responding and salivation. These results provide additional support for similarities in processes that regulate salivation and motivated responding for food and strengthen support for the hypothesis that changes in motivated responding can be understood by habituation theory.

Keywords

Obesity; Appetite; Reward; Habituation; Eating; Satiety

Repeated presentation of food is associated with a reduction in salivary responding, which can be dishabituated or recovered by presentation of a new food cue (Epstein, Mitchell, & Caggiula, 1993; Epstein, Rodefer, Wisniewski, & Caggiula, 1992; Wisniewski, Epstein, & Caggiula, 1992). The rate of habituation and the degree of dishabituation are related to food consumption (Wisniewski et al., 1992). Non-food dishabituation, such as listening to audiobooks or performing a memory task, also prevent habituation with tasks that involve greater allocation of attention associated with greater disruption of salivary habituation (Epstein et al., 1993; Epstein et al., 1992; Epstein, Saad, Giacomelli, & Roemmich, 2005; Epstein et al., 2003). The rates of habituation and dishabituation are also related to the pattern of eating. For example, obese adults, who tend to consume more food and find food more reinforcing, habituate to repeated food cues slower than lean adults (Epstein, Paluch, & Coleman, 1996), and bulimia nervosa patients do not habituate, and may sensitize, to repeated food cues (Wisniewski, Epstein, Marcus, & Kaye, 1997).

Habituation is a basic property of the nervous system (Groves & Thompson, 1970), which can be applied to many response systems. Habituation theory has been extended to understand changes in motivated behavior (McSweeney & Swindell, 1999; McSweeney, Hinson, & Cannon, 1996). It is common in basic operant conditioning experiments to observe a reduction

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in response rate during a session, which can be recovered by presenting a different food. In a series of empirical and theoretical papers McSweeney and colleagues have hypothesized that changes in motivated behavior that occur during sessions are due to habituation (McSweeney & Swindell, 1999; McSweeney et al., 1996). This is a novel extension of habituation theory, with practical and theoretical implications. However, there are few data on the use of habituation theory to understand changes in motivated behavior in humans. We have shown that food variety slows the rate of reduction in motivated responding for food (Ernst & Epstein, 2002), consistent with the changes in salivation that occur when a variety of foods is presented. In addition, we have shown similar patterns of responding for salivation and for motivated responding for food in children (Epstein et al., 2003).

The goal of this study was to provide a replication and extension of the comparison of salivation and motivated responding to repeated food cues and the recovery of responses when a new food is introduced (Epstein et al., 2003). In our previous research, all children were studied within the same session with the salivation trials always preceding the motivated behavior trials (Epstein et al., 2003). This study randomized youth to conditions that presented the same food stimulus on all eight trials versus presenting a new food stimulus on trial 8 to assess recovery. The order of stimulus tasks was counterbalanced, with some subjects having motivated behavior trials first, while other subjects had salivation trials first. The previous study presented a dessert food, apple pie, as the novel stimulus to promote recovery, while the present study used French fries, which extends the types of foods that recover responding. Finally, the present study included a much larger sample, which provided the opportunity to use regression models to estimate the relationship between salivation and motivation over the habituation and recovery trials.

Methods

Participants

Participants were 18 male and 18 female non-overweight (<95th BMI percentile) children between the ages of 9 and 12 years. They were recruited from a magazine advertisement and compensated US \$40.00 for participation. The average participant was 11.2 ± 1.2 years of age, had a mean body mass index (BMI) of 18.5 ± 2.2 , and was at the 58.4 ± 25.7 percentile for BMI. The sample included 84% Caucasian, 8% Asian and 8% African American children. Exclusionary criteria were as follows: current psychopathology or developmental disability, medications or conditions that could influence appetite or olfactory sensory responsiveness (e.g. upper respiratory illness, diabetes, methylphenidate) and dietary restrictions that would interfere with participation in the study. Inclusion in the study required that participants reported at least a moderate liking (three on a five point likert-type scale) of the test foods.

Procedures

Parents of participants were screened by telephone to determine whether children met the above criteria. Eligible participants were scheduled for two appointments at least 72 h but no more than 1 week apart between 2:30 and 6:00 p.m. Parents were instructed that children were not to consume the test foods 24 h prior and were not to eat or drink (except water) 3 h prior to the appointments. Upon arrival to the first laboratory session, participants and parents read and signed assent and informed consent forms. Parents then completed a demographic questionnaire and participants completed scales assessing food preferences and the Dutch eating behavior questionnaire adapted for children (Hill & Pallin, 1998). Same-day dietary recall and hunger scales were completed by participants during both study sessions. Participant's height and weight were measured at the end of the first session.

Children were assigned to one of two groups. In group 1 ($n=17$) participants were presented with a new food stimulus on trial 8 of the salivation task and during minutes 15 and 16 of the food reinforcement task, while group 2 ($n=19$) was presented with the same food stimulus for all trials during both sessions. The salivation paradigm and the food reinforcement paradigm were completed on different days, and the order of the tasks was counterbalanced. All procedures were conducted with the approval of the University at Buffalo Health Sciences Institutional Review Board.

Laboratory environment

The laboratory used for these experiments was specially constructed for eating and olfactory experiments. The laboratory is equipped with an air delivery system that circulates new air through each room approximately 10 times per hour. The laboratory rooms are also equipped with HEPA air purifiers containing a CPZ (carbon, permanganate, zeolite) filter to remove airborne odorants.

Salivation task

To assess habituation of salivary responses to food cues, whole mouth parotid salivary flow was measured using the Strongin–Hinsie Peck method (Peck, 1959). Participants were seated in a comfortable chair and trained in the correct placement of three dental cotton rolls (cylindrical, 7 mm diameter, 38 mm length, Richmond Dental, Charlotte, NC); one on each side of the mouth between the cheek and lower gum and one under the tongue. Participants were instructed not to swallow, talk, or move the cotton rolls once they had been placed in the mouth. Participants listened to 62 DB of white noise through headphones for the duration of the experiment to minimize attention to auditory stimuli. The experiment consisted of 10 1-min trials; a baseline trial using water as a neutral olfactory stimulus followed by nine trials of a food stimulus. Group 1 was presented with half of a fresh Wendy's™ cheeseburger for trials 1–7; for trial 9 participants were presented with a 56.5 g portion of Wendy's™ French fries. Group 2 was presented with the cheeseburger half for all eight trials. All food stimuli were heated in a microwave oven for ~25 s and presented on a paper plate. The plate was placed on small rolling table adjusted to the height of the participants' lower lip while seated and the table was placed approximately one inch from the participants' mouth for each trial. Participants were instructed to look at the food, smell the food, and think about eating the food, but not to actually eat it. After each trial, the food stimulus was taken out of the room and participants removed the dental cotton rolls and returned them to the plastic bag. Each trial was followed by a 1 min inter-trial interval. After the experimental session participants were again asked to complete a hunger scale and were given two whole cheeseburgers with instructions to eat as much or as little as they liked. Salivation was measured by pre- and post-weights of cotton rolls to 0.001 g on an Ohaus precision standard scale (Florham Park, NJ). The difference from baseline served as the dependent measure.

Food reinforcement task

To assess habituation of motivated responses for food, participants were instructed on a computer-generated task to earn points for food. The experimenter first demonstrated the use of the task, after which participants were given a 2-min practice trial. The task involved having participants respond on a mouse button to earn points on a variable interval (VI) 120 (s) schedule of reinforcement. Two slightly different versions of the task were used. In one version, every time the mouse button was pressed three shapes rotated, and when color and shape matched in the squares participants earned one point ($n=19$). In the other task, pressing the mouse button one of two squares changed color. If the bottom of two squares flashed red no point was earned, or if the top square flashed green a point was earned ($n=17$). There were no

differences in the rate of motivated responding between these two games ($p>0.05$), so the data have been combined.

Participants in group 1 were provided with 14 1-min blocks to respond for a half of a cheeseburger, followed by two 1-min blocks to respond for 56.5 g portion of French fries. Participants in group 2 responded for cheeseburger for all 16 1-min blocks. After earning a point, participants were given a 100 kcal portion of food which they could eat while playing the game to earn additional points. They were told that they would be playing a computer game to earn points to eat food, but if they no longer wished to earn points toward food, they could engage in an alternate activity (puzzles, mazes, crosswords, word finds and magazines). Participants were provided water ad libitum and were able to communicate with the experimenter over an intercom provided at the computer station.

Analytic plan

Analysis of variance (ANOVA) was used to test whether salivation and motivated responding reliably decreased over trials, and whether introduction of the novel food on trial 8 was associated with an increase in responding for participants in group 1. The mixed ANOVA had the between factors of groups and order (salivation first task, motivated responding first task), and the within factors of type of response (salivation, motivated responding) and trial (1–8). Based on the omnibus ANOVA, linear contrasts were used to test changes over time across groups on trials 1–7 and differential change by group from trials 7–8.

Random or mixed regression models (RRM) of the pattern of motivated responding predicted the pattern of salivation over the eight trials. Random regression models create individual slopes and intercepts for dependent variables, and assess predictors of the slopes. These models are ideally suited to the study of habituation, since the individual slopes and intercepts characterize the usual pattern of change in habituated responses. Random regression models can handle repeated measurements, which are used to study changes in responding over time in habituation experiments. Rather than each participant providing one measure for each variable, random regression models stack the data so that each participant provided eight measures of salivation and of motivated responding. The random regression model estimates the relationship between salivation and motivated responding over the eight trials. The dependent variable was salivation, with motivated responding as the independent within subject variable, participant number as the identifier and the model was estimated using random intercepts.

Results

Participant characteristics are shown in Table 1, with no differences observed for any measure as a function of group or order. The analysis of variance showed a significant interaction of type of response over trials by group ($F(7,217)=7.11$, $p<0.0001$). Contrasts showed that both responses reliably decreased over the first seven trials ($F(5,31)=13.32$, $p<0.0001$), with no differences by group during trials 1–7 ($F(1,31)=0.83$, $p>0.05$). There was no significant interaction of order by responses and trials. A significant difference in responding from trials 7–8 by groups was observed across both responses ($F(3,31)=16.73$, $p=0.0003$). The pattern of motivated responding for food (left graph) and salivation (right graph) are shown for trials 1–8 are shown in Fig. 1.

The random regression model showed a significant relationship between motivated responding and salivation ($p=0.017$) for the 36 participants with 288 observations, with an intercept of 1.04 and a regression coefficient of 0.0003.

Discussion

The results from this study demonstrate that patterns of reductions in salivation and motivated responding are similar when food stimuli are presented repeatedly, and there are similar increases in both responses when subjects are presented with novel food stimuli. The similarity in the pattern of motivated responding for food and salivary responses to food within subjects and the identical pattern of recovery when a new food was presented, supports the argument that these processes both undergo habituation. In addition, because presentation of a novel food reinstates motivated responding for food, it is unlikely that the decreases in responding in this task can be attributed to what is traditionally thought of as satiety. Physiological responses often attributed to satiety, such as increasing blood glucose levels, stomach distension, and hormonal changes will not recover their initial levels when a novel food is presented (De Graaf, Blom, Smeets, Stafleu, & Hendriks, 2004). The similarity in the pattern of responses is consistent with previous results from this laboratory (Epstein et al., 2003). These data provide additional support for the hypothesis that reductions in motivated responding are an example of habituated behavior (McSweeney & Swindell, 1999; McSweeney et al., 1996).

There are several potential mechanisms for the similarity in the pattern of salivary and motivated responding. It is possible that the patterns of responding are the same for salivation and motivated responding because they are both mediated in part by the same pathways. For example, both salivation and motivated responding may be related to changes in dopaminergic pathways, since motivation to obtain food is mediated in part by dopaminergic response systems (Berridge, 1996). An alternative explanation is that salivation and motivated responding are controlled by separate pathways, and the physiological responses for both behaviors habituate. This may be more likely, since habituation is a basic property of the nervous system (Groves & Thompson, 1970), and habituation has been observed across a wide variety of response systems (Baker & Tiffany, 1985; Kimmel & Bevil, 1985; Lammers & Badia, 1989; Swithers, 1995; Wagner, 1979).

One advantage of studying motivated responding is that, unlike salivary habituation, it provides a measure of food consumption and energy intake. Therefore, by applying habituation theory to motivated behavior we can test factors that directly influence ingestive behavior. If motivated responding to food habituates, and the rate of habituation is related to energy intake, such that participants with faster habituation rates will eat less food, then these findings may inform interventions that are designed to prevent or treat obesity. One implication from habituation theory is the need to reduce food variety, since variety reduces the rate of habituation, and increases food intake (Raynor & Epstein, 2001). Likewise, non-food related factors that cause dishabituation during eating (Epstein et al., 2005), such as television, should be removed from the environment. The focus of this study was on within-session habituation, but habituation also may influence response patterns across eating situations and over days (Murphy, McSweeney, Smith, & McComas, 2003). Additional research is needed to examine changes over repeated identical meals to determine if carryover or long-term effects due to habituation occur. Likewise, it is necessary to determine if conditioning to repeated pairings of contextual cues and dishabitators occurs, which may increase the strength of dishabituation over time (Wagner, 1976).

One interesting theoretical implication of considering the reductions in motivated behavior as habituation is the integration of diverse theoretical approaches to signals that terminate a meal. One of the reasons in reinforcement theory for a reduction in motivated behavior is satiation for the reinforcer (Murphy et al., 2003). In this study, participants decreased their responding for cheeseburger over trials, suggesting that they were developing satiation for this reinforcer. The observation that introduction of a new food recovered responding suggests that the reduction in responding for cheeseburger was not entirely due to energy repletion or 'fullness'.

It is interesting that the term satiation also describes meal termination in ingestive behavior research (De Graaf et al., 2004). Generalization of the meaning of the term satiation across food reinforcement and ingestive behavior research areas would suggest a common process for meal termination and reductions in reinforcer effectiveness. Further integration is possible if the reductions in motivated behavior are due to habituation (Murphy et al., 2003), which would make reinforcer satiation, meal termination satiation, and habituation alternative ways to describe similar processes relevant for cessation of eating.

In summary, these results show that salivation to repeated food cues and motivated responding for food habituate at the same rate within subjects, and that, in both behavioral paradigms, there is recovery of responding when new foods are presented. These results strengthen support for the hypothesis that changes in motivated responding can be understood by habituation theory.

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Fig. 1.

Motivated responding (left graph) and salivation (right graph) across the eight trials. During the first seven trials to the left of the dotted line all participants were provided cheeseburger during the trials. On trial 8, to the right of the dotted line, participants in group 1 were provided French fries, while participants in group 2 received another trial of cheeseburger. Both responses decreased over the first seven trials ($p < 0.0001$), and both responses showed recovery of responding when the novel food was presented on trial 8 in comparison to another trial of the same food ($p = 0.0003$).

Table 1
 Characteristics of participants by task order and by group

Measure	Group		Order	
	Same food	Novel food	Motivation 1st	Salivation 1st
Sex (M/F)	8/9	10/9	10/7	8/11
Age	11.2 (1.1)	11.2 (1.3)	11.1 (1.1)	11.3 (1.2)
Body mass index	18.1 (1.6)	18.8 (2.6)	18.1 (2.1)	18.8 (2.3)
Baseline salivation (g)	1.02 (0.51)	1.03 (0.58)	0.86 (0.50)	1.18 (0.54)
Dietary restraint	2.9 (1.9)	3.1 (2.4)	3.2 (2.4)	2.9 (1.9)
Hunger (salivation)	4.3 (0.8)	4.2 (1.0)	4.1 (1.1)	4.3 (0.8)
Hunger (motivation)	3.7 (0.7)	4.0 (0.7)	3.9 (0.7)	3.9 (0.7)