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Reliability and Validity of a Transdiagnostic Measure of Reward Valuation Effort

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Abstract

To identify biobehavioral mechanisms underlying excessive reward consumption, reward valuation – effort (RV-E) assessments should 1) parallel measures in basic science to permit translation from preclinical to clinical studies; 2) quantify constructs dimensionally from healthy to disease states; and 3) hold relevance across different diagnostic categories. To address these aims, we developed a progressive ratio (PR) task whereby RV-E is measured as breakpoint when participants worked for access to playing a game. We evaluated test-retest reliability of breakpoint and convergent and discriminant validity of interpretations of this score against an established PR task for food. In Study 1, female undergraduates (N=71; 33% racial minority; 28% ethnic minority) completed the game and food tasks in fasted and fed states. In Study 2, women (N=189; 29% racial minority; 27% ethnic minority) with eating disorders (n=158) were compared to controls (n=31) on tasks. Game task breakpoint demonstrated excellent test-retest reliability (ICC=.91, 95% CI [.80-.96]) over 2 weeks and convergent validity with the fasted food task ($r = .51$, $p < .001$). Consistent with animal models, breakpoint was lower in fed compared to fasted states across tasks ($B (SE)$=321.01 (552.40), $p < .001$). Finally, the game task demonstrated discriminant validity from measurement of satiation. In Study 2, women with eating disorders demonstrated higher breakpoint on both tasks compared to controls, and game PR task breakpoint decreased from a fasted to fed state. The game PR task offers a novel approach for translating results from animal models of RV-E into testable hypotheses in nonclinical and clinical samples.

The Research Domain Criteria (RDoC) construct of Reward Valuation – Effort (RV-E) (National Institute of Mental Health [NIMH], 2021) has a long and well-established history in the field of psychology (Hodos, 1961). Originally defined as the amount of work or effort a subject is willing to put forth to obtain a reward (NIMH, 2011), this construct comprises biobehavioral mechanisms underlying disorders characterized by over and underconsumption of rewards, including eating disorders, substance use disorders, and depression. In this paper, we set out to assess the reliability and validity of an RV-E assessment that (1) parallels assessment from animal studies, (2) measures RV-E dimensionally from a healthy to disease state, and (3) can be used across different diagnostic categories in which RV-E may play an etiological role.

The initial NIMH Positive Valence Workshop Proceedings (2011) recommended progressive ratio (PR) tasks as a behavioral assay of "Effort Valuation/Willingness to Work." The PR task is a mainstay in assessment of reward valuation in animal research (Hodos, 1961), and has been used in humans (Epstein, Leddy et al., 2007). PR tasks require subjects to put forth effort to obtain a reward across trials over which required work progressively increases. To measure RV-E of a primary reinforcer, the reward must be consumed immediately upon completing each trial. This ensures that behavior is an operant measure of the reinforcing value of the reward versus a measure of other RDoC Positive Valence constructs, such as Reward *Anticipation* or Reward *Probability.* PR tasks that have subjects work for a secondary reinforcer require subjects to anticipate the value of consuming a reward that is delayed. PR tasks that involve variable reinforcement introduce uncertainty about whether effort will be rewarded and require subjects to weigh probability of reward against effort. Breakpoint is the amount of work (e.g., number of lever or computer key presses) in the final completed trial that earns the reward. This score is sensitive to both effort and reward contingencies (i.e., magnitude of effort required to obtain the reward, and magnitude of reward obtained upon completion; Rickard et al., 2009). As such, breakpoint represents a behavioral measure for RV-E (NIMH, 2021).

PR tasks remain the dominant behavioral task in animal studies examining neural regulation of rewarding behavior (Beloate & Coolen, 2017; Lamontagne & Olmstead, 2019; Prieto-Garcia et al., 2015; Robinson et al., 2014; Smith, 2020; Treasure & Eid, 2019). These include studies tracking site-specific influence of dopamine release via use of selective dopamine agonists and antagonists, receptor knock-down models, and optogenetics. Thus, much of what has been established regarding molecular and neural regulation of reward-related behavior is based on findings from PR tasks conducted in animals. Further, preclinical trials determine mechanisms and behavioral outcomes of potentially therapeutic drugs. Thus, ensuring fidelity in translating PR tasks from animal to human studies supports successful translation from preclinical models in animals to clinical research in humans.

Several studies have used PR tasks to measure RV-E in humans, particularly in the fields of substance use and eating disorders (Bulik & Brinded, 1993; Haney et al., 1998; Klein et al.,

2010; Perkins et al., 2019; Richardson & Roberts, 1996; Rush et al., 2001; Schebendach et al., 2013; Stoops, 2008). However, as applied to clinical samples, PR tasks have demonstrated varying degrees of fidelity to their use in animal studies. For example, PR tasks in humans often have subjects work for points, money, or a visual representation of a reward rather than an immediately consumable reward (Klein et al., 2010; Schebendach et al., 2013). Unlike money or points, food is a primary reinforcer for which RV-E can be quantified in animals and humans. In addition, RV-E for food can be measured from the healthy to the disease state and across a range of diagnostic categories. Bodell and Keel (2015) developed a PR task in which participants pressed the space bar on a computer that was attached to a small machine that distributed 10 M&M's into a cup after each completed trial. Participants consumed M&M's immediately and resumed pressing the space bar until they chose to stop or until they completed the final trial. The initial trial required 50 key presses, and the criterion increased by 200 presses on each subsequent trial. Women with bulimia nervosa (BN) demonstrated higher breakpoint compared to controls (Bodell & Keel, 2015). In both the full sample and the subsample with BN, higher breakpoint was significantly positively associated with greater weight suppression, a variable that has been linked to the development and maintenance of eating disorders in longitudinal studies (Keel et al., 2019). This last finding underscores the value of this behavioral measure of RV-E across the full range from healthy to disease states – a goal for measurement of RDoC constructs (Insel et al., 2010).

Despite these strengths, the food PR task has limitations. First, given that food represents the object of symptomatic behavior in BN, breakpoint for food does not reflect whether RV-E is elevated in general or only for food in BN. This has important implications for the RDoC's driving principle that dysregulation in core constructs gives rise to comorbidity (Sanislow et al., 2010). Second, as participants consume food, behavior may be influenced by activation of neural circuits responsible for homeostatic (vs. hedonic) regulation of feeding. Although providing a small amount of food for each completed trial can minimize this impact (Miras et al., 2012), it cannot be fully eliminated. A similar problem emerges when psychoactive substances serve as primary reinforcers in PR tasks to understand RV-E in substance use disorders. The intoxicating effects of substances may impact breakpoint independently of RV-E. This is why studies of eating and substance use disorders have used money as a reward; money is not disorder specific and does not trigger neural changes unrelated to RV-E. However, money is a secondary reinforcer, and using money blurs measurement of RV-E with Reward Anticipation and creates gaps in RV-E assessment in animal and human research.

Animal research supports game play as a primary reinforcer (Reinhold et al., 2019) that may hold promise for applications in human research. Thus far, gameplay has been used on a limited basis in human studies (Epstein, Beecher et al., 2007; Epstein et al., 1991). For example, in the "apple picker" game, participants work in a video game to pick apples that are later exchanged for money or food (Epstein et al., 1991) or for music, a video, or money (Perkins et al., 2019). Thus, the game itself is not presented as the reward, and the apples represent a secondary reinforcer. Building off the "apple picker" game, Kirschenbaum and Hughes (2021) recently used immediate consumption of game play as a primary reinforcer in humans. However, after pressing a key to earn access to the game

in a PR task, participants then received unlimited access to game play. This deviates from animal-based studies in which the reward remains fixed throughout the duration of the PR task and across subjects. In addition, duration of game play when given unlimited access represents a different RDoC construct, Reward *Satiation.* That is, individual differences in the extent that reward consumption brings about a state of satisfaction, completion or consummation leading to spontaneous termination of consumption. Finally, Kirschenbaum and Hughes (2021) did not report data on reliability or validity for their tasks.

Present Study Aims and Hypotheses

The current study aimed to produce and evaluate a translational measure of RV-E for a primary reinforcer that is not the object of symptomatic behavior, can be used from a healthy to disease state, and does not induce satiety or intoxication. To do this, we developed a game PR task to parallel Bodell and Keel's (2015) food PR task. Participants were reinforced with an immediately consumable reward after each completed trial (i.e., access to playing the game Angry Birds). We chose Angry Birds due to the game's wide-spread popularity, grossing $136.8 million in a single year (Bernal, 2018), the absence of disorder-specific cues, and ethical ability to offer game access to all participants. This provides a direct parallel to designs used in animal-based research, maximizing the ability to translate findings from basic science to clinical science.

In Study 1, we sought to establish the psychometric properties of the game task in a sample of undergraduate students by examining test-retest reliability and convergent validity of breakpoint with Bodell and Keel's (2015) food task. In Study 2, we examined the clinical utility of the game task breakpoint in discriminating between participants with and without eating disorders. In Study 1, we hypothesized that breakpoint would demonstrate good test-retest reliability, such that individual differences in willingness to work for the game or food under the same conditions would demonstrate consistency over time. We hypothesized that breakpoint for the game task would be significantly correlated with breakpoint for the food task, using a threshold of $r \geq .50$ for evidence of convergent validity (Abma et al., 2016). In support of discriminant validity, we hypothesized that breakpoint for game play would be less impacted by homeostatic mechanisms than breakpoint for food. Specifically, we predicted that changes in breakpoint from the fasted to the fed condition would be less pronounced on the game task compared to the food task and that self-reported hunger, fullness, and satiation would be less influenced by the game task than the food task. If these hypotheses were supported, findings would suggest that we successfully developed a PR task that may be well-suited to translational research in human samples. In Study 2, we hypothesized that women with eating disorders characterized by binge eating would demonstrate higher breakpoint on both tasks compared to controls. Based on prior research demonstrating the influence of nutritional state on breakpoint for non-food rewards in animals (Carroll et al., 1984) and humans (Rusted et al., 1998), we predicted that breakpoint for the game task would decrease from a fasted to a fed state in both studies. Finally, we explored whether breakpoint was associated with self-report momentary and trait measures in both studies, using $r \geq .30$ for evidence that measures using different methods assess the same underlying construct (Patrick et al., 2019). These were considered exploratory because

animals cannot self-report subjective states and the overarching goal of this study was to produce and evaluate a translational measure of RV-E. This study was not preregistered.

Study 1 Method

Participants

Women (N = 71) between the ages of 18-45 years were recruited from undergraduate psychology courses at a large southeastern university for two study visits in which they completed the food and game PR tasks and self-report assessments. Study advertisements asked "Do you like to play Angry Birds? What about eating M&M's?" and participants who responded to these recruitments and subsequently rated their liking for M&Ms and Angry Birds >5 on a 10-point Likert scale (0=extremely dislike; 10=extremely like) were included. Using on-line and telephone screens, participants were excluded if they endorsed any medical conditions or medications known to affect appetite or weight, pregnancy or nursing in the previous six months, or a food allergy that might affect food consumption. Participants completed informed consent prior to their participation, including permission to video record their sessions to ensure task fidelity. Recordings were deleted immediately after review. Of the participants who completed visit 1, 80.2% (n = 57) completed visit 2. We recruited a subset of these participants to complete a third visit (n=26) to achieve adequate power for a stable test-retest reliability statistic. Measures completed at visit 1 did not differ between participants who completed only one visit, two visits, or all three visits (all p-values > .20).

The mean (SD) age of participants was 18.9 (1.16) years. Racial background was 67.2% White, 18.9% African American, 5.2% Asian or Pacific Islander, and 8.6% other/multiple races, and 27.6% endorsed Hispanic/Latina ethnicity across these racial groups. Their mean (SD) body mass index (BMI) was 23.3 (3.8) kg/m^2, based on objective height and weight assessment.

Procedures

Figure 1 presents a flowchart for Study 1. Participants were instructed to abstain from eating or drinking anything, except water, after 10 AM prior to their visits, which occurred between 2 to 3 PM. At the beginning of each visit, participants were asked to report the last time they consumed food or beverage. Participants who were not fasting since 10 AM were rescheduled for another day.

Participants completed self-report questionnaires described below. Then they completed visual analogue scales (VAS) that measured current levels of wanting, liking, and rewarding value of Angry Birds and M&Ms as well as current levels of hunger, fullness, and satiation. Next, they completed a computerized PR task to measure RV-E for either Angry Birds or M&Ms in the fasted state. The order of the tasks was counterbalanced across visits, and participants were randomly assigned to task order. Participants then completed post-task VAS ratings.

Participants were then given a standardized meal of Ensure Plus® (660 grams; 900 kcal) to induce a fed state. Following the standardized meal, participants completed another VAS

packet and the alternate PR task. Manipulation checks of hunger, fullness, and satiation ratings indicated participants reported significantly less hunger [$B(SE) = -64.8$ (2.4), $p < .001$], and greater fullness [$B(SE) = 62.9$ (2.6), $p < .001$] and satiation [$B(SE) = 23.2$ (3.0), $p < .001$] after consuming the meal. Participants then completed either the food or game task. After completing the second task, participants completed a fourth and final VAS packet (see Figure 1).

Participants returned after approximately one week (mean = 8.6 days, SD = 9.0) to complete visit 2. Procedures were identical for visit 2, except participants did not complete initial trait-level self-report measures and task order was reversed. Approximately one week later, a subset of participants returned for study visit 3 and completed the game task and then the food task so that both tasks were initiated in a fasted state to establish one to two-week[1] test-retest reliability of breakpoint in a fasted state. At the end of their participation, participants were debriefed about the purpose of the study and given course credit for their time.

Reward Valuation – Effort (RV-E) Tasks

We used the same PR task described by Bodell and Keel (2015) to measure RV-E for food in all three visits. To measure RV-E for the game, we modified this task to measure willingness to work for playing Angry Birds. Instructions were presented on a printed card and played via audio recording, to minimize experimenter influence. Participants were instructed, "During this computer task, you will have the opportunity to earn access to the game Angry Birds by repeatedly pressing the space bar." Participants were told the number of keypresses required to earn the reward would increase as they went through the trials, but they were not told by how much. The task instructions relayed that the task consisted of 10 trials and at the end of each trial, participants would earn one minute of play time[2]. Participants received access and played the game after each completed trial. After one minute of play, the computer locked them out of the game and returned them to the PR task. Participants were told to continue to tap for as long as they still wanted to play the game, they could end the task at any time and that there were no right or wrong responses. Participants were left alone to the complete the task and asked to alert the experimenter once they decided to stop or completed the last trial.

Replicating prior PR tasks (Klein et al., 2010; Bodell & Keel, 2015; Schebendach et al., 2013), the work required for the first trial was 50 presses and increased by 200 presses for each subsequent trial (i.e., 250 presses for trial 2, 450 for trial 3, 650 for trial 4…up to 1850 for trial 10) in both tasks. RV-E was quantified as the participant's breakpoint. Video recordings indicated compliance across participants, and all data were used in analyses.

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[1]Time frame for test-retest reliability depended on whether the participant had been randomly assigned to complete the food or game task in the fasted condition during their first or second visit, resulting in a mean (SD) time frame of 10 (6) days, and did not differ between tasks (p>.30).
[2]Different durations of game play were tested during initial development of the task. One minute was sufficient to elicit the full range of breakpoints from 50 to 1850 key presses in pilot participants and reduced the overall time required to the complete the full task compared to two minutes of game play.

Self-report Measures

Demographic questionnaire.—Demographic information was obtained through self-report. Participants also reported if they took hormonal contraceptives, and if not, the first day of their last menstrual cycle to account for potential influence of ovarian hormones on RV-E (Dreher et al., 2007). Inclusion of menstrual data did not impact results (see Supplemental Table S1).

Sensitivity to Punishment/Sensitivity to Reward Questionnaire (SPSRQ).—This 48-item questionnaire measures behavioral approach, in a Sensitivity to Reward (SR) subscale, and behavioral avoidance mechanisms, in a Sensitivity to Punishment (SP) subscale (Torrubia et al., 2001). The SPSRQ scale scores demonstrated good internal consistency in our sample (SR score $\alpha = .82$, $\omega = .82$; SP score $\alpha = .69$, $\omega = .70$).

Power of Food Scale (PFS).—This 18-item scale assesses appetitive and psychological responsiveness to food (Lowe et al., 2009). In our sample, the PFS total score demonstrated excellent internal consistency ($\alpha = .90$, $\omega = .90$).

Visual Analogue Scale (VAS).—Participants were asked to place a vertical mark on 100mm line, anchored from "None/Not at All" to "Extremely," to indicate their current level of hunger, fullness, satiation, and wanting M&Ms (or Angry Birds), liking M&Ms (or Angry Birds), and finding M&Ms (or Angry Birds) rewarding before and after each PR task. VAS have previously been used to measure momentary reward value in humans (Sherdell et al., 2012), and momentary ratings of subjective states of hunger and fullness have demonstrated expected associations with postprandial gut peptide responses (Keel et al., 2018).

Data Analyses

All data were examined for outliers, missing data, data entry errors, and possible violations of assumptions of relevant statistical analyses. Test-retest reliability of breakpoints in fasted states was determined through calculation of intraclass correlations (ICCs) using a 2-way mixed-effects model. Descriptive statistics and bivariate correlations were computed to examine the normality and interrelatedness of all variables. Correlations between breakpoint across the two tasks were examined to determine convergent validity of tasks in measuring the same underlying construct of RV-E. A linear mixed model (Bryk & Raudenbush, 1992) was computed to analyze whether breakpoint differed by nutritional state, task type, and/or the interaction between nutritional state and task. This was used to evaluate discriminant validity of breakpoint as an assessment of RV-E versus homeostatic mechanisms. Linear mixed models were conducted to account for the non-independent nature of repeated observations and chosen over repeated measures ANOVA to account for missing data (i.e., attrition). In linear mixed models, the interpretation of fixed effects is analogous to traditional linear regression models. Linear mixed models were also used to test changes in VAS ratings of liking, wanting, and feeling rewarded by playing Angry Birds or eating M&Ms from pre- and post-task with repeated measures nested within individuals including participant ID as a random intercept. Models were run separately by task and included time, nutritional state, and their interaction as predictors. Finally, these same models assessed changes in self-reported ratings of hunger, fullness, and satiation from pre- and post-task in

the fasted and fed conditions. For exploratory analyses, breakpoint on tasks were correlated with VAS ratings of liking, wanting, and finding the food or game rewarding, and self-reported sensitivity to reward, sensitivity to punishment, and psychological responsiveness to food. Dependent variables were left in their original metrics to facilitate interpretation of results.

Missing data were handled using maximum likelihood estimation. All analyses were conducted in R v. 3.5.3 using the *lme4* (Bates et al., 2015), *lmerTest* (Kuznetsova et al., 2017), *irr* (Gamer et al., 2012), and *psych* (Revelle & Revelle, 2015) packages.

Transparency and Openness

Data, materials, and code are available upon request from the corresponding author.

Study 1 Results

Test-retest reliability of breakpoint in a fasted state was excellent for the game task (ICC = .91, 95% CI [.80, .96]) and good for the food task (ICC = .85, 95% CI [.52, .87]) over the one-to two-week period. Participants who demonstrated greater willingness to work for a food reward were also more willing to work for access to play Angry Birds in both fasted ($r(57) = .51$, $p < .001$) and fed ($r(56) = .29$, $p = .031$)[3] states. However, evidence of convergent validity, using a criterion of r>.50, was not achieved when RV-E for food was measured in the fed state, potentially reflecting the impact of homeostatic mechanisms on food task breakpoint.

Results of the linear mixed models predicting breakpoint revealed a main effect for nutritional state ($B\ (SE) = 321.01\ (552.40)$, $p < .001$). Across tasks, participants in a fasted state had a significantly higher breakpoint for reward than when in a fed state (see Figure 2). A significant main effect for task indicated that participants put forth more effort towards playing the game compared to consuming food across fasted and fed states ($B\ (SE) = 398.40\ (55.63)$, $p < .001$). Finally, a significant interaction between nutritional state and task supported that the difference between fasted versus fed breakpoint was greater in the food task than in the game task ($B\ (SE) = -207.94\ (73.45)$, $p < .001$).

Because the fed state consistently represented the second task in visits 1 and 2, lower breakpoint in the fed state could be impacted by fatigue. To test this possibility, we compared breakpoint on the food task when it was administered in a fed state as the second task in study visits 1 or 2 to when it was administered in a fasted state in study visit 3 after participants had completed the game task. In this comparison, reward type (food) and task order (second) are held constant but nutritional state (fasted vs. fed) differs. The significant decrease in breakpoint from the fed to fasted state remained ($t(24) = -5.57$, $p < .001$, d = 2.27), supporting our interpretation that the decreases in breakpoint reflect nutritional state and not fatigue. To examine potential for practice effects, we examined whether completing a PR task in the fasted condition in visit 1 (no prior practice) vs. visit 2 (one prior practice)

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[3]One participant was missing data for breakpoint on the game task in the fed state due to experimenter error (experimenter did not save record of breakpoint at end of task).

influenced differences from the same task completed in the fasted condition at visit 3. We found no evidence for practice effects for the game (p=.58) or food task (p=.54). This may reflect that the total practice, combined across conditions, was constant across participants throughout the study. Finally, we examined whether task order (game vs. food first) in visit 1 influenced breakpoint on these tasks in visit 2 and found no effects (t-values from −1.82 to 1.17; p-values from .19 to .99).

Changes in momentary ratings of liking, wanting, and perceived reward of M&Ms or Angry Birds, respectively, were examined separately by task. For the food task, the main effects of time and nutritional state were significant across ratings, such that ratings decreased from pre- to post-task for liking ($B \, (SE) = -17.6 \, (3.7)$, $p < .001$), wanting ($B \, (SE) = -27.6 \, (3.4)$, $p < .001$), and perceived reward $(B \, (SE) = -18.5 \, (4.2)$, $p < .001)$. Participants reported greater liking ($B \, (SE) = 22.03 \, (3.7)$, $p < .001$), wanting ($B \, (SE) = 33.9 \, (3.4)$, $p < .001$), and reward ($B \, (SE) = 25.2 \, (4.2)$, $p < .001$) in fasted compared to fed states. In addition, for ratings of wanting, there was a significant interaction between time and nutritional state ($B \, (SE) = -18.6 \, (4.8)$ $p < .001$), such that wanting decreased more from pre-to post-task in the fasted compared to the fed state. The interaction between time and nutritional state was not significant for subjective reports of liking M&M's ($B \, (SE) = -1.9 \, (5.2)$, $p > .05$) or for finding them rewarding ($B \, (SE) = -3.7 \, (5.9)$, $p > .05$).

For the game task, there were significant main effects for time on ratings of liking $(B \, (SE) = 12.6 \, (4.3)$, $p < .01)$, wanting ($B \, (SE) = 8.8 \, (4.5)$, $p < .05$) and perceived reward ($B \, (SE) = 11.8 \, (4.3)$, $p < .001$) and for nutritional state on liking ($B \, (SE) = 16.9 \, (4.2)$, $p < .001$), wanting $(B(SE) = 17.4 \, (4.4)$, $p < .001)$, and perceived reward $(B(SE) = 13.7 \, (4.3)$, $p < .01)$. Likewise, across ratings of liking ($B \, (SE) = -19.9 \, (5.9)$, p< .001), wanting $(B(SE) = -24.6 \, (6.2)$, $p < .001)$, and reward $(B(SE) = -20.1 \, (5.9)$, $p < .001)$, there were significant interactions between time and nutritional state. Overall, participants reported greater liking, wanting, and perceived reward at post-task and when fasted. Decomposition of interactions revealed that from pre-to post-task, participants' ratings of liking, wanting, and perceived reward *decreased* in a fasted state but *increased* in a fed state. Figure 3 depicts mean values for momentary ratings of finding the food (panel a) and the game (panel b) rewarding to illustrate the pattern of results.

Finally, linear mixed models predicting change in ratings of hunger, fullness, and satiation from pre- to post-task revealed significant interactions (all $p < .001$) between time and task and between nutritional state and task for all three outcomes (see Table 1). Decomposition of interactions revealed that participants reported decreased hunger and increased fullness and satiation after the food task but not after the game task. A significant 3-way interaction for task, nutritional state, and time on hunger revealed the decline in hunger during the food task was greater in the fasted state than in the fed state. Decomposition of nutritional state and task interaction revealed a significant difference between the game and food tasks for hunger, satiation, and fullness in a fasted state but not in a fed state. In the fed state, participants reported less hunger and greater satiation and fullness in the food compared to the game task.

Exploratory analyses indicated that VAS ratings of liking, wanting, and finding the game rewarding demonstrated inconsistent associations with breakpoint on the game task, with the most consistent associations emerging in the fed state for momentary ratings made immediately after the task. Associations between momentary VAS ratings and food breakpoint were most consistent in the fed state as well; however, there was no clear distinction between ratings made pre-versus post food task (see Supplemental Table S2). In contrast, breakpoints for tasks were unrelated to age, BMI, and trait measures of sensitivity to reward, sensitivity to punishment, or psychological responsiveness to food (see Supplemental Table S3).

Study 2 Methods

Participants

Women (N=210) were recruited from the community for a multi-visit longitudinal study testing a biobehavioral model for maintenance of bulimic eating disorders (see Keel et al., 2019 for further information). Telephone screens and in-person assessments established eligibility criteria, including age 18-35 years, BMI between 16.5-35 kg/m^2, no medical conditions or medications that could influence appetite or weight or ability to consume foods used in the study, not pregnant or nursing in the past 6 months, endorsed liking M&Ms and playing computer games, had no plans to move from the local area within the next year, and either met DSM-5 criteria for an eating disorder characterized by binge eating (n=173) or had no history of eating pathology (n=37). Data included in the current report come from participants' baseline visits. Participants' mean (SD) age was 20.9 (2.7) years, BMI across visits was mean (SD) of 24.2 (4.2), 24.1 (4.1) and 24.2 (4.3) kg/m^2 and did not change significantly over sessions (F(1, 208)=0.004, p=.95). Racial/ethnic breakdown was 26.7% Hispanic or Latina, 71% White, 11.9% Black or African American, 7.1% Asian, 3.3% Native American, 0.5% Pacific Islander, and 6% Other. Totals exceed 100% because participants were asked to endorse all applicable racial/ethnic identities. All participants completed written informed consent, and the protocol was approved by the university's Institutional Review Board.

Procedure

Participants completed five visits over the course of three days and were paid for each visit they completed and provided a financial incentive for completing visits as originally scheduled. The first visit established eligibility through a medical screen, pregnancy test, objectively measured height and weight, vital signs, and interview and self-report assessments. Eating disorder diagnosis was established with the Eating Disorder Examination (EDE) interview version 16.0D (Fairburn, Cooper, & O'Connor, 2008), and lifetime history was assessed with the Structured Clinical Interview for DSM-5 disorders (First et al., 2015). All eating disorder participants were required to meet DSM-5 criteria for anorexia nervosa, bulimia nervosa, binge-eating disorder, or an other specified feeding or eating disorder (OSFED). characterized by objectively large binge eating episodes. The minimum threshold for an OSFED diagnosis was 12 disordered eating behaviors (i.e., binge eating, self-induced vomiting, laxative or diuretic misuse, fasting, compulsive exercise) over the prior 12 weeks and the presence of clinically significant distress and impairment as

indicated by 1) marked distress about binge-eating on the EDE, 2) clinically significant distress or impairment due to the eating disorder on the Structured Clinical Interview for DSM-5 (First et al., 2015) or 3) score 16 on the Clinical Impairment Assessment (Bohn et al., 2008; Reas et al., 2016). Non-eating disorder controls had no current dieting for weight loss and no lifetime history of eating disorder symptoms based on EDE and SCID-5 interviews, respectively.

During their first visit, participants completed the SPSRQ (SR score Cronbach's alpha = .76, ω = .76; SP score Cronbach's alpha = .90, ω = .90) and the Behavioral Inhibition System (BIS)/Behavioral Activation System (BAS) scale (Carver & White, 1994), (BIS subscale Cronbach's alpha = .82, ω = .82; BAS Drive subscale Cronbach's alpha = .82, ω= .82; BAS Fun Seeking Cronbach's alpha = .75, ω = .75 ; BAS Reward Responsiveness Cronbach's alpha =.79, ω = .80).

On the second day, participants returned to the lab between 8:30 and 10:30 AM, after an overnight fast (no food after 11 PM the previous night) to complete the game task in a fasted condition. Replicating prior methods (Bodell & Keel, 2015), participants received a standardized breakfast of a yogurt parfait and juice (approximately 300 kcal) and were asked to abstain from eating or drinking anything except water until they returned to the lab in the afternoon for a third visit between 2 and 3 PM to complete the food task.

On the third day, participants returned to the lab between 7:30 and 9:30 AM after an overnight fast (no food after 11 PM the previous night) to complete a fixed test meal during which they consumed the same liquid meal used in Study 1 and had subjective and gut peptide response measured through 30 minutes following the test meal. After this, they completed the game task in a fed state. The second and fourth visits were scheduled to ensure that participants completed the game task at approximately the same time in the morning across days. Only the game task was completed during the morning visits.

VAS measures in Study 1 were used before and after all PR tasks in Study 2. Participants who completed all 3 days of the baseline assessments (n=210) did not differ on demographic, physical, or clinical variables from participants who dropped out or could not complete their baseline visits due to COVID-19 suspension of in person assessments (n=95) (all p-values > .15).

Data Analyses

All data were examined for outliers, missing data, data entry errors, and possible violations of assumptions of relevant statistical analyses. Participants were video recorded while completing all three PR tasks with their informed consent, and recordings indicated participants followed instructions. One participant chose not to initiate the game task in the fed condition. In addition, equipment failures (e.g., the mechanism jamming, the computer code not running) prevented the dispenser from delivering M&M's to 18 participants during the food task and from providing game access to 2 participants in the fasted condition and one participant in the fed condition. Tasks were restarted for these participants to generate data on breakpoint; however, technical problems were discovered only after participants did not receive the reward despite having put forth effort. Thus, task interruption altered

the amount of effort in relation to the amount of reward received, and data from impacted participants (n=21; 10% of the initial sample) were excluded from analyses. This resulted in a final sample size of N=189 participants, including 31 controls and 158 participants with an eating disorder. There was no significant association between presence of an eating disorder and technical problems with the PR tasks (χ^2(1)=1.93, p=.17). In addition, findings remained the same with or without excluding these data (see Supplement for results including all available data).

A repeated measures ANOVA with diagnostic group (eating disorder vs. control) as a between-subjects factor and nutritional state (fasted vs. fed) as a within-subjects factor was used to test whether game breakpoint was higher in those with eating disorders compared to those without and higher in the fasted compared to the fed condition. A t-test was used to compare food breakpoint between groups. Exploratory analyses replicated those in Study 1.

Transparency and Openness

Data are publicly available through the NIMH Data Archive (https://nda.nih.gov/). Data analytic code and materials are available upon request from the corresponding author.

Study 2 Results

There was a significant effect of group (F(1, 187)=5.78, p=.02, eta^2=.03) and nutritional state (F(1, 187)=27.32, p<.001, eta^2=.13) on breakpoint in the game task, and no significant group X nutritional state interaction (F(1, 187)=2.62, p=. 11, eta^2=.01). Breakpoint for the game was significantly higher in eating disorder participants (mean (SE)=727 (31)) compared to controls (mean (SE)=544 (70)), and RV-E was significantly higher in the fasted (mean (SE)=733 (47)) compared to the fed condition (mean (SE)=537 (38)). This bolsters interpretations from Study 1 by replicating the decrease in RV-E in the fed compared to the fasted condition when the game task was the sole PR task in each visit. In addition, participants with eating disorders demonstrated significantly higher breakpoint for food (mean (SE)=826 (36)) compared to controls (mean (SE)=566 (61); t(187)=3.00, p=.003). Similar to results from Study 1, significant correlations were found for breakpoints between the food and game tasks (food with fasted game: r(189)=.44, p<.001; food with fed game: r(189)=.45, p<.001; and between the game task in the fasted and fed conditions: r(189)=.63, p<.001).

Momentary pre- and post-task VAS ratings of liking, wanting, and finding the game rewarding demonstrated significant associations with breakpoint in the game task in both the fasted and fed conditions, and the same was true for VAS ratings of liking, wanting, and finding food rewarding and breakpoint for food (see Supplemental Table S4). Although some effect sizes were small, most associations between breakpoint and momentary ratings of liking, wanting, and finding the game (or food) rewarding had medium effect sizes (r

.30). Similar to results from Study 1, breakpoint on the PR tasks did not significantly correlate with age, self-report trait measures of sensitivity to reward or the Drive subscale of the Behavioral Activation Scale or with any other trait measures (see Supplemental Table S5). However, there were small statistically significant positive associations between BMI and breakpoint on PR tasks.

Discussion

Results support the reliability of breakpoint and validity of interpretations of breakpoint from the game task as a behavioral measure of reward valuation – effort (RV-E). The taksk 1) parallels animal paradigms, 2) is appropriate for use in nonclinical and clinical samples, and 3) has potential transdiagnostic relevance. Breakpoints from the game task demonstrated good test-retest reliability in both the fasted and fed condition and convergent validity with food task breakpoint in the fasted condition. Beyond serving as a foundation for validity of stable constructs (Hammersley, 1987), good test-retest reliability is crucial for evaluating the effect of manipulating independent variables, such as nutritional state or pharmacological agents, on measures of states by minimizing random variance over time.

Our results support that both tasks measured the same underlying construct in the fasted state. Weaker associations in the fed state may reflect the influence of homeostatic mechanisms on breakpoint in the food task given that the association between the game task in the fed state and the food task in the fasted state was r=.63 (see Supplemental Table S3). Further, the magnitude of correlations between the fasted food task and fasted vs. fed game tasks did not significantly differ (using a Fisher's z-test; $p = .17$ in Study 1 and p = .19 in Study 2). Somewhat lower associations between the fasted food and fasted and fed game tasks in Study 2 (r=.44 and .45, respectively, see Supplemental Table S5) may reflect differences related to the time of day. In Study 1, all tasks were completed in the afternoon. In Study 2, participants completed the game tasks in the morning and the food task in the afternoon. Despite these differences, participants demonstrated consistency in effort towards playing the game and consuming food, thereby supporting the convergent validity of the game task.

Our finding that nutritional state had a greater impact on breakpoint for M&Ms than for Angry Birds supports one of the purposes of evaluating game task breakpoint as a measure of RV-E – to isolate assessment of RV-E for an immediately consumable primary reinforcer from the influence of homeostatic mechanisms. Unlike the food task, participation in the game task demonstrated no significant changes in self-reported hunger, fullness, or satiation, further supporting greater discriminant validity for the game task compared to the food task.

In addition, as expected, participants worked significantly harder for both food and game rewards when fasted compared to fed. Such findings are consistent with prior animal findings in which subjects put forth greater effort towards food and non-food rewards when nutritionally deprived (de Vaca et al., 2004; Carroll et al., 1984). Moreover, our findings are in line with hypothesized neurobiological effects of glucagon-like-petitide-1 (GLP-1) on dopamine activations in reward pathways (Dickson et al., 2012; Keel et al., 2019; Williams, 2014). Study 2 replicated prior differences between women with eating disorders and controls on RV-E for food (Bodell & Keel, 2015) and extended this by showing significantly greater RV-E for a non-food reward in eating disorder participants. Study 2 also replicated the effect of nutritional state on RV-E for the game found in Study 1.

Study 2 revealed a small significant positive correlation between BMI and breakpoint on the game PR task in the fed state not observed in Study 1. PR tasks have been used in the study

of obesity (Epstein, Leddy et al., 2007), but, to our knowledge, this may be the first study to suggest an association between BMI and RV-E for a non-food primary reinforcer. However, given the inconsistency of findings from Study 1 and 2, independent replication would be required before drawing meaningful conclusions to ensure this is not a chance finding.

Momentary ratings of liking, wanting, or finding the game/food rewarding consistently demonstrated significant associations with breakpoints on both the game and food task in Study 2, with several above the threshold for convergent validity (Patrick et al., 2019) (see Supplementary Table S4). Less consistent associations were observed in Study 1, with only a few supporting convergent validity (see Supplementary Table S2). Differences in sample size, time of day for the game task, inclusion of participants with eating disorders, or any combination of these factors may account for differences between studies.

We did not observe significant correlations between our behavioral measures of RV-E and scores on self-report trait measures of sensitivity to reward in either study or the BAS Drive subscale in Study 2, which has been proposed as a self-report measure of RV-E in the RDoC (NIMH, 2021). In addition to expected differences in measures of states vs. traits, this may reflect the more general challenge of integrating across units of analysis due to method variance issues (Campbell & Fiske, 1959). Moreover, factor analytic efforts to conceptualize other psychological constructs across units of analysis indicate largely non-convergent self-report and behavioral construct networks (Meda et al., 2009; MacKillop et al., 2016; Eisenberg et al., 2019). Taken together, the food and game tasks likely capture a behavioral component of RV-E that differs from the higher-order cognitive process of self-report, especially for trait measures. Importantly, we developed the game task to translate measures from animal models into clinical samples. Although humans can self-report their perceived underlying responsiveness to reward, animals cannot. Thus, our task matches measurement in animals to clinical samples. That said, future research should pursue convergence between self-report and behavioral measures of RV-E – particularly given promising associations between momentary self-report and behavioral RV-E assessment in Study 2.

Of interest, in Study 1, we observed a time by nutritional state interaction for ratings of wanting, liking, and reward in the game task, but not in the food task. This same interaction between time and nutritional state was found for reports of liking Angry Birds in Study 2 (p=.001), with trend level significance for reports of wanting to play Angry Birds (p=.055) and finding it rewarding in Study 2 (p=.065). Similar to Study 1, momentary ratings of liking the game in the fasted state decreased from pre- to post-task whereas they increased in the fed state. Given that breakpoint for the game was higher in the fasted versus fed condition in both studies, participants exerted more effort and consumed more game play in the fasted compared to the fed condition. Although highly consistent with animal-based research that motivation to work for rewards is enhanced when food deprived, consumption of non-food rewards does not relieve the underlying physiological drive state – hunger. This may account for subjectively reported diminished liking, wanting, and reward value of game play when fasted despite higher levels of effort to obtain access to the game.

The game task extends prior PR paradigms in multiple ways. The game task uses a general, non-disorder specific reward that can be used transdiagnostically in the study of problems

characterized by excessive reward consumption, such as binge eating, gambling, sexual behavior and substance use. This advances the goals of RDoC to study underlying constructs that contribute to comorbidity. For instance, prior research has consistently documented high cooccurrence between eating and alcohol/substance use disorders (Udo & Grilo, 2019). Elevations in RV-E, regardless of reward type, may explain these patterns.

The game task may also provide an alternative measure for RV-E to the Effort Expenditure for Rewards Task (EEfRT) (Treadway et al., 2009), which was recommended in the NIMH's (2016) *Behavioral Assessment Methods for RDoC Constructs.* Similar to the EEfRT, the game task involves minimal movement, making it feasible to incorporate the game task with measurement of neural activation via fMRI or psychophysiological recording. Compared to the EEfRT, the game task provides greater translation from animal-based studies of RV-E because it does not require participants to choose concurrently between "easy" and "hard" tasks, does not involve a risk of failing to achieve the criterion for reward, does not vary probability of reward receipt, and uses an immediately consumable reward.

Finally, we experienced fewer technical difficulties with the game task when employed with a larger number of participants; whereas mechanical problems with M&M dispensing required a redesign of the mechanism after repeated interruptions. Overall, the process of programming the PR task to open and close access to the game was comparatively easy and inexpensive. It minimizes contamination with other RDoC positive valence constructs such as Reward Probability, Reward Anticipation, and Reward Satiation. As such, the current game task is well-suited for translational research from animal-based models to non-clinical and clinical samples.

Our study had several strengths that lend confidence to conclusions that may be drawn. We observed replication of findings across two independent samples, including a convenience sample of undergraduates who offer the proving ground for much psychological research and a community-based sample of participants with and without eating disorders. Both samples demonstrated racial and ethnic diversity, representative of the populations from which they were drawn. Video recording of behavioral tasks permitted us to confirm compliance with instructions, and our self-report assessment scores demonstrated good psychometric properties, lending additional support that participants attended to assessments. In both studies, participants consumed the same fixed test meal to induce a change in nutritional state, and findings from this manipulation were consistent across samples. Both studies included both momentary and trait measures of related constructs, which revealed some promising results for potential convergence between momentary ratings and behavioral assessment of RV-E. Last, we had a high retention rate, with 80% of those who completed the first visit returning for the second visit in Study 1 and 69% of eligible participants completing all baseline assessments across three days in Study 2, and no evidence of biased attrition. Lower participant retention in Study 2 also partly reflects cessation of in person visits from March 2020 to February 2021 due to COVID-19.

Constraints on Generality

Despite these strengths, our study has limitations. We only included young adult women. This reflects our lab's primary focus on eating disorders. These tasks should be examined

in men, in different age groups, and in other clinical populations (e.g., individuals with substance use or mood disorders) to address these clear constraints on generality. Although we objectively manipulated nutritional status in both studies, we relied on participants' self-report for whether or not they followed instructions regarding not eating before coming into the lab for fasted assessments. Importantly, in Study 2, we have confirmation through gut peptide assessment that participants were indeed fasted, and any lack of compliance would have reduced rather than produced significant effects of nutritional state on RV-E. Moreover, we did not examine the impact of play time on subsequent response to the game PR. It could be that, unlike with food, playing 1 minute of a fun game increases the desire or motivation to play again; thus, increasing the relative value of the reward. Future studies assessing possible reactivity are warranted. Finally, we encountered mechanical problems with the food task that caused loss of nearly 10% of data in Study 2. Analyses excluding data from these participants did not differ from analyses including all available data (see Supplement), but this reveals a weakness in tasks designed to provide immediate access to consumable rewards. Although we cannot rule out the potential influence of demand characteristics on participants' responses, Bodell and Keel (2015) found no differences in breakpoint between recorded and unrecorded tasks in women with BN and controls.

In conclusion, the current study provides evidence for the reliability of breakpoint and validity of interpretations of breakpoint on the game task as an assessment of RV-E. This task may facilitate translation of findings from animal models into testable hypotheses in human samples ranging from healthy to disease states. Research that improves understanding of biobehavioral mechanisms underlying this construct may reveal etiological and maintenance factors for excessive reward consumption. Identification of these novel targets for intervention may contribute to transdiagnostic prevention and treatment of a range of mental disorders.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Funding:

References

Abma IL, Rovers M, & van der Wees PJ (2016). Appraising convergent validity of patient-reported outcome measures in systematic reviews: constructing hypotheses and interpreting outcomes. BMC research notes, 9, 226. 10.1186/s13104-016-2034-2 [PubMed: 27094345]

Bernal N (2018). Angry Bird maker boosts sales from its gaming division. The Telegraph. https://www.telegraph.co.uk/technology/2018/08/17/angry-birds-maker-boosts-sales-gaming-division/ Accessed: May 6, 2019.

Bates D, Maechler M, Bolker B, & Walker S (2015). lme4: Linear mixed-effects models using Eigen and S4. R package version 1.1–7. 2014.

Beloate LN, & Coolen LM (2017). Influences of social reward experience on behavioral responses to drugs of abuse: review of shared and divergent neural plasticity mechanisms for sexual reward and drugs of abuse. Neuroscience & Biobehavioral Reviews, 83, 356–372. [PubMed: 29108963]

Bodell LP, & Keel PK (2015). Weight suppression in bulimia nervosa: Associations with biology and behavior. Journal of Abnormal Psychology, 124(4), 994. [PubMed: 26191637]

Bohn K, Doll HA, Cooper Z, O'Connor M, Palmer RL, & Fairburn CG (2008). The measurement of impairment due to eating disorder psychopathology. Behaviour Research and Therapy, 46(10), 1105–1110. 10.1016/j.brat.2008.06.012 [PubMed: 18710699]

Bryk AS, & Raudenbush SW (1992). Hierarchical linear models: Applications and data analysis methods. Sage: Thousand Oaks, CA.

Bulik CM, & Brinded EC (1993). The effect of food deprivation on alcohol consumption in bulimic and control women. Addiction (Abingdon, England), 88(11), 1545–1551. 10.1111/j.1360-0443.1993.tb03140.x [PubMed: 8287000]

Campbell DT, & Fiske DW (1959). Convergent and discriminant validation by the multitrait-multimethod matrix. Psychological Bulletin, 56(2), 81–105. [PubMed: 13634291]

Carroll ME, Stotz DC, Kliner DJ, & Meisch RA (1984). Self-administration of orally-delivered methohexital in rhesus monkeys with phencyclidine or pentobarbital histories: effects of food deprivation and satiation. Pharmacology, Biochemistry, and Behavior, 20(1), 145–151. 10.1016/0091-3057(84)90115-1 [PubMed: 6694994]

Carver CS, & White TL (1994). Behavioral inhibition, behavioral activation, and affective responses to impending reward and punishment: The BIS/BAS scales. Journal of Personality and Social Psychology, 67(2), 319–333.

de Vaca SC, Krahne LL, & Carr KD (2004). A progressive ratio schedule of self-stimulation testing in rats reveals profound augmentation of d-amphetamine reward by food restriction but no effect of a "sensitizing" regimen of d-amphetamine. Psychopharmacology, 175(1), 106–113. [PubMed: 14985931]

Dickson SL, Shirazi RH, Hansson C, Bergquist F, Nissbrandt H, & Skibicka KP (2012). The glucagon-like peptide 1 (GLP-1) analogue, exendin-4, decreases the rewarding value of food: a new role for mesolimbic GLP-1 receptors. Journal of Neuroscience, 32(14), 4812–4820. [PubMed: 22492036]

Dreher JC, Schmidt PJ, Kohn P, Furman D, Rubinow D, & Berman KF (2007). Menstrual cycle phase modulates reward-related neural function in women. Proceedings of the National Academy of Sciences, 104(7), 2465–2470.

Eisenberg IW, Bissett PG, Enkavi AZ, Li J, MacKinnon DP, Marsch LA, & Poldrack RA (2019). Uncovering the structure of self-regulation through data-driven ontology discovery. Nature Communications, 10(1), 1–13.

Epstein LH, Beecher MD, Graf JL, & Roemmich JN (2007). Choice of interactive dance and bicycle games in overweight and nonoverweight youth. Annals of Behavioral Medicine, 33(2), 124–131. [PubMed: 17447864]

Epstein LH, Bulik CM, Perkins KA, Caggiula AR, & Rodefer J (1991). Behavioral economic analysis of smoking: money and food as alternatives. Pharmacology, Biochemistry, and Behavior, 38(4), 715–721. 10.1016/0091-3057(91)90232-q [PubMed: 1871188]

Epstein LH, Leddy JJ, Temple JL, & Faith MS (2007). Food reinforcement and eating: a multilevel analysis. Psychological Bulletin, 133(5), 884–906. 10.1037/0033-2909.133.5.884 [PubMed: 17723034]

Fairburn CG, Cooper Z & O'Connor ME (2008). Eating Disorder Examination (16.0D ed.). In: Fairburn CG(Ed.), Cognitive Behavior Therapy and Eating Disorders (pp. 265–308). New York: Guilford Press.

First MB, Williams JB, Karg RS, & Spitzer RL (2015). Structured Clinical Interview for DSM-5® Disorders-Research Version (SCID-5 for DSM-5, Research Version; SCID-5-RV) Arlington, VA: American Psychiatric Association.

Gamer M, Lemon J, Fellows I, & Singh P (2012). IRR: various coefficients of interrater reliability and agreement. 2012. R package version 0.84, 1.

Hammersley M (1987). Some notes on the terms 'validity' and 'reliability'. British Educational Research Journal, 13(1), 73–82.

Haney M, Foltin RW, & Fischman MW (1998). Effects of pergolide on intravenous cocaine self-administration in men and women. Psychopharmacology, 137(1), 15–24. 10.1007/s002130050588 [PubMed: 9631952]

Hodos W (1961). Progressive ratio as a measure of reward strength. Science, 134, 943–944. [PubMed: 13714876]

Insel T, Cuthbert B, Garvey M, Heinssen R, Pine DS, Quinn K, …Wang P. (2010). Research domain criteria (RDoC): toward a new classification framework for research on mental disorders. American Journal of Psychiatry, 167, 748–751. doi: 167/7/748 [pii] 10.1176/appi.ajp.2010.09091379 [PubMed: 20595427]

Keel PK, Bodell LP, Forney KJ, Appelbaum J, & Williams D (2019). Examining weight suppression as a transdiagnostic factor influencing illness trajectory in bulimic eating disorders. Physiology & Behavior, 208, 112565. 10.1016/j.physbeh.2019.112565 [PubMed: 31153878]

Keel PK, Eckel LA, Hildebrandt BA, Haedt-Matt AA, Appelbaum J, & Jimerson DC (2018). Disturbance of gut satiety peptide in purging disorder. The International Journal of Eating Disorders, 51(1), 53–61. 10.1002/eat.22806 [PubMed: 29219202]

Kirshenbaum AP, & Hughes JR (2021). Reinforcement enhancement by nicotine: A novel abuse-liability assessment of e-cigarettes in young adults. Experimental and clinical psychopharmacology, 10.1037/pha0000496. Advance online publication. https://doi.org/10.1037/pha0000496

Klein DA, Schebendach JE, Gershkovich M, Bodell LP, Foltin RW, & Walsh BT (2010). Behavioral assessment of the reinforcing effect of exercise in women with anorexia nervosa: further paradigm development and data. International Journal of Eating Disorders, 43(7), 611–618. [PubMed: 19806608]

Kuznetsova A, Brockhoff PB, & Christensen RHB (2017). lmerTest package: tests in linear mixed effects models. Journal of Statistical Software, 82(13).

Lamontagne SJ, & Olmstead MC (2019). Animal models in addiction research: A dimensional approach. Neuroscience & Biobehavioral Reviews, 106, 91–101. [PubMed: 30309630]

Lowe MR, Butryn ML, Didie ER, Annunziato RA, Thomas JG, Crerand CE, … & Halford J. (2009). The Power of Food Scale. A new measure of the psychological influence of the food environment. Appetite, 53(1), 114–118. [PubMed: 19500623]

MacKillop J, Weafer J, Gray JC, Oshri A, Palmer A, & de Wit H (2016). The latent structure of impulsivity: impulsive choice, impulsive action, and impulsive personality traits. Psychopharmacology, 233(18), 3361–3370. [PubMed: 27449350]

Meda SA, Stevens MC, Potenza MN, Pittman B, Gueorguieva R, Andrews MM, … & Pearlson GD. (2009). Investigating the behavioral and self-report constructs of impulsivity domains using principal component analysis. Behavioural Pharmacology, 20(5-6), 390. [PubMed: 19724194]

National Institute of Mental Health (2011). NIMH Research Domain Criteria (RDOC) Project Positive Valence Systems: Workshop Proceedings. Rockville, MD. https://www.nimh.nih.gov/research/research-funded-by-nimh/rdoc/positive-valence-systems-workshop-proceedings. Accessed July 2, 2021.

National Institute of Mental Health (2016). Behavioral Assessment Methods for RDoC Constructs. https://www.nimh.nih.gov/about/advisory-boards-and-groups/namhc/reports/rdoc_council_workgroup_report_153440.pdf. Accessed July 2, 2021.

National Institute of Mental Health (2021). RDoC Constructs: Subconstruct: Effort. https://www.nimh.nih.gov/research/research-funded-by-nimh/rdoc/constructs/effort. Accessed: June 25, 2021

Patrick CJ, Iacono WG, & Venables NC (2019). Incorporating neurophysiological measures into clinical assessments: Fundamental challenges and a strategy for addressing them. Psychological Assessment, 31(12), 1512–1529. 10.1037/pas0000713 [PubMed: 30896211]

Perkins KA, Karelitz JL, & Boldry MC (2019). Reinforcement enhancing effects of nicotine via patch and nasal spray. Nicotine & Tobacco Research, 21(6), 778–783. 10.1093/ntr/nty038 [PubMed: 29514317]

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Prieto-Garcia L, Egecioglu E, Studer E, Westberg L, & Jerlhag E (2015). Ghrelin and GHS-R1A signaling within the ventral and laterodorsal tegmental area regulate sexual behavior in sexually naive male mice. Psychoneuroendocrinology, 62, 392–402. [PubMed: 26398679]

Reas DL, Stedal K, Lindvall Dahlgren C, & Rø Ø. (2016). Impairment due to eating disorder pathology: Identifying the cut-off score on the Clinical Impairment Assessment in a clinical and community sample. The International journal of eating disorders, 49(6), 635–638. 10.1002/eat.22517 [PubMed: 26968998]

Reinhold AS, Sanguinetti-Scheck JI, Hartmann K, & Brecht M (2019). Behavioral and neural correlates of hide-and-seek in rats. Science, 365(6458), 1180–1183. [PubMed: 31515395]

Revelle W, & Revelle MW (2015). Package 'psych'. The Comprehensive R Archive Network.

Richardson NR, & Roberts DC (1996). Progressive ratio schedules in drug self-administration studies in rats: a method to evaluate reinforcing efficacy. Journal of Neuroscience Methods, 66(1), 1–11. 10.1016/0165-0270(95)00153-0 [PubMed: 8794935]

Rickard JF, Body S, Zhang Z, Bradshaw CM, & Szabadi E (2009). Effect of reinforcer magnitude on performance maintained by progressive-ratio schedules. Journal of the Experimental Analysis of Behavior, 91(1), 75–87. [PubMed: 19230513]

Robinson MJ, Warlow SM, & Berridge KC (2014). Optogenetic excitation of central amygdala amplifies and narrows incentive motivation to pursue one reward above another. The Journal of Neuroscience, 34(50), 16567–16580. 10.1523/JNEUROSCI.2013-14.2014 [PubMed: 25505310]

Rush CR, Essman WD, Simpson CA, & Baker RW (2001). Reinforcing and subject-rated effects of methylphenidate and d-amphetamine in non-drug-abusing humans. Journal of clinical psychopharmacology, 21(3), 273–286. 10.1097/00004714-200106000-00005 [PubMed: 11386490]

Rusted JM, Mackee A, Williams R, & Willner P (1998). Deprivation state but not nicotine content of the cigarette affects responding by smokers on a progressive ratio task. Psychopharmacology, 140(4), 411–417. [PubMed: 9888615]

Salamone JD, Cousins MS, McCullough LD, Carriero DL, & Berkowitz RJ (1994). Nucleus accumbens dopamine release increases during instrumental lever pressing for food but not free food consumption. Pharmacology, Biochemistry, and Behavior, 49(1), 25–31. 10.1016/0091-3057(94)90452-9 [PubMed: 7816884]

Sanislow CA, Pine DS, Quinn KJ, Kozak MJ, Garvey MA, Heinssen RK, … & Cuthbert BN (2010). Developing constructs for psychopathology research: research domain criteria. Journal of Abnormal Psychology, 119(4), 631. [PubMed: 20939653]

Schebendach J, Broft A, Foltin RW, & Walsh BT (2013). Can the reinforcing value of food be measured in bulimia nervosa? Appetite, 62, 70–75. [PubMed: 23178173]

Sherdell L, Waugh CE, & Gotlib IH (2012). Anticipatory pleasure predicts motivation for reward in major depression. Journal of Abnormal Psychology, 121(1), 51. [PubMed: 21842963]

Smith MA (2020). Nonhuman animal models of substance use disorders: Translational value and utility to basic science. Drug and alcohol dependence, 206, 107733. 10.1016/j.drugalcdep.2019.107733 [PubMed: 31790978]

Miras AD, Jackson RN, Jackson SN, Goldstone AP, Olbers T, Hackenberg T, Spector AC, & le Roux CW (2012). Gastric bypass surgery for obesity decreases the reward value of a sweet-fat stimulus as assessed in a progressive ratio task. The American journal of clinical nutrition, 96(3), 467–473. 10.3945/ajcn.112.036921 [PubMed: 22836034]

Stoops WW (2008). Reinforcing effects of stimulants in humans: Sensitivity of progressive-ratio schedules. Experimental and Clinical Psychopharmacology, 16(6), 503. [PubMed: 19086771]

Torrubia R, Avila C, Moltó J, & Caseras X (2001). The Sensitivity to Punishment and Sensitivity to Reward Questionnaire (SPSRQ) as a measure of Gray's anxiety and impulsivity dimensions. Personality and Individual Differences, 31(6), 837–862.

Treadway MT, Buckholtz JW, Schwartzman AN, Lambert WE, & Zald DH (2009). Worth the 'EEfRT'? The effort expenditure for rewards task as an objective measure of motivation and anhedonia. PloS one, 4(8), e6598. 10.1371/journal.pone.0006598 [PubMed: 19672310]

Treasure J, & Eid L (2019). Eating disorder animal model. Current Opinion in Psychiatry, 32(6), 471–477. 10.1097/YCO.0000000000000550 [PubMed: 31335333]

Udo T, & Grilo CM (2019). Psychiatric and medical correlates of DSM-5 eating disorders in a nationally representative sample of adults in the United States. International Journal of Eating Disorders, 52(1), 42–50. [PubMed: 30756422]

Williams DL (2014). Neural integration of satiation and food reward: role of GLP-1 and orexin pathways. Physiology & Behavior, 136, 194–199. [PubMed: 24650552]

Public Significance Statement.

This study examines whether a measure used in animal-based research can be adapted for use in humans. Findings support that a task that allows people to work for access to play a game may produce scores that can be used in future research to understand what causes excessive consumption of food, alcohol, and other rewarding activities.
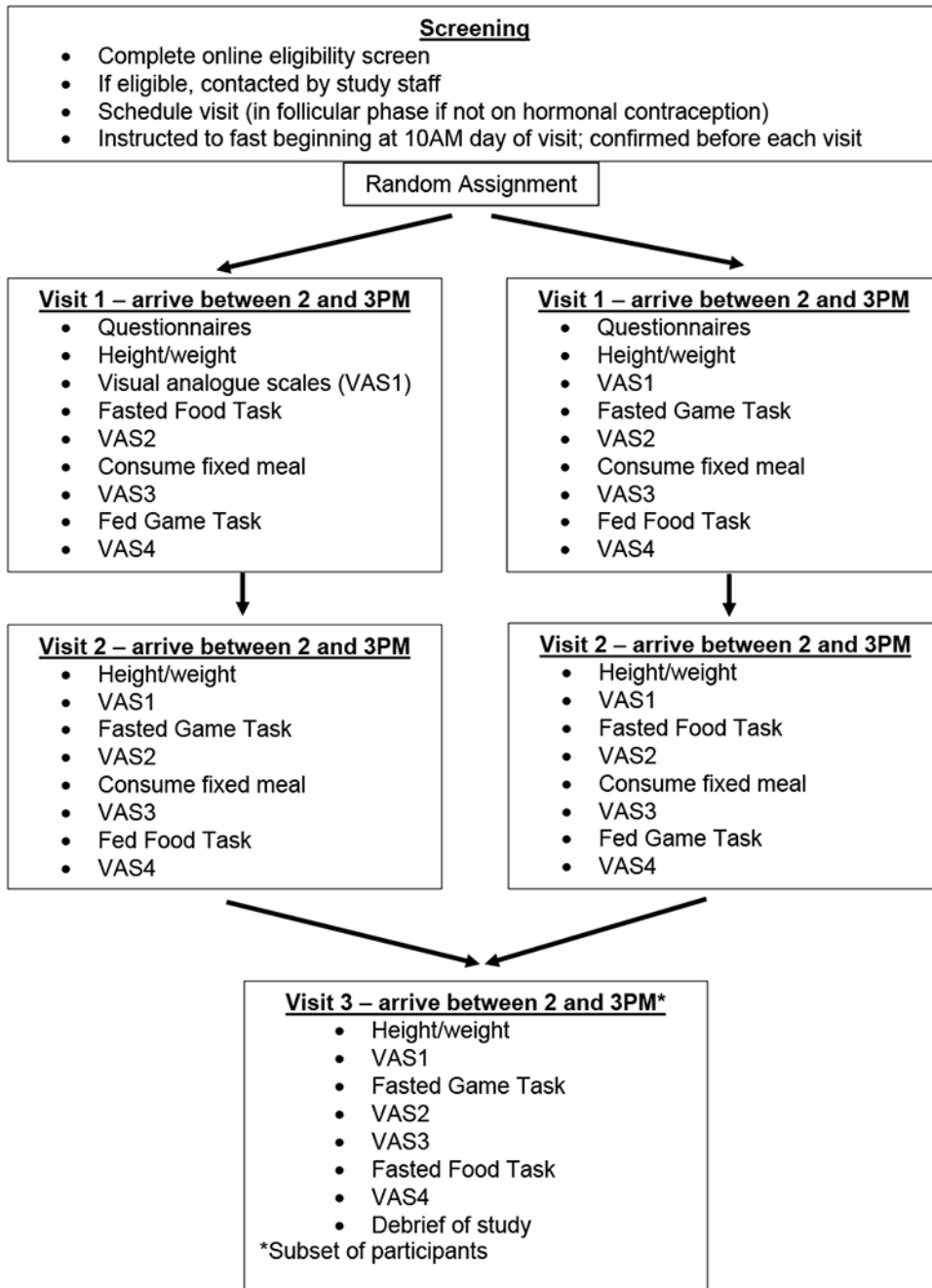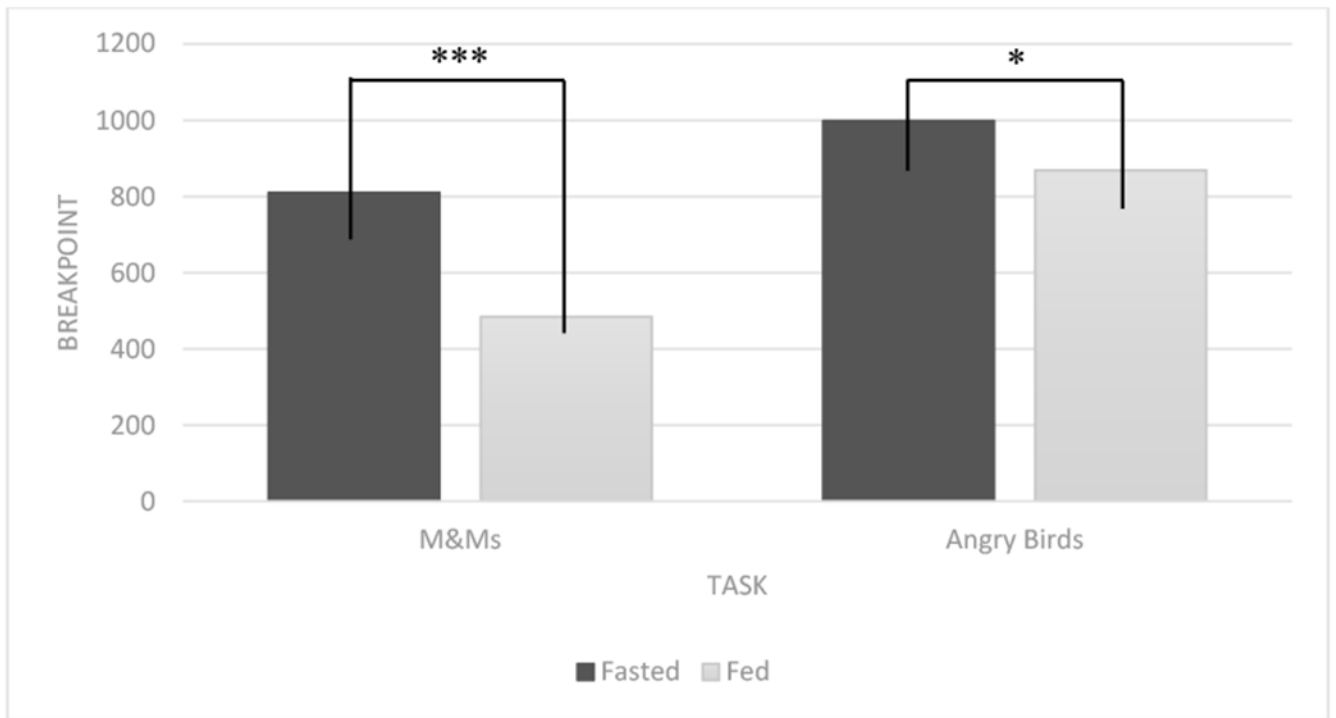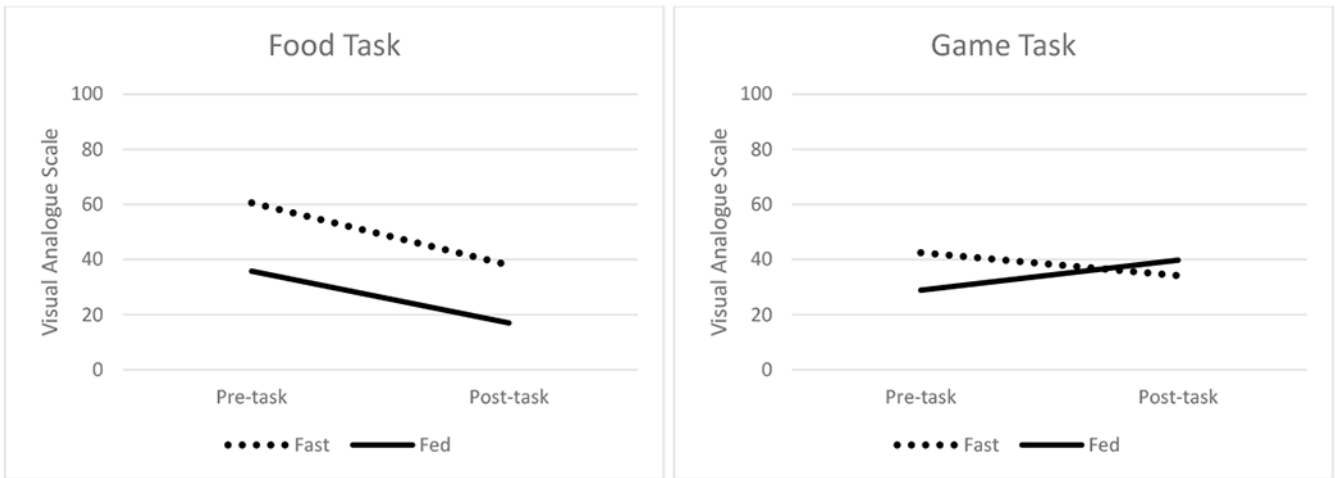
Figure 1.
Flow Chart of Visits in Study 1

Figure 2: Breakpoint for Food and Game Tasks in Fasted and Fed States in a Sample of Undergraduate Women
*p< .05, ** p<.01, *** p < .001

Figure 3:
Changes in momentary ratings of rewarding value of food and game pre to post-task in a sample of undergraduate women

Table 1:

Changes in Hunger, Fullness, and Satiation across Game and Food Tasks across Fasted and Fed States in a Sample of Undergraduate Women.

Effect	Time	Nutrition	Task	Time x Nutrition	Time x Task	Nutrition x Task	Task x Nutrition x Time	Game M (SD)	Food M (SD)
Outcome = Hunger									
B (SE)	−4.08 (3.2)	**−62.32 (3.3)**	**−32.64 (3.3)**	3.15 (4.6)	**31.67 (4.6)**	**28.47 (4.7)**	**−17.68 (6.5)**	Pre/Post 40.9 (34.9)/42.7 (36.8)	Pre/Post 44.2 (32.4)/23.9 (26.6)
								Fast/Fed 71.5 (19.7)/10.9 (18.4)	Fast/Fed 54.9 (27.3)/13.7 (19.2)
Outcome = Fullness									
B (SE)	5.33 (3.5)	**69.99 (3.5)**	**33.63 (3.5)**	−2.18 (4.9)	**−32.67 (5.0)**	**−24.60 (5.0)**	12.58 (7.0)	Pre/Post 49.0 (39.7)/46.2 (40.3)	Pre/Post 67.2 (31.9)/45.4 (36.0)
								Fast/Fed 13.7 (18.4)/82.3 (22.2)	Fast/Fed 30.7 (27.6)/81.4 (22.4)
Outcome = Satiation									
B (SE)	7.03 (3.9)	**33.42 (3.9)**	**21.76 (3.9)**	−6.92 (5.5)	**−18.39 (5.5)**	**−18.90 (5.7)**	11.69 (7.9)	Pre/Post 47.6 (30.5)/44.4 (31.8)	Pre/Post 47.7 (27.2)/56.7 (27.5)
								Fast/Fed 31.6 (24.8)/60.9 (30.0)	Fast/Fed 43.5 (23.9)/60.9 (28.5)

Note. Bold indicates significant effect. Task: 0 = Angry Birds, 1 = M&Ms. Time: 0 = Pre-task, 1 = Post-task. Nutrition: 0 = Fasted, 1 = Fed. Results presented without covariates; controlling for menstrual status did not change results (see Supplement Table S1).