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Non-Food Rewards and Highly Processed Food Intake in Everyday Life

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Abstract

Reducing intake of highly processed, energy-dense food may prevent chronic disease. One proposed intervention strategy for reducing intake of these foods is to increase non-food reward experiences (e.g., music, socializing, art) in their place. However, research supporting this strategy has yet to establish temporal order between non-food reward experiences and highly processed food intake, and has yet to test mediators. The current study sought to build upon this literature with an ambulatory electronic diary study wherein the time-specific associations between non-food reward experiences and highly processed food intake were observed. A sample of 84 young adults reported on multiple types of non-food reward experiences and highly processed food intake hourly for two weekdays and two weekend days through an application on their personal electronic devices. Time-lagged analysis was employed to predict the odds of highly processed food intake in the following hour from non-food rewards experienced in the current hour. Secondary (e.g., receiving positive social feedback) and hedonic (e.g., viewing pleasant images) non-food reward experiences in the current hour predicted greater instead of lower odds of highly processed food intake in the following hour. These associations were mediated by increased subjective pleasure. Purely eudaimonic (e.g., affirming values), social (e.g., cooperating with others), and primary (e.g., having sex) reward experiences generally did not predict odds of highly processed food intake in the following hour. These results suggest that—at least for young adults—many non-food reward experiences may fail to reduce highly processed food intake, and some may even backfire. A different intervention strategy targeting reward processes implicated in highly processed food intake (e.g., interfering with conditioned learned associations) may prove a more promising avenue for improving physical health.

Keywords

behavior substitution; highly processed food intake; pleasure; reward

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Chronic diseases including cardiovascular disease and diabetes may be prevented by reducing highly processed, energy-dense food intake. However, highly processed food intake is pervasive in the U.S.; it is estimated that 57.9% of a typical person's diet comprises highly-processed foods such as sweet high-fat foods (e.g., cakes, cookies), fast foods (e.g., French fries, hamburgers), and non-alcoholic sugary beverages (e.g., soft drinks, fruit drinks; Martinez Steele et al., 2016). Reward processes in part explain the excessive levels of highly processed food intake. With an abundance of highly processed, energy-dense food available in the environment, people often eat highly processed foods for pleasure rather than just to satisfy a physiological need (Lowe & Butryn, 2007). Indeed, exposure to highly processed foods compared to other foods greatly recruits neural reward circuitry associated with subjective pleasure (DiFeliceantonio et al., 2018). Novel intervention strategies that target reward processes underlying highly processed food intake may thus prove effective at improving physical health.

One such proposed intervention strategy is increasing how often people experience alternative, non-food rewards (e.g., music, socializing, art; Carr & Epstein, 2017; Volkow, Wang, Tomasi, & Baler, 2013). This approach, known broadly as behavioral substitution, presumes that—when individuals experience pleasure from an alternative source—they will be less motivated for pleasure from a food source. Indeed, young adults who report experiencing more non-food rewards have lower Body Mass Indexes (BMI; Doell & Hawkings, 1982; Pagoto, Spring, Cook, McChargue, & Schneider, 2006), and adults on average chose a non-food reward (i.e., their favorite social activity) over their favorite food in a hypothetical forced-choice task, even though they had to work harder for the non-food reward (Carr & Epstein, 2017).

Nevertheless, support for reward-related behavioral substitution for highly processed food intake in adults is limited. First, most of the existing literature uses BMI as a proxy for highly processed food intake. Using an anthropometric measure like BMI rather than assessing eating behavior makes it difficult to interpret if experiencing non-food rewards directly impacts eating behavior. Second, prior work using a hypothetical forced-choice task limited adults to choosing between one non-food reward and their favorite food (Carr & Epstein, 2017). This is in stark contrast to real world situations where adults have access to multiple rewards and, for example, can engage in their favorite social activity and eat their favorite food. Third, the type of non-food rewards that may substitute for highly processed food has not been clearly established. One study's results suggest that social activities (e.g., helping someone) have the greatest potential to substitute for favorite foods (Carr & Epstein, 2017). Other research has not explored which types of non-food rewards may best substitute for highly processed food (Doell & Hawkings, 1982; Pagoto et al., 2006). Fourth, temporal order between non-food reward experiences and highly processed food intake has not yet been established. Without demonstrating whether non-food reward experiences precede less highly processed food intake, we cannot infer whether non-food reward experiences can have a causal (and beneficial) effect on highly processed food intake. Fifth, increased subjective pleasure from non-food reward experiences has yet to be tested as a mediator in associations between non-food reward experiences and highly processed food intake. This gap limits support for the notion that *pleasure* experienced from non-food reward reduces motivation for pleasure from a food source, leaving open the possibility of other explanations.

The current study was therefore conducted to build upon the existing literature in several ways. Associations between non-food reward experiences and highly processed food intake (rather than BMI) were investigated. Prior work has operationalized non-food reward experiences using the Pleasant Events Schedule, a checklist of 320 everyday pleasant events identified by qualitative methods (MacPhillamy & Lewinsohn, 1982). However, the theoretical framework behind reward-related behavioral substitution suggests that, when individuals experience subjective pleasure via activated neural reward circuitry, they will be less motivated for pleasure from a food source (Volkow et al., 2013). Thus, the current study narrowed the operationalization of non-food reward experiences to 25 experiences that have been empirically shown to activate neural reward circuitry associated with subjective pleasure (i.e., the ventral striatum; see Methods). In addition, each non-food reward experience was categorized *a priori* based on prior work and the basic reward literature (i.e., social, primary, secondary, eudaimonic, hedonic) so to dissociate which types of non-food rewards may best substitute for highly processed food intake (Carr & Epstein, 2017; Hull, 1943; Skinner, 1938; Telzer, Fuligni, Lieberman, & Galván, 2014).

The current study utilized an ambulatory electronic diary design so that non-food reward experiences and highly processed food intake were investigated in real time outside the constraints of a laboratory context, which limits recall bias and improves ecological validity (Shiffman, Stone, & Hufford, 2008). The ambulatory electronic diary design also allowed temporal associations between non-food reward experiences and highly processed food intake to be tested (Shiffman et al., 2008). That is, through time-lagged analysis, the current study investigated whether experiencing non-food reward would be followed by less highly processed food intake. If supported, this would provide temporal precedence that supports the case for causality (Shiffman et al., 2008). Moreover, the current study tested whether subjective pleasure would indeed mediate associations between non-food reward experiences in one hour and highly processed food intake in the following hour (Carr & Epstein, 2017; Volkow et al., 2013). An hourly sampling density was selected because emotion research indicates that 90% of positive emotional experiences end by one hour later (Verduyn, Van Mechelen, & Tuerlinckx, 2011). Thus, if the pleasure experienced from experiencing a non-food reward causes changes in highly processed food intake, it would be expected to happen in a relatively short time period. In accordance with prior work, the first pre-registered hypothesis was that individuals would be less likely to eat highly processed foods after experiencing non-food reward. The second preregistered hypothesis was that increased subjective pleasure would mediate this association.

Method

Participants

Methods were preregistered on the Open Science Framework at https://osf.io/cn85q/, with an amendment at https://osf.io/8j7p6/. A sample of 85 young adults was recruited through flyer and online advertisements. Advertisements targeted young adults who regularly eat sweets and drink alcohol. Young adults were chosen as the target population for some specific reasons. Foremost, young adulthood is a developmental stage characterized by several changes (e.g., changes in autonomy, living environments, psychological identities) that create a period when eating behavior may be particularly amenable to change (Nelson, Story, Larson, Neumark-Sztainer, & Lytle, 2008). Even though younger adults tend to have lower BMIs, body fat doubles from young adult to middle adulthood (Shimokata et al., 1989) and younger adults report greater intake of highly processed, energy-dense foods (e.g., cakes, cookies, French fries, hamburgers, soft drinks, fruit drinks; Howarth, Huang, Roberts, Lin, & McCrory, 2007). Thus, if the current study hypotheses were supported, young adults would be an ideal target group for an intervention trial to reduce highly processed food intake and prevent chronic disease. Moreover, since prior work has already shown that young adults who report experiencing more non-food rewards have lower BMIs (Doell & Hawkings, 1982; Pagoto et al., 2006), this study will directly expand on existing research related to young adults, their non-food reward experiences, and their physical health.

The sample size was based on simulation multilevel modeling studies that show that sample sizes > 50 at the highest level of analysis reduce likelihood of biased estimates (Maas & Hox, 2005) and based on available research funds. Inclusion criteria were: (1) age 18–24, (2) fluency in English, and (3) owning an electronic device compatible with the ambulatory electronic diary delivery method. Exclusion criteria were: (1) following a strict diet that would prevent participants from eating highly processed foods (e.g., sweet high-fat foods, fast foods, non-alcoholic sugary drinks) and (2) remaining abstinent from drinking alcohol.

Following the preregistration plan, participants were excluded from analysis if they (1) missed any of the three quality control questions designed to identify participants who responded without reading the questions (e.g., “For this question, please mark the answer, ‘Often.’”) or (2) scored > 25 on the Marlowe-Crowne Social Desirability Scale, which detects individuals who respond to questions in a manner that others will view favorably (Crowne & Marlowe, 1960). No participant incorrectly answered any quality control question. However, one participant scored > 25 on the Marlowe-Crowne Social Desirability Scale and was excluded from all analyses.

The final sample thus comprised 84 participants (76.2% female). On average, participants were 20.06 (*SD* = 1.65) years old. The sample was 41.7% Asian American, 22.6% Caucasian, 13.1% Hispanic/Latinx, 11.9% Multi-racial/Other, 7.1% Arabic/Middle Eastern, and 3.6% African American. Yearly household income before taxes was as follows: 3.6% < $5000, 13.2% $5001-$30000, 30% $30001-$75000, 34.9% $75001-$150000, 18.1% > $150001. On average, participants subjectively placed themselves on the sixth step (*SD* = 1.62) of the MacArthur Ladder (Adler & Stewart, 2007). Average BMI was “normal” at 22.84 (*SD* = 3.72; 21.7% “underweight,” 55.4% “normal,” 19.3% “overweight,” and 3.6% “obese”). In regards to highly processed food intake (i.e., intake of sweet high-fat foods, fast foods, and non-alcoholic sugary drinks), 34.5% participants reported eating these foods 10–19 days in the past month, 22.6% reported 20–29 days, 16.7% reported 6–9 days, 10.7% reported 3–5 days, 8.3% reported everyday, and 7.1% reported 1 or 2 days.

Procedure

The University Institutional Review Board approved the research procedure in accordance with the provisions of the World Medical Association Declaration of Helsinki. The study design was a four-day hourly ambulatory electronic diary study conducted via the Personal Analytic Companion (PACO; Evans, 2017) application available free for Android and Apple electronic devices. The study description (which blinded participants) stated that researchers were studying how people experience reward in everyday life and did not directly mention observation of eating behavior. Research assistants were not informed of the study hypotheses until after data analysis.

All participants were scheduled for a baseline laboratory session on a Wednesday, Thursday, or Friday; the ambulatory electronic diary procedure began the next day, which ensured that each participant reported on two weekdays and two weekend days so to capture weekday-weekend variability. At the baseline laboratory session, participants provided informed consent, completed a baseline questionnaire including quality control questions and measurement of demographics, and learned the ambulatory electronic diary procedure. Participants downloaded PACO onto their personal electronic devices, trained for comprehension of each diary question, and practiced one diary entry under supervision. Participants were instructed to engage in normal activities and to complete the diaries each time they were alerted. However, participants were instructed to skip any entry that occurred during an incompatible event such as an exam or while driving (see Tomiyama, Mann, & Comer, 2009).

Over the following four days, PACO alerted participants once each hour (minus sleep times) from an hour after waking to sleeping time. This included 15 alerts/day per participant based on participants sleeping 7–9 hours/day. PACO allowed for participants to set their own unique waking time. Each alert was followed by a diary entry, which included questions on: participants' experience of non-food rewards in the last hour, current subjective pleasure, and highly processed food intake in the last hour. After participants completed four days of the requested diary entries, they were notified of study completion and scheduled for a final laboratory session. At the final laboratory session, participants were led through funnel debriefing (Mills, 1976), and either compensated with 1 point of course credit and $2.50 for each full day of study participation or with $10 for each full day of study participation.

Measures

Non-food rewards.—Participants reported on a variety of non-food rewards experienced each hour. In accordance with the theoretical framework behind reward-related behavioral substitution (Volkow et al., 2013), non-food rewards were operationally defined as any experience that has been empirically shown to activate neural reward circuitry (i.e., the ventral striatum). Table 1 provides a complete list of the included non-food rewards, and provides citations of the literature that empirically shows that those non-food rewards activate neural reward circuitry. The ambulatory electronic diary, PACO, prompted participants with the question, "In the last hour, did you…" followed by a list of these non-food rewards. Participants selected as many responses as applicable or "none of the above."

Subjective pleasure.—To assess subjective pleasure as a mediator of any effects, participants reported on a modified Positive and Negative Affect Schedule each hour (Watson, Clark, & Tellegen, 1988) with the statement: "Read each item and then indicate to what extent you feel this way right now at the present moment, on a scale from 1–5." The items "rewarded," and "pleasured," were used because of their prevalence in the scientific nomenclature of reward (Berridge & Kringelbach, 2008).

Highly processed food intake.—Each hour, participants reported in a similar manner as several prior ambulatory electronic diary studies of eating behavior on whether they ate specific food/drink groups (Boggiano et al., 2015; Elliston, Ferguson, Schuz, & Schuz, 2017; Schuz, Bower, & Ferguson, 2015; Strahler & Nater, 2017; Tomiyama et al., 2009). The ambulatory electronic diary, PACO, prompted participants with the question, "In the last hour, did you…" for the following: "eat sweet high-fat foods (e.g., brownies, ice cream, cookies, cake, chocolate)?" "eat fast foods (e.g., food from a place like McDonald's, Kentucky Fried Chicken, Pizza Hut)?" and, "drink non-alcoholic sugary drinks (e.g., cokes, diet cokes, other soda drinks, sweet tea, milkshakes, and sweet coffee drinks)?" The specific food/drink groups were selected based on prior literature indicating reward processes are implicated in intake these foods but also because greater proportional intake of these foods can damage physical health (Burgess, Turan, Lokken, Morse, & Boggiano, 2014; DiFeliceantonio et al., 2018; Lustig, Schmidt, & Brindis, 2012; Schnabel et al., 2019; Schulte, Avena, & Gearhardt, 2015; Stice, Yokum, Blum, & Bohon, 2010). Participants were also prompted with the question, "In the last hour, did you eat palatable foods (e.g., food that is most pleasurable to you)?" This food group was selected based on longstanding literature indicating that unique foods are pleasurable to each individual (Rozin & Vollmecke, 1986). The percent of the sample reporting the same palatable foods was highest for ice cream (20.24%), pizza (14.29%), chocolate (9.52%), and chips (8.33%), which are all highly processed foods.

Potential covariates.—During their initial laboratory visit, participants reported a number of potential time-invariant covariates including age, sex, race/ethnicity, objective socioeconomic status (yearly household income before taxes), and subjective socioeconomic status (Adler & Stewart, 2007). The Marlowe-Crowne Social Desirability Scale (completed at baseline) yielded continuous scores for response bias. The research assistant measured participant height and weight to calculate BMI (kg/m^2).

In addition, a number of potential time-varying covariates were measured. Cigarette smoking may suppress eating; thus, participants reported in the ambulatory electronic diary, PACO, whether they smoked cigarettes in the last hour. Working, being in class, or having obligations (e.g., doctor's appointment) may influence the likelihood of eating, so participants reported in PACO the occurrence of these events in the last hour. Day of week, time of day, week of academic quarter, and day in study (to test for reactivity) were coded from time stamps in PACO.

Data Analytic Plan

Data and syntax are publicly available on the Open Science Framework at https://osf.io/wn69h/. Hypotheses were tested with multilevel modeling to account for repeated measurement (i.e., nested data) and to handle missing data via maximum likelihood estimation. Time-lagged analysis was employed to predict the odds of whether each of the food groups was eaten in the following hour from the non-food rewards experienced in the current hour. Random effects for intercepts were included but random effects for slopes were not included because Level 1 variance for dichotomous outcomes is non-constant and dependent on success probability. Fast food intake had too few positive occurrences and the model with this dependent variable would not converge; thus, results could not be estimated for this dependent variable.

Non-food rewards experienced were composited into *a priori* non-exclusive categories based on the literature (Carr & Epstein, 2017; Hull, 1943; Skinner, 1938; Telzer et al., 2014), and entered as within-subjects variables at Level 1. See Tables A.2–4 in Supplemental Materials for results with non-food rewards independently entered. Categories included:

- Eudaimonic rewards = Sum of affirming values, donating, expressing compassion, starting a new monogamous relationship, spending time with a monogamous partner, feeling a sense of accomplishment
- Hedonic rewards = Sum of playing video games, viewing funny videos, viewing pleasant images, getting a lot of likes on social media, seeing an attractive person gazing, having sex/masturbating, viewing sexual videos, winning money
- Social rewards = Sum of disclosing self-relevant information, getting recognized, getting special recognition, expressing compassion, spending time with a monogamous partner, starting a new monogamous relationship, getting positive feedback that improved reputation, getting positive feedback from a liked person, seeing an attractive person gazing, having sex/masturbating, cooperating with others
- Primary rewards = Sum of exercising and having sex/masturbating
- Secondary rewards = Sum of all rewards except exercising and having sex/masturbating

Initial descriptive examination indicated that non-food reward composites evidenced skew (>1) and kurtosis (>3); natural log transformations corrected for this.

Mediation was tested using standard guidelines for a Level 1 → Level 1 → Level 1 mediation (Krull & MacKinnon, 2001), and was only tested for results that supported the first preregistered hypothesis. The Sobel test was used to obtain estimates of mediated effect and standard error of the mediated effect, and to examine significance. The Sobel test yields a critical Z-value; any critical Z-value higher than 1.645 indicates a significant mediated effect at $p < .05$.

Time-invariant potential covariates were entered as between-subjects variables at Level 2 and time-varying potential covariates were entered as within-subjects variables at Level 1 to determine significance. Older age predicted less odds of sweet high-fat food intake, OR = 0.85, $p = .018$, 95% CI [0.75, 0.97], palatable food intake, OR = 0.87, $p = .033$, 95% CI [0.77, 0.99], and sugary drink intake, OR = 0.73, $p < .001$, 95% CI [0.61, 0.87]. Greater subjective socioeconomic status predicted less odds of sugary drink intake, OR = 0.84, $p = .045$, 95% CI [0.71, 1.00]. There were greater odds of sweet high-fat food intake and palatable food intake later in the day, OR = 1.06, $p < .001$, 95% CI [1.04, 1.09], and OR = 1.03, $p = .003$, 95% CI [1.01, 1.05], respectively. There were also greater odds of palatable food intake on days later in the week/in the weekend, OR = 1.04, $p = .031$, 95% CI [1.004, 1.09]. Hypotheses were tested with and without these significant covariates in their respective analyses. Results were interpreted as supportive for the preregistered hypotheses if (1) the adjusted model remained significant at $p < .05$ and (2) at least the unadjusted model remained significant after correction for multiple testing with the false discovery rate (Benjamini & Hochberg, 1995; see Table A.1 in Supplemental Materials for false discovery rate corrections).

Results

Descriptives

On average, participants answered 83% (Range = 7–100%) of the diary prompts, yielding 4,167 Level 1 observations ($M = 49.61$, $SD = 10.81$, Range = 4–60 per participant). Percent of diary occasions in the study in which participants reported experiencing each of the non-food rewards is presented in Figure 1. Percent of diary occasions in the study in which participants reported consuming each of the food/drink groups is presented in Figure 2.

Non-Food Rewards and Highly Processed Food Intake

Multilevel estimates of fixed effects are presented in Table 2. Results indicated secondary rewards experienced in the current hour predicted *greater* odds of sweet high-fat food, sugary drink, and palatable food intake in the following hour. Odds Ratios ranged from 1.32 to 1.50 (with covariates in the model); this indicates that—over and above the effects of any covariates—for each secondary reward experienced, the expected odds of highly processed food intake were increased by 32% to 50%. Results also indicated that hedonic rewards experienced in the current hour predicted *greater* odds of palatable food intake in the following hour. The Odds Ratio was 1.41 (with covariates in the model); this indicates that —over and above the effects of any covariates—for each hedonic reward experienced, the expected odds of highly processed food intake was increased by 41%. Other reward categories did not predict the odds of consuming each of the food/drink groups in the following hour.[1]

[1]Because the reward value of certain self-disclosures (e.g., disclosing an embarrassing secret about oneself) is debatable, in response to a reviewer comment, we removed self-disclosure from the social rewards composite and retested whether social rewards in the current hour would be associated with highly processed food intake in the following hour. Results from these analyses indicated that—similar to the secondary and hedonic reward results reported above—social rewards in the current hour predicted greater odds of sweet high-fat food intake in the following hour (Unadjusted: OR = 1.43, $p = .014$, 95% CI [1.07, 1.90], Adjusted: OR = 1.35, $p = .039$, 95% CI [1.02, 1.80]) but not sugary drink (Unadjusted: OR = 1.14, $p = .44$, 95% CI [0.82, 1.60], Adjusted: OR = 1.15, $p = .41$, 95% CI [0.82, 1.62]) or palatable food (Unadjusted: OR = 1.28, $p = .053$, 95% CI [1.00, 1.65], Adjusted: OR = 1.24, $p = .12$, 95% CI [0.96, 1.53]) intake in the following hour. The above results were not corrected for multiple testing with the false discovery rate.

Mediation by Subjective Pleasure

Estimates of *a*, *b*, and *c'* pathways in addition to the estimates of mediated effects, standard errors of mediated effects, and critical Z-values are presented in Table 3. The *a* pathway models tested whether non-food reward experiences in the prior hour predicted current subjective pleasure. The *b* pathway models tested whether current subjective pleasure predicted highly processed food intake in the following hour. The *c'* pathway models tested whether non-food rewards in one hour predicted highly processed food intake in the following hour after controlling for subjective pleasure. Sobel tests indicated that three of the four tested mediated effects were significant. Mediation patterns were such that non-food rewards experienced in the current hour predicted increased subjective pleasure; this increased subjective pleasure in turn predicted *greater* odds of highly processed food intake.

Discussion

Novel intervention strategies that target reward processes underlying highly processed food intake may change eating behavior and improve physical health. One such proposed intervention strategy is to increase how often people experience non-food rewards (e.g., music, socializing, art), and to utilize that as behavioral substitution for food intake (Carr & Epstein, 2017; Volkow et al., 2013). However, the current ambulatory electronic diary study found that— above and beyond the influence of several covariates—when participants experienced secondary (e.g., listening to music, getting positive social feedback) and hedonic (e.g., viewing pleasant images, viewing sexual videos) non-food rewards in everyday life, they in fact had greater, not lower, odds of eating highly processed foods such as sweet high-fat foods, non-alcoholic sugary drinks, or palatable foods an hour later. Additionally, when participants experienced purely eudaimonic (e.g., affirming their values), social (e.g., cooperating with others), and primary (e.g., having sex) types of non-food reward, there were no observed changes in the odds of highly processed food intake an hour later.

The current study findings challenge interpretations from prior work (Carr & Epstein, 2017; Doell & Hawkings, 1982; Pagoto et al., 2006). Whereas prior work has assessed non-food reward experiences retrospectively at one time point and used BMI as a proxy for eating behavior, the current study's design incorporated immediate assessment of non-food reward experiences and highly processed food intake hourly for four days in young adults' everyday lives. Moreover, the current study employed time-lagged analysis, which captures antecedents of highly processed food intake and supports the case for causality (Shiffman et al., 2008). Also, although a hypothetical forced-choice task can provide useful metrics on the relative reinforcing value of food (Carr & Epstein, 2017), in many real world situations adults face decisions which are non-binary such that they can experience non-food reward and obtain highly processed food (e.g., hang out with others and buy a sweet high-fat snack). The current study provided an ecologically valid way of capturing those behaviors (Shiffman et al., 2008).

The current study's findings might also reflect which non-food rewards were assessed. Specifically, the current study investigated a range of non-food reward experiences (i.e., social, primary, secondary, eudaimonic, hedonic) that have been empirically shown to activate neural reward circuitry associated with subjective pleasure. Prior work suggests that social activities (e.g., helping someone) have the greatest potential to substitute for highly processed food (Carr & Epstein, 2017). In the current study, however, many of the non-food rewards (e.g., getting positive social feedback, getting special recognition, donating money to a charity or person in need, seeing an attractive person gazing at them) that increased the odds of highly processed food intake involved social aspects. Moreover, purely eudaimonic (e.g., expressing compassion), social (e.g., cooperating with others), and primary[2] (e.g., having sex) non-food rewards generally failed to decrease the odds of highly processed food intake. Future research might consider exploring time-lagged associations between highly processed food intake and categories of non-food rewards that were not captured by the current study's operationalization.

Another critical finding of the current study was that subjective pleasure mediated the majority of associations between secondary/hedonic non-food reward experiences and increased highly processed food intake. This finding does not support the notion that pleasure experienced from non-food reward *reduces* motivation for pleasure from a food source. However, this finding may provide preliminary insight in the underlying biological reward mechanism explaining the current study's results. Subjective pleasure is closely tied to ventral striatal activity in the brain (Burgdorf & Panksepp, 2006). An increase in pleasure that then predicts highly processed food intake might indicate that experiencing alternative, non-food reward potentiates neural reward pathways can encourage highly processed food intake (Volkow et al., 2013). This is consistent with the idea of cross-sensitization, wherein exposure to one substance (e.g., alcohol) may influence someone to also be sensitive to a different but similar substance (e.g., sweets)—yet cross-sensitization research has not examined how actual behaviors intersect within an acute time period (Robinson & Berridge, 1993). The current study thus contributes a novel addition to the basic reward literature by suggesting that a non-food reward experience may acutely initiate highly processed food intake (i.e., a different reward experience) via subjective pleasure.

Other untested psychosocial mechanisms may further explain the current study findings. For instance, when individuals are motivated to relax or to comfort themselves, they may seek multiple reward experiences one after another in a short time period (e.g., listening to music then eating highly processed food). Indeed, many individuals in the U.S. (approximately 39%) report overeating or unhealthy eating because of subjective stress (American Psychological Association, 2016). Future research might investigate levels of subjective stress/negative affect that precede engagement in the non-food reward experiences that predict highly processed food intake. In addition, some non-food reward experiences that predicted future highly processed food intake were behaviors that might boost self-esteem (e.g., getting special recognition, getting positive social feedback). Perhaps individuals felt "licensed" to eat highly processed foods after these events (see Chiou, Yang, & Wan, 2010) or wanted to celebrate. In fact, individuals report wanting highly processed foods "to

[2]Exercise, in this study, did not predict greater highly processed food intake in the following hour, despite that some suggest that exercise may increase energy intake (see Blundell & King, 1999). Indeed, multiple exercise intervention studies of free-living adults show no acute effect of exercise on appetite and/or energy intake (Hubert, King, & Blundell, 1998; Imbeault, Saint-Pierre, AlméRas, & Tremblay, 1997; King, Lluch, Stubbs, & Blundell, 1997; Stubbs et al., 2002). The current study results corroborate with findings from these prior studies.

celebrate a special occasion," and this motive predicts highly processed food intake in everyday life (Boggiano et al., 2015). Future research might test this by incorporating items from the Palatable Eating Motives Scale into the current study design (Burgess et al., 2014).

The current study results should be interpreted in light of study limitations. First, although the study controlled for a number of potential confounds and used time-lagged analysis, the non-experimental methodology cannot completely rule out third variables. Second, although many prior ambulatory electronic diary studies have measured eating behavior with self-report questions (Boggiano et al., 2015; Elliston et al., 2017; Schuz et al., 2015; Strahler & Nater, 2017; Tomiyama et al., 2009), newer objective measures such as the Remote Food Photography Method may improve measurement accuracy (Martin et al., 2014). Third, reporting on highly processed food intake may cause reactivity where someone starts eating less highly processed food. This is possible, but to mitigate this concern, the current study tested if day in the study predicted highly processed food intake and it did not. Moreover, other ambulatory electronic diary studies on eating behavior have not observed reactivity (le Grange, Gorin, Dymek, & Stone, 2002; Stein & Corte, 2003; Tomiyama et al., 2009). Fourth, participants reported few occurrences of certain non-food reward experiences (i.e., entering into a new monogamous relationship, watching a close friend win money, winning money) and intake of certain food groups (i.e., fast food). It is therefore possible that the current study failed to capture some positive or negative associations between these specific behaviors due to floor effects. Fifth, it is plausible that participants did not interpret the items describing non-food reward experiences in a way that reflected how these experiences were operationalized in prior work; thus, it cannot be guaranteed that the experiences participants based their reports on activated neural reward circuitry (i.e., the ventral striatum).

These limitations notwithstanding, the current study had several strengths. Using a four-day hourly ambulatory electronic diary design that assessed behavior within young adults in their everyday lives greatly enhanced ecological validity and allowed for time-lagged analysis. The current study also captured a breadth of non-food reward experiences but all these experiences shared the operational definition of activating the ventral striatum (Volkow et al., 2013). Critically, the current study results have practical implications because they suggest that interventionists should exercise caution with regards to the development and implementation of reward-related behavioral substitution strategies for highly processed food intake—at least for young adults. Other intervention strategies that target reward processes relevant to highly processed food intake [e.g., decreasing rewarding properties of highly processed food, interfering with conditioned learned associations for highly processed food intake (Volkow et al., 2013)] may prove more promising avenues for reducing highly processed food intake and improving physical health.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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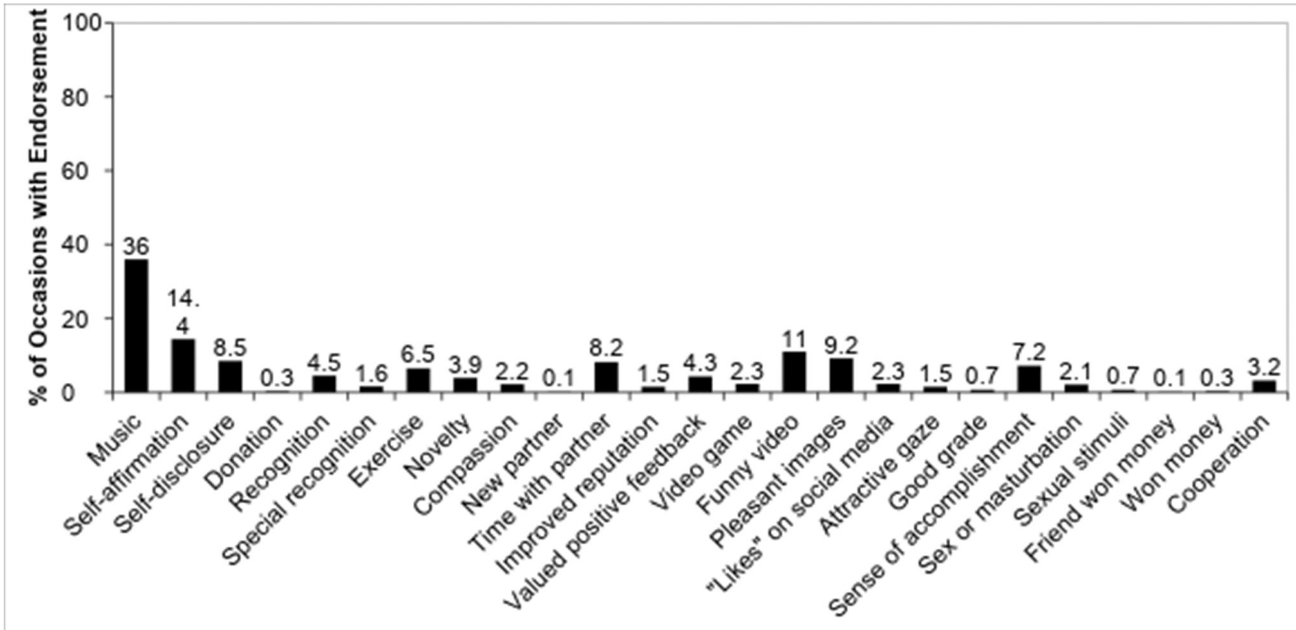

Figure 1.
Percent of diary occasions in the study in which participants reported experiencing each of the non-food rewards.

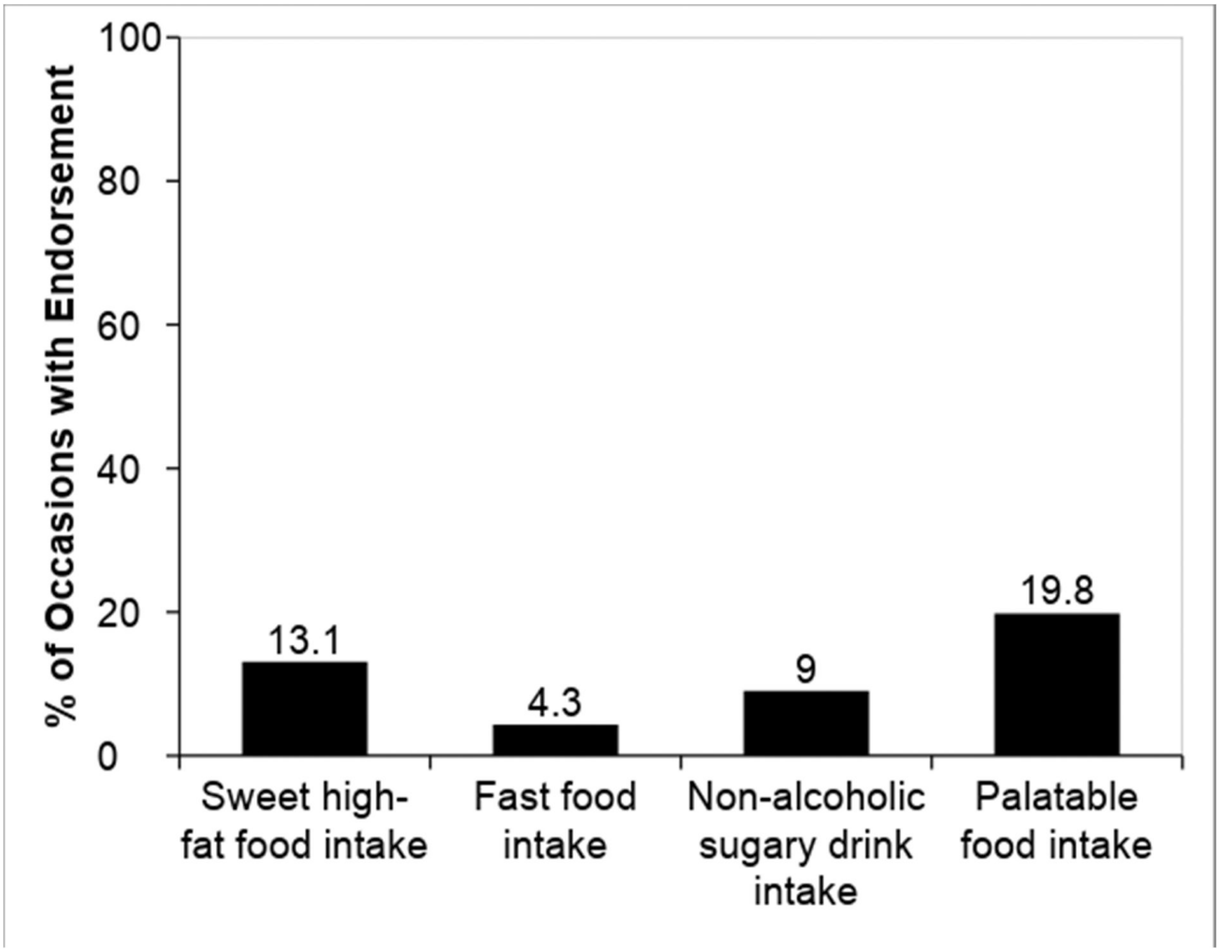

Figure 2.
Percent of diary occasions in the study in which participants reported consuming each of the food/drink groups.

Table 1

Non-Food Rewards

Reward	Citation(s)
Listen to music	(Brown, Martinez, & Parsons, 2004)
Think about values important to you	(Dutcheretal., 2016)
Disclose information about yourself	(Tamir& Mitchell, 2012)
Donate money to a charity or a person in need	(Moll et al., 2006)
Get recognized	(Fliessbach et al., 2007)
Get special recognition others did not get	(Fliessbach et al., 2007)
Exercise	(MacRae, Spirudso, Walters, Farrar, & Wilcox, 1987)[1]
Do an activity that you have never done before	(Guitart-Masip, Bunzeck, Stephan, Dolan, & Duzel, 2010)
Express compassion to someone who was suffering	(Kim et al., 2009)
Enter into a new monogamous relationship	(Aragona et al., 2006)[2]
Spend time with your monogamous partner	(Aragona et al., 2006)[2]
Get positive feedback that improved your reputation	(Korn, Prehn, Park, Walter, & Heekeren, 2012)
Get positive feedback from someone you like	Hughes, Leong, Shiv, & Zaki, 2018
Play a video game	(Koepp et al., 1998)
View a funny video or cartoon	(Mobbs, Greicius, Abdel-Azim, Menon, & Reiss, 2003)
View pleasant images	(Aharon et al., 2001)
Receive a lot of “likes” for a post on social media	(Sherman, Payton, Hernandez, Greenfield, & Dapretto, 2016)
See an attractive person gazing at you	(Kampe, Frith, Dolan, & Frith, 2002)
Get a good grade in an academic context	(Satterthwaite et al., 2012)
Have a sense of accomplishment	(Satterthwaite et al., 2012)
Have sex or masturbate	(Hamann, Herman, Nolan, & Wallen, 2004)
View sexual videos or photos	(Hamann et al., 2004)
Watch a close friend win money	(Mobbs et al., 2009)
Win money	(Zink, Pagnoni, Martin-Skurski, Chappelow, & Berns, 2004)
Work with others to achieve the same goal	(Rilling et al., 2002)

Notes:

[1]Dopamine receptor binding observed in rodents.

[2]Dopamine receptor binding observed in voles.

Table 2

Estimates of Fixed Effects for Sweet High-Fat Food, Sugary Drink, and Palatable Food Intake

	Unadjusted				**Adjusted**			
			95% CI				**95% CI**	
	OR	***p***	**Lower**	**Upper**	**OR**	***p***	**Lower**	**Upper**
Sweet High-Fat Food Intake								
Eudaimonic	0.90	.535	0.65	1.26	0.88	.456	0.63	1.23
Hedonic	1.08	.615	0.80	1.46	1.04	.794	0.77	1.41
Social	1.37	.021	1.05	1.78	1.28	.071	0.98	1.67
Primary	1.19	.509	0.71	2.01	1.19	.512	0.71	2.01
Secondary	**1.40**	**.002**	**1.13**	**1.74**	**1.32**	**.014**	**1.06**	**1.64**
Sugary Drink Intake								
Eudaimonic	1.29	.192	0.88	1.88	1.31	.168	0.89	1.91
Hedonic	1.43	.034	1.03	1.98	1.41	.041	1.02	1.95
Social	1.19	.268	0.87	1.63	1.20	.261	0.88	1.63
Primary	1.16	.642	0.63	2.12	1.18	.596	0.64	2.16
Secondary	**1.54**	**.001**	**1.19**	**1.99**	**1.50**	**.002**	**1.16**	**1.94**
Palatable Food Intake								
Eudaimonic	1.06	.687	0.80	1.41	1.05	.759	0.79	1.40
Hedonic	**1.46**	**.003**	**1.13**	**1.88**	**1.41**	**.008**	**1.10**	**1.82**
Social	1.25	.064	0.99	1.58	1.21	.115	0.96	1.53
Primary	1.18	.479	0.74	1.88	1.17	.497	0.74	1.87
Secondary	**1.39**	**<.001**	**1.15**	**1.67**	**1.35**	**.002**	**1.11**	**1.63**

Notes: Unadjusted models do not include covariates. Adjusted models include identified covariates specific to each dependent variable. Results were interpreted as supportive for the first preregistered hypothesis and **bolded** if (1) the adjusted model remained significant at $p < .05$ and (2) at least the unadjusted model remained significant after correction for multiple testing with the false discovery rate (see Table A.1 in Supplemental Materials).

Table 3

Estimates of a, b, and c' Pathways & Estimates of Mediated effects, Standard Errors of Mediated Effects, and Critical Z-values

	a					***b***				***c´***						
				95% CI				**95% CI**				**95% CI**				
	β	**SL**$_\beta$	***P***	**Lower**	**Upper**	**OR**	***P***	**Lower**	**Upper**	**OR**	***P***	**Lower**	**Upper**	$\hat{\beta}_a\hat{\beta}_b$	$\widehat{SE}_{\beta a\beta b}$	***z***
Sweet High-Fat Food Intake																
Secondary rewards	**0.50**	**0.04**	**<.001**	**0.41**	**0.59**	**1.18**	**.017**	**1.03**	**1.34**	**1.22**	**.084**	**0.97**	**1.54**	**0.08**	**0.04**	**2.25**
Sugary Drink Intake																
Secondary rewards	0.50	0.04	<.001	0.41	0.59	1.11	.167	0.96	1.30	1.45	.007	1.11	1.90	0.06	0.04	1.37
Palatable Food Intake																
Hedonic rewards	**0.34**	**0.07**	**<.001**	**0.21**	**0.47**	**1.15**	**.014**	**1.03**	**1.29**	**1.38**	**.014**	**1.07**	**1.78**	**0.05**	**0.02**	**2.26**
Secondary rewards	**0.50**	**0.04**	**<.001**	**0.41**	**0.59**	**1.12**	**.056**	**1.00**	**1.26**	**1.29**	**.012**	**1.06**	**1.57**	**0.06**	**0.03**	**1.81**

Notes: Only adjusted models that were interpreted as supportive for the first preregistered hypothesis were tested for mediation. Results were interpreted as supportive for the second preregistered hypothesis and **bolded** if (1) the model remained significant at $p < .05$ and (2) the model remained significant after correction for multiple testing with the false discovery rate (see Table A.1 in Supplemental Materials). Any critical Z-value higher than 1.645 indicates a significant mediated effect at $p < .05$.