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Highly processed food intake and immediate and future emotions in everyday life

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ABSTRACT

Increased consumption of highly processed foods may result in lower diet quality, and low diet quality is associated with elevated risk of cardiovascular disease, type 2 diabetes, and cancer. One mechanism driving highly processed food intake is the expectation that eating these foods will improve emotional experiences, particularly in individuals with elevated "highly processed food addiction" symptoms. However, experimental findings about the emotional experiences following highly processed food intake are mixed. Furthermore, prior studies have generally failed to capture the potentially prolonged emotional effects of eating highly processed foods and not tested for individual differences. The present study was a preregistered archival data analysis of an ambulatory electronic diary study that captured real-life emotions following highly processed food intake. Multilevel modeling was used to predict the effects of highly processed food intake on subsequent positive and negative emotions immediately, 1 h, and 3 h after consumption. Intake of sweet high-fat foods, fast foods, and non-alcoholic sugary drinks was associated with greater positive emotions immediately after eating, and sweet high-fat food intake remained associated with greater positive emotions 1 h later. Sweet high-fat food and non-alcoholic sugary drink intake were associated with fewer negative emotions 1 h after consumption, and the negative association between non-alcoholic sugary drink intake and negative emotions was stronger for those with elevated highly processed food addiction symptoms. Overall, results suggest that highly processed food intake results in small alterations in positive and negative emotions immediately and up to 1 h after intake; however, these do not persist through 3 h after intake. The ability of highly processed foods to briefly alter emotions may be key to their reinforcing nature.

1. Introduction

Non-communicable, chronic diseases are prevalent. For example, in the United States, about 35 million individuals have cardiovascular disease (Virani et al., 2020), 31 million individuals have type 2 diabetes (Centers for Disease Control and Prevention, 2021a), and 23 million individuals have cancer (Centers for Disease Control and Prevention, 2021b). One modifiable factor robustly associated with increased risk of non-communicable diseases is low diet quality (Schwingshackl et al., 2018). Low diet quality may result from greater intake of "highly processed foods," which are foods designed to be particularly rewarding through the addition of fat and/or refined carbohydrates including sweets (e.g., cookies, ice cream), fast foods (e.g., cheeseburgers, pizza), and sugary drinks (e.g., soda, sweet coffee drinks; Schulte, Avena, & Gearhardt, 2015, 2017; Schulte, Sonneville, & Gearhardt, 2019).

Multiple factors including pleasurable taste, affordability, and availability lead individuals to eat highly processed foods (Hawkes et al., 2015). Individuals also eat highly processed foods to change their emotions, especially to enhance their positive emotions and reduce their negative emotions (Boggiano, 2016; Boggiano et al., 2017; Burgess, Turan, Lokken, Morse, & Boggiano, 2014). In one study, greater expectations that highly processed food intake will enhance positive emotions caused individuals to eat more highly processed foods in the laboratory (Cummings et al., 2021). Although individuals are motivated

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to eat highly processed foods for emotional reasons, it remains unclear how this behavior *actually* affects emotions.

In a growing number of experiments researchers have tested the effect of eating highly processed food on emotions, but findings are mixed. Eating chocolate (vs. not eating) reduced laboratory-induced negative emotions in two experiments; in the first, eating chocolate also sustained laboratory-induced positive emotions and, in the second, it increased positive emotions (Macht & Mueller, 2007). These emotional effects occurred within 3 min after eating. In a within-subjects study, participants reported feeling higher levels of positive emotions in a dose-dependent manner based on the sugar content of the chocolate they tasted (Casperson, Lanza, Albajri, & Nasser, 2019). In another set of experiments, eating "comfort foods" (i.e., foods believed to reduce negative mood like chocolate, ice cream, cookies, brownies) did not affect laboratory-induced negative emotions compared to not eating, but it sustained positive emotions for 3 min (Wagner, Ahlstrom, Redden, Vickers, & Mann, 2014). Other experiments showed that eating comfort foods (vs. not eating) did not affect negative nor positive emotions within 1 h of a laboratory stressor (Finch, Cummings, & Tomiyama, 2019), and eating Twix® candy (vs. not eating) did not affect laboratory-induced negative emotions immediately nor within 1 h (McKay et al., 2021). Overall, the body of experimental evidence suggests that eating highly processed food does not consistently reduce negative emotions, but it may more consistently sustain or enhance positive emotions.

Experimental studies have many strengths including randomization to groups and controlled study conditions that permit causal inferences from results. However, when investigating the emotional effects of eating, there are key limitations worth considering. First, the laboratory setting may inhibit emotional responses to food because people often inhibit their eating when they believe someone is watching (Herman, Roth, & Polivy, 2003). Second, to experimentally examine the emotional effects of eating, researchers can induce positive and negative emotions with video clips and stress tasks. Yet, how eating food affects emotional reactivity to laboratory stimuli may differ from how eating affects naturally occurring emotions (Finch & Tomiyama, 2015). Third, to reduce participant burden, experimenters typically refrain from measuring emotions beyond 1 h after the eating manipulation. This prevents understanding of the potentially prolonged emotional effects of eating food. For example, although positive emotions may increase and negative emotions may decrease immediately after eating, this may reverse a few hours after eating due to later negative cognitive processing of the eating episode (e.g., "I ate junk"; Smith, Mason, & Lavender, 2018) or delayed physiological changes related to eating (e.g., postprandial drops in blood glucose levels; Ludwig, 2002).

A methodology that complements experiments is the ambulatory electronic diary (Shiffman, Stone, & Hufford, 2008). Using portable devices, and without being directly watched or constrained, participants report on their behaviors and emotions as they naturally occur during their everyday lives. A major advantage of this approach is that data may be collected across several time points within a day without increasing participant burden (Shiffman et al., 2008). Studies using this method have shown that highly processed food intake was associated with positive emotions immediately after eating (Franja, Wahl, Elliston, & Ferguson, 2021; Liao et al., 2018; Wahl et al., 2017); however, these studies either found no significant associations with negative emotions immediately after eating or did not include measurement of negative emotions. Only one of those studies examined emotions up to 3 h after eating (Franja et al., 2021). This study found that eating highly processed foods was immediately followed by a slight increase in positive emotions and then followed by a decline in positive emotions through 3 h later; however, this temporal trend was non-significant.

The present study was an archival data analysis of ambulatory electronic diary data from the UCLA Rewards in Everyday Life Study, which included measurement of highly processed food intake and emotions hourly for four days in young adults' everyday lives (Cummings, Mamtora, & Tomiyama, 2019). The primary aim of the present study was to build upon the limitations of prior work by separately examining the immediate and future, positive and negative, emotions following an eating event. Moreover, the focus on the emotional sequelae of *highly processed food* intake is theoretically relevant because individuals expect these foods to change their emotions (Boggiano et al., 2017; Burgess et al., 2014). We hypothesized that highly processed food intake would be associated with greater positive and lower negative emotions immediately after eating (i.e., within the hour), and with lower positive and greater negative emotions 1 h later. In addition, we conducted *post hoc* exploratory analysis testing how highly processed food intake was associated with positive and negative emotions 3 h after eating. We selected 3 h because research demonstrates that there is a rapid decline in blood glucose levels between 2 to 4 h after food intake (Ludwig, 2002), which has been associated with experiences of negative emotions (e.g., irritability, nervousness; Deary & Zammitt, 1999; Strachan, Deary, Ewing, & Frier, 2000).

In a prior experiment, the immediate effects of highly processed food intake on laboratory-induced emotions were moderated by a tendency to eat any food for emotional reasons (van Strien, Gibson, Banos, Cebolla, & Winkens, 2019) and, in a double-blind placebo controlled study, consuming high-carbohydrate (vs. high-protein) milkshakes reduced laboratory-induced negative emotions in women who self-identified as "carb cravers" (Spring et al., 2008). Similarly, eating highly processed foods may elicit heightened emotions in individuals with "highly processed food addiction," a phenotype marked by strong cravings for highly processed foods, diminished control over intake of those foods, and overconsumption despite negative consequences such as clinically significant distress or development of chronic disease (Schulte et al., 2015; Schulte, Sonneville, & Gearhardt, 2019). Individuals with elevated highly processed food addiction symptoms hold greater expectations that highly processed foods enhance positive emotions (Cummings, Joyner, & Gearhardt, 2020) and demonstrate greater negative urgency, or the tendency to act impulsively in order to alleviate negative emotions (Murphy, Stojek, & MacKillop, 2014; Pivarunas & Conner, 2015). Thus, the secondary aim of the present study was to test whether highly processed food addiction symptoms moderated associations of highly processed food intake with immediate and future emotions. We hypothesized that—for individuals with higher levels of highly processed food addiction symptoms—highly processed food intake would be more strongly associated with greater positive and lower negative emotions immediately after eating, and with lower positive and greater negative emotions in the future. The present study aims, hypotheses, and analytic plan were preregistered on the Open Science Framework: https://osf.io/276qw.

2. Methods

2.1. Participants

The UCLA Rewards in Everyday Life study was an ambulatory electronic diary study conducted from May 2017 to February 2018. See Cummings et al. (2019) for full details on recruitment, inclusion and exclusion criteria, study procedure, and measures. Young adults were the target population and recruited through flyer and online advertisements geared towards UCLA students. Inclusion criteria for participants were (a) age 18–24, (b) fluency in English, and (c) owning an electronic device compatible with the ambulatory electronic diary delivery method; exclusion criteria were (a) following a strict diet that would prevent participants from highly processed food intake and (b) remaining abstinent from drinking alcohol. Young adults were the study population of interest because younger compared to older adults eat more snacks including highly processed foods (Howarth, Huang, Roberts, Lin, & McCrory, 2007), thus reducing the likelihood of floor effects. Simulation multilevel modeling studies indicating that sample sizes >50 at the highest level of analysis reduce likelihood of biased estimates and available research funds guided sample size selection (Maas & Hox, 2005). The present analysis used the complete sample from the original analysis [$n = 84$, $M_{age}(SD) = 20.06(1.65)$, $M_{BMI}(SD) = 22.84(3.72)$, 76.2% female, 41.7% Asian American]. About one third (34.5%) of participants reported eating highly processed foods on 10–19 days/month, 22.6% reported 20–29 days/month, 16.7% reported 6–9 days/month, 10.7% reported 3–5 days/month, 8.3% reported everyday/month, and 7.1% reported 1–2 days/month (Cummings et al., 2019).

2.2. Procedure

The UCLA Institutional Review Board approved the research procedure in accordance with the provisions of the World Medical Association Declaration of Helsinki. Researchers informed participants that the study was about how people experience reward in everyday life and did not mention the study was about eating behavior, blinding participants to the true purpose of the study. At the baseline laboratory session, participants provided informed consent, completed questionnaires including the Yale Food Addiction Scale 2.0 (Gearhardt, Corbin, & Brownell, 2016), and learned the ambulatory electronic diary procedure. Participants practiced one diary entry under supervision (Cummings et al., 2019).

Participants started the ambulatory electronic diary procedure on Thursday, Friday, or Saturday and continued their entries for a total of four days; this procedure ensured that each participant reported on two weekdays and two weekend days to capture weekday-weekend variability in food intake (de Castro, 1991). From the time they woke until they went to bed, participants responded to hourly alerts for four days via the Personal Analytic Companion application (PACO; Evans, 2017) installed on their personal smartphone. Each alert was followed by questions regarding highly processed food intake and items from the Positive Affect and Negative Affect Schedule (Watson, Clark, & Tellegen, 1988). Researchers instructed participants to behave as they would on an average day and answer questions each time they were alerted. Researchers instructed participants to skip responses during an incompatible event such as an exam or while driving (Tomiyama, Mann, & Comer, 2009). At the end of the study, researchers led participants through funneled debriefing (Mills, 1976). Participants were 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 (Cummings et al., 2019).

2.3. Measures

2.3.1. Highly processed food intake

Participants reported on whether they ate highly processed foods within the previous hour analogously to prior ambulatory electronic diary studies of eating behavior (Boggiano, Wenger, Turan, Tatum, Sylvester, et al., 2015; Elliston, Ferguson, Schüz, & Schüz, 2017; Schüz, Schüz, & Ferguson, 2015; Schüz, Revell, Hills, Schüz, & Ferguson, 2017; Strahler & Nater, 2017; Tomiyama et al., 2009). The prompt was, "*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)?*" We based the specific wordings of the food/drink categories on the Palatable Eating Motives Scale, which was used in prior work finding that individuals eat highly processed foods for emotional reasons (Burgess et al., 2014), and food reports from the National Heart, Lung, and Blood Institute Growth and Health Study (Morrison, Sprecher, Barton, Waclawiw, & Daniels, 1999). Ambulatory electronic diary questions regarding food intake have shown convergent validity with objectively-measured body mass index (BMI) (Schüz et al., 2015), yet have not been validated against objective measures of diet.

2.3.2. Positive and negative emotions

Participants responded to four items from the Positive and Negative Affect Schedule each hour (Watson et al., 1988). The prompt was: "*Read each item and then indicate to what extent you feel this way right now at the present moment, on a scale from 1 to 5.*" 1 represented "*Very slightly or not at all*," 2 represented "*A little*," 3 represented "*Moderate*," 4 represented "*Quite a bit*," and 5 represented "*Extremely*." The four items included "*enthusiastic*" and "*happy*" to measure positive emotions, and "*afraid*" and "*distressed*" to measure negative emotions. We included only four items to reduce participant burden, which is a typical practice with ambulatory electronic diary studies (Shiffman et al., 2008). We selected the particular items because they had the highest factor loadings for positive and negative emotion factors in our laboratory's previous experimental work using a 22-item Positive and Negative Affect Schedule to assess emotional effects of eating food (Cummings & Tomiyama, 2019; Finch et al., 2019). We composited scores for positive ($r = .69$, $p < .001$) and negative ($r = .58$, $p < .001$) emotions by calculating averages across the positive and negative items, respectively. While the highly processed food intake questions asked about eating "in the last hour," the positive and negative emotion questions asked about feelings "right now at the present moment" to ensure that the emotions followed the eating event. The Positive and Negative Affect Schedule has demonstrated convergent and discriminant validity with self-report measures of psychopathology (Watson et al., 1988).

2.3.3. Highly processed food addiction

The 35-item Yale Food Addiction Scale 2.0 measures addictive-like responses to highly processed foods based on the *Diagnostic and Statistical Manual of Mental Disorders* (5th ed.) criteria for substance use disorders (Gearhardt et al., 2016). The prompt was: "*People sometimes have difficulty controlling how much they eat of certain foods such as:* ***sweets*** *like ice cream, chocolate, doughnuts, cookies, cake, candy,* ***starches*** *like white bread, rolls, pasta, and rice,* ***salty snacks*** *like chips, pretzels, and crackers,* ***fatty foods*** *like steak, bacon, hamburgers, cheeseburgers, pizza, and French fries, and* ***sugary drinks*** *like soda pop, lemonade, sports drinks, and energy drinks. When the following questions ask about "CERTAIN FOODS" please think of ANY foods or beverages similar to those listed in the food or beverage groups above or ANY OTHER foods you have had difficulty with in the past year.*" Sample items include "*I had such strong urges to eat certain foods that I couldn't think of anything else*," and "*If I had emotional problems because I hadn't eaten certain foods, I would eat those foods to feel better.*" Participants rated items on an 8-point Likert scale from 0 ("*Never*") to 7 ("*Every day*"). We calculated symptoms of highly processed food addiction by using publicly available scoring tools that add the number of symptoms each participant endorsed (FASTLab, 2021). The average number of symptoms observed was 2.52 ($SD = 2.65$). The Yale Food Addiction Scale 2.0 has demonstrated convergent validity with self-reported binge eating frequency and BMI and discriminant validity with self-reported dietary restraint (Gearhardt et al., 2016).

2.3.4. Potential covariates

2.3.4.1. Potential time-invariant covariates. Participants reported on their age, biological sex, race/ethnicity, and subjective socioeconomic status (Adler & Stewart, 2007). Participants reported how often they felt stressed in the past month [$M(SD) = 1.89\ (0.54)$, where 1 = "Never" and 5 = "Very Often"] on the Perceived Stress Scale (Cohen, Kamarck, & Mermelstein, 1983), which has demonstrated convergent validity with a self-report measure of stressful life events. Participants reported their depressive symptoms in the past week [$M(SD) = 15.82\ (9.60)$, where ≥ 16 indicates risk for depression] on the Center for Epidemiological Studies Depression Scale (Radloff, 1977), which has demonstrated convergent validity with clinical ratings of depression. We yielded continuous scores of response bias using the Marlowe-Crowne Social Desirability Scale (Crowne & Marlowe, 1960), which has demonstrated convergent and discriminant validity with self-report measures of psychopathology. Researchers measured participant height and weight in the laboratory for BMI calculation (kg/m^2).

2.3.4.2. Potential time-invariant covariates. Participants reported hourly on their cigarette smoking ("*In the last hour, did you smoke cigarettes?*") and alcohol use ("*In the last hour, how many standard drinks of alcohol did you drink? (1 standard drink = 1 12 oz. beer, 1 5 oz. wine, 1 1.5 oz. liquor)*"); ambulatory electronic diary questions regarding cigarette and alcohol use have demonstrated convergent validity with diagnosis of substance use disorders determined by clinical interviews (Serre et al., 2012). We coded for day in study (to test for reactivity, or changes in the behavior because of an increased attention on the behavior), day of week, time of day, and week of academic quarter from time stamps in PACO.

2.4. Statistical approach

Data and syntax are publicly available at: https://osf.io/wn69h/. Hypotheses for the preregistered archival data analysis were specified after data collection but before data analysis. The analytic plan was prespecified and any data-driven analyses are clearly identified as *post hoc* exploratory analysis. We tested hypotheses with multilevel modeling to account for repeated measurement. Independent variables included intake of sweet high-fat foods, fast foods, and non-alcoholic sugary drinks entered at Level 1. Dependent variables included positive and negative emotions within the hour of eating, 1 h after eating, and 3 h after eating entered at Level 1. Lagging the data hourly created positive and negative emotions variables to represent emotions 1 and 3 h after eating. The moderator was highly processed food addiction symptoms entered at Level 2.

All variables were assessed for normality before hypothesis testing. Negative emotions showed small skew (2.06) and kurtosis (4.58) and were log-transformed for analysis. Hypothesis testing was thus conducted with untransformed and log-transformed negative emotions; results were consistent across these approaches. We report the results from the untransformed analysis for ease of interpretation.

Likelihood Ratio Tests compared models with or without random effects for intercept and slope. Models with sweet high-fat food and non-alcoholic sugary intake included random effects for intercept and slope because of better fit (significantly smaller −2LL). Models with fast food intake fit better with random effects for intercept only.

Reported results include estimates from unadjusted and covariate-adjusted models. Adjusted models include the potential covariates that demonstrated a significant association with dependent variables. We conducted model estimations in SAS University Edition (Cary, NC) using the restricted maximum likelihood estimation approach, which accounts for missing data.

3. Results

3.1. Descriptives

The mean response rate to the ambulatory electronic diary hourly alerts was 83% (*min-max* = 7–100%) (Cummings et al., 2019). This resulted in 4,167 Level 1 observations [*M(SD)* = 49.61 (10.81) per participant, *min-max* = 4–60 per participant]. On average, participants reported consuming sweet high-fat foods on 13.1% of the diary occasions (during about 1.63 h/day), fast foods on 4.3% of the diary occasions (during about 0.54 h/day), and non-alcoholic sugary beverages on 9.0% of the diary occasions (during about 1.12 h/day). Fig. 1 presents the hourly mean levels of positive and negative emotions.

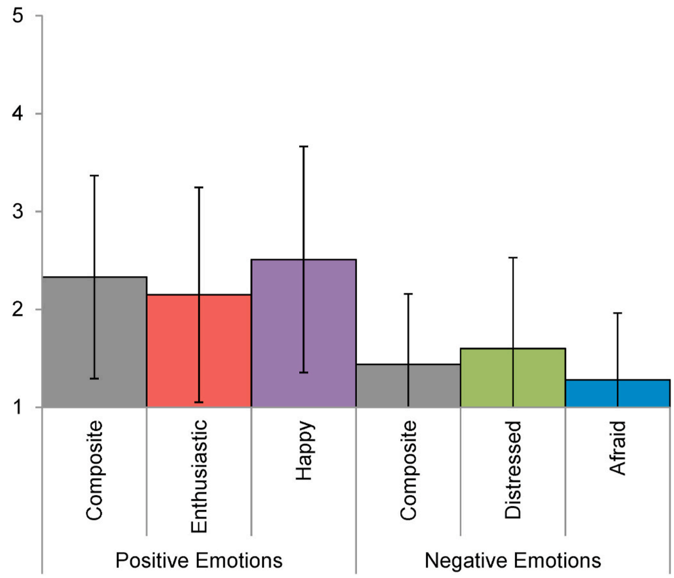

Fig. 1. Hourly mean levels of positive and negative emotions across four days. Standard deviations are depicted by capped bars. Greater scores indicate greater emotions.

3.2. Positive emotions

Table 1 presents multilevel estimates of fixed effects. Sweet high-fat food intake, non-alcoholic sugary beverage intake, and fast food intake were associated with greater positive emotions immediately after eating. Specifically, over and above the effects of covariates, eating sweet high-fat food was associated with an average 0.22 ± 0.04 point increase in positive emotions ($p < .001$, 95% CI [0.13, 0.31]); drinking non-alcoholic sugary beverages was associated with an average 0.25 ± 0.07 point increase in positive emotions ($p < .001$, 95% CI [0.11, 0.39]); and eating fast food was associated with an average 0.20 ± 0.07 point increase in positive emotions ($p = .002$, 95% CI [0.07, 0.34]).

Sweet high-fat food intake and non-alcoholic sugary drink intake (and at a trend level fast food intake) were also prospectively associated with greater positive emotions 1 h later. When adjusting for the effects of covariates, only sweet-high fat food intake was prospectively associated with a 0.09 ± 0.04 point increase in positive emotions 1 h later ($p = .021$, 95% CI [0.01, 0.17]). Additionally, sweet high-fat food intake was prospectively associated with greater positive emotions 3 h later; however, when adjusting for the effects of covariates, this association was no longer significant. The prospective associations between non-alcoholic sugary drink intake and positive emotions 3 h later, and between fast food intake and positive emotions 3 h later, were not significant in unadjusted or adjusted models.

3.3. Negative emotions

There were no significant associations between highly processed food intake and concurrent negative emotions. Sweet high-fat food intake and non-alcoholic sugary drink intake were prospectively associated with fewer negative emotions 1 h later. Specifically, over and above the effects of covariates, eating sweet high-fat food was (at a trend level) associated with a 0.05 ± 0.03 point decrease in negative emotions 1 h later ($p = .074$, 95% CI [-0.10, 0.00]) and drinking non-alcoholic sugary beverages was associated with a 0.12 ± 0.03 point decrease in negative emotions 1 h later ($p < .001$, 95% CI [-0.18, −0.06]). There were no significant prospective associations between any type of highly processed food intake and negative emotions 3 h later in unadjusted or adjusted models.

Table 1
Fixed effects estimates of highly processed food intake on concurrent and future positive and negative emotions.

	Unadjusted					Adjusted				
	β	*SE*$_β$	*p*	95% CI		*β*	*SE*$_β$	*p*	95% CI	
				Lower	Upper				Lower	Upper
Concurrent Positive Emotions										
Sweet high-fat food intake	0.23	0.04	<.001	0.14	0.32	0.22	0.04	<.001	0.13	0.31
Non-alcoholic sugary drink intake	0.27	0.07	<.001	0.12	0.41	0.25	0.07	<.001	0.11	0.39
Fast food intake	0.23	0.07	<.001	0.10	0.36	0.20	0.07	.002	0.07	0.34
Positive Emotions 1 Hour Later										
Sweet high-fat food intake	0.21	0.05	<.001	0.11	0.30	0.09	0.04	.021	0.01	0.17
Non-alcoholic sugary drink intake	0.16	0.07	.031	0.02	0.31	0.04	0.06	.546	−0.09	0.16
Fast food intake	0.16	0.08	.061	−0.01	0.33	0.06	0.07	.400	−0.08	0.21
Positive Emotions 3 Hours Later										
Sweet high-fat food intake	0.10	0.05	.033	0.01	0.19	0.05	0.05	.303	−0.04	0.14
Non-alcoholic sugary drink intake	0.01	0.07	.884	−0.13	0.15	−0.02	0.06	.694	−0.15	0.10
Fast food intake	0.06	0.08	.488	−0.10	0.22	0.01	0.08	.929	−0.15	0.16
Concurrent Negative Emotions										
Sweet high-fat food intake	−0.01	0.03	.691	−0.08	0.05	−0.01	0.00	.700	−0.08	0.05
Non-alcoholic sugary drink intake	−0.01	0.03	.833	−0.07	0.06	−0.01	0.03	.868	−0.07	0.06
Fast food intake	−0.04	0.04	.332	−0.13	0.04	−0.04	0.04	.374	−0.12	0.05
Negative Emotions 1 Hour Later										
Sweet high-fat food intake	−0.06	0.03	.044	−0.11	−0.00	−0.05	0.03	.074	−0.10	0.00
Non-alcoholic sugary drink intake	−0.13	0.03	<.001	−0.19	−0.07	−0.12	0.03	<.001	−0.18	−0.06
Fast food intake	−0.03	0.04	.449	−0.12	0.05	0.01	0.05	.863	−0.10	0.12
Negative Emotions 3 Hours Later										
Sweet high-fat food intake	−0.01	0.03	.775	−0.07	0.05	0.00	0.03	.965	−0.06	0.06
Non-alcoholic sugary drink intake	−0.02	0.04	.615	−0.11	0.06	−0.02	0.04	.616	−0.11	0.07
Fast food intake	0.05	0.05	.298	−0.04	0.14	0.07	0.06	.227	−0.04	0.18

Notes: Adjusted models predicting concurrent positive emotions controlled for time of day, day of week, and concurrent alcohol use. Adjusted models predicting future positive emotions controlled for concurrent positive emotions, time of day, and day of week. Adjusted models predicting concurrent negative emotions controlled for day of week. Adjusted models predicting future negative emotions controlled for concurrent negative emotions.

3.4. Highly processed food addiction symptoms

Overall, highly processed food addiction symptoms did not significantly moderate the relations of highly processed food intake with immediate positive emotions, future positive emotions, and immediate negative emotions. However, there was a significant interaction between non-alcoholic sugary beverage intake and food addiction symptoms on negative emotions 1 h later [$\gamma = -0.03(0.01)$, $p = .025$, 95% CI (-0.05, −0.00)]. Tests for simple effects revealed that non-alcoholic sugary beverage intake prospectively predicted a greater decrease in negative emotions 1 h later among individuals with a higher number of highly processed food addiction symptoms [$\beta = -0.21(0.06)$, $p = .002$, 95% CI (-0.33, −0.09)] compared to those with a lower number of highly processed food addiction symptoms [β −0.08(0.03), p = .017, 95% CI (-0.15, −0.02)].

4. Discussion

Many individuals eat highly processed foods to enhance positive emotions and reduce negative emotions (Boggiano, 2016; Boggiano et al., 2017; Burgess et al., 2014), and greater expectations about the positive emotional effects of highly processed food intake increased intake of those foods in a laboratory setting (Cummings et al., 2021). However, there are gaps in the scientific literature on the emotional experiences following highly processed food intake. Evidence from experimental and ambulatory electronic diary studies suggests that highly processed food intake may sustain or enhance positive emotions but inconsistently reduce negative emotions immediately after eating in or outside of the laboratory (Casperson et al., 2019; Finch et al., 2019; Franja et al., 2021; Liao et al., 2018; Macht & Mueller, 2007; McKay et al., 2021; Wagner et al., 2014; Wahl et al., 2017). The present ambulatory electronic diary study filled scientific gaps by examining the relations of highly processed food intake with immediate positive and negative emotions, and with future emotions 1 and 3 h after eating, in a naturalistic setting.

Consistent with our hypothesis and findings from prior studies, highly processed food intake predicted greater positive emotions immediately after eating. Counter to hypothesis, highly processed food intake also predicted greater rather than lower positive emotions 1 h later. The magnitudes of associations between highly processed food intake and positive emotions decreased 1 h later and, for some types of highly processed food intake (i.e., non-alcoholic sugary drinks, fast food), these associations were non-significant when accounting for covariates. By 3 h later, there were no significant associations between highly processed food intake and positive emotions after adjusting for covariates. Compared with prior work, the present study results provide a fuller understanding of the magnitude and time course of the positive emotions that follow highly processed food intake (Liao et al., 2018; Wahl et al., 2017). Specifically, eating highly processed foods may have a small and immediate ability to enhance positive emotions, but emotional effects of highly processed food intake last at most 1 to 2 h. Moreover, since these associations weakened when accounting for covariates, the time of day, day of week, and simultaneous alcohol use may partially explain why people feel greater positive emotions after eating highly processed food.

The potential ability of highly processed food intake to briefly increase positive emotions is consistent with evidence that intake of highly processed foods engages reward and pleasure systems in a manner akin to addictive substances (DiFeliceantonio et al., 2018; Small & DiFeliceantonio, 2019). When addictive substances trigger pleasurable experiences that are short in duration, this actually increases the addictiveness of the substance (Henningfield & Keenan, 1993; McColl & Sellers, 2006). When the pleasurable experience dissipates, this may trigger a desire to seek out more of the addictive substance. Thus, the short duration of the positive emotions that result from consuming highly processed food may be reinforcing and also lead to additional highly processed food intake to maintain positive emotions over time. While a 4–5% increase in positive emotions immediately following highly processed food intake is statistically small, intravenous intake of ~1 standard drink of alcohol (0.02 g/dL BAC) was similarly significantly associated with about a 5% increase in positive emotions (Ray, Bujarski, Squeglia, Ashenhurst, & Anton, 2014). Intravenous intake of a small dose of cocaine (12.5 mg/70 kg) was significantly associated with about a 10% increase in positive emotions (Smith, Jones, & Griffiths, 2001).

With regard to negative emotions, we hypothesized that highly processed food intake would predict lower negative emotions immediately after eating. Furthermore, we predicted greater negative emotions in the future because of later negative cognitive processing of the eating episode (e.g., "I ate junk"; Smith et al., 2018) and drops in blood glucose levels that occur between 2 and 4 h after eating resulting in potential negative emotional experiences (e.g., irritability, nervousness; Deary & Zammitt, 1999; Ludwig, 2002; Strachan et al., 2000). However, highly processed food intake was not associated with negative emotions immediately after eating, and some types of highly processed food intake (i.e., sweet high-fat foods, non-alcoholic sugary drinks) predicted lower, not greater, negative emotions 1 h later. These associations were small in magnitude and, by 3 h later, there were no significant associations between highly processed food intake and negative emotions.

It is important to consider sample characteristics of the present study that may have impacted the negative emotion findings. Individuals who followed a strict diet were excluded from the study, and participants were mostly young with "normal" BMIs. Those who harshly restrict food intake tend to ruminate more often and may be more likely to have negative thoughts about eating episodes (Smith et al., 2018). Also, drops in blood glucose levels after food intake are more pronounced among those with obesity (Ludwig, 2002). It is therefore conceivable that, in a sample of those strictly dieting or with obesity, highly processed food intake would predict greater negative emotions in the hours after eating.

A potential explanation for the association of highly processed food intake with lower, not greater, negative emotions 1 h later comes from the animal literature on "comfort eating" (Dallman et al., 2003). In multiple experiments, rodents who eat sweet high-fat food have shown blunted activity in the hypothalamic-pituitary-axis (HPA), a neuroendocrine system that in humans has been shown to regulate psychological processes including negative emotions (Dallman et al., 2003). HPA reactivity to input is delayed rather than immediate (Spencer & Deak, 2017) so it is possible that HPA reactivity could have mediated the delayed reductions in negative emotions that occurred 1 h after highly processed food intake. Furthermore, the types of highly processed food intake that were associated with delayed reductions in negative emotions in the present study were sugary. In a human experiment, consuming sugar three times per day for two weeks resulted in blunted HPA activity, suggesting that changes in HPA activity might be especially relevant to the emotional effects of sugary food intake (Tryon et al., 2015). It will be important for future research to replicate the negative emotion findings from the present study and test for HPA activity as a potential mediator.

Those with greater symptoms of highly processed food addiction in the sample showed even lower negative emotions 1 h after non-alcoholic sugary beverage intake. This is similar to findings that those who report eating any food for emotional reasons or self-identify as a carb craver showed enhanced mood improvement after highly processed food intake in the laboratory (Spring et al., 2008; van Strien, Gibson, Banos, Cebolla, & Winkens, 2019). Individuals with highly processed food addiction may be especially attuned to the reinforcing effects of highly processed food intake, and this may potentially explain the strong cravings for highly processed food, diminished control over intake, and overconsumption despite negative consequences observed with this phenotype (Schulte et al., 2015). Nevertheless, symptoms of highly processed food addiction did not moderate the relations of highly processed food intake with other emotions. This may be due to the low number of symptoms (< 3) observed on average in the sample, and the small magnitude of associations between highly processed food intake and emotions across the whole sample.

Results should be interpreted in light of study strengths and limitations. Foremost, the recruitment and inclusion/exclusion criteria likely led to sample selection bias in the results. Flyer advertisements for the study were on a university campus and included pictures of food and alcohol, which may have enticed certain young adults to be interested in joining, and young adults who followed a strict diet and abstained from alcohol use were excluded from the study. This may limit extrapolation of the results to other young adults and more general populations. Sample selection bias is a common limitation in the scientific literature on the emotional consequences of highly processed food intake (Casperson et al., 2019; Finch et al., 2019; Franja et al., 2021; Liao et al., 2018; Macht & Mueller, 2007; McKay et al., 2021; Wagner et al., 2014; Wahl et al., 2017), indicating a need for future research in more representative samples.

For theoretical reasons (i.e., individuals are motivated to eat highly processed foods for emotional reasons), we focused on the behavior of highly processed food intake rather than general food intake (Boggiano, 2016; Boggiano et al., 2017 Burgess et al., 2014). However, comparing the magnitude and time course of emotions that follow intake of other foods may provide novel information about the relative influence of different types of food intake on emotions (Liao et al., 2018). Similar to prior ambulatory electronic diary studies on food intake (Boggiano, Wenger, Turan, Tatum, Sylvester, et al., 2015; Elliston et al., 2017; Schüz et al., 2015; Schüz et al., 2017; Strahler & Nater, 2017; Tomiyama et al., 2009), we measured highly processed food intake using yes/no questions. Yet, the caloric amount of highly processed intake may modify associations between intake and emotions, so future research measuring caloric amount may yield novel results. Additionally, we separately measured positive and negative emotions using items from the Positive and Negative Affect Schedule that had the highest factor loadings in our laboratory's previous work (Cummings & Tomiyama, 2019; Finch et al., 2019), but inclusion of other emotion words like "guilt" may have yielded unique results. Previous research demonstrated sustained, elevated guilt following loss of control eating episodes in individuals prone to overeating (Stevenson, Dvorak, Wonderlich, Crosby, & Gordon, 2018). Exploration of additional negative emotions, such as guilt, may therefore be important for examining the effects of highly processed food intake in individuals with elevated food addiction symptoms, other disordered eating, and obesity or in those strictly dieting.

Although we adjusted for several potential confounds (including emotions in the prior hour), the causal emotional effects of eating highly processed foods cannot be determined from an ambulatory electronic diary study. Potential confounds unaddressed in the present study include intake of other foods, which may also influence emotions, and history of disordered eating, which may influence food intake and emotional responses to food intake. Social desirability bias may be relevant, yet participants typically do not censor their reports in ambulatory electronic studies (Trull & Ebner-Priemer, 2013), and the participants' scores on the Marlowe-Crowne Social Desirability Scale were unassociated with highly processed food intake, positive emotions, and negative emotions in the present study. Repeatedly reporting on highly processed food intake may also cause reactivity. This was unlikely in the present study given our efforts at blinding and given that there was no association between day in study and highly processed food intake. Other ambulatory electronic diary studies on food intake have similarly found no evidence of reactivity (le Grange, Gorin, Dymek, & Stone, 2002; Stein & Corte, 2003; Tomiyama et al., 2009).

In sum, in the present study, highly processed food intake was associated with greater immediate positive emotions, and with greater positive and lower negative emotions 1 h later. These results suggest that motivations to eat highly processed food to enhance positive emotions and reduce negative emotions are not unfounded; however, conclusions should be drawn in context of findings from the broader scientific literature, which suggest that eating highly processed food to reduce negative emotions may be misguided. The ability of highly processed food intake to alter emotional states, particularly to increase positive emotions, may contribute to their reinforcing nature and underscore the difficulty with changing this behavior. Since associations between highly processed food intake and emotions were small and did not persist through 3 h after intake, it is plausible that individuals may repeatedly consume highly processed foods throughout the day to maintain positive emotions. More research is needed to test the hypothesis that brief peaks in positive emotions after highly processed food intake encourage additional intake, and to investigate the association of highly processed food intake with concurrent and future emotions in clinical populations.

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Author contributions

J.R.C., E.T.S., and A.N.G. developed the study concept. J.R.C. performed the data analysis and interpretation under the supervision of A.J. T. and A.N.G. E.T.S. confirmed reported estimates based on publicly available data and syntax. J.R.C. drafted the paper with assistance from E.T.S. in drafting the abstract. T.M. confirmed the paper adhered to journal guidelines. All authors provided revisions and approved the final version of the paper for submission.

Ethical statement

The University Institutional Review Board approved the original study procedure in accordance with the provisions of the World Medical Association Declaration of Helsinki. The current study is an archival data analysis of de-identified data available in a public repository.

Declaration of competing interest

None.

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