It's craving time: Time of day effects on momentary hunger and food craving in daily life

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Keywords: food craving; food categories; hunger; ecological momentary assessment;

Abstract

Objective. A key determinant of food intake besides hunger is food craving, which refers to an intense desire to consume a specific food. Although both frequently co-occur, they are conceptually different and their dissociation is thought to underlie unhealthy eating (e.g., eating in the absence of hunger). To date, we know almost nothing about their coherence (or dissociation) in daily life, or about the role of time of the day and different food types.

Research Methods & Procedure. The present investigation assessed both hunger and food craving for several food categories in daily life using smartphone-based ecological momentary assessment. Across three independent studies (n = 50, n = 51 and n = 59), participants received five/six prompts a day and reported their momentary hunger and desire for tasty food (a subcomponent of food craving).

Results. Consistent across studies, hunger and desire for tasty food exhibited largely similar patterns throughout the day with two peaks (roughly corresponding to lunch and dinner). Examining more specific food categories, study 3 showed that while desire for main meal-type foods showed a two peak pattern in coherence with hunger, this pattern was different for snack-type foods: desire for fruits decreased, whereas desire for sweets and salty snacks increased throughout the day with less coherence with hunger.

Conclusions. These findings suggest that dissociations between hunger and craving are seen only for snack-type foods while hunger and general food cravings cohere strongly. Interventions addressing snacking may take these circadian patterns of food cravings into account.

Introduction

In affluent, urban societies, food intake not only serves energy balancing but has also adopted psychological functions (Cleobury & Tapper, 2014; Verhoeven, Adriaanse, de Vet, Fennis, & de Ridder, 2015). Studies show that the hedonic appeal inherent in 'hyperpalatable foods' plays an important role in food intake, particularly in regard to unhealthy snack consumption in the absence of hunger (Cleobury & Tapper, 2014; Verhoeven et al., 2015). An overreliance on hedonic eating motives, however, is likely to result in an unfavorable energy balance and potential weight gain over time. Hence, investigating reasons for food consumption seems necessary to optimally tackle the rising prevalence of overweight and obesity (Ng et al., 2014).

Homeostatic *hunger* is defined as a "biological state of acute energy deprivation or the subjective state presumably reflecting an actual or impending state of energy deprivation" (Lowe & Butryn, 2007; p. 433). Others define hunger as the absence of fullness (Rogers & Brunstrom, 2016). Although hunger has a physiological basis, it may be influenced by environmental or cognitive factors like availability or habitual meal patterns (for an overview see Lowe & Levine, 2005). Thus, homeostatic hunger does not necessarily lead to food intake (e.g., a person is hungry, however, no food is currently available, or the person is on a diet) (Mattes, 1990). Apart from such homeostatic processes, food intake can also be driven by hedonic process. In this context, the concept of *food craving* has gained prominence. Food craving has been defined as an intense desire or urge to consume specific foods (Hormes & Rozin, 2010; Weingarten & Elston, 1991) and is sometimes compared with drug cravings in addiction (Pelchat, 2002). Although hunger and food craving often co-occur, food cravings can also occur without being hungry; that is, without an energy deficit (e.g., craving a desert after a satiating meal). This dissociation has also been shown repeatedly in experimental, laboratory-based studies (e.g., Gibson & Desmond, 1999; Meule & Hormes, 2015; Pelchat & Schaefer, 2000) or retrospective psychometric measures (Hill, Weaver, & Blundell, 1991; Meule, Hermann, & Kübler, 2014). This research has revealed a general and robust positive correlation between the two, unless specific conditions are created – such as exposure to attractive foods under conditions of satiety or 'hedonic deprivation', that is, the selective withholding of craved foods alongside adequate homeostatic feeding (Blechert, Naumann, Schmitz, Herbert, & Tuschen-Caffier, 2014; Pelchat & Schaefer, 2000; Richard, Meule, Friese, & Blechert, 2017). Of note, food cravings have been prospectively associated with low dieting success, increased food intake, and weight gain (Boswell & Kober, 2016; Meule, Richard, & Platte, 2017) and, thus, are an important target of most comprehensive weight loss approaches.

This conceptual and empirical distinction between hunger and food craving has implication for their respective measurements: Whereas hunger is not directed towards a specific food category, as any energy-containing or filling food can satisfy hunger, food craving is typically directed at a particular food type and taste and can only be satisfied by consumption of the craved or very similar food (Hill, 2007). Previous studies showed that food cravings are mainly directed at energy-dense, high-caloric foods such as chocolate or salty snacks (e.g., Martin, O'Neil, Tollefson, Greenway, & White, 2008; Rozin, Levine, & Stoess, 1991), but healthy foods (e.g., fruits and vegetables) are also sometimes reported (Hill & Heaton-Brown, 1994; Richard, Meule, Reichenberger, & Blechert, 2017). Thus, although momentary hunger can be measured with simple 'how hungry are you at the moment?" questions, the assessment of food cravings may require reference to specific foods / food categories, or to the tastiness of food.

Thus, as reviewed above, although the distinction between hunger and food craving has been shown, what is missing almost entirely are studies on *when and how often* this dissociation occurs in everyday life. Furthermore, studies in the natural environments could reveal the common and distinct trajectories of the hunger and food craving and characterize their circadian rhythms. The methodology of Ecological Momentary Assessment (EMA), consisting of repeated assessments within individuals over time, is ideally suited for this purpose (see Smyth, Juth, Ma, & Sliwinski, 2017). To close this gap, we employed EMA in a naturalistic study of hunger and craving. We hypothesized that subjective hunger ratings exhibit two clear circadian peaks, approximately around midday and evening meal times (Huh, Shiyko, Keller, Dunton, & Schembre, 2015; Mattes, 1990). Furthermore, some incidental evidence indicates that cravings gain prominence during afternoon and early evening (Pelchat, 1997), leading to the expectations that concordance between hunger and craving will drop during those times. In addition, as food cravings seems specific to distinct foods, the role of specific food categories (carbohydrates, fatty, salty and sweet foods, fruits and vegetables) in this relationship will be explored in a more exploratory fashion. To increase the generalizability and rigor of findings, a three-study design in three independent samples was used.

Material and methods

Study 1[1]

Participants

Fifty-three participants, predominantly students, were recruited into the study. Three individuals were excluded after the data collection phase because of overall low compliance rates (<50%). The remaining 50 participants (mean age of 23.6 years, *SD* = 2.75 years) were predominantly female (66%) with a mean Body Mass Index (BMI) of 22.1 kg/m² (*SD* = 3.27 kg/m²; range: 16.6 – 34.9 kg/m²). Participants signed an informed consent form approved by the ethics committee of the University of Salzburg and were paid for their participation (€ 30 to 50 depending on compliance).

[1] Other data from this sample have been reported in Reichenberger, Smyth, and Blechert (2017).

Procedure

Initially, participants completed several diagnostic measures and demographic information (e.g. weight/height) at an online survey platform. Afterwards, individuals were personally instructed on the installation and usage of a smartphone app and received a user manual. After one practice day (data not used in the study), participants completed six days of EMA with data completeness being monitored closely by study staff. At the end of this period, participants completed a second block of online questionnaires. A second week of EMA assessment (again one practice day and six days of data collection) was conducted to increase contextual variability and thereby generalizability. After a last questionnaire block, participant were debriefed and compensated.

The study used signal-, event-, and interval-contingent sampling (see Shiffman, Stone, & Hufford, 2008), prompting individuals at five equidistant times (10 a.m., 1 p.m., 4 p.m., 7 p.m., 10 p.m.). Immediately after waking up and shortly before going to bed, as well as before every eating episode, participants self-initiated questionnaires on their smartphone that are not of relevance for the present study. Diary entries could be delayed for one hour with or without reminders every 10 minutes with entries provided any later resulting in missing values. Participants completed 87.1% (*SD* = 11.6%) of their signal-contingent daily signals. Delayed entries were delayed, on average, for 11.8 minutes (*SD* = 15.2 minutes).

Study 2[2]

Participants

Fifty-nine participants (mean age 39.9 years, *SD* = 11.9 years), predominantly female (78%) and with a mean BMI of 26.7 kg/m² (*SD* = 5.76 kg/m²; range: 17.5 – 38.6 kg/m²), signed an informed consent form approved by the ethics committee of the University of Salzburg and

[2] Other findings from this sample have been reported in Reichenberger et al. (2018) and Reichenberger et al. (2017).

were compensated for their participation with their choice of individualized feedback report or a compliance dependent remuneration of € 35 - 60.

Procedure

Participants first completed several questionnaires and demographic information (e.g. weight/height) via an online survey platform. Afterwards, individuals were contacted via telephone to instruct participants on the installation and usage of a smartphone app; participants were also sent a user manual via email. After one to two practice days (data not used in the study), participants completed 10 days of EMA with data completeness being monitored closely by the study staff. At the end of this period, participants completed several questionnaires via an online platform and were compensated for their participation.

The study used signal-contingent sampling, prompting individuals at five equidistant times (9 a.m., 12 a.m., 3 p.m., 6 p.m., 9 p.m.). Because of a higher percentage (49%) of employees with regular work shifts the sampling times started with an earlier first prompt. Participants completed 83.6 % (*SD* = 12.3%) of their daily signals and delayed entries were delayed, on average, for 15.7 minutes (*SD* = 15.1 minutes).

Study 3

Participants

Fifty-one participants (mean age 23.5 years, *SD* = 2.61 years), predominantly female (78%) and with a mean BMI of 22.4 kg/m² (*SD* = 3.21 kg/m²; range: 17.3 – 33.2 kg/m²), signed an informed consent form approved by the ethics committee of the University of Ulm and were compensated for their participation with their choice of € 25 or 3.5 course credits.

Procedure

Participants initially completed several diagnostic measures and demographic information using an online survey platform. Individuals were then scheduled for a short laboratory testing at the University of Ulm (data not reported here; measurement of weight and height, application of a mobile heartrate monitor and physical activity tracker) that included the installation of the smartphone app and detailed instruction on its usage. Participants were handed a user manual and completed one practice day. Afterwards, individuals completed seven days of EMA with data completeness being monitored closely by the study staff. At the end of this period, participants completed several questionnaires via an online platform, returned study equipment, and were compensated for their participation.

The study used signal-contingent sampling for the EMA. Because of a shorter sampling duration, the frequency of daily prompts was increased. Specifically, participants were prompted at six equidistant times (9 a.m., 11.30 a.m., 2 p.m., 4.30 p.m., 7 p.m., 9.30 p.m.) each day for one week. Participants completed 85.0 % (*SD* = 11.2%) of their daily signals. When entries were delayed, they were delayed, on average, for 17.3 minutes (*SD* = 16.0 minutes).

EMA measures in Study 1, 2, and 3

At each of the intraday signals, participants completed questions about affect, stress as well as several eating-related behaviors. Among them, participants rated ‘How hungry are you right now?’ from *0 – 100 (not at all – very much).* One subcomponent of food craving – *desire to eat tasty foods* – appears to tap into the intensity of food craving (Cepeda-Benito, Gleaves, Williams, & Erath, 2000). As this intensity seems to be conceptualized as a state-like (rather than trait-like) aspect of food craving (Cepeda-Benito et al., 2000), desire for tasty foods might be best suited for assessing momentary changes of food craving in daily life. Hence, in study 1 and 2, food craving was assessed by asking participants ‘Do you have a desire to eat something tasty right now?’ from *0 – 100 (not at all – very much).* Similarly, study 3 asked participants ‘What do you feel like eating right now?’ followed by a list of food categories and desire for each food category was answered from *0 – 100 (nothing – very much).* Food categories were initially derived from the *Yale Food Addiction Scale 2.0* (Gearhardt, Corbin, & Brownell, 2016; Meule, 2016), comprising specifically high-fat and high-sugar foods, and extended by healthy food categories (also supported by previous research; Richard, Meule, Reichenberger, et al., 2017). The assessment thus included: salty snacks (e.g. chips, pretzel sticks), sweets (e.g., chocolate, cookies, ice cream), fatty snacks (e.g., burger, pizza, fries), carbohydrates (e.g., bread, pasta, rice), vegetables and salads (e.g., tomatoes, carrots), as well as fruits (e.g., apples, berries).

Calculation

For visualization, hunger and desire for tasty food were averaged over days separately for each signal and each study. In addition, each of the six food categories was also separately averaged for each signal but across days in order to compare daily courses for different food categories with hunger. To statistically assess coherence between hunger and desire for tasty food (in general in study 1 and 2, or food category specific in study 3), within-person correlations were calculated. Time of day effects in study 3 were tested using hierarchical multilevel models with signals (Level 1) nested in participants (Level 2) using the software HLM7 (Raudenbush, Byrk, & Congdon, 2011). Food categories of study 3 were used as separate outcomes, whereas signals were used as predictors on Level 1 (uncentered; fixed slopes). After linear trends, higher-order trends (quadratic trends with signals*signals) were tested, however, these were only retained and presented when statistically significant. The alpha level for all analyses was set to .05. In addition, we controlled for BMI (grand-mean centered) and weekday (weekday = 0 versus weekend-day = 1).

Results

Momentary hunger and desire for tasty food over the day

As expected study 1 and study 2 showed a relatively consistent pattern of two hunger peaks – roughly corresponding with lunch and dinner – over the day (see Figure 1). Desire for tasty food and hunger time series increased and decreased simultaneously, thus demonstrating a relatively high coherence: The within-person correlations between desire for tasty food and hunger were $r = .80$, $p < .001$ in study 1[3] and $r = .83$, $p < .001$ in study 2[4]. Desire for tasty food mean levels were slightly higher than hunger in both studies.[5]

<< insert Figure 1 here >>

Momentary desire for different food categories over the day

When plotting desire for different food categories separately, other time-of-day effects emerge (see Figure 2). Typical *main meal food categories* (left panel in Figure 2) like carbohydrates, fatty foods (like pizza, fries) and vegetables exhibit two peaks, similar to hunger, at usual lunch and dinner times. Supporting this impression, within-person correlations between hunger and desire for tasty food like carbohydrates ($r = .68$, $p < .001$), fatty foods ($r = .49$, $p < .001$) and vegetables ($r = .54$, $p < .001$) were high and statistically significant. This contrasts with the time courses of *typical snack-type foods*: desire for sweets and salty snacks gradually increased over the day (sweets: linear $\beta_{10} = 1.12$, $p < .001$; quadratic $\beta_{10} = -.068$, $p = .002$, salty snacks: linear $\beta_{10} = 1.34$, $p < .001$), see right panel in Figure 2. In contrast, desire for fruits gradually decreased over the day (linear $\beta_{10} = -2.82$, $p < .001$). Consistent with this, the within-person correlation between hunger and desire for sweets ($r = .15$, $p = .043$), salty snacks ($r = .20$,

[3] The within-person correlation between desire for tasty food and hunger was $r = .81$, $p < .001$ at signal 1, $r = .80$, $p < .001$ at signal 2, $r = .80$, $p < .001$ at signal 3, $r = .81$, $p < .001$ at signal 4, and $r = .75$, $p < .001$ at signal 5.
[4] The within-person correlation between desire for tasty food and hunger was $r = .86$, $p < .001$ at signal 1, $r = .81$, $p < .001$ at signal 2, $r = .84$, $p < .001$ at signal 3, $r = .86$, $p < .001$ at signal 4, and $r = .78$, $p < .001$ at signal 5.
[5] Adding weekday or BMI as covariates did not change the pattern of results.

$p < .001$) and fruits ($r = .37$, $p < .001$), albeit statistically significant, were of much smaller absolute magnitude as the ones observed for main meal foods.[6]

<< insert Figure 2 here >>

Discussion

The aim of the present study was to characterize the daily course of hunger and food craving with a focus on their coherence in a naturalistic environment during daily life, using three independent samples. Previous work using other methods, notably laboratory and questionnaire studies, have often demonstrated the dissociation between hunger and food craving. In contrast, these three studies using EMA in daily life demonstrated a relatively high concordance between hunger and food craving. In addition, similarities and differences between the two constructs as a function of food categories were explored. This work has the potential to help inform theory and empirical understanding of food cravings as they are experienced in daily life, and suggest a number of lines of future research

Replicating and extending previous naturalistic studies, our three studies demonstrated that hunger exhibited two peaks, roughly around lunch and dinner times (Huh et al., 2015; Mattes, 1990). This indicates a high correspondence of hunger with traditional main meal times (Warde & Yates, 2017), displaying a cyclical pattern with about 6 hours between lunch and dinner. Similarly, the timing of daily hunger ratings was consistent with socially entrained and normative patterns of eating episodes (de Castro, 2004; Leech, Worsley, Timperio, & McNaughton, 2017; Lhuissier et al., 2013). Across the three studies, food craving in general closely followed hunger ratings (i.e., indicated by strong positive correlations). This strong association could indicate that a) craving and hunger are more closely associated as assumed and

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[6] Adding weekday or BMI as covariates did not change the pattern of results. Higher BMI significantly predicted stronger desire for sweets ($\beta_{01} = 1.25$, p = .038).

diverge only under particular circumstances such as experimental satiety or deprivation, and/or b) participants have difficulties differentiating and reporting on the two constructs in naturalistic settings. This might be particularly difficult during and around main meals where hunger can be expected to mirror cravings: hardly anyone likes to satisfy hunger with tasteless and unattractive foods that would then show this dissociation with cravings.

Study 3 further qualified this interpretation of generic craving patterns by exploring cravings for several more specific food types. Whereas the pattern of craving for typical meal-type foods (carbohydrates, vegetables, and fatty foods) was consistent with hunger patterns, the snack-type food categories (sweets, salty snacks, fruits) (Warde & Yates, 2017) deviated from the M-shaped hunger-pattern and revealed increasing (sweets, salty snacks) or linearly decreasing (fruits) trajectories across the day. Although food craving does not necessarily lead to consumption of the respective food (Hill, 2007), these results are in line with studies on actual food intake. Warde and Yates (2017) examined snack patterns and found that confectionary (sweets) and crisps/potato chips (salty) were more popular during the evenings, and fruits earlier in the day compared to the rest of the day. Moreover, a study by Haynes, Kemps, and Moffitt (2016) proposed that unhealthy food categories increase in appeal in the afternoon/evening relative to healthy foods because of decreasing self-control over the day. Insofar as we are aware, this is the first naturalistic demonstration of these patterns in daily life using EMA. Importantly, although these observed patterns are consistent with theoretical explanations (e.g., loss of regulatory control), additional work will need to be done to explicitly test mechanisms as our data is fundamentally correlational in nature. For example, and alternative (non-self-control-related) account might suggest that certain food types are more frequently eaten during certain times of the day due to social modeling, advertising, etc.; and that this in turn establishes eating habits and leads to respective cravings.

A notable methodological implication of study 3 is that it may be essential to separate craving reports by food category in order to understand the differentiated set of craving vs. hunger trajectories. In other words, if cravings are averaged across several food categories, the resultant average trajectory obscures the specific temporal patterns we observed. This not only provides insight into important timing issues in intervention (e.g., reducing snack intake in the afternoon, maintaining fruit consumption across the day) but also represents an elegant demonstration of the hunger-craving difference: If hunger was the only driver of cravings, all food categories should have shown the same general trajectory. Future studies on eating patterns in various populations or conditions or during/after interventions should therefore consider a per-category assessment of cravings and should not rely solely on hunger ratings or generic craving ratings. This call for additional specification dovetails with approaches taken in the broader craving literature; for example, that relates cravings for specific foods to physiological or nutritional deficiencies (e.g., during menstrual cycling; e.g., Bruinsma & Taren, 1999). Relatedly, future research might profit from an examination of the coherence of hunger and food craving in populations with disordered eating behaviors as these individuals might be less susceptible to homeostatic and more susceptible to hedonic processes (Berridge, 2009). Likewise, while we focused on one component of food craving – desire for tasty food – due to its relationship with momentary craving intensity, other food craving dimensions remain to be explored (such as environmental cues triggering food cravings or intention and plans to consume food) and might well reveal different temporal trajectories (or even more complex interactions, such as with specific contexts or contexts by time of day or day of week).

Despite the strengths of each of the present studies, and the general consistency of the results across three independent studies, we note several important issues and limitations. The first smartphone prompt each day was relatively late (9 am), thus resulting in very few hunger ratings before breakfast, as previous studies showed that breakfast typically occurs around 7 to 8 am (Leech et al., 2017; Lhuissier et al., 2013). Another limitation is the omission of behavioral measures of actual food intake, and this would be a promising avenue for future research. However, typical challenges with food intake reports (Blechert, Liedlgruber, Lender, Reichenberger, & Wilhelm, 2017) and availability (Blechert, Klackl, Miedl, & Wilhelm, 2016) arise and have to be addressed. Similarly, the exact time when participants ate could not be obtained from the current data. Future studies might profit from a time-stamping of eating episodes in order to more precisely study their dynamic influence on subsequent hunger/food craving reports.

Conclusions

To conclude, this work provides evidence that hunger and food craving show concurrence in some domains but that, especially with regard to different food categories, should be distinctly measured in daily life. The varying trajectories for these food categories provide empirical evidence that may help inform the tailoring of interventions for diet control (e.g., those with components addressing snack food and fruit intake) may benefit by taking circadian patterns of food cravings into account.

Acknowledgements

JB, JR and AR were supported by the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation program (ERC-StG-2014 639445 NewEat). This work was supported by the Austrian Science Fund (FWF): [I 02130-B27]. Study 3 was supported by the Peer-Mentoring Team-Program (Line A) of the German Psychology Society (DGPs, section Health Psychology).

The authors declare no conflict of interest.

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Figure(s)

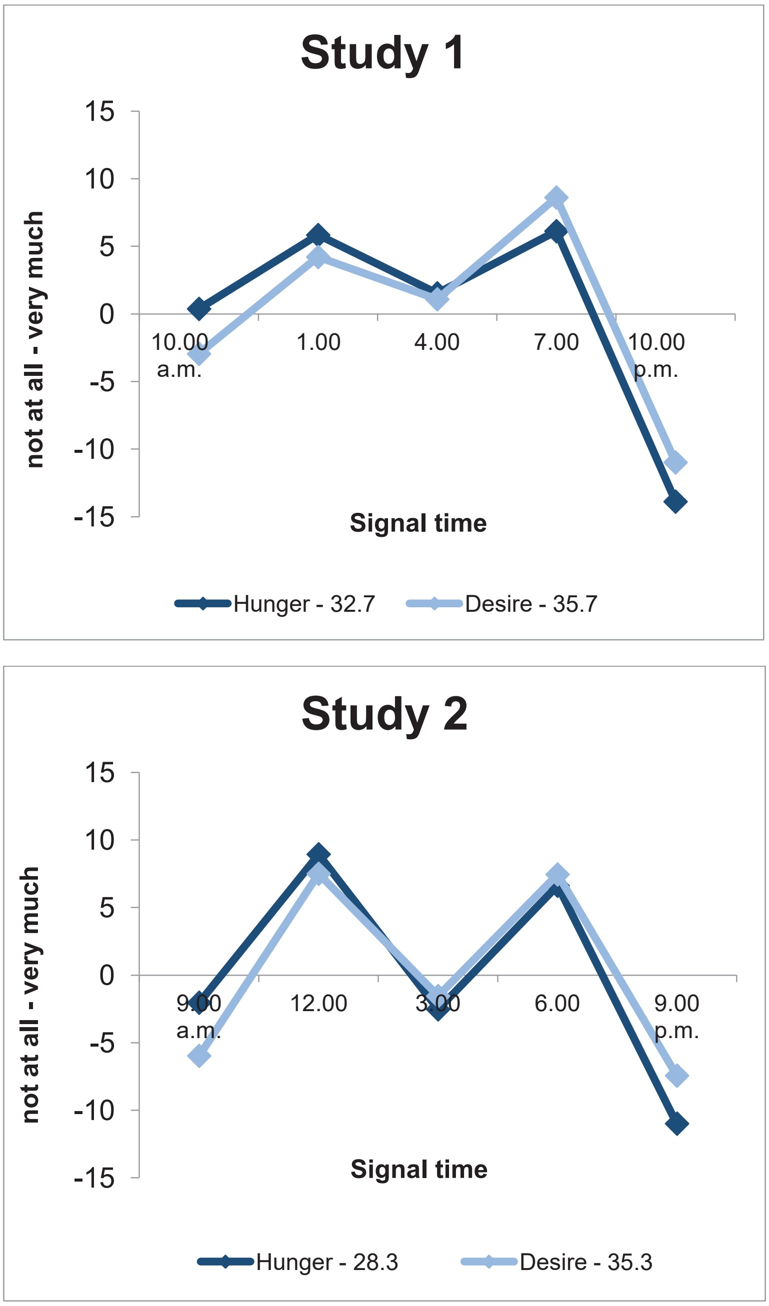

Figure 1. Course of subjective hunger and desire for tasty foods ratings (mean centered across the day) in study 1 and study 2 across the day.

Figure(s)

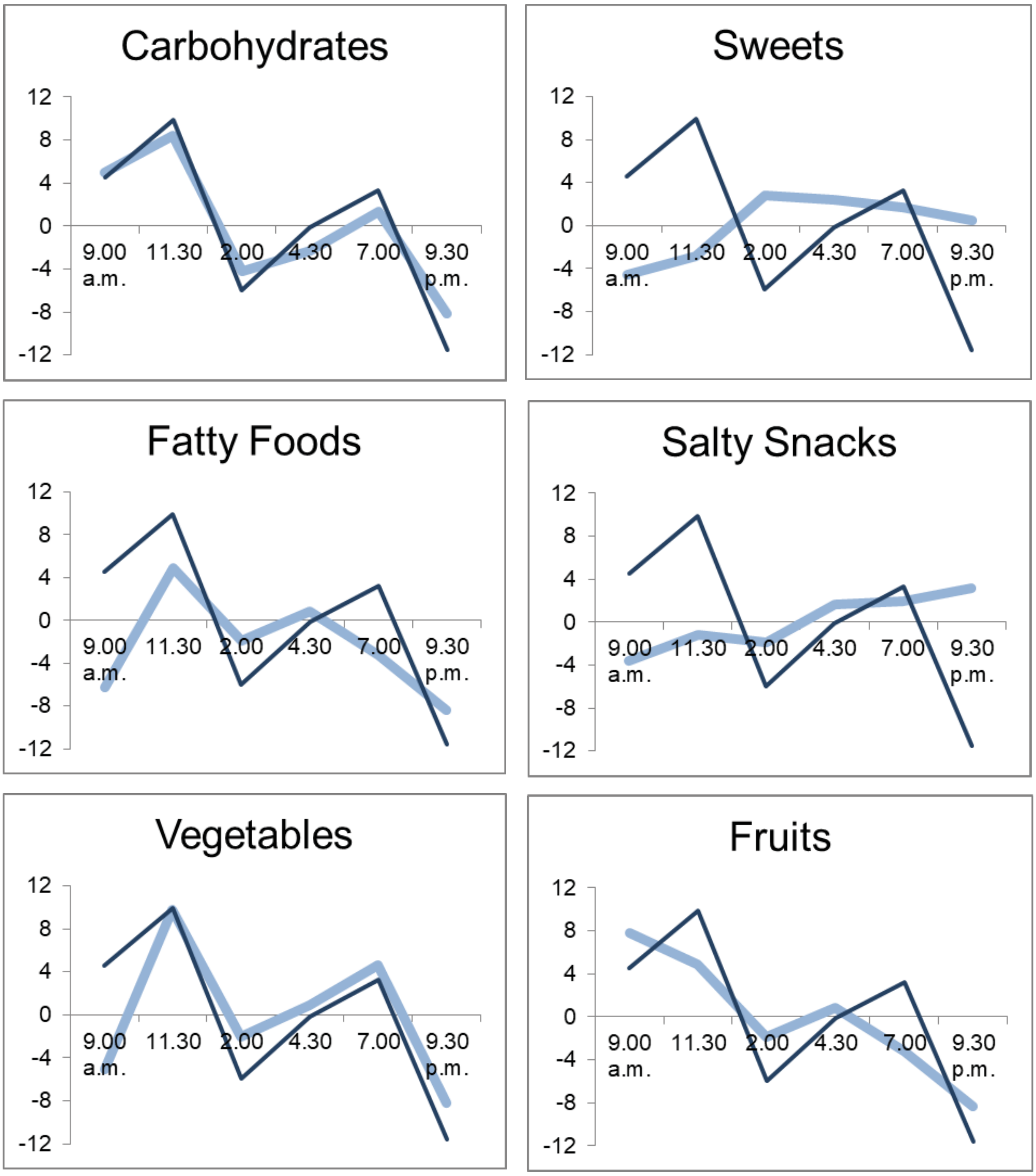

Figure 2. Desire for different food categories (centered by *M*=10.9 for sweets, *M*=17.8 for

carbohydrates, M=6.50 for salty snacks, M=11.7 for fatty foods, M=21.5 for fruits and M=16.0 for vegetables) and general hunger (centered by M=26.7) across six daily signals.