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Food Approach Dynamics in Daily Life: Speed and Force of Food Approach Movements Fluctuate With Hunger, but Less so for People With High BMI

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Researchers have suggested that the overconsumption of food, alcohol, and drugs could be explained by chronically elevated approach tendencies to rewarding but unhealthy stimuli. Here, we use the example of food to show that dysregulated rather than chronically elevated approach tendencies are associated with adverse health outcomes. To this end, we developed a new smartphone-based paradigm to measure dynamic changes in food approach tendencies outside the laboratory (piloted with $n = 48$). We demonstrated in three preregistered experiments (total $N = 367$) that food approach tendencies decrease from before to after people have eaten. We further show that in overweight and obese participants, these dynamics are disrupted as their food approach tendencies increase rather than decrease after meals. In addition to showing these effects based on traditional reaction time-based food approach tendencies, we also demonstrate these patterns in a novel measure of response force—a measure that has long been used to study motivation in animals but has received little attention in humans. Together, our findings suggest that both reaction time-based and force-based approach tendencies change dynamically in accordance with people's need states and that disruptions in these dynamics are associated with adverse health outcomes, such as overweight and obesity.

Keywords: AAT, approach–avoidance tendencies, BMI, obesity, hunger

Dynamic Food Approach Tendencies

Some of today's deadliest diseases, such as diabetes, cancers, and cardiovascular diseases, can be caused by habitual overconsumption of unhealthy foods, alcohol, and other drugs (World Health Organization, 2020). It is likely that overconsumption is at least partially caused by modern environments, which are characterized by an abundance of attractive but unhealthy stimuli, such as high-caloric processed foods. Yet, why some people are more vulnerable than others to such abundant environments is still not well known (Devoto et al., 2018). Recently, several researchers have suggested that overconsumption could be explained by chronically elevated approach tendencies (e.g., Brockmeyer et al., 2015; Kakoschke et al., 2019). Approach tendencies are automatic, implicit action tendencies that work independently of conscious or reflective processes (Strack & Deutsch, 2004). In general, approach tendencies drive people toward attractive stimuli even when they consciously intend otherwise. For example, a tasty piece of cake can trigger a tendency to approach—even in people who consciously intend to avoid unhealthy foods (Piqueras-Fiszman et al., 2014). Similarly, a drinking-related environment such as a bar can trigger approach tendencies to alcohol, even for people trying to reduce their drinking (Wiers et al., 2013). Owing to this independence from intentions, approach tendencies might be a powerful driver of unhealthy consumption. Accordingly, increased approach tendencies have been found in drinkers toward alcohol, in smokers toward cigarettes, and in drug users toward drugs (Cousijn et al., 2011; Mogg et al., 2005; Peeters et al., 2012). As parallels have been drawn between "classical" addictions and food overconsumption (Finlayson, 2017), researchers have recently begun to study the involvement of food approach tendencies in the current obesity crisis (for an overview, see Kakoschke et al., 2019).

Yet, evidence for a link between chronically elevated food approach tendencies and overeating is still mixed. Although several studies have tested the relationship between food approach

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tendencies and body mass index (BMI)—the basis for definitions of overweight and obesity—and, as such, a proxy for overconsumption, clear evidence for this relationship is still lacking (for a review, see Kakoschke et al., 2019). Some researchers do find the expected positive association, but only in clinical populations (e.g., Neimeijer et al., 2015, in restrained eaters; Paslakis et al., 2016, in anorexic participants). Others only find associations when focusing on subsamples of their data (e.g., Havermans et al., 2011, in men but not in women; Maas et al., 2017, for sweet but not for salty food stimuli). Yet, other studies report no relationship between food approach tendencies and BMI (Booth et al., 2018; Brignell et al., 2009; Brunyé et al., 2013; Cheval et al., 2017; Kakoschke et al., 2015, 2017a, 2017b, 2017c; Moore et al., 2022; Schumacher et al., 2016).[1]

Here we propose that these mixed findings could be explained by the dynamic nature of food approach tendencies. Healthy approach tendencies likely fluctuate with changes in homeostatic need states (Cacioppo et al., 1993; Corr, 2013; Strack & Deutsch, 2004, 2015). For example, in healthy people, food approach tendencies should be stronger prior to consumption than afterward because satiation should decrease motivation to eat. Such fluctuations could make it difficult to detect consistent differences in approach tendencies and link these to slower-changing individual characteristics, such as BMI. Based on both previous research and theoretical predictions, we argue that such dynamic food approach tendencies are plausible: For example, in an ecological momentary assessment study using self-reports, Hofmann et al. (2012) showed that conscious desires for food fluctuate significantly with the time of the day and in different contexts. Cacioppo et al. (1993), moreover, argued that: "subjects who have undergone food deprivation and who are exposed to edible ideographs […] may show stronger [approach tendencies] than un-deprived subjects" (see also Strack & Deutsch, 2004, 2015). Another indication of dynamic approach tendencies is that the approach–avoidance tasks (AATs) test–retest reliability is generally reported to be low, whereas its split-half reliability is generally reported to be high (Kahveci et al., 2021; Machulska et al., 2022; Zech et al., 2022)—a pattern that indicates that a measure likely detects state changes (Hedge et al., 2018). If approach tendencies indeed fluctuate, overconsumption may be associated with a dysregulation of need-based fluctuations of approach tendencies rather than chronically elevated approach tendencies.

Empirical evidence for such need-based, dynamic changes in food approach tendencies is, however, scarce. Of the various studies that measured both hunger and food approach tendencies (Booth et al., 2018; Brignell et al., 2009; Brunyé et al., 2013; Cheval et al., 2017; Havermans et al., 2011; Kakoschke et al., 2015, 2017a, 2017b, 2017c; Piqueras-Fiszman et al., 2014; Schumacher et al., 2016; Seibt et al., 2007; Staats & Warren, 1974; Veenstra & de Jong, 2010, 2011), only two found a positive relationship (Seibt et al., 2007; Staats & Warren, 1974).

This lack of evidence for dynamic food approach tendencies could be due to methodological constraints. It is, for example, noteworthy that studies that showed dynamic food approach tendencies tested participants systematically before and after meals (Seibt et al., 2007; Staats & Warren, 1974), whereas studies that did not find such dynamics simply assessed hunger cross-sectionally whenever participants completed the experiment. Such "cross-sectional" designs might not create enough variance in need states to overcome measurement error and successfully detect dynamic approach tendencies.

Testing participants before and after meals (especially when done within-participants) comes with additional methodological difficulties. Traditional tasks that measure approach tendencies (AATs) require stationary equipment, which is difficult to deploy in field and longitudinal studies. For example, during most classic AATs, participants have to use joysticks or response levers to repeatedly approach and avoid visual stimuli displayed on a computer screen (Chen & Bargh, 1999; Rinck & Becker, 2007). As most people do not have access to such hardware at home, they have to come to the laboratory, making it difficult to test the same participants in different need states. This methodological constraint might explain why, so far, no study has reported within-participant changes in food approach tendencies based on physiological needs (and only one study investigated such changes; Kahveci et al., 2020).

One goal of the current research, therefore, is to show that approach tendencies can change with changing need states. A second goal is to assess how these (dynamic) approach tendencies relate to eating-related outcome variables, such as BMI. To this end, we used a newly developed mobile AAT that has been specifically designed to overcome the limitations of classical AATs (we previously validated this task in Zech et al., 2020). Unlike traditional AATs, the mobile AAT runs on regular smartphones and can easily be deployed in the field and in longitudinal designs. Instead of relying on stationary computers, participants are presented with stimuli on their smartphone screens and approach stimuli by pulling the phone toward themselves and avoid stimuli by pushing the phone away (see Figure 1).

Just like traditional AATs, the mobile AAT measures participants' automatic approach tendencies by detecting their reaction times (RTs) during each of these movements. These RTs give insight into participants' food approach tendencies, as automatically controlled movements are initiated faster than consciously controlled movements (Strack & Deutsch, 2015). In addition to measuring RTs, the mobile AAT detects response forces. Response forces are thought to be closely related to motivation. For example, Pirc et al. (2019) demonstrated that hungry participants use more force to self-administer chocolate milk than satiated participants. In an approach–avoidance context, force has long been used to study motivation in animals. For example, in a seminal study, Brown (1948) demonstrated that rats use more force to approach food when they are hungry compared to when they are satiated. How need states affect force-based approach tendencies in humans, however, is still unexplored territory.

In the current research, we used the mobile AAT in four experiments to test how food approach tendencies vary with changing physiological needs and how these dynamics, in turn, are related to important consumption-related health outcomes—such as participants' BMI. In the first (pilot) experiment, we explored the relationship between food approach tendencies, self-reported hunger, BMI, and other eating-related variables in the laboratory. In Experiment 2, we deployed the mobile AAT in participants' daily life and tested participants before and after meals (within-participant hunger).

[1] Note that in the domain of undereating, findings are also mixed. For example, although Paslakis et al. (2016) found differences in food approach tendencies between patients with anorexia and healthy controls, Kollei et al. (2022) did not find such differences. Although undereating is likely not driven by the same processes as overeating, it is possible that dynamic approach tendencies could also explain these mixed findings.

Figure 1
The Mobile Approach–Avoidance Task

Note. Movements in the mobile AAT. Arm position between trials (left), after an approach movement (middle), and after an avoidance movement (right). AAT = Approach–Avoidance Task.

Experiment 3 served as an exact replication of Experiment 2 to confirm exploratory findings. Experiment 4 further refined the design of Experiments 2 and 3 to specifically focus on the relationship between BMI, within-participant hunger, and food approach tendencies.

Experiment 1 (Pilot; Not Preregistered)

Experiment 1 was designed to explore the relationship between food approach tendencies and eating-related variables in the laboratory. To this end, each participant completed one food AAT. As food approach tendencies have been suggested to explain overconsumption (Brockmeyer et al., 2015), we expected a positive association between food approach tendencies and BMI—a consequence of overconsumption of food (H1). To test this hypothesis, we asked participants to report their weight and height. We also expected a positive association between physiological needs and food approach tendencies (H2). To test this hypothesis, we asked participants to report their subjective hunger and time since their last meal. In addition to testing these main hypotheses, we explored the associations between food approach tendencies and food attractiveness as well as caloric density (the desire to eat a certain food, a variable potentially related to food attractiveness, has previously been shown to influence food approach tendencies; Kahveci et al., 2020, 2021). To examine these associations, we varied the attractiveness and caloric density of the food stimuli used in the AAT. Finally, because we expected that susceptibility to obesogenic environments is positively related to food approach tendencies, the Power of Food Scale (PFS), which measures individual differences in this susceptibility, was also included in the experiment (Lowe & Butryn, 2007).

Method

Participants

Fifty students from Leiden University (the Netherlands) participated for a monetary reward (€3.50) or course credit. Two participants were excluded because of having too few valid trials (see data preprocessing section). The analyzed sample included 48 participants (39 women, 81.2%) between the ages of 18 and 29 years ($M = 22.4$, $SD = 2.8$); see Table 1. Participants' BMI ranged from 16.9 to 27.2 ($M = 21.8$, $SD = 2.7$). Ten participants (20.8%) reported being vegetarian, and four participants (8.3%) reported being on a diet. Participants reported on a scale ranging from 1 (*not healthy at all*) to 5 (*very healthy*) to eat fairly healthy ($M = 3.5$, $SD = 0.6$, range = 2–4) and indicated on a scale ranging from 1 (*not important at all*) to 5 (*very important*) that eating healthy was fairly important to them ($M = 4.0$, $SD = 0.8$, range = 2–5).

Materials

Demographic Questions. Participants indicated their gender, age, and occupation (all open questions), and responses to these questions were used to describe the sample.

Physiological Need State Questions. In line with previous studies (e.g., Van Dillen & Andrade, 2016), participants were asked to indicate their subjective hunger ("How hungry are you right now?") on a scale ranging from 1 (*not hungry*) to 5 (*very hungry*) and to indicate the time since their last meal (open question) as a more objective measure of deprivation. We separately tested the relationship of each of these variables with food approach tendencies.

Eating Behavior Questions. In the eating behavior questions, participants indicated whether they are a vegetarian or vegan (yes,

Table 1
Sample Characteristics

Exp	*N*	Population	Age *M* (*SD*)	Gender (% women)	BMI *M* (*SD*) [range]	Overweight (%)	Vegetarian (%)	Diet (%)	Healthy eating	Importance of healthy eating	Compliance (%)
1	48	Dutch students	22.4 (2.8)	82.2	21.8 (2.7) [16.9–27.2]	14.6	20.8	8.3	3.4 (0.6)	4.0 (0.8)	—
2	95	Dutch students	20.7 (2.2)	84.2	22.3 (3.8) [16.5–38.7]	16.8	7.2	3.2	3.4 (0.7)	3.9 (0.8)	92
3	123	Dutch students	22.3 (3.0)	77.2	22.3 (3.0) [16.2–37.6]	15.4	18.7	7.3	3.5 (0.8)	3.9 (0.7)	94
4	149	Unselected Americans	26.0 (5.0)	40.3	25.4 (7.0) [14.9–56.6]	40.3	6.7	16.8	—	—	82

Note. BMI = body mass index.

no), whether they are following a diet (yes, no), how healthy they usually eat, and how important it is for them to eat healthy (see subsection "Participants" for scale details). Answers to these questions were used to describe the sample. Here, participants also indicated their height and weight (open questions), which were used to calculate their BMIs.

Food Attractiveness Ratings. Participants rated the attractiveness of each of the food pictures used in the AAT on a scale ranging from 1 (*not attractive at all*) to 5 (*very attractive*). These ratings were used to assess the relationship between attractiveness and food approach tendencies.

PFS. The PFS measures how susceptible participants report themselves to be to external food stimuli (Lowe et al., 2009) and thus provides a measure of individual vulnerability to obesogenic environments. The scale consists of 21 statements, which are answered on 5-point scales (ranging from 1 = *I don't agree at all* to 5 = *I strongly agree*). Example items include: "I find myself thinking about food, even if I'm not hungry" and "When I see delicious foods in advertisements or commercials, it makes me want to eat." Participants' answers were aggregated into a mean score, which was used to assess the relationship between PFS scores and food approach tendencies. The internal consistency was high across experiments ($\alpha s \geq 0.88$).

Mobile AAT. During the mobile AAT, pictures of food and objects were presented on a smartphone which participants were instructed to either pull toward themselves or push away from themselves. Participants completed two blocks—the order of which was counterbalanced between participants. In one block, they were instructed to pull food toward themselves and to push objects away from themselves (these instructions have been previously shown to maximize approach–avoidance effects; Phaf et al., 2014). In the other block, the instructions were reversed. During each block, 20 object stimuli and 40 food stimuli were presented (see below for details). As each stimulus was presented only once, this yielded a total of 120 trials. Throughout the task, participants were instructed to hold the phone in a horizontal orientation and, between trials, to move the phone to a starting position from which they could easily pull it toward themselves or push it away from themselves (see Figure 1). Before each block, they were instructed which stimuli to pull and which to push. They were also instructed to react as quickly and accurately as possible.

Each stimulus was preceded by a fixation cross, which remained on the screen for 1.5 s. During each response, the phone's accelerometer and gyroscope tracked the gravity- and rotation-corrected acceleration of the movement in the direction perpendicular to the face of the screen (100 Hz sampling rate). Based on this acceleration, the response direction, RTs, and response forces were calculated. RT is defined as the time between the picture onset to the first movement of the phone. Force is defined as the peak acceleration of the response (for details, see Zech et al., 2020; note that traditional AATs often intermix these two response dimensions by defining RTs as the time between picture onset and movement completion). If no response was given within 2 s, a clock was displayed on the screen to inform participants that the trial had timed out. Before each block, participants were presented with an additional 10 practice trials, which, unlike experimental trials, were followed by response feedback (a checkmark for a correct response and an "x" for an incorrect response). Completing the AAT took an average of 6 min.

Stimuli. We selected our stimuli from the food-pics database (Blechert et al., 2019). This database includes 896 pictures of foods and objects, including available image characteristics (e.g., brightness, contrast), food characteristics (e.g., calories, macronutrients), and normative data (e.g., recognizability, how much people craved the food). We limited our selection to stimuli with an average recognition rating of above 85 out of 100. From these stimuli, we selected 80 food and 40 object stimuli. Note that we decided to show more food than object stimuli to further generalize our food stimuli and to increase power to explore the effects of stimulus-level variables (e.g., calories). To increase variance in stimulus attractiveness, we selected, based on Blechert et al.'s (2019) normative data, food stimuli that were either highly craved (1 *SD* above the mean) or lowly craved (1 *SD* below the mean; based on the "craving" variable in Blechert's database). Within each category, we selected both foods with high- and low-caloric density. The final stimulus set thus contained food stimuli that were low-caloric and attractive (e.g., fruit salad), low-caloric and not attractive (e.g., rice crackers), high-caloric and attractive (e.g., pizza), and high-caloric and not attractive (e.g., cold cuts). This variance in attractiveness and caloric density allowed us to test whether these variables influence food approach tendencies. The exact stimuli can be found in the Stimuli Appendix.

Procedure

Participants completed Experiment 1 in the laboratory, either on their own phone (if it had an Android OS) or on a phone supplied by the experimenter (LG Nexus 5). Participants first answered demographic questions and two questions about their physiological need state. Next, the experimenter explained the AAT, and participants completed one AAT session. The experimenter remained in the room during the practice trials but left the room during the experimental trials. After completing the AAT, participants rated each food stimulus' attractiveness. Finally, they filled in the PFS, indicated their height and weight, and answered questions about their eating behavior. The study was approved by the institutional ethics board (CEP16-1216/379), and informed consent was obtained from all participants.

Analysis

Data Preprocessing and Exclusions. We followed the exact preprocessing and exclusion procedure as Zech et al. (2020). After extracting RTs, response forces, and movement direction from raw acceleration data, we removed practice trials. Next, we removed error trials, trials with missing sensor data, trials with implausibly short RTs (<200 ms), and trials with low absolute maximum forces (<1 m/s^2; indicating nonresponses). Data of participants with fewer than 80% valid experimental trials were also removed. Data preprocessing was performed using Python (Version 3.5.5).

Modeling. As suggested by Zech et al. (2020; see also Baayen & Milin, 2010), we used linear mixed-effects models (LMMs) to explore the relationship between eating-related variables and food approach tendencies. Food approach tendencies were modeled as the interaction effect between response direction (pull [0.5] vs. push [−0.5]) and stimulus type (food [0.5] vs. object [−0.5]) with *inverted RT* or *force* as outcome variables. In these models, a positive interaction effect of these two variables indicates a positive food approach tendency, which means that participants are faster to approach food compared to avoiding food and that this difference is more pronounced for food than for object stimuli. To this food approach tendency interaction effect, we added[2] moderator variables BMI (*bmi*), subjective hunger (*hunger*), deprivation,[3] and PFS scores (*pfs*)—as well as their two-way interactions (e.g., *response direction* × *stimulus type* × *bmi* × *hunger*).[4] The main regression models (one for RT and one for force) were therefore defined in the following way (note that the first line represents food approach tendencies, the second line moderators of food approach tendencies, and the third line by-participant random slopes):

$$
\begin{aligned}
&1/RT(resp.force)\ (response\_direction \times stimulus\_type) \\
&\quad \times (bmi + hunger + deprivation + pfs)^2 \\
&\quad + (response\_direction \times stimulus\_type|participant)
\end{aligned}
\tag{1}
$$

To explore the effects of variables that only apply to food stimuli, we ran an additional model, after excluding object trials. This model was specified like the above model, but the food-specific variables—food attractiveness rating (*rating*) and caloric density (*kcal_g*)—were added, and the stimulus type variable (*stimulus type*) was omitted. Next to the confirmatory models, exploratory models to test all two-way interactions between moderators were defined.

Significance Tests and Reporting. Significance tests were based on *p* values (using the lmerTest package; Satterthwaite corrected degrees of freedom for all tests can be found in the online materials at https://osf.io/deyzk/).[5] In addition, we report bootstrapped 95% confidence intervals. Effect sizes are reported in their original unit (as recommended by Pek & Flora, 2018)—RTs in reactions per second (1/s) and forces in meters per second squared (m/s^2). For clarity and conciseness, we only report interaction effects related to food approach tendencies (i.e., interactions including the *response direction* and *stimulus type* interaction). For the food-specific models, we only report interactions between response direction and food-specific variables (*rating* and *kcal*). For the sake of brevity, in the exploratory models, we only report effects that differ from the confirmatory models. All other effects, including descriptions and figures, in the online supplemental materials, which can be found on the project's Open Science Framework page (https://osf.io/deyzk/). Statistical analyses were performed using R (Version 3.4.3).

Transparency and Openness

Note that methods and hypotheses of Experiments 2–4 were preregistered, and all analysis scripts, additional exploratory analyses, robustness tests, and manipulation checks, as well as the source code of the mobile AAT and the complete data, are available on the project's Open Science Framework page (https://osf.io/deyzk/).

Results

Descriptives

Participants' mean PFS scores ranged from 1.81 to 4.67 ($M = 3.09$, $SD = 0.60$). Participants' self-reported subjective hunger ranged from 1 to 4 ($M = 2.25$, $SD = 1.06$), and they reported having eaten between 0 and 16 hr before the experiment (the distribution was highly skewed as most participants ate not too long before the experiment; $M = 2.21$, $SD = 3.29$). The two measures did not correlate with each other ($r = .14$; $p = .33$). Stimulus attractiveness ratings ranged from 1 to 5 ($M = 3.17$, $SD = 1.36$). Participants' food attractiveness ratings were positively correlated with the normative ratings provided by Blechert et al. (2019; $b = 0.040$ [0.040, 0.041], $t = 31.19$, $p < .001$). High-caloric stimuli and low-caloric stimuli were not rated differently on attractiveness (3.13 vs. 3.20, $b = 0.077$ [−0.059, 0.218], $t = 1.92$, $p = .055$). Inverted RTs ranged from 0.54 to 4.93 reactions per second ($M = 2.16$, $SD = 0.51$). Response forces ranged from 1.30 to 54.77 m/s^2 ($M = 11.70$, $SD = 6.24$). The average error rate was 6.2%.

Reliability

For RT-based food approach tendencies, internal consistencies (average Spearman–Brown corrected split-half reliabilities) were acceptable for basic research ($r = .86$). For force-based food approach tendencies, internal consistencies (average Spearman–Brown corrected split-half reliabilities) were excellent ($r = .97$). Overall, split-half reliabilities were higher than those generally reported in AAT research (mean $r = .52$; Zech et al., 2022).

Approach Tendencies

RTs (Confirmatory Model). The confirmatory RT model revealed a two-way interaction between response direction and stimulus type, $b = 0.207$ [0.092, 0.309], $t(42.81) = 4.14$, $p < .001$, indicating that participants' average food approach tendencies were positive (see Figure 1.1 in the online materials at https://osf.io/deyzk/). More importantly, as predicted in H1, there was a three-way interaction between BMI, response direction, and stimulus type, $b = 0.059$ [0.025, 0.096], $t(43.00) = 2.91$, $p = .006$, indicating a positive relationship between BMI and food approach tendencies (see Figure 1.2 in the online materials at https://osf.io/deyzk/). However, neither physiological need variables nor PFS scores influenced the interaction between response direction and stimulus type, which means that H2 was not supported (see Table 2).

RT (Food Trials). When focusing on food trials and food-specific variables, we found a significant two-way interaction between stimulus attractiveness and response direction, $b = 0.028$ [−0.002, 0.042], $t(3{,}551.61) = 2.50$, $p = .012$, in which participants' food approach tendencies increased the more attractive participants rated food stimuli (see Figure 1.4 in the online materials at https://osf.io/deyzk/).

RT (Exploratory Model). The exploratory RT model revealed an additional four-way interaction between hunger, PFS scores, response direction, and stimulus type, $b = -0.281$ [−0.537, −0.009], $t(37.15) = -2.99$, $p = .005$, indicating that food approach tendencies had a positive relationship with self-reported subjective

[2] Note that we added all variables at the same time.

[3] Note that subjective hunger and time since last eaten were added separately in the models, as they did not correlate with each other.

[4] Note that we also ran additional extended models including stimulus characteristics (e.g., caloric density), which yielded no significant findings.

[5] Note that in Experiment 2, we pre-registered significance tests based on chi-square tests. However, after pre-registering the study, it came to our attention that *p* values based on chi-square tests are anti-conservative and *p* values as implemented in the lmerTest package should be used instead (based on Satterthwaite approximations; Luke, 2017). We pre-registered this type of significance testing for subsequent experiments and use it here also, for consistency.

Table 2
Main Hypothesis Tests

Hypothesis	Outcome	Exp. 2	Exp. 3	Exp. 4	Meta
Food approach tendencies are positively associated with BMI.	RT	(H2) 0.015*	(H2) −0.007	(H2) −0.002	0.000
	Force	(H2) −0.070	(H2) −0.083	(H2) −0.015	−0.027
Food approach tendencies are positively associated with manipulated hunger	RT	(H1) 0.094***	(H4) 0.012	(H4) 0.052**	0.049***
	Force	(H1) 1.092***	(H4) 0.473*	(H4) 0.511**	0.637***
The effect of hunger on food approach tendencies is more expressed in participants with a healthy BMI	RT	−0.032***	(H5) −0.003	(H5) −0.010***	−0.012***
	Force	−0.115	(H5) −0.181**	(H5) −0.090***	−0.101***

Note. This table gives an overview of the main hypotheses that were tested across all three field experiments. For preregistered hypotheses, numbers corresponding to the hypothesis in the preregistration are given in parentheses. Additional hypotheses were preregistered but excluded from this overview for the sake of brevity. These include the interaction of PFS with hunger and approach tendencies that was preregistered in Experiment 2 (H4) but dropped from later experiments; the interaction of stimulus attractiveness with approach tendencies (H2 in Experiment 2 and H3 in Experiment 3, dropped in Experiment 4); and tests of general approach tendencies (H3 and H4 in Experiments 3 and 4). BMI = body mass index; RT = reaction time; PFS = Power of Food Scale.
*$p < .05$. **$p < .01$. ***$p < .001$.

hunger, but only in participants with low PFS scores (see Figure 1.3 in the online materials at https://osf.io/deyzk/).

Force. None of the force models revealed any significant main effects or interactions with food approach tendencies.

Discussion

The results of Experiment 1 indicate that the mobile AAT is indeed able to measure behavioral food approach tendencies. Internal consistencies were acceptable for RT-based tendencies and excellent for force-based tendencies, indicating little measurement error. As predicted in H1, we found that food approach tendencies were positively associated with participants' BMI. Mirroring other studies with cross-sectional designs, we found no relationship between food approach tendencies and self-reported need states (H2).

The inability to find dynamics in approach tendencies based on self-reported need states might be due to two reasons: First, participants might interpret explicit questions about hunger differently (see Lowe & Butryn, 2007). Support for this idea comes from the lack of correlation between self-reported subjective hunger and self-reported time since the last meal. In this regard, it is also noteworthy that the effect of hunger on approach tendencies was influenced by participants' PFS scores, which might indicate that participants with low PFS scores interpret the hunger question in a different way compared to participants with high PFS scores. It is possible that measuring hunger in a cross-sectional design does not generate sufficient variance to overcome measurement errors and successfully detect dynamic approach tendencies. Indeed, the variances in both self-reported subjective hunger and the time since participants had their last meal were heavily skewed toward the lower end in this experiment. To overcome these problems, in Experiment 2, we tested hunger in a within-participant design by testing participants' food approach tendencies in daily life—both before and after their meals.

Experiment 2

After establishing that the mobile AAT could successfully measure food approach tendencies, Experiment 2 was designed to detect dynamic approach tendencies. To this end, we improved upon Experiment 1 in several ways. First, tested hunger in a within-participant design rather than relying solely on self-reported need states. Second, to calculate BMIs, we measured participants' height and weight in the laboratory rather than relying on their self-reports.

Based on the results from Experiment 1, we predicted a positive association between food approach tendencies and BMI (H1), hunger (now quasi-manipulated; H2), and attractiveness ratings (H3). We also aimed to replicate the exploratory finding in Experiment 1 that hunger would be positively associated with food approach tendencies, but only in participants with low PFS scores (H4).

Method

Participants

Participants were recruited at Leiden University and participated in exchange for €20 or course credits. In this and all subsequent experiments, we only included participants with access to an Android phone. Of the 137 participants who downloaded the study app, 39 did not come to the laboratory appointment to have their BMI measured. Of the remaining 98 participants, three had to be excluded because of too few valid trials in the AAT. The analyzed sample included 95 participants (80 women, 84.2%) between the ages of 18 and 27 years ($M = 20.7$, $SD = 2.2$). Participants' BMI ranged from 16.5 to 38.7 ($M = 22.3$, $SD = 3.8$).

Procedure and Materials

Except for the BMI measurement, participants completed all of Experiment 2 on their own smartphones in daily life. After downloading the app, participants first completed an introduction session, in which they answered the demographics questions (cf., Experiment 1) and practiced the AAT. Starting on the following day, each participant completed three AAT sessions (see Experiment 1)—around breakfast, lunch, and dinner, of which at least one had to be completed before a meal, and at least one had to be completed after a meal. The order of sessions and whether each session had to be completed before or after a meal was counterbalanced between participants and controlled by the app (note that this implies that participants who started with the lunch or dinner session had to complete the sessions over a period of two days). The app further controlled that a session could only be completed during a specific time (breakfast: 5:00 a.m.–11:00 a.m.; lunch: 11:00 a.m.–4:00 p.m.; dinner: 4:00 p.m.–00:00 a.m.). In addition, we ran manipulation checks to verify that times since the last meals were higher in the before-meal sessions than in the after-meal sessions (see the online materials at https://osf.io/deyzk/). Following each AAT session, participants filled in the two physiological need state questions (see Experiment 1). For exploratory reasons, we also added additional questions for how satisfying their last meal was (1 = *not satisfying at all* to 5 = *very satisfying*), how sleepy participants were during the session (1 = *not sleepy at all* to 5 = *very sleepy*), what their last meal was, and where they completed the task (open questions). This data is not reported in this manuscript but can be found on the project's Open Science Framework page. After the third and final AAT session, participants rated each stimulus' attractiveness, completed the PFS (see Experiment 1), answered the eating behavior questions (see Experiment 1), and were invited to the laboratory where their height and weight were measured and where they were debriefed and rewarded for their participation. The study was approved by the institutional ethics board (CEP17-1024/357), and informed consent was obtained from all participants.

Analysis

Data Preprocessing and Exclusions. The data were preprocessed mostly as described in Experiment 1. However, instead of excluding participants based on overall error rates, we first excluded sessions with less than 80% valid experimental trials and then excluded participants without valid AAT sessions (see preregistration). We also excluded participants who did not come to the laboratory to have their BMI measured.[6] All data, including that of excluded participants, is available on the project's Open Science Framework page (https://osf.io/deyzk/).

Modeling. We made two changes to the confirmatory models specified in Experiment 1. First, we replaced self-reported hunger (*hunger*) and time since the last meal (*deprivation*) with within-participant hunger (*is_before_meal*). Second, we added the interaction between PFS and hunger to test H4:

$$\begin{aligned} 1/RT(resp.force) &\sim (response\_direction \times stimulustype) \\ &\times (bmi + pfs \times is\_before\_meal) \\ &+ (response\_direction \times stimulus\_type | participant) \end{aligned} \tag{2}$$

Similar to the analyses in Experiment 1, we followed the models with food-specific models to assess food-specific effects and exploratory models testing all two-way interactions between moderators of food approach tendencies.

Figures. To create all figures, we collapsed the *response direction × stimulus type* interaction in the confirmatory RT models into one value representing food approach tendencies. These scores were created by predicting RTs (resp., forces) with the response direction and stimulus type interaction using a mixed model and extracting random slopes for the interaction for each participant (see the online materials at https://osf.io/deyzk/). Next, we predicted this value with the remaining independent variables from each model and extracted the predicted means for each hunger condition. The error bars represent 95% confidence intervals around predicted values.

Results

Descriptives and Checks

Mean PFS scores ranged from 1.29 to 4.90 ($M = 2.99$, $SD = 0.65$). Self-reported hunger ranged from 1 to 5 ($M = 2.69$, $SD = 1.32$). Times since meals ranged from 0 to 15 hr ($M = 3.49$, $SD = 4.20$). Self-reported hunger was higher before meals (3.54) compared to after meals (1.82; $b = 1.723$ [1.560, 1.881], $t = 14.23$, $p < .001$). Time since the last meal was also higher before (6.06 hr) compared to after meals (0.87 hr; $b = 5.190$ [4.476, 5.904], $t = 12.76$, $p < .001$). Stimulus attractiveness ratings ranged from 1 to 5 ($M = 3.39$, $SD = 1.29$). Participants' food attractiveness ratings were positively correlated with normative ratings ($b = 0.041$ [0.040, 0.041], $t = 49.38$, $p < .001$). High-caloric stimuli were rated somewhat more attractive (3.52) than low-caloric stimuli (3.27, $b = 0.243$ [0.152, 0.334], $t = 9.49$, $p < .001$). Inverted RTs ranged from 0.53 to 5.00 reactions per second ($M = 2.17$, $SD = 0.54$). Response forces ranged from 1.05 to 98.26 m/s^2 ($M = 12.29$, $SD = 6.77$). The average error rate was 9.2%.

Reliability

For RT-based food approach tendencies, internal consistencies (average Spearman–Brown corrected split-half reliabilities) were acceptable for basic research ($r = .80$) but higher than those generally reported in AAT research (mean $r = .52$; Zech et al., 2022). We assessed test–retest reliability both based on the consistency of two single sessions (ICC_1; following the terminology of McGraw & Wong, 1996) and based on the average of all sessions (ICC_k; for a detailed explanation of this approach, see Zech et al., 2022). Test–retest reliability was poor when scores were based on single sessions (ICC_1 = 0.153) and moderate when scores were based on all sessions (ICC_k = 0.684). This test–retest reliability is similar to that generally reported in AAT research (mean $r = .15$). For force-based food approach tendencies, internal consistencies (average Spearman–Brown corrected split-half reliabilities) were excellent ($r = .95$). Test–retest reliability was poor when scores were based on single sessions (ICC_1 = 0.021) and when scores were based on all sessions (ICC_k = 0.203). Note that the low test–retest reliability observed in this experiment could also be due to the need state manipulation.[7] Indeed, another study that we specifically designed to study the test–retest reliability of the mobile AAT showed higher ICCs than the ones reported here, although the retest period in that study was much longer (1 month; ICC_1 = 0.25; ICC_k = 0.73 for RT-based approach tendencies; Zech et al., 2022).

Approach Tendencies

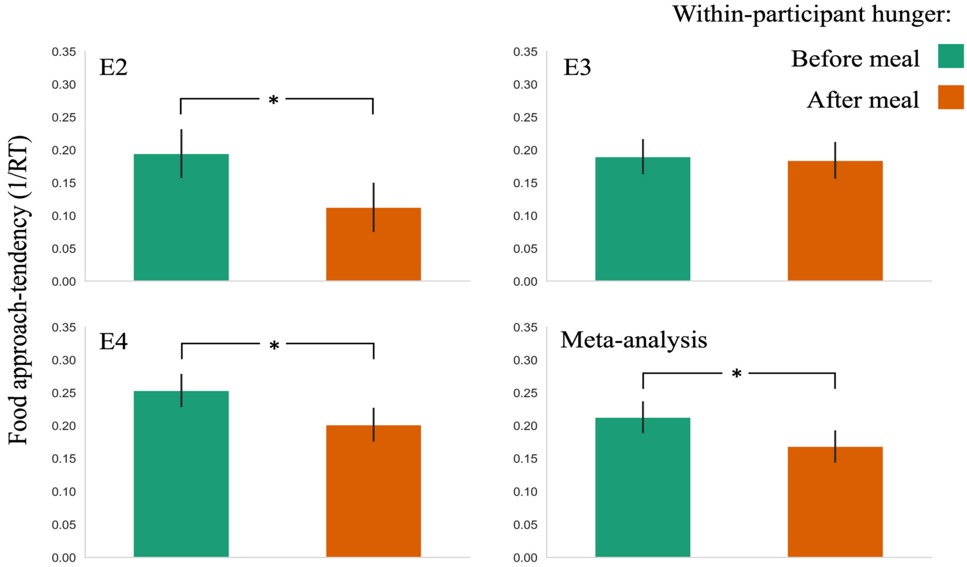
RT (Confirmatory Model). Similar to Experiment 1, there was a significant two-way interaction between response direction and stimulus type, $b = 0.148$ [0.096, 0.207], $t(87.94) = 5.06$, $p < .001$, indicating that participants' average food approach tendencies were positive (see Figure 2.1 in the online materials at https://osf.io/deyzk/). More importantly, as predicted by H1, there was a three-way interaction between BMI, response direction, and stimulus type, $b = 0.015$ [−0.001, 0.031], $t(87.10) = 2.01$, $p = .048$ (see Figure 2). Participants' RT-based food approach tendencies were larger, the

[6] Note that this exclusion was not pre-registered. However, as all models in this experiment included BMI variables, these participants were, by default, not included in any of the analysis. We therefore decided, for the sake of clarity, to add this as an explicit exclusion criterion.

[7] Separate ICC analyses for before and after meals can be found in the online materials at https://osf.io/deyzk/.

Figure 2

Relationship Between Within-Participant Hunger and RT-Based Food Approach Tendencies



Note. This figure shows RT-based food approach tendencies (*y*-axes; ms) and within-participant hunger (*x*-axes, colors; before meal: green, left bars; after meal: orange, right bars). The panels show the effects separately for each field experiment (Experiment 2: upper left, Experiment 3: upper right, Experiment 4: lower left) and for the pooled data (meta-analysis: lower right). RT = reaction time. See the online article for the color version of the figure.

higher their BMI. There was also a significant three-way interaction between within-participant hunger, response direction, and stimulus type, $b = 0.094$ [−0.006, 0.177], $t(20{,}923.23) = 3.89$, $p < .001$. As predicted by H2, participants' food approach tendencies were higher before a meal than after (see Figure 2). The predicted four-way interaction between PFS, hunger, response direction, and stimulus type, however, was not significant, $b = -0.025$ [−0.193, 0.124], $t(24{,}437.74) = -0.69$, $p = .488$.

RT (Food Trials). Against our prediction in H3, there was no two-way interaction between response direction and attractiveness ratings.

RT (Exploratory Model). When exploring all two-way interactions between moderator variables, the three-way interaction between BMI, response direction, and stimulus type became nonsignificant, $b = 0.015$ [−0.003, 0.033], $t(85.79) = 1.94$, $p = .056$. However, the four-way interaction between BMI, response direction, stimulus type, and within-participant hunger was significant, $b = -0.032$ [−0.040, 0.003], $t(20{,}708.65) = -5.01$, $p < .001$. Simple effects analyses in which we tested the effect of within-participant hunger on food approach tendencies separately for healthy (BMI < 25; $N = 79$) and overweight participants (BMI ≥ 25; $N = 16$) further revealed that whereas in healthy-weight participants, food approach tendencies declined from before to after meals, $b = 0.132$ [0.015, 0.202], $t(16{,}543.64) = 4.88$, $p \leq .001$, no such decline was present in overweight participants, $b = -0.068$ [−0.302, 0.352], $t(4{,}477.31) = -1.18$, $p = .237$ (note, however, that this absence of an effect could also be due to the small number of participants in this group; see Figure 3).

Force (Confirmatory Model). The confirmatory model revealed a three-way interaction between within-participant hunger, response direction, and stimulus type, $b = 1.092$ [−0.166, 2.720], $t(25{,}087.07) = 4.21$, $p < .001$. In line with H2 and the results of the RT analyses, participants' force-based food approach tendencies were higher before a meal than after (see Figure 4). Moreover, as predicted in H4, there was a four-way interaction between PFS scores, response direction, stimulus type, and within-participant hunger, $b = -1.332$ [−4.188, 0.972], $t(26{,}863.45) = -3.40$, $p = .001$. The effect of within-participant hunger on force-based food approach tendencies was less expressed in participants with high PFS scores (see the online materials at https://osf.io/deyzk/).

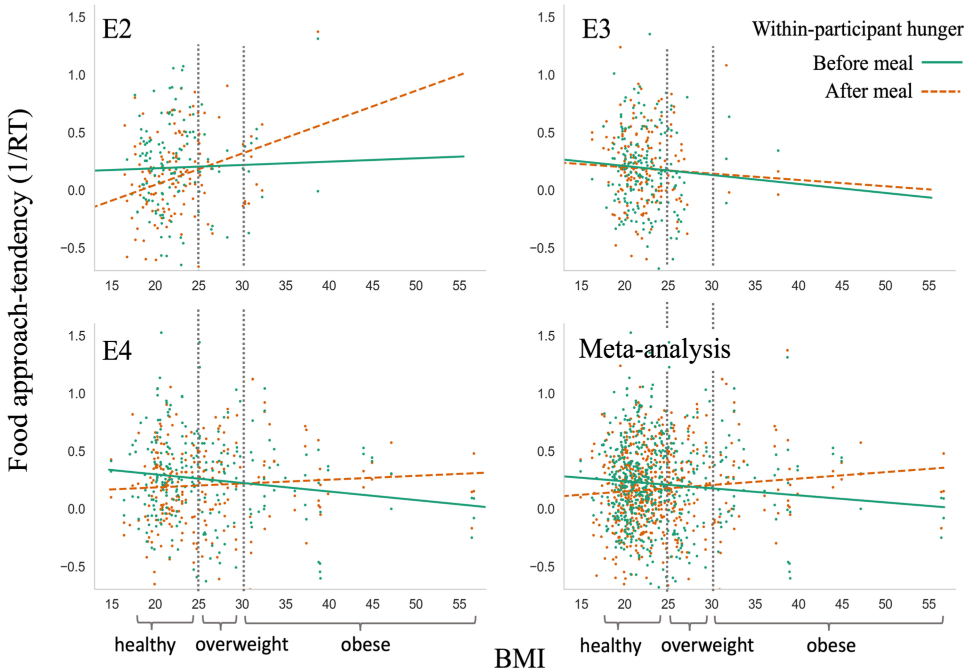
Force (Food Only and Exploratory Models). When focusing on food trials, there was also a two-way interaction between response direction and rating, $b = 0.142$ [−0.154, 0.308], $t(18{,}871.68) = 2.51$, $p = .012$. As predicted in H3, force-based food approach tendencies increased the more attractive stimuli were rated (see Figure 7.4 in the online materials at https://osf.io/deyzk/). The exploratory model revealed no additional significant effects. Note that although four-way interaction between BMI, response direction, stimulus type, and within-participant hunger was in the same direction as the RT data, it did not reach significance in the force data, $b = -0.115$ [−0.364, 0.117], $t(24{,}528.11) = -1.71$, $p = .088$.

Discussion

In Experiment 2, we replicated and extended the findings of Experiment 1 by deploying the mobile AAT in participants' daily life. Similar to Experiment 1, internal consistencies were acceptable for RT-based tendencies and excellent for force-based tendencies, indicating little measurement error. Test–retest reliabilities were, however, overall low (although comparable to other behavioral tasks; see Enkavi et al., 2019). This pattern of low measurement error and low test–retest reliability indicates significant temporal

Figure 3

Relationship Between Within-Participant Hunger, BMI, and RT-Based Food Approach Tendencies



Note. This figure shows RT-based food approach tendencies (*y*-axes; 1/ms) and BMI (*x*-axes) split by within-participant hunger (solid green line: before meals; striped, orange line: after meals). The panels show the effects for each field experiment separately (Experiment 2: upper left, Experiment 3: upper right, Experiment 4: lower left) and for the pooled data (meta-analysis: lower right). To ease interpretation, we overlayed the data with relevant BMI cutoffs (18–24 = *healthy*, 25–29 = *overweight*, >30 = *obese*; dotted gray lines). BMI = body mass index; RT = reaction time. See the online article for the color version of the figure.

fluctuations in food approach tendencies, suggesting that these tendencies should be perceived as a state rather than a trait (Hedge et al., 2018).

As predicted in H1, we found that participants' food approach tendencies were positively associated with BMI. As predicted in H2, we found that food approach tendencies were stronger before compared to after meals. This latter effect was also present in force-based food approach tendencies. The effect of stimulus attractiveness on food approach tendencies (H3) was not present in the RT data but was found in the force data. Similarly, the interaction effect of hunger and PFS (H4) was not significant in the RT data but was significant in the force data.

In an exploratory analysis, we moreover found that the positive relationship between BMI and food approach tendencies seems to depend upon within-participant hunger—as it is specifically present after meals. This finding indicates that being overweight may be associated with a disturbance in the satiety-based regulation of food approach tendencies. Whereas food approach tendencies declined for individuals with a normal BMI, individuals with a high BMI failed to display such a reduction in food approach tendencies after meals. This finding is in line with neurocognitive research that shows that reward-related centers in obese but not healthy-weight individuals stay active after food is consumed (Devoto et al., 2018). As this effect was discovered in an exploratory analysis, we conducted Experiment 3 to replicate it in a confirmatory analysis.

Experiment 3

Experiment 3 was conducted as an exact replication of Experiment 2 to confirm exploratory findings. We predicted that approach tendencies would be positively associated with BMI (H1), within-participant hunger (H2), and attractiveness ratings (H3). We further predicted that the relationship between BMI and food approach tendencies would be especially present after meals (H4).

Method

Power Analysis

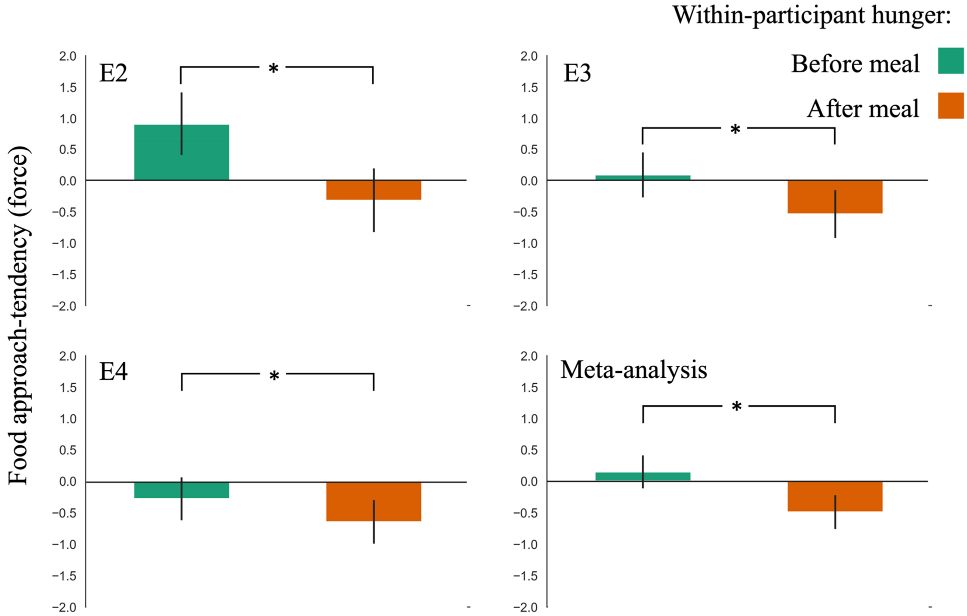
To determine the sample size, we conducted a power analysis using the R simr package (Green et al., 2016). We based the analysis on a slightly reduced effect size of the four-way interaction between BMI, response direction, stimulus type, and within-participant hunger from Experiment 2 ($b = -0.020$). This analysis indicated that 150 participants would be sufficient to detect the effect with a power of 97% [93%, 99%].

Participants

Participants were recruited at Leiden University and participated in exchange for €8 or course credits. Of the 126 participants who completed the experiment, three had to be excluded because of

Figure 4

Relationship Between Within-Participant Hunger and Force-Based Food Approach Tendencies



Note. This figure shows force-based food approach tendencies (*y*-axes; m/s^2) and within-participant hunger (*x*-axes; before meal: green; after meal: orange). The panels show the effects separately for each field experiment (Experiment 2: upper left, Experiment 3: upper right, Experiment 4: lower left) and for the pooled data (meta-analysis: lower right). See the online article for the color version of the figure.

insufficient valid experimental trials. The analyzed sample included 123 participants (95 women, 77.2%) between the ages of 17 and 34 years ($M = 22.5$, $SD = 3.5$). Participants' BMI ranged from 16.2 to 37.6 ($M = 22.3$, $SD = 3.0$).

Procedure and Materials

Participants followed the same procedure as in Experiment 2, with two exceptions. First, instead of measuring participants' height and weight in the laboratory, participants reported their height and weight in the study app. Second, for an associated master's thesis project, participants completed three extra questionnaires at the end of the experiment (a dietary restraint scale, a stress questionnaire, and an impulsivity questionnaire). The analyses of this data are not reported but the relevant data can be found on the project's Open Science Framework page.

Analysis

The data was preprocessed, as described in Experiment 1. We followed the same exclusion procedure as in Experiment 2. The confirmatory models were defined as:

$$\begin{aligned} 1/RT(resp\_force) &\sim (response\_direction \times stimulus\_type) \\ &\times (bmi \times is\_before\_meal) \\ &+ (response\_direction \times stimulus\_type | participant) \end{aligned} \tag{3}$$

Similar to Experiments 1 and 2, we ran additional food-specific models.

Results

Descriptives and Checks

Mean PFS scores ranged from 1.00 to 4.52 ($M = 2.95$, $SD = 0.62$). Self-reported hunger ranged from 1 to 5 ($M = 2.55$, $SD = 1.30$). Times since meals ranged from 0 to 17 hr ($M = 4.17$, $SD = 4.50$). Self-reported hunger was higher before meals (3.36) compared to after meals (1.64; $b = 1.714$ [1.290, 2.089], $t = 17.36$, $p < .001$). Time since the last meal was also higher before (6.86 hr) compared to after meals (1.13 hr; $b = 5.731$ [5.556, 5.906], $t = 15.35$, $p < .001$). Stimulus attractiveness ratings ranged from 1 to 5 ($M = 3.29$, $SD = 1.32$). Participants' food attractiveness ratings were positively correlated with normative ratings ($b = 0.040$ [0.039, 0.042], $t = 55.17$, $p < .001$). High-caloric stimuli were rated more attractive (3.46) than low-caloric stimuli (3.17; $b = 0.293$ [0.237, 0.348], $t = 12.92$, $p < .001$). Inverted RTs ranged from 0.52 to 5.00 reactions per second ($M = 2.15$, $SD = 0.51$). Response forces ranged from 1.29 to 66.12 m/s^2 ($M = 11.15$, $SD = 6.09$). The average error rate was 5.5%.

Reliability

For RT-based food approach tendencies, internal consistencies (average Spearman–Brown corrected split-half reliabilities) were acceptable for basic research ($r = .80$) but higher than those generally reported in AAT research (mean $r = .52$; Zech et al., 2022). Test–retest reliability was poor when scores were based on single sessions (ICC_1 = 0.196) and moderate when scores were based on all sessions (ICC_k = 0.746). This test–retest reliability is similar to that generally reported in AAT research (mean $r = .15$). For force-based food approach tendencies, internal consistencies (average Spearman–Brown corrected split-half reliabilities) were excellent ($r = .90$). Test–retest reliability was poor when scores were based on single sessions (ICC_1 = 0.032) and when scores were based on all sessions (ICC_k = 0.287).

Approach Tendencies

RT. Similar to Experiments 1 and 2, there was a significant two-way interaction between response direction and stimulus type, $b = 0.184$ [0.144, 0.226], $t(119.04) = 8.64$, $p < .001$, indicating that participants' average food approach tendencies were positive. Unlike predicted in H1, H2, and H4, there were, however, no significant higher order interactions (see Table 2).

RT (Food Trials). Against our prediction in H3, there was no two-way interaction between response direction and rating, $b = 0.009$ [0.000, 0.022], $t(24,723.89) = 1.79$, $p = .059$.

Force. The confirmatory force model revealed a significant three-way interaction between response direction, stimulus type, and within-participant hunger, $b = 0.473$ [−0.295, 1.553], $t(36,129.07) = 2.45$, $p = .014$. As predicted in H2, participants' force-based food approach tendencies were stronger before compared to after meals (see Figure 4). Moreover, as predicted in H4, there was a four-way interaction between response direction, stimulus type, within-participant hunger, and BMI, $b = -0.181$ [−0.313, 0.172], $t(37,081.54) = -2.77$, $p = .006$. Whereas participants with low BMIs had reduced force-based food approach tendencies after compared to before meals, $b = 0.419$ [−0.476, 1.521], $t(31,021.62) = 2.05$, $p = .041$, participants with high BMIs did not show this pattern, $b = 0.957$ [−1.594, 3.899], $t(3,904.29) = 1.73$, $p = .084$ (see Figure 5).

Force (Food Trials). The food-specific model revealed no additional effects of interest.

Discussion

Experiment 3 was conducted as an exact replication of Experiment 2 to confirm exploratory findings. Similar to Experiment 2, internal consistencies were acceptable for RT-based tendencies and excellent for force-based tendencies, and test–retest reliability was low.

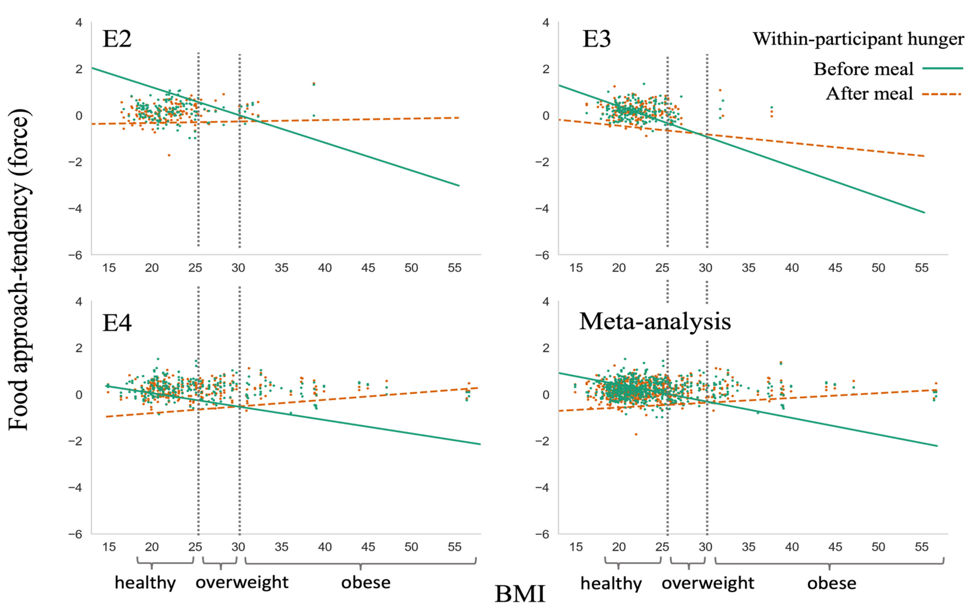
In the RT data, none of the findings of Experiment 2 were replicated. We did not find that BMI (H1), hunger (H2), or food attractiveness ratings (H3) influenced food approach tendencies. Also, the interaction between BMI and hunger was not significant (H4).

In the force data, on the other hand, we did replicate the finding of Experiment 2 that force-based food approach tendencies were stronger before compared to after meals (H2). We also confirmed our prediction that the effect of BMI on force-based food approach tendencies depends on hunger (H4).

There are several possible explanations why Experiment 3 failed to replicate the RT findings of Experiment 2. First, a counterbalancing problem in Experiment 3 caused slightly more sessions to be completed before breakfast compared to all other time points (see the online materials at https://osf.io/deyzk/). Robustness checks further revealed that both general food approach tendencies and the effect of within-participant hunger on food approach tendencies

Figure 5

Relationship Between Within-Participant Hunger, BMI, and Force-Based Food Approach Tendencies



Note. This figure shows force-based food approach tendencies (*y*-axes; m/s^2) and BMI (*x*-axes) split by within-participant hunger (solid green line: before meals; striped, orange line: after meals). The panels show the effects separately for each field experiment (Experiment 2: upper left, Experiment 3: upper right, Experiment 4: lower left) and for the pooled data (meta-analysis: lower right). To ease interpretation, we overlayed the data with relevant BMI cutoffs (18–24 = *healthy*, 25–29 = *overweight*, >30 = *obese*; dotted gray lines). BMI = body mass index. See the online article for the color version of the figure.

were smaller around breakfast than around other meals (see the online materials at https://osf.io/deyzk/). Together these problems could explain why the effect of within-participant hunger on RT-based food approach tendencies was not significant. Indeed, excluding breakfast sessions from the data in Experiment 3 led to a significant effect of within-participant hunger on RT-based food approach tendencies as well (although BMI effects remained nonsignificant; see the online materials at https://osf.io/deyzk/). Second, the designs of Experiments 2 and 3 might not have been ideal to detect effects of hunger as participants completed hungry and satiated sessions around different meals rather than the same meal. To overcome these limitations, we designed Experiment 4.

Experiment 4

Experiment 4 was specifically designed to confirm whether food approach tendencies are positively associated with BMI (H1), whether food approach tendencies increase with hunger (H2), and whether the effect of BMI depends on hunger (H3). We improved upon Experiments 2 and 3 in several ways: First, rather than running the experiment in a Dutch student sample, we ran it in an unselected sample of U.S. Americans, to increase variance in BMI. Second, as we discovered in Experiment 3 that the effect of our hunger manipulation was less expressed during breakfast sessions, we only tested participants around lunch and dinner. Third, we tested participants around the same meals rather than different meals, so that each participant completed one session before lunch, one after lunch, one before dinner, and one after dinner. This design change was made to decrease possible noise from time effects and further increase the power to detect the effect of within-participant hunger on food approach tendencies.

Method

Participants

A power analysis (see Experiment 3) indicated that 150 participants would be sufficient to detect the interaction between BMI, response direction, stimulus type, and within-participant hunger with a power of 97% [93%, 99%]. Participants were unselected U.S. Americans recruited via the online recruitment platform Prolific Academic (https://www.prolific.co/). Of the 168 participants who started the experiment, 19 had to be excluded because of insufficient valid experimental trials. The analyzed sample of Experiment 4 included 149 participants (60 women, 40.3%) between the ages of 18 and 35 years ($M = 26.0$, $SD = 5.0$). Participants' BMI ranged from 14.9 to 56.6 ($M = 25.4$, $SD = 7.0$).

Procedure and Materials

Similar to Experiments 2 and 3, participants first downloaded the study app and completed an introduction session with demographic questions and a practice AAT. On the following day, each participant completed four AAT sessions—one before lunch, one after lunch, one before dinner, and one after dinner. Following each AAT session, participants filled in the two physiological need state questions (see Experiment 1). After the last session, participants were debriefed and rewarded for their participation. Unlike Experiments 2 and 3, we did not ask participants to fill in the PFS or to rate the attractiveness of food stimuli.

Analysis

The data was preprocessed, as described in Experiment 1. We followed the same exclusion procedure as described in Experiment 2. We tested the same models as described in Experiment 3, except for the food-specific model, which was not tested, as participants did not rate the attractiveness of the stimuli.

Results

Descriptives and Checks

Self-reported hunger ranged from 1 to 5 ($M = 2.62$, $SD = 1.48$). Times since meals ranged from 0 to 24 hr ($M = 3.40$, $SD = 3.86$). Self-reported hunger was higher before meals (3.73) compared to after meals (1.49; $b = 2.238$ [2.122, 2.350], $t = 27.32$, $p < .001$). Time since the last meal was also higher before (5.82 hr) compared to after meals (0.95 hr; $b = 4.865$ [4.457, 5.307], $t = 18.58$, $p < .001$). Inverted RTs ranged from 0.51 to 5.00 reactions per second ($M = 2.04$, $SD = 0.53$). Response forces ranged from 1.23 to 92.67 m/s^2 ($M = 11.92$, $SD = 6.54$). The average error rate was 6.6%.

Reliability

For RT-based food approach tendencies, internal consistencies (average Spearman–Brown corrected split-half reliabilities) were acceptable for basic research ($r = .82$) but higher than those generally reported in AAT research (mean $r = .52$; Zech et al., 2022). Test–retest reliability was poor when scores were based on single sessions (ICC_1 = 0.213) and moderate when scores were based on all sessions (ICC_k = 0.685). This test–retest reliability is similar to that generally reported in AAT research (mean $r = .15$). For force-based food approach tendencies, internal consistencies (average Spearman–Brown corrected split-half reliabilities) were excellent ($r = .94$). Test–retest reliability was poor when scores were based on single sessions (ICC_1 = 0.079) and when scores were based on all sessions (ICC_k = 0.417).

Approach Tendencies

RT. Similar to Experiments 1–3 there was a significant two-way interaction between response direction and stimulus type, $b = 0.220$ [0.184, 0.267], $t(143.88) = 10.43$, $p < .001$, indicating that participants' average food approach tendencies were positive. More importantly, as predicted in H2, there was a three-way interaction between within-participant hunger, response direction, and stimulus type, $b = 0.052$ [0.002, 0.113], $t(5{,}078.18) = 3.17$, $p = .002$, as participants' food approach tendencies were higher before a meal than after (see Figure 2). Finally, there was a significant four-way interaction between BMI, within-participant hunger, response direction, and stimulus type, $b = -0.010$ [−0.016, −0.003], $t(53{,}663.20) = -4.47$, $p < .001$. As predicted in H3, the positive relationship between BMI and food approach tendencies was more expressed after meals compared to before meals (see Figure 3). Simple effects analyses further revealed that whereas in healthy-weight participants (BMI < 25; $N = 89$) food approach tendencies declined after meals, $b = 0.118$ [0.054, 0.193], $t(28{,}441.43) = 5.52$, $p \leq .001$, no such effect was present in overweight participants (BMI ≥ 25; $N = 60$), $b = -0.039$ [−0.118, 0.053], $t(22{,}082.40) = -1.55$, $p = .120$ (see Figure 3).

Force. The force model revealed a two-way interaction between response direction and stimulus type, $b = -0.563$ [-0.945, 0.013], $t(139.78) = -2.02$, $p = .046$, indicating that participants' average food approach tendencies were negative. The predicted three-way interaction between BMI, response direction, and stimulus type was not significant (H1). The three-way interaction between within-participant hunger, response direction, and stimulus type was significant, $b =$ 0.511 [-0.706, 1.334], $t(52{,}740.00) = 2.96$, $p = .003$. As predicted by H2 participants' force-based food approach tendencies were higher before compared to after meals (see Figure 4). Finally, the predicted four-way interaction between BMI, within-participant hunger, response direction, and stimulus type was significant, $b = -0.090$ [-0.227, 0.055], $t(53{,}949.15) = -3.88$, $p < .001$. As predicted in H3, the positive relationship between BMI and force-based food approach tendencies was more expressed after meals compared to before meals (see Figure 5). Whereas participants with low BMIs had reduced force-based food approach tendencies after compared to before meals, $b = -1.080$ [-0.642, 2.332], $t(30{,}438.18) = 4.83$, $p < .001$, participants with high BMIs did not show this pattern, $b = -0.272$ [-1.1669, 0.857], $t(22{,}136.17) = -1.01$, $p = .313$ (see Figure 5).

Discussion

Experiment 4 was specifically designed to test whether food approach tendencies are positively associated with BMI (H1) and hunger (H2) and whether the association between BMI and food approach tendencies depends on hunger (H3). As in Experiment 2, internal consistencies were acceptable for RT-based tendencies and excellent for force-based tendencies, and test–retest reliability was low. The association between BMI and food approach tendencies was not significant. As predicted, the relationship between hunger and food approach tendencies, on the other hand, was positive both in the RT and in the force data. Finally, as predicted, the association between food approach tendencies and BMI did depend on hunger as the positive association between BMI and food approach tendencies was more expressed after compared to before meals. Similar to Experiment 2, it can be seen that whereas food approach tendencies declined for individuals with healthy BMIs (<25), individuals with high BMIs (≥ 25) failed to display such a reduction and instead displayed an increase in food approach tendencies after meals (Figures 3 and 5).

In sum, Experiment 4 confirmed our expectations. Yet, as our findings across all four experiments were not fully consistent, we conducted an additional mini meta-analysis to test which effects were present across the four experiment samples.

Mini Meta-Analysis

Analysis

As suggested by Fernández-Castilla et al. (2020), we ran the mini meta-analysis based on the pooled data from all four experiments. To model dependence of errors within experiments, we added a nested random effect to the model tested in Experiments 3 and 4. The model was therefore defined as:

$$1/RT(resp.force) \sim (response\_direction \times stimulus\_type) \times (bmi \times is\_before\_meal) + (response\_direction \times stimulus\_type | experiment/participant) \quad (4)$$

Results

Approach Tendencies

RT. The RT model revealed a two-way interaction between response direction and stimulus type, $b = 0.185$ [0.167, 0.220], $t(2.29) = 8.03$, $p = .010$, indicating that general food approach tendencies were positive. More importantly, there was a three-way interaction between response direction, stimulus type, and within-participant hunger, $b = 0.049$ [0.003, 0.080], $t(102{,}447.02) =$ 4.39, $p < .001$. As predicted (see Experiment 4, H2), participants' food approach tendencies were stronger before compared to after meals (see Figure 2). The three-way interaction between response direction, stimulus type, and BMI was, however, not significant (see Table 2). More importantly, the four-way interaction between response direction, stimulus type, BMI, and within-participant hunger was significant, $b = -0.012$ [-0.016, -0.003], $t(118{,}146.69) = -5.77$, $p < .001$. As predicted (see Experiment 4, H3), the association between BMI and food approach tendencies was more expressed after compared to before meals. Simple effects analyses further revealed that whereas in healthy-weight participants (BMI < 25; $N = 272$), food approach tendencies declined after meals, $b = 0.085$ [-0.009, 0.158], $t(69{,}578.58) = 6.47$, $p \leq .001$, food approach tendencies increased for overweight participants (BMI ≥ 25; $N = 95$), $b = -0.045$ [-0.156, 0.064], $t(31{,}624.11) =$ -2.15, $p = .021$ (see Figure 3).

Force. The predicted three-way interaction between BMI, response direction, and stimulus type was not significant (H1; see Table 2). There was, on the other hand, a significant three-way interaction between within-participant hunger, response direction, and stimulus type (H2), $b = 0.637$ [0.044, 1.233], $t(115{,}449.46) =$ 5.52, $p < .001$. As predicted, participants' food approach tendencies were higher before compared to after meals (see Figure 4). Finally, the predicted four-way interaction between BMI, within-participant hunger, response direction, and stimulus type was significant (H3), $b = -0.101$ [-0.214, 0.030], $t(120{,}878.05) = -4.95$, $p < .001$. As predicted, the positive relationship between BMI and food approach tendencies was more expressed after meals compared to before meals (see Figure 5). Simple effects analyses further revealed that whereas in healthy-weight participants (BMI < 25; $N = 272$) food approach tendencies declined after meals, $b = 0.989$ [0.250, 1.747], $t(49{,}428.15) = 7.39$, $p \leq .001$, no such effect was present in overweight participants (BMI ≥ 25; $N = 95$), $b = -0.303$ [-1.362, 0.676], $t(31{,}876.12) = -1.34$, $p = .179$ (see Figure 3).

General Discussion

Summary of Results

In four experiments, we used a novel mobile AAT to examine whether approach tendencies change dynamically with changing physiological needs. Importantly, we also researched whether disruptions of these dynamics can explain unwanted health outcomes related to overconsumption (i.e., high BMIs). We examined food approach tendencies expressed in both RTs and the novel measure of response food, and we did so in both single-session laboratory settings and in participants' daily life, with multiple sessions over several days. Accordingly, we were able to assess need-based food approach dynamics from converging angles. In an initial cross-sectional laboratory experiment, we found a positive association between BMI and average food approach tendencies. However, we did not find a positive association between food approach tendencies and self-reported hunger in the laboratory, which might have been attributable to too little variation in participants' hunger states. When we took our ideas outside the laboratory and tested the effect of hunger within participants in three subsequent field experiments, we overall found that participants had stronger approach tendencies before compared to after meals supporting our need-based dynamics account of food approach tendencies. We moreover found no general association between BMI and food approach tendencies, but rather that the effect of BMI interacted with within-participant hunger. Whereas food approach tendencies decreased after meals in healthy-weight participants, food approach tendencies of overweight and obese participants did not decrease after meals (and might even have increased, although future research needs to confirm this particular finding). These two effects were not only detected in traditionally measured RT-based food approach tendencies but also in force-based food approach tendencies. Together, our findings confirm the idea that approach tendencies can change dynamically in accordance with homeostatic needs. Our findings further demonstrate that disruptions of these healthy dynamics can explain unwanted health outcomes, such as overweight and obesity.

Limitations

In the present research, we found that participants' food approach tendencies fluctuate around meals, suggesting an association between need states and food approach tendencies. We did, however, not directly manipulate need states but only quasi-manipulated them by testing participants before and after they had eaten. Although our findings suggest that food approach tendencies changed because of changes in need states, other variables, such as motivation or alertness, might have covaried with need states around meals, which, in turn, might have influenced food approach tendencies. To exclude this possibility, future studies could link food approach tendencies to biological markers of physiological needs (e.g., hormones such as insulin, leptin, and ghrelin; see, e.g., Kroemer et al., 2013). Future studies could also employ more sophisticated hunger scales. As the app used in this study was limited to Likert scales, we measured hunger only on a 5-point scale. Future studies could employ visual analog scales that might allow for more variance in hunger measurements instead. To further test the effects of deprivation, future studies could also use well-established food deprivation manipulations such as overnight fasting (e.g., Van Dillen et al., 2021).

Although we found that, after meals, not before, BMIs were positively associated with food approach tendencies, given the design of these studies, we cannot make any causal claims about this relationship. It is possible that less need-responsive food approach tendencies cause people to overeat, resulting in increased BMIs. However, the reverse may also be the case—namely that altered reward processing in people with higher BMIs disrupts healthy regulation of food approach tendencies. Kroemer et al. (2013)], for example, showed that, after the consumption of high-calorie foods, altered reward processing in the nucleus accumbens was associated with greater dietary disinhibition and increased BMIs. Ultimately, longitudinal studies are necessary to establish the possible causal relationships between need-based food approach dynamics and health outcomes like BMI. These studies could use mobile versions of the AAT, such as our current one—which are uniquely suited for longitudinal study designs.

Whereas Experiments 1–3 consisted primarily of young female Dutch university students with comparably low BMIs and possibly very specific eating patterns, our nonselective sample in Experiment 4 had a wider range in BMI. We, therefore, believe that our results can be generalized to a broader population.

Implications

In the present research, we, for the first time, showed that changes in need states influence within-participant fluctuations in approach tendencies. Existing studies that showed an association between need states and approach tendencies could not examine such within-participant fluctuations, as they relied on between-participant designs (Seibt et al., 2007; Staats & Warren, 1974). By using a mobile version of the AAT that allowed for repeated assessments in an ecologically valid manner, we were able to quasi-manipulate need states and detect clear need-based fluctuations in food approach tendencies. This could also explain why other studies that did not manipulate need states, and relied on cross-sectional designs, did not find such fluctuations (e.g., Booth et al., 2018; Brignell et al., 2009; Brunyé et al., 2013; Cheval et al., 2017; Kakoschke et al., 2015, 2017a, 2017b, 2017c; Havermans et al., 2011; Piqueras-Fiszman et al., 2014; Schumacher et al., 2016; Seibt et al., 2007; Staats & Warren, 1974; Veenstra & de Jong, 2010, 2011). This implication illustrates the usefulness of modern versions of the AAT, which can easily be deployed in participants' daily life, and accordingly be attuned to daily natural need state changes (e.g., Meule et al., 2020; Zech et al., 2020).

Our finding that food approach tendencies dynamically change with need states might explain so far mixed findings of studies that try to link these tendencies to more stable individual variables such as BMI. This interpretation is supported by our reliability analyses, which indicated that whereas adequate as a state measure, as evidenced by a high internal consistency, the AAT should not be used as a trait measure of food approach tendencies (see also Zech et al., 2022). The use of variables as trait measures requires high reliability, as low reliability limits the correlation that can be observed between two variables (Spearman, 2010).

On a theoretical level, our findings are in line with predictions by several researchers that approach tendencies *should* change dynamically with context and changes in physiological needs (Cacioppo et al., 1993; Corr, 2013; Strack & Deutsch, 2004, 2015), something that should concur with low test–retest reliability, as we observed. On the other hand, our findings seemingly conflict with associative accounts of approach–avoidance that posit that approach–avoidance tendencies are automatic (e.g., Chen & Bargh, 1999; Strack & Deutsch, 2004)—that is directly or rigidly triggered by stimulus presentations (Smith & DeCoster, 2000). Our findings indicate that, at least in some cases, the effect of stimuli on approach–avoidance tendencies is not direct but moderated by participants' need states. To integrate these findings into associative accounts of approach and avoidance, the principle of pattern activation could be helpful (Smith, 1996). In this framework, (approach–avoidance) tendencies are not rigidly triggered by a stimulus but by the combination of a context (e.g., food deprivation) and the stimulus.

Importantly, we found that disrupted need-based approach dynamics are associated with negative health outcomes linked to overconsumption. Whereas healthy-weight participants showed decreased food approach tendencies after meals, overweight and obese participants (BMI $\geq$ 25) did not show a decrease in food approach tendencies, as expressed in both RTs and force, and might even have shown increased tendencies, as expressed in RTs of the mini meta-analysis. This finding that overweight participants' food approach tendencies did not decline from before to after meals is in line with neurocognitive data showing that people suffering from obesity do not show the same decrease in the activity of reward-related neurocognitive circuits after meals as healthy-weight people (Devoto et al., 2018; Ferrario et al., 2020; Kroemer & Small, 2016; Sun et al., 2015). Our findings, therefore, indicate that obese individuals may not get the same level of satisfaction from meals or may be less responsive to their bodily states than healthy-weight individuals (Herbert & Pollatos, 2014). This, in turn, could lead to compensatory responses, such as people consuming more food than they need (Nummenmaa & van Dillen, 2021). Our findings also imply that unhealthy approach tendencies operate like addictions, which are resistant to need-based adjustments in outcome values, thereby leading people to seek out stimuli that are ultimately bad for their health (Berridge et al., 2009; Parkinson et al., 2005). Future research could further investigate the link between (dysregulated) approach dynamics and compensatory consumption by assessing how our findings extend to substance use disorders. It could also investigate why (food-)approach tendencies in unhealthy populations might not decrease or even increase after (food) consumption.

Finally, we found that changes in need states not only influenced the speed with which participants approached food stimuli but also their movement force. Movement force has already been used in animal studies to research motivation (e.g., Brown, 1948), but studies of approach force in humans are extremely rare. Pirc et al. (2019) recently demonstrated that hungry participants use more force to self-administer chocolate milk compared to satiated participants, indicating that force plays a central role in need-based motivation. To the best of our knowledge, we are the first to show that need states influence the force of approach-related responses. Further neurocognitive and comparative studies could inform whether these force-based approach tendencies are driven by the same or different mechanisms than RT-based approach tendencies.

Conclusion

Although researchers have suggested that chronically elevated approach tendencies could explain unhealthy consumption, evidence of such a link, especially in the food domain, is still mixed. Here, we showed that the difficulty in relating food approach tendencies to individual characteristics, such as BMIs, might be explained by their dynamic nature. In addition to demonstrating that approach tendencies fluctuate with need states, we show that a disruption of such approach dynamics is associated with adverse health outcomes such as high BMIs. Next to illustrating the importance of studying the dynamics of (food) approach tendencies in addition to treating it as a trait-based variable, our study demonstrated the usefulness of novel, mobile behavioral measures that allow researchers to study the dynamics of cognitive and behavioral measures in longitudinal and field studies.

Constraints on Generality

One of the main findings of this study is that disruptions in the dynamics of food approach tendencies can be related to negative health outcomes, such as overweight and obesity. To study this question, we first focused on convenience samples (primarily of young female Dutch university students) and then broadened our population to a larger sample of unselected U.S. Americans. We believe these samples are sufficiently general to support this first demonstration. We hope that future research can replicate our findings in more diverse (e.g., non-Western) and more specific samples (e.g., participants with eating disorders).

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References

Baayen, H. R., & Milin, P. (2010). Analyzing reaction times. *International Journal of Psychological Research*, *3*(2), 12–28. https://doi.org/10.21500/20112084.807

Berridge, K. C., Robinson, T. E., & Aldridge, J. W. (2009). Dissecting components of reward: 'Liking', 'wanting', and learning. *Current Opinion in Pharmacology*, *9*(1), 65–73. https://doi.org/10.1016/j.coph.2008.12.014

Blechert, J., Lender, A., Polk, S., Busch, N. A., & Ohla, K. (2019). Food-pics_extended—An image database for experimental research on eating and appetite: Additional images, normative ratings and an updated review. *Frontiers in Psychology*, *10*, Article 307. https://doi.org/10.3389/fpsyg.2019.00307

Booth, C., Spronk, D., Grol, M., & Fox, E. (2018). Uncontrolled eating in adolescents: The role of impulsivity and automatic approach bias for food. *Appetite*, *120*, 636–643. https://doi.org/10.1016/j.appet.2017.10.024

Brignell, C., Griffiths, T., Bradley, B. P., & Mogg, K. (2009). Attentional and approach biases for pictorial food cues. Influence of external eating. *Appetite*, *52*(2), 299–306. https://doi.org/10.1016/j.appet.2008.10.007

Brockmeyer, T., Hahn, C., Reetz, C., Schmidt, U., & Friederich, H. C. (2015). Approach bias and cue reactivity towards food in people with high versus low levels of food craving. *Appetite*, *95*, 197–202. https://doi.org/10.1016/j.appet.2015.07.013

Brown, J. S. (1948). Gradients of approach and avoidance responses and their relation to level of motivation. *Journal of Comparative and Physiological Psychology*, *41*(6), 450–465. https://doi.org/10.1037/h0055463

Brunyé, T. T., Hayes, J. F., Mahoney, C. R., Gardony, A. L., Taylor, H. A., Kanarek, R. B., & Balasubramaniam, R. (2013). Get in my belly: Food preferences trigger approach and avoidant postural asymmetries. *PLoS ONE*, *8*(8), Article e72432. https://doi.org/10.1371/journal.pone.0072432

Cacioppo, J. T., Priester, J. R., & Berntson, G. G. (1993). Rudimentary determinants of attitudes: II. Arm flexion and extension have differential effects on attitudes. *Journal of Personality and Social Psychology*, *65*(1), 5–17. https://doi.org/10.1037/0022-3514.65.1.5

Chen, M., & Bargh, J. A. (1999). Consequences of automatic evaluation: Immediate behavioral predispositions to approach or avoid the stimulus. *Personality and Social Psychology Bulletin*, *25*(2), 215–224. https://doi.org/10.1177/0146167299025002007

Cheval, B., Audrin, C., Sarrazin, P., & Pelletier, L. (2017). When hunger does (or doesn't) increase unhealthy and healthy food consumption through food wanting: The distinctive role of impulsive approach tendencies toward healthy food. *Appetite*, *116*, 99–107. https://doi.org/10.1016/j.appet.2017.04.028

Corr, P. J. (2013). Approach and avoidance behaviour: Multiple systems and their interactions. *Emotion Review*, *5*(3), 285–290. https://doi.org/10.1177/1754073913477507

Cousijn, J., Goudriaan, A. E., & Wiers, R. W. (2011). Reaching out towards cannabis: Approach-bias in heavy cannabis users predicts changes in cannabis use. *Addiction*, *106*(9), 1667–1674. https://doi.org/10.1111/j.1360-0443.2011.03475.x

Devoto, F., Zapparoli, L., Bonandrini, R., Berlingeri, M., Ferrulli, A., Luzi, L., Banfi, G., & Paulesu, E. (2018). Hungry brains: A meta-analytical review of brain activation imaging studies on food perception and appetite in obese individuals. *Neuroscience and Biobehavioral Reviews*, *94*, 271–285. https://doi.org/10.1016/j.neubiorev.2018.07.017

Enkavi, A. Z., Eisenberg, I. W., Bissett, P. G., Mazza, G. L., MacKinnon, D. P., Marsch, L. A., & Poldrack, R. A. (2019). Large-scale analysis of test–retest reliabilities of self-regulation measures. *Proceedings of the National Academy of Sciences of the United States of America*, *116*(12), 5472–5477. https://doi.org/10.1073/pnas.1818430116

Fernández-Castilla, B., Jamshidi, L., Declercq, L., Beretvas, S. N., Onghena, P., & Van den Noortgate, W. (2020). The application of meta-analytic (multi-level) models with multiple random effects: A systematic review. *Behavior Research Methods*, *52*(5), 2031–2052. https://doi.org/10.3758/s13428-020-01373-9

Ferrario, C. R., Labouèbe, G., Liu, S., Nieh, E. H., Routh, V. H., Xu, S., & O'Connor, E. C. (2020). Homeostasis meets motivation in the battle to control food intake. *Journal of Neuroscience*, *36*(45), 11469–11481.

Finlayson, G. (2017). Food addiction and obesity: Unnecessary medicalization of hedonic overeating. *Nature Reviews Endocrinology*, *13*(8), 493–498. https://doi.org/10.1038/nrendo.2017.61

Green, P., MacLeod, C. J., & Nakagawa, S. (2016). SIMR: An R package for power analysis of generalized linear mixed models by simulation. *Methods in Ecology and Evolution*, *7*(4), 493–498. https://doi.org/10.1111/2041-210X.12504

Havermans, R. C., Giesen, J. C., Houben, K., & Jansen, A. (2011). Weight, gender, and snack appeal. *Eating Behaviors*, *12*(2), 126–130. https://doi.org/10.1016/j.eatbeh.2011.01.010

Hedge, C., Powell, G., & Sumner, P. (2018). The reliability paradox: Why robust cognitive tasks do not produce reliable individual differences. *Behavior Research Methods*, *50*(3), 1166–1186. https://doi.org/10.3758/s13428-017-0935-1

Herbert, B. M., & Pollatos, O. (2014). Attenuated interoceptive sensitivity in overweight and obese individuals. *Eating Behaviors*, *15*(3), 445–448. https://doi.org/10.1016/j.eatbeh.2014.06.002

Hofmann, W., Baumeister, R. F., Förster, G., & Vohs, K. D. (2012). Everyday temptations: An experience sampling study of desire, conflict, and self-control. *Journal of Personality and Social Psychology*, *102*(6), 1318–1335. https://doi.org/10.1037/a0026545

Kahveci, S., Meule, A., Lender, A., & Blechert, J. (2020). Food approach bias is moderated by the desire to eat specific foods. *Appetite*, *154*, Article 104758. https://doi.org/10.1016/j.appet.2020.104758

Kahveci, S., Van Alebeek, H., Berking, M., & Blechert, J. (2021). Touchscreen-based assessment of food approach biases: Investigating reliability and item-specific preferences. *Appetite*, *163*, Article 105190. https://doi.org/10.1016/j.appet.2021.105190

Kakoschke, N., Albertella, L., Lee, R. S., & Wiers, R. W. (2019). Assessment of automatically activated approach–avoidance biases across appetitive substances. *Current Addiction Reports*, *6*(3), 200–209. https://doi.org/10.1007/s40429-019-00254-2

Kakoschke, N., Kemps, E., & Tiggemann, M. (2015). Combined effects of cognitive bias for food cues and poor inhibitory control on unhealthy food intake. *Appetite*, *87*, 358–364. https://doi.org/10.1016/j.appet.2015.01.004

Kakoschke, N., Kemps, E., & Tiggemann, M. (2017a). The effect of combined avoidance and control training on implicit food evaluation and choice. *Journal of Behavior Therapy and Experimental Psychiatry*, *55*, 99–105. https://doi.org/10.1016/j.jbtep.2017.01.002

Kakoschke, N., Kemps, E., & Tiggemann, M. (2017b). Differential effects of approach bias and eating style on unhealthy food consumption in overweight and normal weight women. *Psychology and Health*, *32*(11), 1371–1385. https://doi.org/10.1080/08870446.2017.1327587

Kakoschke, N., Kemps, E., & Tiggemann, M. (2017c). Impulsivity moderates the effect of approach bias modification on healthy food consumption. *Appetite*, *117*, 117–125. https://doi.org/10.1016/j.appet.2017.06.019

Kollei, I., Leins, J., Rinck, M., Waldorf, M., Kuhn, M., Rauh, E., & Steins-Loeber, S. (2022). Implicitapproach-avoidance tendencies toward food and body stimuli absent inindividuals with anorexia nervosa, bulimia nervosa, and healthycontrols. *International Journal of EatingDisorders*, *55*(1),85–97. https://doi.org/10.1002/eat.v55.1

Kroemer, N. B., Krebs, L., Kobiella, A., Grimm, O., Pilhatsch, M., Bidlingmaier, M., Zimmermann, U. S., & Smolka, M. N. (2013). Fasting levels of ghrelin covary with the brain response to food pictures. *Addiction Biology*, *18*(5), 855–862. https://doi.org/10.1111/j.1369-1600.2012.00489.x

Kroemer, N. B., & Small, D. M. (2016). Fuel not fun: Reinterpreting attenuated brain responses to reward in obesity. *Physiology and Behavior*, *162*, 37–45. https://doi.org/10.1016/j.physbeh.2016.04.020

Lowe, M. R., & Butryn, M. L. (2007). Hedonic hunger: A new dimension of appetite? *Physiology and Behavior*, *91*(4), 432–439. https://doi.org/10.1016/j.physbeh.2007.04.006

Lowe, M. R., Butryn, M. L., Didie, E. R., Annunziato, R. A., Thomas, J. G., Crerand, C. E., Ochner, C. N., Coletta, M. C., Bellace, D., Wallaert, M., & Halford, J. (2009). The Power of Food Scale. A new measure of the psychological influence of the food environment. *Appetite*, *53*(1), 114–118. https://doi.org/10.1016/j.appet.2009.05.016

Luke, S. G. (2017). Evaluating significance in linear mixed-effects models in R. *Behavior Research Methods*, *49*(4), 1494–1502. https://doi.org/10.3758/s13428-016-0809-y

Maas, J., Woud, M. L., Keijsers, G. P., Rinck, M., Becker, E. S., & Wiers, R. W. (2017). The attraction of sugar: An association between body mass index and impaired avoidance of sweet snacks. *Journal of Experimental Psychopathology*, *8*, 40–54. https://doi.org/10.5127/jep.052415

Machulska, A., Kleinke, K., & Klucken, T. (2022). Same same, but different: A psychometric examination of three frequently used experimental tasks for cognitive bias assessment in a sample of healthy young adults. *Behavior Research Methods*. Advance online publication. https://doi.org/10.3758/s13428-022-01804-9

McGraw, K. O., & Wong, S. P. (1996). Forming inferences about some intraclass correlation coefficients. *Psychological Methods*, *1*(1), 30–46. https://doi.org/10.1037/1082-989X.1.1.30

Meule, A., Richard, A., Lender, A., Dinic, R., Brockmeyer, T., Rinck, M., & Blechert, J. (2020). Measuring approach–avoidance tendencies towards food with touchscreen-based arm movements. *Psychological Research*, *83*(7), 1789–1800. https://doi.org/10.1007/s00426-019-01195-1

Mogg, K., Field, M., & Bradley, B. P. (2005). Attentional and approach biases for smoking cues in smokers: An investigation of competing theoretical views of addiction. *Psychopharmacology*, *180*(2), 333–341. https://doi.org/10.1007/s00213-005-2158-x

Moore, S., Rudaizky, D., MacLeod, C., & Dondzilo, L. (2022). Healthiness matters: Approach motivation for healthy food in overweight and obese individuals. *Appetite*, *168*, Article 105760. https://doi.org/10.1016/j.appet.2021.105760

Neimeijer, R. A., de Jong, P. J., & Roefs, A. (2015). Automatic approach/avoidance tendencies towards food and the course of anorexia nervosa. *Appetite*, *91*, 28–34. https://doi.org/10.1016/j.appet.2015.03.018

Nummenmaa, L., & van Dillen, L. (2021). Carnal pleasures. *Current Opinion in Behavioral Sciences*, *39*, 85–92. https://doi.org/10.1016/j.cobeha.2021.02.026

Parkinson, J. A., Roberts, A. C., Everitt, B. J., & Di Ciano, P. (2005). Acquisition of instrumental conditioned reinforcement is resistant to the devaluation of the unconditioned stimulus. *The Quarterly Journal of Experimental Psychology Section B*, *58*(1b), 19–30. https://doi.org/10.1080/02724990444000023

Paslakis, G., Kühn, S., Schaubschläger, A., Schieber, K., Röder, K., Rauh, E., & Erim, Y. (2016). Explicit and implicit approach vs. avoidance tendencies towards high vs. low calorie food cues in patients with anorexia nervosa and healthy controls. *Appetite*, *107*, 171–179. https://doi.org/10.1016/j.appet.2016.08.001

Peeters, M., Wiers, R. W., Monshouwer, K., van de Schoot, R., Janssen, T., & Vollebergh, W. A. (2012). Automatic processes in at-risk adolescents: The role of alcohol-approach tendencies and response inhibition in drinking behavior. *Addiction*, *107*(11), 1939–1946. https://doi.org/10.1111/j.1360-0443.2012.03948.x

Pek, J., & Flora, D. B. (2018). Reporting effect sizes in original psychological research: A discussion and tutorial. *Psychological Methods*, *23*(2), 208–225. https://doi.org/10.1037/met0000126

Phaf, R. H., Mohr, S. E., Rotteveel, M., & Wicherts, J. M. (2014). Approach, avoidance, and affect: A meta-analysis of approach-avoidance tendencies in manual reaction time tasks. *Frontiers in Psychology*, *5*, Article 378. https://doi.org/10.3389/fpsyg.2014.00378

Piqueras-Fiszman, B., Kraus, A. A., & Spence, C. (2014). “Yummy” versus “Yucky”! Explicit and implicit approach–avoidance motivations towards appealing and disgusting foods. *Appetite*, *78*, 193–202. https://doi.org/10.1016/j.appet.2014.03.029

Pirc, M., Čad, E. M., Jager, G., & Smeets, P. A. (2019). Grab to eat! Eating motivation dynamics measured by effort exertion depend on hunger state. *Food Quality and Preference*, *78*, Article 103741. https://doi.org/10.1016/j.foodqual.2019.103741

Rinck, M., & Becker, E. S. (2007). Approach and avoidance in fear of spiders. *Journal of Behavior Therapy and Experimental Psychiatry*, *38*(2), 105–120. https://doi.org/10.1016/j.jbtep.2006.10.001

Schumacher, S. E., Kemps, E., & Tiggemann, M. (2016). Bias modification training can alter approach bias and chocolate consumption. *Appetite*, *96*, 219–224. https://doi.org/10.1016/j.appet.2015.09.014

Seibt, B., Häfner, M., & Deutsch, R. (2007). Prepared to eat: How immediate affective and motivational responses to food cues are influenced by food deprivation. *European Journal of Social Psychology*, *37*(2), 359–379. https://doi.org/10.1002/ejsp.365

Smith, E. R. (1996). What do connectionism and social psychology offer each other?*Journal of Personality and Social Psychology*, *70*(5), 893–912. https://doi.org/10.1037/0022-3514.70.5.893

Smith, E. R., & DeCoster, J. (2000). Dual-process models in social and cognitive psychology: Conceptual integration and links to underlying memory systems. *Personality and Social Psychology Review*, *4*(2), 108–131. https://doi.org/10.1207/S15327957PSPR0402_01

Spearman, C. (2010). The proof and measurement of association between two things. *International Journal of Epidemiology*, *39*(5), 1137–1150. https://doi.org/10.1093/ije/dyq191 (Original work published 1904)

Staats, A. W., & Warren, D. R. (1974). Motivation and the three-function learning: Food deprivation and approach–avoidance to food words. *Journal of Experimental Psychology*, *103*(6), 1191–1199. https://doi.org/10.1037/h0037417

Strack, F., & Deutsch, R. (2004). Reflective and impulsive determinants of social behavior. *Personality and Social Psychology Review*, *8*(3), 220–247. https://doi.org/10.1207/s15327957pspr0803_1

Strack, F., & Deutsch, R. (2015). The duality of everyday life: Dual-process and dual system models in social psychology. In M. Mikulincer, P. R. Shaver, E. Borgida, & J. A. Bargh (Eds.), *APA handbook of personality and social psychology, vol. 1: Attitudes and social cognition* (pp. 891–927). American Psychological Association. https://doi.org/10.1037/14341-028

Sun, X., Kroemer, N. B., Veldhuizen, M. G., Babbs, A. E, de Araujo, I. E., Gitelman, D. R., Sherwin, R. S., Sinha, R., & Small, D. M. (2015). Basolateral amygdala response to food cues in the absence of hunger Is associated with weight gain susceptibility. *The Journal of Neuroscience*, *35*(20), 7964–7976. https://doi.org/10.1523/JNEUROSCI.3884-14.2015

Van Dillen, L. F., & Andrade, J. (2016). Derailing the streetcar named desire. Cognitive distractions reduce individual differences in cravings and unhealthy snacking in response to palatable food. *Appetite*, *96*, 102–110. https://doi.org/10.1016/j.appet.2015.09.013

Van Dillen, L. F., Lelieveld, G. J., Hofmann, W., & de Kwaadsteniet, E. W. (2021). ‘Sharing in need’: How allocator and recipient’s hunger shape food distributions in a dictator game. *Journal of Experimental Social Psychology*, *95*, Article 104152. https://doi.org/10.1016/j.jesp.2021.104152

Veenstra, E. M., & de Jong, P. J. (2010). Restrained eaters show enhanced automatic approach tendencies towards food. *Appetite*, *55*(1), 30–36. https://doi.org/10.1016/j.appet.2010.03.007

Veenstra, E. M., & de Jong, P. J. (2011). Reduced automatic motivational orientation towards food in restricting anorexia nervosa. *Journal of Abnormal Psychology*, *120*(3), 708–718. https://doi.org/10.1037/a0023926

Wiers, R. W., Gladwin, T. E., Hofmann, W., Salemink, E., & Ridderinkhof, K. R. (2013). Cognitive bias modification and cognitive control training in addiction and related psychopathology: Mechanisms, clinical perspectives, and ways forward. *Clinical Psychological Science*, *1*(2), 192–212. https://doi.org/10.1177/2167702612466547

World Health Organization. (2020, March 3). *Obesity and overweight*. https://who.int/news-room/fact-sheets/detail/obesity-and-overweight

Zech, H. G., Gable, P., van Dijk, W. W., & van Dillen, L. F. (2022). Test–retest reliability of a smartphone-based approach–avoidance task: Effects of retest period, stimulus type, and demographics. *Behavior Research Methods*. Advance online publication. https://doi.org/10.3758/s13428-022-01920-6

Zech, H. G., Rotteveel, M., Van Dijk, W. W., & Van Dillen, L. F. (2020). A mobile approach–avoidance task. *Behavior Research Methods*, *52*(5), 2085–2097. https://doi.org/10.3758/s13428-020-01379-3

(*Appendix follows*)

Appendix

Stimuli

We used the following stimuli from the food-pics_extended picture set (Blechert et al., 2019) in all experiments:

Food stimuli (practice trials): 0005, 0026, 0029, 0053, 0154, 0187, 0192, 0195, 0198, 0204, 0205, 0208, 0215, 0221, 0227, 0230, 0232, 0241, 0249, 0250.

Food stimuli (experimental trials): 0196, 0201, 0203, 0206, 0209, 0210, 0214, 0217, 0218, 0219, 0220, 0223, 0229, 0281, 0284, 0325, 0345, 0391, 0467, 0531, 0193, 0226, 0244, 0259, 0262, 0303, 0343, 0348, 0356, 0360, 0401, 0409, 0428, 0444, 0445, 0520, 0537, 0540, 0550, 0557, 0004, 0009, 0010, 0016, 0025, 0033, 0036, 0056, 0060, 0074, 0089, 0106, 0107, 0111, 0115, 0126, 0173, 0291, 0317, 0465, 0063, 0094, 0123, 0124, 0125, 0185, 0189, 0302, 0323, 0338, 0400, 0439, 0439, 0462, 0496, 0535, 0536, 0538, 0548, 0559.

Object stimuli (practice trials): 1264, 1270, 1271, 1272, 1256, 1276, 1277, 1279, 1273, 1259.

Object stimuli (experimental trials): 1004, 1005, 1008, 1009, 1011, 1012, 1013, 1015, 1017, 1019, 1022, 1026, 1027, 1028, 1031, 1032, 1033, 1035, 1036, 1038, 1049, 1050, 1055, 1056, 1057, 1058, 1060, 1067, 1078, 1080, 1086, 1087, 1095, 1140, 1143, 1236, 1246, 1247, 1274, 1275.

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