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Easy to get, difficult to avoid: Behavioral tendencies toward high-calorie and low-calorie food during a mobile approach-avoidance task interact with body mass index and hunger in a community sample

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ABSTRACT

In recent years, different studies highlighted the importance of assessing behavioral tendencies toward different food stimuli in healthy and pathological samples. However, heterogeneities in experimental approaches and small sample sizes make this literature rather inconsistent. In this study, we used a mobile approach-avoidance task to investigate the behavioral tendencies toward healthy and unhealthy foods compared to neutral objects in a large community sample. The role of some contextual and stable subjective variables was also explored. The sample included 204 participants. The stimuli comprised 15 pictures of unhealthy foods, 15 pictures of healthy foods, and 15 pictures of neutral objects. Participants were required to approach or avoid stimuli by respectively pull or push the smartphone toward or away from themselves. Accuracy and reaction time of each movement were calculated. The analyses were conducted using a generalized linear mixed-effect model (GLMMs), testing the two-way interaction between the type of movement and the stimulus category and the three-way interactions between type of movement, stimulus, and specific variables (BMI, time passed since the last meal, level of perceived hunger). Our results evidenced faster approaching movement toward food stimuli but not toward neutrals. An effect of BMI was also documented: as the BMI increased, participants became slower in avoiding unhealthy compared to healthy foods, and in approaching healthy compared to unhealthy stimuli. Moreover, as hunger increased, participants became faster in approaching and slower in avoiding healthy compared to unhealthy stimuli. In conclusion, our results show an approach tendency toward food stimuli, independent from caloric content, in the general population. Furthermore, approach tendencies to healthy foods decreased with increasing BMI and increased with perceived hunger, indicating the possible influence of different mechanisms on eating-related behavioral tendencies.

1. Introduction

Eating behaviours are determined by multiple factors, which include hedonic drives, homeostatic needs, and deliberate choices. These systems do not work independently from each other, but they are integrated at different levels, ranging from genes to behaviours (Saper et al., 2002). To date, many research efforts have been made to understand how these mechanisms work in determining food intake and weight regulation (Makaronidis & Batterham, 2018; Woods & D'Alessio, 2008). Physiological models suggest the presence of feedback mechanisms regulating the balance between caloric intake and expenditure at a set point, which is probably encoded in the brain (Speakman et al., 2011). However, they

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struggle to explain many aspects related to social, environmental, and psychological determinants of eating behaviours, that appear particularly relevant in modern Western environments as well as in abnormal eating behaviours, such as sustained overeating or undereating often observed in eating disorders (Giskes et al., 2011; Keel & Forney, 2013). Cognitive research on nutrition has particularly focused on trying to understand how the balance between cognitive control mechanisms and behavioural automaticity may alter respective to certain food categories and contribute to abnormal eating patterns (Fürtjes et al., 2020; Kakoschke et al., 2017). Various experimental paradigms have been proposed in order to explore the role of the different bottom-up/top-down processes in the regulation of eating behaviours, focusing in particular on those mechanisms sustaining the cognitive processing of foods from early attention to motor action (Hou et al., 2011). Exploring these mechanisms could help explain the respective role of cognitive control/behavioural automaticity in regulating food intake and identifying potential treatment targets if dysregulation occurs at that level.

In recent years, an experimental paradigm that has sparked some interest in assessing automatic tendencies toward food is the approach-avoidance task (AAT). This task was introduced by Solarz (1960) and later adapted for use on personal computers (Chen & Bargh, 1999; Rinck & Becker, 2007). The traditional AAT requires participants to pull or push a joystick in response to a picture, e.g., high-calorie food. Automatic approach tendencies are reported if pulling in response to food is faster than pushing. The central assumption of this paradigm is that approach and avoidance behaviours deploy with a certain level of congruity with the appetitive or aversive value of a stimulus (Kakoschke et al., 2019). In the eating domain, approach/avoidance tendencies have been assessed with respect to different characteristics related to both food qualities (for example, palatability, calorie content, level of processing) and subjective status or attitudes (for example, levels of food craving or hunger scores) (Castellanos et al., 2009; Moore et al., 2022). Moreover, some studies have focused on clinical samples to explore whether biased tendencies toward food may sustain specific disordered eating patterns (Kollei et al., 2022; Loijen et al., 2020). However, a methodological limitation in assessing behavioural tendencies toward food has been recently highlighted with regard to the experimental setup. To date, most studies have used a joystick-based paradigm, which has been criticized since it might excessively limit the extension of motor trajectories (Schroeder et al., 2016), the naturalistic value of movements (Meule et al., 2020), and, more in general, the ecological experimental validity (Lange & Pauli, 2019). Based on these observations, recent research has used paradigms that allow the assessment of reaching and avoiding tendencies through more naturalistic movements using virtual reality or touchscreen-based AAT (Schroeder et al., 2016; van Alebeek et al., 2021). Another experimental implementation of the AAT has been proposed by Zech et al. (2020), which involves executing the task on a smartphone. In this mobile version of the AAT, the phone must be moved closer or away from oneself in order to simulate, in a flexible and naturalistic way, an approach or avoidance movement toward a specific item. The advantages offered by this method over more conventional ones are manifold and include the possibility of performing the task through extensive and naturalistic approach/avoidance arm movements and the opportunity to perform the task in non-laboratory settings. The latter is key to recruiting larger samples and ensuring greater ecological validity.

To date, approach/avoidance tendencies towards food stimuli have been measured mostly in response to appetitive and highly palatable stimuli, in order to explore how biases in these behaviours might be associated with craving or hunger measures (van Alebeek et al., 2021; Wittekind et al., 2021). However, recent studies have broadened this focus by also including healthy and/or low-calorie food items, in order to understand whether mechanisms other than hedonics may support automatic action execution. These studies reported the presence of a greater approach tendency toward low-calorie foods compared to high-calorie foods in both the general population and overweight/obese individuals, thus suggesting a possible role of motivational drives in influencing approach tendencies (Kahveci et al., 2021; Moore et al., 2022). Overall, the heterogeneity observed among AAT research in the eating domain is suggestive of the presence of different mechanisms underlying automatic behaviours toward food. These probably include both context-related variables (hunger and desire to eat), and more stable parameters, such as liking for specific food items or other individual characteristics. In this second case (behavioural automaticity rooted in stable individual characteristics), it may also be conceivable that behavioural tendencies have some regulatory role, thus sustaining stable subjective traits that may differently influence healthy/unhealthy eating habits and which can contribute to the maintenance of individual BMI (Maas et al., 2017).

The primary aim of this study was to analyze approach/avoidance tendencies toward different types of foods (low calorie/healthy and high calorie/unhealthy) compared to neutral objects, in a large sample of subjects from the general population, ranging from underweight to overweight (BMI ranges from 17 kg/m^2 to 29 kg/m^2). The secondary aim was to test whether approach/avoidance tendencies interact with both contextual factors (i.e., hunger, time elapsed since the last meal, and wanting for specific foods) and more stable variables (i.e., liking and fear scores for specific items and BMI). For the first aim, it was hypothesized that the tested sample would show a bias towards food stimuli compared to neutral items, with no specific preference for low-calorie or high-calorie foods. With regards to the second aim, no specific hypotheses were made due to the large heterogeneity of findings in the literature, and the exploratory nature of this study.

2. Materials and methods

2.1. Participants

Participants were recruited from the general population through flyers, online adverts, and direct contact with the experimenters. Inclusion criteria were: 18 years or older, being fluent in Italian, having a BMI comprised between 17 and 30, and having a score lower than 2.8 on the global scale of the Eating Disorder Examination Questionnaire (EDE-Q) (Mond et al., 2008). In total, 244 participants completed the study. However, 7 were excluded for EDE-Q score higher than 2.8, and 33 were excluded because they did not reach the threshold for the minimum number of valid trials (see data exclusion section). The final sample consisted of 204 participants, with a mean age of 24.14 (SD = 9.12) and a BMI of 22.03 (SD = 2.76). 133 were females (age: 24.29 (SD = 8.76), BMI: 21.35 (SD = 2.57)), and 71 were males (age: 23.87 (SD = 9.83), BMI: 23.28 (SD = 2.68)). Post-hoc power analysis revealed that given the 204 participants, the power to detect a significant interaction with a small (Cohen's $f = 0.10$), medium (Cohen's $f = 0.25$), and large (Cohen's $f = 0.40$) effect size, at a significant level $\alpha = 0.05$, and assuming a correlation among repeated measures of $r = 0.5$ is respectively $1\text{-}\beta = 0.81$, $1\text{-}\beta = 0.99$, $1\text{-}\beta = 1.0$.

All participants provided written informed consent prior to testing. The study was approved by the ethical committee of the Department of Psychology at the University of Padova (protocol number: 4149) and was conducted in accordance with the latest version of the Declaration of Helsinki.

2.2. Mobile AAT application

The mobile AAT app was programmed in Java using Android Studio (Zech et al., 2020). It could be downloaded from the University of Padova website (http://aatmobile.neuroscienze.unipd.it/) and installed on any Android smartphone. Once the application was started, participants provided written informed consent and confirm to be over 18 years old. Then, they were asked to report the following demographic and clinical information: age, education level, work condition, height, weight, and pharmacological treatment. To control for the effect of hunger, participants also reported the time passed since their last meal (in minutes) and the perceived level of hunger (on a scale from 1 to 5). Following this initial assessment, participants completed the approach-avoidance task, which is described in more detail in the following section. At the end of the task, they rated their level of liking (how much do you like the taste of this food?), wanting (how much would you like to eat this food in this moment?), and fear (how much anxiety does the idea of eating this food cause you?) towards each of the food stimuli observed during the task using a likert scale going from 1 to 5.

Lastly, participants completed the EDE-Q (Calugi et al., 2017; Fairburn & Beglin, 1994) which is a 28-item self-report measure of eating disorder psychopathology in which higher scores reflect greater severity, with a cut-off ≥2.8 on the global EDE-Q score for probable clinical cases (Mond et al., 2008).

2.2.1. Approach-avoidance task

In the AAT, participants were required to approach or avoid specific stimuli by either pulling their phone toward themselves or pushing it away, as shown in Fig. 1.

The stimuli comprised 15 pictures of high-calorie and high-processed foods (HCF), 15 pictures of low-calorie and low-processed foods (LCF), and 15 pictures of neutral objects (N). The pictures were all selected from the food.pics database (Blechert et al., 2019),[1] and an analysis of their characteristics revealed that HCF pictures had a significantly higher intensity (F (2,42) = 7.40, p = .002) and complexity (F (2,42) = 10.89, p < .001) than LCF and neutral pictures (Blechert et al., 2019).

Before starting the experiment, participants were provided with written instructions and two animated GIFs that displayed how to perform the approach and avoidance movements. The task was divided into two blocks. In one block, participants were instructed to pull food stimuli toward themselves and push objects away from themselves, while in the other block participants had to approach neutral objects and avoid food stimuli. The order of block presentation was randomized between participants. During each block, 20 pictures of each category (HCF, LCF, neutral objects) were presented, for a total of 120 trials. At the beginning of each block, and in the middle of each block, participants were instructed as to which stimuli to approach and which ones to avoid, and they were asked to respond as fast as possible. Each trial started with a fixation point, displayed for 1500 ms. Following the fixation point, a picture was displayed in the middle of the screen. If participants did not respond to the picture within 2 s, a clock was displayed on the screen to inform them that the trial had timed out. Before starting the real test, participants were provided with a series of additional practice trials, which were followed by a response feedback (an X for incorrect responses, and a V for correct responses). Participants could start the real test only after correctly responding to 16 practice trials.

For each trial, the phone's accelerometers and gyroscopes tracked the gravity- and rotation-corrected acceleration of the movement in the direction perpendicular to the face of the screen (100Hz sampling rate). Based on the acceleration response, the accuracy and reaction time (RT) of each movement were calculated. The procedure to preprocess data was the same used by Zech et al. (2020).

2.3. Statistical analyses

2.3.1. Data exclusion

Following the procedure suggested by Zech et al. (2020), practice trials, error trials, trials with missing sensor data, and trials with RT below 200 ms or over two standard deviations from the mean RT were considered invalid. Participants with less than 80% valid experimental trials were excluded. In total, 33 participants were excluded and within the final sample, 9.75% of the experimental trials were excluded.

2.3.2. Data analysis

Statistical analyses were performed in R (R Core Team, 2022). Firstly, we were interested in assessing whether RTs of approach and avoidance movements were influenced by the type of stimulus. Since RTs were not normally distributed, we decided to test our hypothesis using a generalized linear mixed-effect model (GLMM), with a model tested under a Gamma distribution (identity link function). Participants' ID and trial number were used as clustering and random variable, respectively, and mixed effect models were used because of the advantage to account for repeated measures and missing data. We decided to set a priori comparisons and, in particular, reverse Helmert contrasts were used to test the average difference in RTs between (a) neutral objects and food in general, and (b) between high and low-calorie foods. For both contrasts, we were mainly interested in the two-way interaction between the type of movement (approach vs avoid) and the stimulus category (food vs objects; low vs. high-calorie foods).

The GLMMs were tested using the lme4 package (Bates et al., 2015) on R software (R Core Team, 2022). Effect sizes were estimated by calculating Cohen's d through the t_to_d() function belonging to the effectsize package (Ben-Shachar et al., 2020). To avoid possible confounding factors, gender was added to the model as a covariate. Age was not used as a covariate because it had a very small standard deviation. Post hoc comparisons were tested using the emmeans package (Lenth, 2016).

As a second set of analyses, we wanted to test whether the previous model could be influenced by other variables, such as participants' BMI, time passed since last meal, and level of perceived hunger. For each of those variables, independent GLMMs were calculated to establish the three-way interactions between type of movement, stimulus (food/objects and HCF/LCF), and each variable. Since those variables were measured on continuous scales, whenever significant interactions occurred, both simple slope analyses and/or post hoc comparisons across equivalent intervals on the third variable were performed. For instance, in the case of the BMI, values were clustered into intervals of 3 points (i.e.., 17, 20, 23, and over 26). To control for possible confounding factors, the linear associations between hunger, time passed since the last meal, and BMI were tested with Spearman's rank correlations.

Finally, it was tested whether the RTs of approach and avoidance movements could be influenced by liking, wanting, and fear ratings on a trial-by-trial base. GLMMs were calculated to test two-way interactions between type of movement and liking, wanting, or fear.

3. Results

3.1. Type of movement by stimulus interaction

Concerning the comparison between neutral objects and food in general, a statistically significant two-way interaction between type of movement and stimulus emerged ($\beta = -49.73$, $p < .001$, $d = 0.41$, Fig. 2). In particular, participants were faster in approaching than avoiding food stimuli, while this effect was not observed for neutral objects, suggesting the presence of an approach bias only in response to food stimuli. No significant interaction (stimulus x type of movement) was observed for the comparison between HCF and LCF stimuli ($\beta = -27.63$, $p = .46$, $d < 0.001$).

Considering the main effects, we observed that participants were generally faster in responding to food than neutral stimuli ($\beta = 32.42$, $p < .001$, $d = 0.25$) and they were faster in responding to LCF compared to HCF stimuli ($\beta = 12.17$, $p < .001$, $d = 0.14$). In general, participants were also faster in approaching stimuli rather than avoiding them ($\beta = 24.62$,

[1] IDs of selected pictures: HCF (17, 20, 22, 25, 48, 68, 88, 106, 107, 131, 145, 167, 310, 339, 514); LCF (215, 249, 250, 251, 252, 258, 260, 261, 267, 278, 365, 430, 432, 460, 466); N (1009, 1012, 1026, 1059, 1130, 1132, 1144, 1151, 1155, 1210, 1213, 1218, 1251, 1256, 1273).

Fig. 1. Experimental Setup. The task consists of two blocks, the order of which is randomized. In one block participants are instructed to pull food stimuli toward themselves and push objects away from themselves, while in the other block participants have to approach neutral objects and avoid food stimuli. During each block, 20 pictures of each category (HCF, LCF, neutral objects) are presented, for a total of 120 trials.

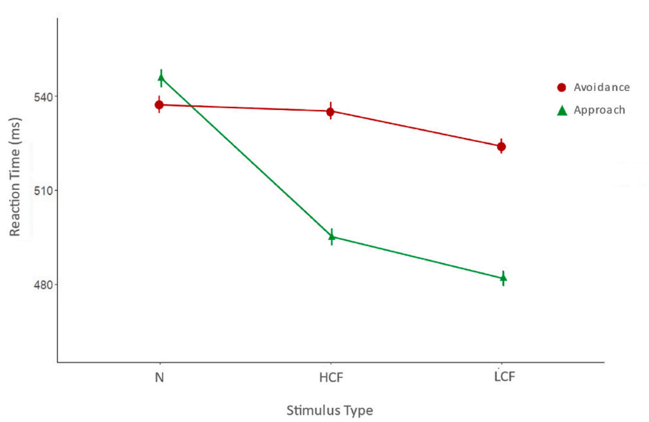

Fig. 2. Mean (SE) reaction times for avoidance and approach movements for the three categories of stimuli. Abbreviations: N, neutral objects; HCF, high-calorie foods; LCF, low-calorie foods.

$p < .001$, $d = 0.22$).

3.2. The association with the BMI

Concerning the comparison between neutral objects and food in general, there was a statistically significant 3-way interaction between BMI, stimulus, and type of movement ($\beta = 1.26$, $p < .001$, $d = 0.05$, Fig. 3). In particular, although participants were generally faster in approaching food compared to neutral stimuli, this difference decreased as BMI increased, thus suggesting a reduced approach bias toward foods with increasing BMI (Table 1). As regards avoidance movements, the difference between food and neutral objects increased as the BMI decreased, and post hoc comparisons revealed that only participants in the lowest BMI range were faster in avoiding food stimuli than neutral objects (Table 1).

Comparing high- and low-calorie food stimuli, the results showed that the 3-way interaction (BMI x stimulus x type of movement) was significant ($\beta = 1.17$, $p < .001$, $d = 0.06$). As the BMI increased, participants became slower in avoiding HCF compared to LCF, and slower in approaching LCF compared to HCF, thus suggesting a reduced approach tendency toward LCF compared to HCF at increasing BMI (Fig. 4).

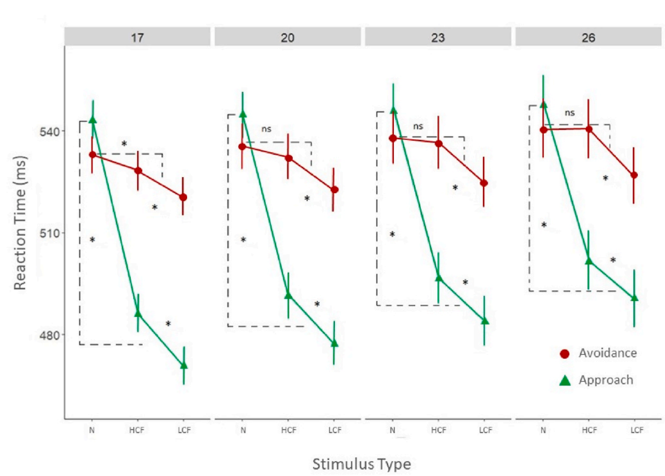

Fig. 3. Mean (SE) reaction times for avoidance and approach movements for the three categories of stimuli at different BMI ranges. Abbreviations: N, neutral objects; HCF, high-calorie foods; LCF, low-calorie foods.

3.3. The association with hunger

As regards the comparison between food stimuli and neutral objects there was no significant 3-way interaction with hunger and type of movement ($\beta = -2.35$, $p = .20$, $d = 0.12$, Fig. 5).

However, there was a significant three-way interaction for hunger, stimulus, and type of movement when considering HCF and LCF ($\beta = -3.28$, $p = .01$, $d = 0.26$). In particular, as hunger increased, participants became faster in approaching and slower in avoiding LCF compared to HCF, thus suggesting an increased approach bias toward LCF compared to HCF at increasing levels of hunger. Accordingly, post hoc analyses showed that while participants were generally faster in avoiding LCF than HCF, participants who reported the higher level of hunger did not show this difference (Table 2).

3.4. The association with time passed since last meal

The mean time passed since the last meal was of 160.92 min (range: 0–802 min). For this model, neither the comparison between food stimuli and neutral objects ($\beta = -0.01$, $p = .695$, $d < 0.001$) or the comparison between HCF and LCF ($\beta = -0.03$, $p = .242$, $d = 0.02$)

Table 1
Post-hoc contrasts for different levels of BMI.

BMI	Food vs Neutral		HCF vs LCF	
	Avoidance Estimate (*p*)	Approach Estimate (*p*)	Avoidance Estimate (*p*)	Approach Estimate (*p*)
17-19 (51)	**17.13 (.040)**	**129.46 (<.001)**	**7.76 (.016)**	**15.56 (<.001)**
20-22 (87)	15.91 (.123)	**120.70 (<.001)**	**9.80 (.008)**	**14.10 (<.001)**
23-25 (51)	14.69 (.262)	**111.95 (<.001)**	**11.83 (.005)**	**12.63 (.001)**
>26 (19)	12.66 (.574)	**97.35 (<.001)**	**15.23 (.003)**	**10.22 (.036)**

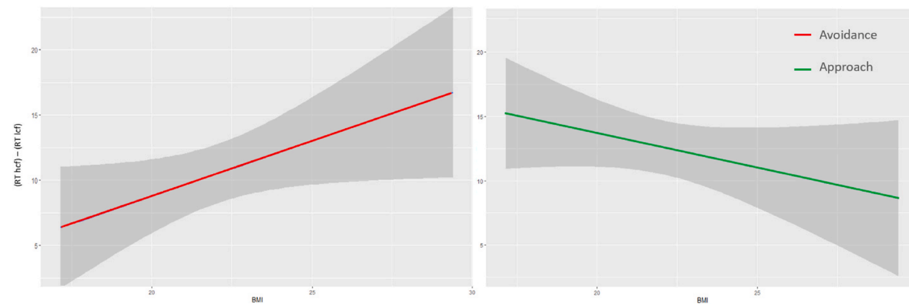

Fig. 4. Differences in RT between HCF and LCF for the two types of movements as a function of the BMI. As the BMI increases participants become slower in avoiding and faster in approaching HCF compared to LCF. Abbreviations: N, neutral objects; hcf, high-calorie foods; lcf, low-calorie foods.

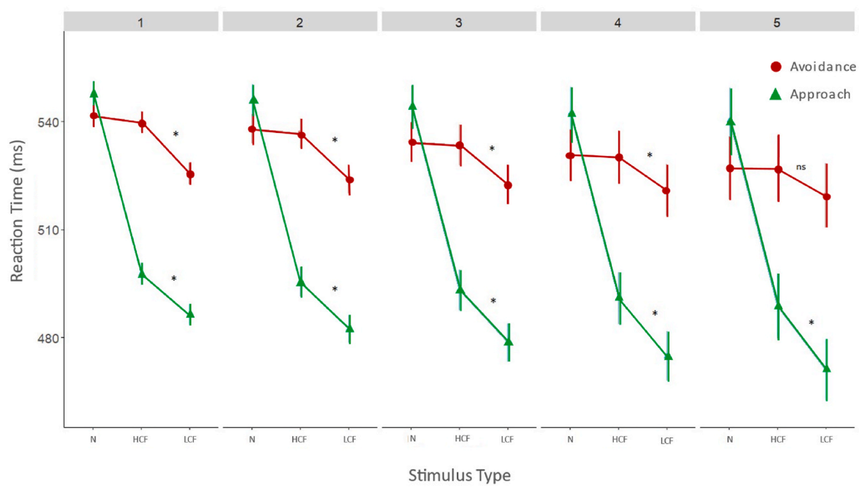

Fig. 5. Mean (SE) reaction times for avoidance and approach movements for the three categories of stimuli at different hunger levels. 1 = lowest hunger, 5 = highest hunger. Abbreviations: N, neutral objects; HCF, high-calorie foods; LCF, low-calorie foods.

Table 2
Post-hoc contrasts for different levels of hunger.

Hunger (N)	HCF vs LCF	
	Avoidance Estimate (*p*)	Approach Estimate (*p*)
1 (63)	**14.33 (<.001)**	**11.42 (<.001)**
2 (59)	**12.63 (<.001)**	**13.00 (<.001)**
3 (45)	**10.93 (.002)**	**14.58 (<.001)**
4 (32)	**9.23 (.030)**	**16.16 (<.001)**
5 (4)	7.53 (.212)	**17.74 (<.001)**

revealed a significant three-way interaction.

3.5. The association with wanting, liking, and fear scores

None of the three scores showed a statistically significant interaction with the type of action (Wanting: $\beta = -0.74$, $p = .64$, $d = 0.04$; Liking: $\beta = -0.05$, $p = .97$, $d < 0.001$; Fear: $\beta = -0.11$, $p = .94$, $d < 0.001$).

3.6. Correlations between different measures

Neither hunger nor time passed since the last meal showed a significant linear correlation with the BMI (hunger: $\rho = 0.02$, $p = .790$; time: $\rho = 0.02$, $p = .740$). Hunger and time passed since the last meal correlated weakly ($\rho = 0.20$, $p < .001$).

4. Discussion

In this study, approach/avoidance tendencies toward food stimuli varying in calorie content (i.e., high-calorie/high-processed and low-calorie/low-processed food) and neutral objects were measured by means of a dedicated mobile-based AAT in a large sample recruited from the general population. Interactions between automatic tendencies toward food and individual variables, such as BMI, hunger level, time elapsed since the last meal, and food liking, wanting, and anxiety were also explored.

As for the first aim of this work, our data demonstrated an automatic preference for food over neutral objects. Indeed, participants were generally faster in approaching food stimuli compared to neutral ones, while no differences were observed concerning avoidance movements. The automatic preference for approaching foods compared to neutral objects is in line with our hypothesis and corroborates the proposal that the appetitive value of a stimulus can play a role in the behavioural disposition toward it (Kemps et al., 2013; Piqueras-Fiszman et al., 2014). The lack of a difference concerning avoidance movements, instead, is probably explained by the absence of negative/aversive stimuli in our experimental setup.

As concerns the difference between high-calorie/high-processed foods and low-calorie/low-processed foods, we didn't observe any significant result. The lack of a difference in reaction times based on calorie content suggests that this behavioural response may be underpinned by a nonspecific propensity towards food in general, rather than towards food items with specific caloric content. Overall, this result is consistent with previous AAT studies that investigated differences in automatic tendencies between foods with different caloric content in the general population (Kahveci et al., 2021; Paslakis et al., 2016). These studies are indeed fairly consistent in not showing a general approach tendency for high-calorie foods compared to low-calorie foods. More consistent differences between high-calorie and low-calorie foods seem, instead, to emerge in more homogeneous samples of individuals with abnormal eating behaviours or attitudes (e.g. patients with eating disorders, obese individuals, or individuals craving for specific foods) (Kemps et al., 2013; Kollei et al., 2022; Moore et al., 2022).

This observation suggests that behavioural dispositions towards specific categories of foods may be sustained and better explained by individual characteristics, and thus support the importance of investigating them more specifically. In this study, we decided to assess the predictive valueof parameters that represent both stable subjective traits, such as BMI and anxiety/liking scores, and context-related features, such as hunger level, time elapsed since the last meal, and craving level for specific items.

Regarding the BMI and the comparison between food in general and neutral objects, a statistically significant effect of the BMI was found. This result indicates that as the BMI changes, different behavioural responses toward food compared to neutral objects are observed. In the current study, unexpectedly, although participants were always faster in approaching food stimuli than neutral items, this difference decreased as BMI increased, suggesting a reduced approach bias toward foods in individuals with higher BMI. Note, however, that this comparison included both high and low-calorie foods. With regards to avoidance tendencies, while participants in the lowest BMI range were faster in rejecting food items compared to neutral stimuli, no differences were observed in the other BMI ranges. Faster avoidance of food stimuli at lower BMI ranges suggests the presence of regulatory mechanisms facilitating the maintenance of a limited caloric intake. Indeed, if this implicit reaction was also reflected in explicit behaviours in everyday life, it could represent a key element of the processes regulating food intake homeostasis (Cifuentes & Acosta, 2022).

When comparing the effect of BMI on the approach/avoidance tendencies toward high- and low-calorie food cues, results showed that as BMI increased, participants became slower in avoiding high-calorie foods compared to low-calorie foods. This evidence is in line with findings from a study using a joystick-based task assessing approach tendencies towards sweet snacks, salty snacks, and neutral pictures, which found that individuals with higher BMI showed an impaired ability to avoid sweet snacks specifically (Maas et al., 2017). Moreover, as the BMI increased, participants became slower in approaching low-calorie foods compared to high-calorie foods. This suggests that the approach tendency towards healthy foods decreases with increasing BMI. Overall, these approach-avoidance tendencies toward food could partially explain why individuals with higher BMI might be more likely to experience difficulties in avoiding high-calorie foods, while participants with lower BMI might be more inclined to consume low-calorie and healthy foods. To establish whether this trend may be associated with actual food intake, further studies that objectively measure food intake and possible associations between these and mobile AAT scores are needed.

With regards to the predictive value of other context-independent factors, results show no significant association of either food-related liking or anxiety with approach and avoidance tendencies toward specific foods. In this regard, it is useful to consider that these data were collected in a sample of subjects recruited from the general population and in a weight range that excludes clinical presentations. It is therefore possible to hypothesize that in non-clinical conditions, these factors do not predict the automatic propensity toward food. At the same time, it is possible that these factors exert a more marked effect in specific clinical populations (e.g., obesity, anorexia nervosa). Moreover, it is important to interpret these findings with caution, as they are based on preliminary data. Specifically, the measures used to assess liking and anxiety tendencies were limited to single items. Future studies should examine the reliability and sensitivity of these items or adopt more comprehensive measures.

Regarding context-dependent measures, the approach tendency toward high-calorie and low-calorie foods seemed to be predicted by perceived hunger, which replicates previous studies (Castellanos et al., 2009). In the present study, higher levels of hunger were associated with a faster approach and a slower avoidance of low-calorie compared to high-calorie foods, suggesting an increase in the approach bias toward healthy foods as hunger increases. The interpretation of this result is not straightforward, and it should also be noticed that hunger was not experimentally manipulated, but only self-reported by participants. Therefore, future studies are needed to better clarify the effect of hunger on approach/avoidance tendencies.

Although time passed since the last meal was positively associated with perceived hunger, it did not predict approach/avoidance tendencies toward foods, and neither did the reported level of craving for specific stimuli.

4.1. *Strengths and limitations*

Compared to previous studies, this study has the strength of having assessed approach/avoidance tendencies toward foods in the general population by recruiting a large number of participants and by adopting a novel and ecological paradigm, i.e., a mobile-AAT. Moreover, the inclusion of both HCF, LCF, and neutral objects, together with the examination of various stable and context-dependent variables, provides a comprehensive description of automatic approach/avoidance tendencies toward foods and of the factors that might influence them.

Despite these strengths, this study has also some limitations. Firstly, as also described in the method sections, the pictures depicting HCF were, on average, more intense and complex than LCF and neutral pictures. These differences in visual characteristics may have affected content processing and recognition, thus influencing reaction times at a general level. Since the main focus of the work was the interaction between stimulus and type of movement, this does not impact conclusions. However, future studies could try to avoid this confounding factor by matching pictures for visual characteristics. The second limitation is that most participants had a BMI comprised between 17 and 25, and therefore splitting the sample into different BMI ranges did not produce equal sample sizes. Similarly, in the post-hoc analysis regarding hunger levels, it should be noted that only 4 participants reported the highest level of hunger, thus possibly explaining the absence of a significant difference in the avoidance of HCF compared to LCF in this subgroup. A third limitation is that by contrasting pleasant food items with neutral objects, it is not possible to assess whether the observed differences in approach-avoidance tendencies are caused by valence (positive vs neutral) or by edibility. Lastly, many of the variables included in the analyses were self-reported (e.g. BMI, time passed since last meal).

4.2. *Conclusions*

To conclude, our results show an overall approach tendency toward food stimuli, independent from caloric content, in the general population. Differences between HCF and LCF only emerged when specific individual characteristics were added to the model. In particular, approach tendencies to low-caloric foods decreased with increasing BMI and increased with perceived hunger, thus suggesting the presence of various mechanisms influencing eating behaviours. The possibility of disentangling the biological, psychological, and behavioural mechanisms underpinning the interaction between BMI and behavioural tendencies appears to be particularly important to understand how food intake is determined and regulated.

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Ethical statement

Hereby, I Enrico Collantoni consciously assure that for the manuscript "Easy to get, difficult to avoid: Behavioral tendencies toward high-calorie and low-calorie food during a mobile approach-avoidance task interact with body mass index and hunger in a community sample" the following is fulfilled:

1) This material is the authors' own original work, which has not been previously published elsewhere.
2) The paper is not currently being considered for publication elsewhere.
3) The paper reflects the authors' own research and analysis in a truthful and complete manner.
4) The paper properly credits the meaningful contributions of co-authors and co-researchers.
5) The results are appropriately placed in the context of prior and existing research.
6) All sources used are properly disclosed (correct citation). Literally copying of text must be indicated as such by using quotation marks and giving proper reference.
7) All authors have been personally and actively involved in substantial work leading to the paper, and will take public responsibility for its content.

Credit statement

Enrico Collantoni: Conceptualization, Methodology, Software, Formal analysis, Investigation, Writing – Original Draft, Visualization, Project administration. Valentina Meregalli: Conceptualization, Methodology, Formal analysis, Investigation, Writing – Original Draft. Umberto Granziol: Methodology, Formal Analysis, Writing – Original Draft. Cristiano Gerunda: Methodology, Software. Hilmar Zech: Methodology, Formal Analysis, Software, Writing – Review & Editing. Philipp A. Schroeder: Conceptualization, Methodology, Writing – Review & Editing. Elena Tenconi: Methodology, Investigation, Resources, Writing – Review & Editing. Valentina Cardi: Methodology, Investigation, Resources, Writing – Review & Editing. Paolo Meneguzzo: Investigation, Writing – Review & Editing. Matteo Martini: Investigation, Writing – Review & Editing. Enrica Marzola: Conceptualization, methodology, investigation, Writing – Review & Editing. Giovanni Abbate-Daga: Conceptualization, Resources, Writing – Review & Editing, Supervision. Angela Favaro: Conceptualization, Methodology, Resources, Funding acquisition, Writing – Review & Editing, Supervision.

Declaration of competing interest

The authors have no competing interests to declare.

Data availability

Data will be made available on request.

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