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Touchscreen-based assessment of food approach biases: Investigating reliability and item-specific preferences

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ABSTRACT

Strong cravings for unhealthy foods and implicit tendencies to approach them threaten the physical and mental health of vulnerable populations. Yet, implicit measures of food approach tendencies have methodological limitations, as existing approach-avoidance tasks (AAT) are often unreliable and require specialized hardware. We propose a novel method to measure approach biases: on a touchscreen, participants slide their hand either toward a food item (and away from control images) or away from it (and toward control images) in separate blocks. Adequate attention to the stimuli is ensured by the coupling of stimulus category to the required response. We found that this touchscreen-variant of the AAT yielded reliable bias scores when approach and avoidance were defined as movements relative to the stimulus rather than to the body. Compared to control images, we found an approach bias for low-calorie foods but not for high-calorie foods. This bias additionally varied on a food-by-food basis depending on the participant's desire to eat individual food items. Correlations with state and trait cravings were inconclusive. Future research needs to address the order effects that were found, in which participants avoiding foods in the first block showed larger biases than participants approaching food in the first block, likely due to insufficient opportunity to practice the task. Our findings highlight the need for approach bias retraining paradigms to use personalized stimulus sets. The task can enrich the methodological repertoire of research on eating disorders, obesity and cognitive bias modification.

1. Introduction

1.1. Approach biases to food

We often eat without feeling hungry, and we consume unhealthy foods despite being aware of their negative physical effects. These eating behaviours conflict with explicit dietary knowledge, and may instead be endorsed by *implicit* approach behaviours towards palatable but unhealthy foods. These approach biases to appetitive stimuli are assumed to arise through reward-based learning mechanisms (Berridge, 2009): With repeated exposure, we implicitly learn which combinations of stimuli and behaviours (e.g., palatable foods and approach movements) precede pleasurable sensations; as a consequence, we automatically prepare the respective behaviour when perceiving the stimuli (Lehner, Balsters, Herger, Hare, & Wenderoth, 2016).

High-calorie food may reinforce stimulus-response associations, as evolutionary theories posit that we are equipped with mechanisms that facilitate energy-dense food intake (Speakman, 2013). For example, new-borns prefer flavours that signal high calorie content, and high-calorie foods elicit more widespread activation than low-calorie foods in brain regions associated with emotion, motivation and response selection (Mennella, Bobowski, & Reed, 2016; Blechert, Klackl, Miedl, & Wilhelm, 2016; Killgore et al., 2003). In the modern world, hyper-appealing foods (high in salt, glutamate, sugar and fat) may lead to the development of stimulus-response associations that are difficult to control (Breslin, 2013). If regulatory mechanisms fail to inhibit strong approach biases, overeating and weight gain may be the consequence (Wiers, Gladwin, Hofmann, Salemink, & Ridderinkhof, 2013). With society facing an obesity epidemic, it is therefore of major interest to be able to reliably assess and modify approach biases towards food (Ravussin & Ryan, 2018).

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1.2. *The approach-avoidance task*

Approach biases towards food have been quantified with the approach-avoidance task (AAT; Phaf, Mohr, Rotteveel, & Wicherts, 2014). In broad terms, the AAT requires some stimuli to be approached and others to be avoided, resulting in reaction time data on how quickly the participant approaches and avoids different types of stimuli. Faster approach than avoidance to food pictures in comparison to neutral pictures is interpreted as an approach bias towards food stimuli. Current AAT implementations differ with regard to the task layout and the input devices that are used to simulate approach and avoidance movements: most studies signal that a stimulus is being approached and avoided by zooming it in or out (e.g. Rinck & Becker, 2007) or by moving an avatar of the participant closer to or further away from it (Krieglmeyer & Deutsch, 2010), but a sizeable minority of studies rotates the stimulus towards or away from the viewer (Voncken, Rinck, Deckers, & Lange, 2012), or moves the stimulus or participant in an on-screen 3D-environment (Rougier et al., 2018) or in virtual reality (Jahn, Niehaves, Gethmann, & Brück, 2019; Schroeder, Lohmann, Butz, & Plewnia, 2016). Participant responses are provided most frequently using a joystick or keyboard, but researchers have also used mechanical levers, touchscreens, computer mice, and motion sensors.

1.3. *Validity of the food approach-avoidance task: craving, calories and food preferences*

Both state and trait characteristics correlate with approach biases in the food domain. When it comes to stable and trait-like characteristics, stronger approach biases to foods have been reported in students with high self-reported levels of unwanted snacking behaviour (Maas, Keijsers, et al., 2017), high self-reported reward sensitivity (May, Juergensen, & Demaree, 2016) and high self-reported trait food craving (Brockmeyer, Hahn, Reetz, Schmidt, & Friederich, 2015). When it comes to state characteristics, a stronger approach bias has sometimes been found to be related to higher state food craving and to an increase in craving following exposure to palatable food images (Lender, Meule, Rinck, Brockmeyer, & Blechert, 2018; Meule, Lender, Richard, Dinic, & Blechert, 2019). Despite this evidence for a relationship between approach bias and self-reported food responsiveness, these correlations are not consistently replicated (Kahveci, Meule, Lender, & Blechert, 2020; Matheson, 2018; Meule, Richard, et al., 2019). Additionally, a recent meta-analysis calls into question whether approach bias has predictive validity for actual eating behaviour: Even though approach biases can be reduced through training, only a minority of studies show that reduced biases translate to reduced food consumption (Aulbach, Knittle, & Haukkala, 2019).

However, most of these studies have selectively assessed and modified approach biases towards a wide range of *high*-calorie foods, even though the influence of calorie density on approach bias is uncertain. Direct comparisons either have shown similar approach biases towards high-calorie and low-calorie foods (Becker, Jostmann, Wiers, & Holland, 2015; Kemps & Tiggemann, 2015; Paslakis et al., 2016) or have only observed stronger biases to high caloric foods in specific subpopulations (e.g. overweight men; Havermans, Giesen, Houben, & Jansen, 2011). While evolutionary accounts predict enhanced approach bias for energy-dense foods, cognitive and socio-cultural accounts predict that approach bias is influenced by learning mechanisms and intentional dietary goals, which may sometimes favor low-calorie foods instead (Watson, De Wit, Hommel, & Wiers, 2012). These two accounts are not mutually exclusive: the rewarding properties of evolutionarily salient food stimuli may drive reward-based learning towards high-calorie foods, while individual experiences modify these innate preferences. Therefore, next to innate evolutionary directives, approach bias may also be explained by individual experiences with food and habitual dietary choices. Indeed, a previous study showed no effect of calorie density on approach bias, but a trial-level analysis revealed faster approach responses to foods that were individually more desired by the participant (Kahveci, Meule, et al., 2020).

1.4. *Reliability of the approach-avoidance task*

In many cases, approach bias effects do not fully replicate and there is no clear picture of their size and correlation with other variables, in part because of a ‘reliability crisis’ in the broader field of cognitive bias measurement (McNally, 2019). While reliability is the basis for reproducibility, stability, and validity, it is rarely investigated in AAT studies: Only three of the aforementioned AAT studies report reliability measures (Kahveci, Meule, et al., 2020; Matheson, 2018; Meule, Lender, et al., 2019). The reliability of the AAT is strongly influenced by the foreground task. AATs instruct participants to approach or avoid stimuli based on a feature that is related to the measured bias (e.g. ‘approach objects/avoid foods’ in a study measuring food approach bias; relevant-feature AAT), or a feature that is unrelated to the measured bias (e.g. ‘approach green frame/avoid blue frame’; irrelevant-feature AAT), thus focusing the participant’s attention on that relevant or irrelevant feature. For long, the consensus has been that approach and avoidance biases occur in the absence of explicit attention to the stimuli, as early studies demonstrated faster approach-avoidance effects for emotional stimuli which were task-irrelevant (Chen & Bargh, 1999). Yet, a later meta-analysis refuted this claim: across studies, irrelevant-feature AATs achieved negligible effect sizes, whereas relevant-feature AATs on average achieved medium effect sizes (Phaf et al., 2014; see also:; Kahveci, Van Bockstaele, Blechert, & Wiers, 2020). The larger effect size of the relevant-feature task instruction is mirrored in its reliability: two studies have found that relevant-feature task instructions produced reasonable to excellent reliabilities ($r = 0.66$ to 0.95), whereas irrelevant-feature task instructions produced unreliable results ($r = -0.11$ to 0.27) (Kahveci et al., 2020; Krieglmeyer & Deutsch, 2010). These findings also apply to the food domain: only in the relevant-feature AAT did participants display an approach bias (Lender et al., 2018) and did bias scores relate to trait chocolate craving and preference for chocolate (Meule, Lender, et al., 2019). Similarly, split-half reliability for participants responding to irrelevant features was lower than for participants responding to the picture category (Meule, Lender, et al., 2019). In the current task, we therefore used relevant-feature task instructions.

1.5. *What causes bias: implementing distance change and evaluative coding*

In setting up an approach-avoidance task, it matters not just which task instructions to use, but also how approach and avoidance are defined. Here, various theoretical accounts of approach and avoidance come into play. Earlier motivational theories assumed that emotional stimuli initiate directional movements by activation of positive approach or negative avoid systems (Chen & Bargh, 1999; Duckworth, Bargh, Garcia, & Chaiken, 2002). Stemming from this motivational theory, the *specific muscle account* suggests that flexion of the biceps and the arm is associated with activation of the positive and approach-related system, whereas flexion of the triceps and extension of the arm is associated with the negative and avoidance-related system (Cacioppo, Priester, & Berntson, 1993). The specific muscle account was later superseded by the *distance-change account,* which posits that contextual factors determine whether arm extension and flexion serve the functional goals of approaching or avoiding a stimulus. Consequentially, positive and negative stimuli stimulate movements that decrease or increase the distance between the person and object, whatever those movements may be (Bamford & Ward, 2008). In this context, approach is defined as reducing the distance between oneself and the stimulus, whereas avoidance is defined as increasing the distance between oneself and stimulus. The most flexible account is the *evaluative coding account.* Without assuming underlying motivational systems, the evaluative coding account suggests that a match or mismatch between event codes of muscle responses and event codes of stimuli produces approach and avoidance biases (Eder & Rothermund, 2008; Lavender & Hommel, 2007). Event codes may be implicitly associated to the muscle movement by the functional goal of the action (distance decrease = approach; distance increase = avoid) or by explicit task instructions which describe muscle movements as ‘approach’ or ‘avoidance’. For example, switching the description for the same muscle movement has been found to change in approach and avoidance biases: Pulling a joystick towards oneself is usually faster for positive stimuli, but if pulling a joystick towards oneself is described as ‘avoidance’, the movement is faster for negative stimuli (Laham, Kashima, Dix, & Wheeler, 2015; Phaf et al., 2014). Consequentially, if a stimulus is associated with positive affective event codes such as approach, then it will facilitate whichever movement is associated with approach at that moment, be it arm flexion or extension; likewise, if a stimulus is associated with negative affective event codes such as avoidance, it will facilitate movements currently associated with avoidance.

Movement labels may especially drive bias effects if the movements themselves are not clearly interpretable as approach or avoidance, as is the case when approach and avoidance responses are initiated by moving a joystick or computer mouse: pulling a joystick towards oneself can be considered an approach movement, as the distance between the hand and the body is reduced, but it can also be considered an avoidance movement, as the distance between the hand and the stimuli on the screen is increased (Seibt, Neumann, Nussinson, & Strack, 2008). The opposite logic applies to pushing the joystick away from oneself. A zoom-effect has been used to disambiguate the meaning of these movements: pushing the joystick shrinks the stimuli, thereby signalling avoidance, whereas pulling the joystick enlarges the stimuli, thereby signalling approach (Rinck & Becker, 2007). While the zoom-effect successfully resolves perspective ambiguity, manipulating a stimulus’ position at distance is less naturalistic than moving oneself to approach or avoid a stimulus (Rougier et al., 2018). Indeed, moving a self-representing avatar towards or away from an unmoving stimulus on a screen was found to yield stronger approach biases in comparison to the joystick AAT and its zoom-variant across three experiments (Krieglmeyer & Deutsch, 2010). To further improve sensitivity of the AAT, we developed a variant of the latter task in which the self-representing avatar is replaced by the real hand of the participant on a touchscreen. Moving one’s hand towards and away from a stimulus avoids abstract representation of the self on a screen, while at the same time, motoric and visual sensations are more ecologically valid.

1.6. *The present study*

We aimed to develop a touchscreen-based measure of food-related approach and avoidance behaviour. In the current experiment, participants moved their hand either towards or away from an image of either a high-calorie food, a low-calorie food, or a neutral object, which was displayed on either the proximal or distal side of a large touchscreen. Participants could interpret the movement differently depending on their point of reference: while we labelled a distance change with respect to the stimuli as approach and avoidance, participants could have perceived the distance change between their hand and their body as approach or avoidance. For example, on approach trials with a distally presented stimulus, the stimulus-relative distance decreases (approach) but the body-relative distance simultaneously increases (avoidance; Fig. 1). Simultaneously, this setup allowed us to investigate the influence of specific muscle activations: approaching proximal stimuli requires arm flexion and avoiding them requires arm extension, which should cause stronger approach bias for proximal than for distal stimuli if the brain is hard-wired to approach through arm flexion and avoid through arm extension. We thus included an examination of the effect of stimulus location (proximal vs. distal) in our analyses, and we compared stimulus-relative and body-relative distance change operationalisations of approach and avoidance.

As pre-registered, we hypothesized significant approach biases toward both low- and high-calorie foods. We expected acceptable validity as evident in positive correlations with picture ratings of palatability and desire to eat (as was found by Kahveci, Meule, et al., 2020), and with state as well as trait food craving (Brockmeyer et al., 2015; Lender et al., 2018). We also examined the task’s overall reliability and explored how its reliability is affected when task length is varied by omitting trials. Exploratory analyses further investigated the relationship between approach bias on the one hand and hunger ratings and body mass index (BMI) on the other hand. Lastly, we explored block order effects: since foods are approached in one half of the experiment but avoided in the other half, this ‘remapping’ of instructions may make the task more difficult and thereby increase errors and reaction times. We explored the effect of block order to examine whether it introduces artificial differences in approach bias scores which do not represent a difference in underlying approach tendencies.

2. Methods

2.1. *Participants*

We tested 40 participants (8 males) between ages 19 and 43 (*M* = 24) and with a BMI between 17 and 32.6 kg/m^2 (*M* = 22.68 kg/m^2). Participants were tested between 3 PM and 7 PM, and they were required to eat something between 2 and 3 h before the testing session. Participants received course credits or €10,- for their participation. Sample descriptives of all questionnaire scores are shown in Table 1. Compared to age-matched German norms for the DEBQ (Nagl, Hilbert, de Zwaan,

Table 1
Descriptive Statistics of all Administered Questionnaires.

Questionnaires	*M*	*SD*	min.	max.
BMI	22.68	3.54	16.98	32.63
FCQ-T-r	39.18	8.51	23.00	56.00
FCQ-S-pre-craving	23.79	9.67	12.00	49.00
FCQ-S-pre-hunger	5.97	2.72	3.00	12.00
FCQ-S-post-craving	25.92	9.26	12.00	41.00
FCQ-S-post-hunger	6.36	3.21	3.00	12.00
DEBQ-restraint	2.50	0.82	1.10	4.20
DEBQ-external	3.11	0.59	1.80	4.40
PSRS	13.41	3.15	8.00	20.00
Mean desire to eat foods	4.18	1.63	1.28	8.22
Mean palatability of foods	6.21	1.03	3.62	8.53

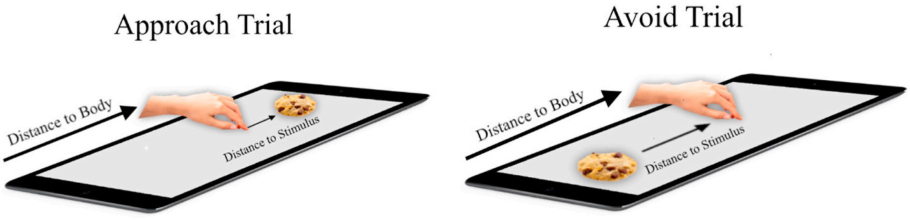

Fig. 1. The Definition of Approach and Avoidance Movements is Independent of Hand-to-Body Distance Change.

Braehler, & Kersting, 2016), the current sample scored slightly higher on restrained eating ($M_{\text{14-44-year-olds}} = 2.18$, $t\,(38) = 2.39$, $p = .022$), and external eating ($M_{\text{14-44-year-olds}} = 2.67$, $t\,(39) = 4.66$, $p < .001$).

2.2. Questionnaires

For reliability, we report both Cronbach's α and McDonald's ω (Mcdonald, 1978), as the former coefficient underestimates reliability and is based on assumptions that do not always hold (Revelle & Zinbarg, 2009; Sijtsma, 2009). In addition to the Food Craving Questionnaires, we administered the Perceived Self-Regulatory Success in dieting scale (Meule, Papies, & Kübler, 2012) as well as the Dutch Eating Behaviour Questionnaire (Van Strien, Frijters, Bergers, & Defares, 1986), but we did not consider these questionnaires for further analysis.

2.2.1. Food craving questionnaire – state (FCQ-S)

The German version of the FCQ-S (Cepeda-Benito, Gleaves, Williams, & Erath, 2000; Meule, Lutz, Vögele, & Kübler, 2012) was used to measure state food craving. It had excellent reliability in this study ($\alpha = 0.94$, $\omega = 0.95$).

2.2.2. Food craving questionnaire – trait (FCQ-T-r)

The FCQ-T-r (Meule, Hermann, & Kübler, 2014) was used to measure trait food craving. It had excellent reliability in this study ($\alpha = 0.87$, $\omega = 0.87$).

2.3. Materials and apparatus

The AAT was administered using a 23-inch iiyama ProLite T2336MSC-B2 touchscreen monitor with a resolution of 1920 × 1080 pixels, placed in portrait-format at a slight incline in front of the participant.

We used 16 low-calorie and 12 high-calorie vegetarian food stimuli from the food-pics_extended database (Blechert, Lender, Polk, Busch, & Ohla, 2019) and 4 additional high-calorie food stimuli retrieved from the internet, as there were not enough easily graspable high-calorie foods in the food-pics_extended database. The high-calorie food stimuli consisted of 8 sweet foods such as chocolate and cookies, and 8 savory foods such as crisps and nuts; the low-calorie food stimuli consisted of crackers, fruits, raw and cooked vegetables, and salads. The high-calorie food-pics_extended image IDs were 0004, 0008, 0009, 0018, 0104, 0110, 0111, 0120, 0154, 0296, 0363, and 0510. The low-calorie food-pics_extended image IDs were 0193, 0209, 0226, 0228, 0258, 0380, 0413, 0429, 0459, 0502, 0513, 0763, 0804, 0819, 0829, and 0831. The additional high-calorie food stimuli included a burrito, a sandwich, a pretzel, and a pizza slice in carton packaging. For the category of control stimuli, we retrieved two picture sets of 16 body care objects from the internet and matched them to the low-calorie and high-calorie food stimulus sets on color and size. For the food stimuli from the food-pics_extended database, we could confirm that high-calorie foods had on average three times as many calories per 100 g as low-calorie foods, $t\,(22) = 5.08$, $p < .001$, $M_{\text{LowCal}} = 143$ kcal, $M_{\text{HighCal}} = 423$ kcal, but the two categories were rated as equally familiar, $t\,(26) = 0.01$, $p = .991$, and equally recognizable, $t\,(26) = 0.23$, $p = .822$. All food stimuli from the food-pics_extended database had recognizability ratings above 90 (on a scale from 0 to 100). Participants rated all stimuli on pleasantness of grasping, and all food stimuli were additionally rated on palatability and desire-to-eat on a 9-point Likert scale.

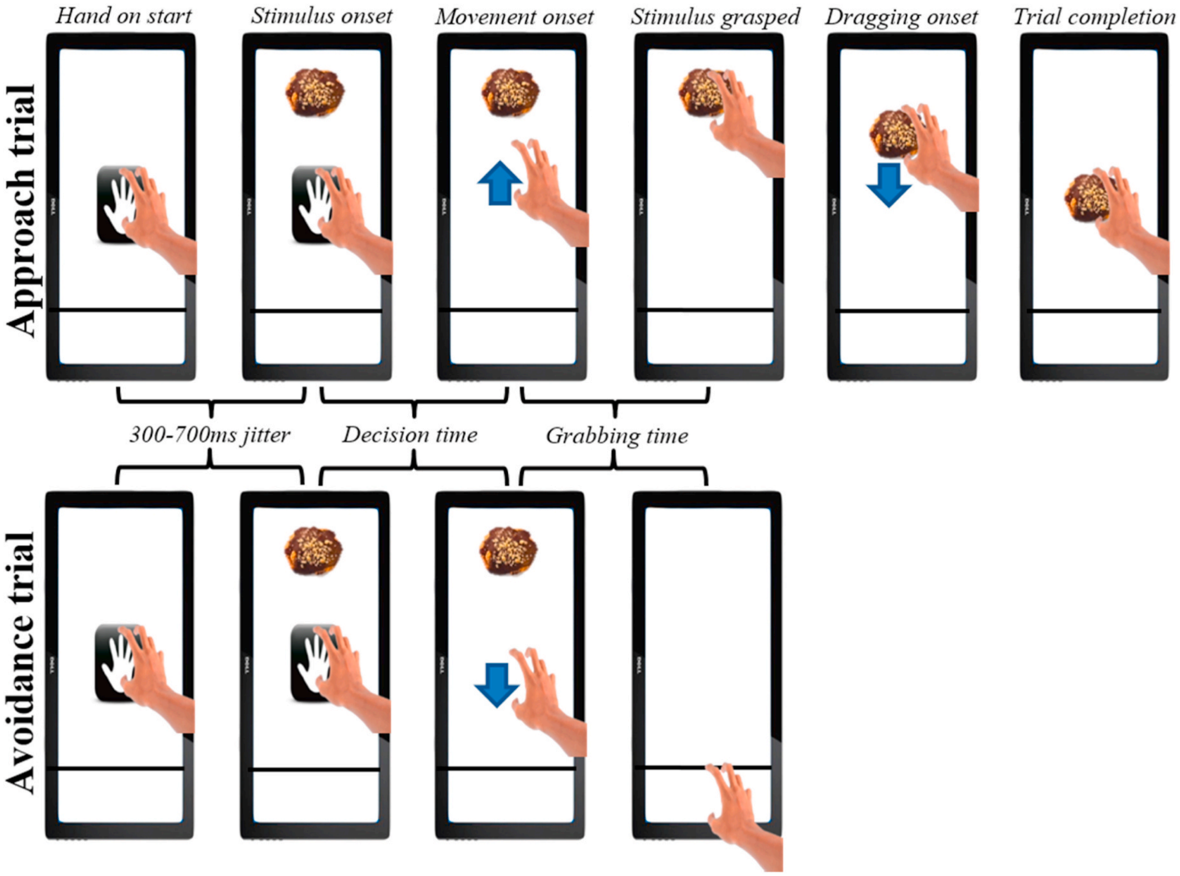

Fig. 2. Exemplary approach and avoidance trials for stimuli displayed distally.

2.4. Approach-avoidance task

Fig. 2 displays the timecourse of the approach- and avoidance trials of the current AAT. In each trial, a hand symbol was first displayed on the screen. Following a random delay between 300 ms and 700 ms after the participant placed their hand on this symbol, a stimulus was displayed either at the distal or proximal side of the screen, about 24 cm above or below the hand; an 'avoidance zone' was simultaneously displayed at the other side. Based on the pre-block instructions, the participant avoided the stimulus by sliding their hand away from it and into the avoidance zone, or they approached the stimulus by sliding their hand towards it, after which the stimulus moved along with the hand back to the center of the screen.

When the task began, participants first completed 12 practice trials featuring butterflies and leaves. Participants then completed 4 blocks with 64 trials each. At the start of each block, participants were instructed to either approach foods and avoid objects, or vice versa; this alternated from one block to the next, and the order was counterbalanced between participants. During the first two blocks, the task displayed either high-calorie food items and their matched object stimuli, or low-calorie food stimuli and their matched object stimuli; the other stimuli were displayed in the last two blocks. The order of low-calorie and high-calorie stimuli was counterbalanced between participants. Stimuli were all either displayed at the distal or the proximal side of the screen, and halfway through each block this was reversed. This was also counterbalanced between participants. Stimuli were displayed in random order. When participants made contact with the wrong side of the screen, a red flash was displayed on the stimulus or avoidance zone to indicate the error. Responses were additionally recorded as errors if the participant initiated a movement in the wrong direction, or if the participant lifted their hand off the screen.

2.5. Procedure

After signing the informed consent form, participants completed the questionnaires described in the Questionnaires section. Participants then completed AAT. After this, participants filled in the FCQ-S again, rated all stimuli on pleasure-to-grasp, and rated the food stimuli on palatability and desire-to-eat. Lastly, participants were weighed and asked to report their height.

2.6. Data processing

This study's hypotheses, data pre-processing routines, and confirmatory analyses have all been pre-registered: https://osf.io/m35td. Two reaction time metrics were computed for each trial. As displayed in Fig. 2, *Decision time* denotes the time from stimulus onset until the participant first moved their hand, and *Grabbing time* denotes how long it took the participant to reach the stimulus (or the avoidance zone) after first initiating their response. For ANOVAs, we computed median reaction times of correct trials separately for decision time and grabbing time. For multilevel analysis, we did not aggregate data. Instead, to analyse decision time, first we excluded reaction times below 200 ms and above 2000 ms, after which we excluded all reaction times deviating more than 3 SD from a participant's mean. For grabbing time, we employed a similar procedure, except we did not exclude trials below 200 ms (and thereby deviated from the pre-registration) as this would exclude a disproportionately large number of trials. We tested the significance of highest-order effects by comparing a model with the effect to a model without the effect using a Wald chi-square test. We conducted the ANOVAs using base R (R Core Team, 2020) and we computed the multilevel models using the R package lme4 (Bates, Maechler, Bolker, & Walker, 2015).

3. Results

Additional pre-registered and exploratory results are available in Appendix A.

3.1. Approach bias: Reliability

We computed bootstrapped split-half reliability coefficients for different operationalisations of approach bias using the R package AATtools (Kahveci, 2020), with 10,000 iterations per bootstrapped reliability coefficient. In each iteration, the sample was randomly split in two, after which reaction times deviating more than 3 *SD*s from the mean were removed. Approach bias scores were then computed in both halves by subtracting the median of approach trial reaction times from the median of avoid trial reaction times for objects and foods, and then subtracting the resulting approach score for objects from that of foods. Split-half reliability was computed for each iteration by correlating the bias scores for both halves, and all correlations were averaged to compute an unbiased split-half reliability coefficient for the double-difference approach bias score.

Because of the perspective ambiguity of hand movements, we computed two sets of approach bias scores. Stimulus-relative bias scores contrast distance increases and decreases between the hand and the stimulus; whereas body-relative bias scores contrast distance increases and decreases between the hand and the body. For the stimulus-relative set, both stimulus presentation locations (proximal and distal) can be included to calculate the approach bias, or each location can be considered separately (distal only, proximal only). For the body-relative set, all trials can be included, or only those involving a movement towards the stimulus (approach-only), or away from it (avoid-only). A distal-proximal approach-only bias score thus contrasts approaching distal foods against approaching proximal foods, controlling for equivalent approach-times for objects; a distal-proximal avoid-only bias score contrasts avoiding distal foods against avoiding proximal foods, controlling for equivalent avoidance-times for objects. A distal-proximal bias score with all trials contrasts moving the hand to the top of the screen to moving the hand to the bottom of the screen in response to foods, regardless of their location or the meaning of the movement, and controlling for the equivalent contrast for objects. If participants interpret the distance change with respect to the body as approach and avoidance, or if stimuli trigger hard-wired arm flexion/extension, this latter bias score should be reliable.

Confidence intervals and split-half reliability coefficients, raw and corrected for test length, are displayed in Table 2. Also displayed are median double-difference scores denoting the average size of the approach bias. Differences between reliability values were compared using the 95% confidence intervals. Stimulus-relative and body-relative approach bias reliabilities were not improved or impaired by using only trials that involved stimuli displayed at the top or bottom or defined as approach or avoidance, respectively. However, full-sample stimulus-relative contrasts were significantly more reliable than full-sample body-relative contrasts.

Using this stimulus-relative operationalization of approach bias, we separately calculated reliability for high-calorie foods and low-calorie foods, paired with their matched objects. Reliability of high-calorie food biases (r = .58, 95% CI [0.40, 0.74], $p < .001$, $r_{SB} = 0.73$) did not significantly differ from reliability of low-calorie food biases (r = 0.62, 95% CI [0.45, 0.76], $p < .001$, $r_{SB} = 0.76$).

3.2. Trial removal and reliability

We ran additional analyses to compute how reliability is influenced by the removal of trials. We removed a trial at the end of all blocks for all participants, then computed the reliability, and repeated this process until only 4 trials per block remained. We also separately examined the effect of block-initial trial removal. For these analyses, we used data

Table 2
Reliability Measures of Different Approach Bias Operationalisations.

	r	95% CI	r_{SB}	95%CI	ms.
Decision time, stimulus-relative					
Approach – Avoid	.70	[.56, .82]	.82	[.71, .90]	36.75
Approach – Avoid (distal only)	.73	[.60, .83]	.84	[.75, .91]	43.04
Approach – Avoid (proximal only)	.51	[.29, .69]	.68	[.45, .82]	35.00
Decision time, body-relative					
Distal – Proximal	-.08	[-.34, .20]	.00	[0, .33]	−14.11
Distal – Proximal (approach only)	.34	[.09, .56]	.50	[.17, .72]	−8.13
Distal – Proximal (avoid only)	.33	[.09, .56]	.50	[.17, .72]	−16.09
Grabbing time, stimulus-relative					
Approach – Avoid	.56	[.33, .74]	.71	[.50, .85]	−4.12
Approach – Avoid (distal only)	.49	[.24, .69]	.66	[.39, .82]	2.74
Approach – Avoid (proximal only)	.60	[.42, .75]	.75	[.59, .86]	−6.69
Grabbing time, body-relative					
Distal - Proximal	-.18	[-.47, .17]	.00	[0, .29]	−1.53
Distal - Proximal (approach only)	.35	[.12, .57]	.52	[.21, .73]	3.15
Distal - Proximal (avoid only)	.41	[.14, .63]	.58	[.25, .77]	−6.29

without errors or outlying reaction times below 200 ms or above 2000 ms. Reliability was computed using the bootstrapped split-half method, described in the Methods section.

Fig. 3 displays the effect of trial removal on reliability. It is clear that removing the first or last few trials of each block had no noticeable effect on reliability; on the contrary, using the confidence intervals it could be determined that reliability did not significantly decrease in comparison to the full dataset until either 54 trials were removed from the start of each block or 50 trials from the end of each block. This indicates that the task could be drastically shortened at little cost. Additionally, in terms of reliability there was no significant difference between the removal of block-initial and block-final trials at any point. As the exclusion of early trials did not improve reliability, we did not exclude those trials in further analysis.

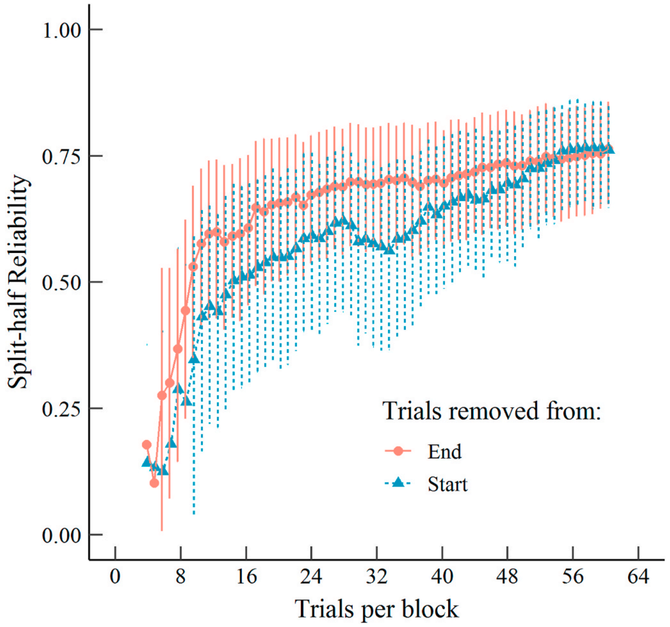

Fig. 3. Changes in Reliability due to Removal of Trials from the Start or End of Each Block.
Note. Error bars represent bootstrapped 95% confidence intervals; these were not available for reliability computations with a very small number of trials and are thus not shown.

3.3. *Approach bias: Bias size, stimulus position, and influence of calorie content*

We examined the influence of stimulus type (object, low-calorie food, high-calorie food), stimulus position (top, bottom), and movement direction (approach, avoid) on decision time and grabbing time using two repeated-measures ANOVAs.[2] The results of these analyses are displayed in Fig. 4.

For decision time, there was a significant main effect of movement direction, as approach was faster than avoidance, F (1, 39) = 82.97, $p <$ .001, $\eta_p^2 = 0.68$;. there was also a significant main effect of stimulustype, F (2, 78) = 10.62, $p <$ .001, $\eta_p^2 = 0.21$, qualified by an interaction of movement direction by stimulustype, F (2, 78) = 6.39, p = .002, η_p^2 = 0.14. Stimulus position did not have a significant main effect, F (1, 39) = 2.62, p = .113, $\eta_p^2 = 0.06$, and no significant interactions, $ps >$ .159, and was thus not considered in the following analyses.

We subsequently conducted three post-hoc ANOVAs contrasting each of the three different stimulus categories with each other to further elucidate the movement × stimulustype interaction. There was no movement × stimulustype interaction for objects and high-calorie foods, indicating there was no difference in how fast they were approached, relative to how fast they were avoided, F (1, 39) = 1.90, p = .175, η_p^2 = 0.05. However, movement and stimulustype did interact for objects and low-calorie foods, F (1, 39) = 11.20, p = .002, $\eta_p^2 = 0.22$; low-calorie foods were approached faster than objects, t (39) = 5.50, $p <$ .001, but they were not avoided faster or slower, t (39) = 0.35, p = .728. Similarly, there was a movement × stimulustype interaction for the contrast of low-calorie and high-calorie foods, F (1, 39) = 6.37, p = .016, $\eta_p^2 = 0.14$, indicating that low-calorie foods were approached faster than high-calorie foods, t (39) = 2.42, p = .020, but they were not avoided any differently, t (39) = 0.05, p = .957.

For grabbing time, the same three-way repeated-measures ANOVA was run. Again, approach was faster than avoidance, F (1, 39) = 294.31, $p <$ .001, $\eta_p^2 = 0.88$, but it was also modulated by stimulus position, F (1, 39) = 21.86, $p <$ .001, $\eta_p^2 = 0.05$, such that distal stimuli were avoided slower, t (39) = 4.21, $p <$ .001, ΔRT = 22 ms, and approached faster, t (39) = 3.92, $p <$ .001, $\Delta RT = -24$ ms, indicating that moving the hand upwards on the screen took less time than moving the hand downwards. Overall, there was no significant difference in reaction times between proximal and distal stimuli, F (1, 39) = 3.52, p = .068, $\eta_p^2 = 0.08$, and there were no main effects or interactions involving stimulustype, $ps >$ .126.

3.4. *Validity: Desire and palatability*

Low-calorie foods, compared to high-calorie foods, were on average rated as 0.65 points more desired, t (38) = 3.00, p = .006, and they were rated as 0.30 points more pleasant to grasp, t (38) = 2.0, p = .040; they were not rated as more palatable, t (38) = 0.60, p = .600.

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[2] In doing so, we deviated from the pre-registration, which prescribed that the approach bias effects of high-calorie and low-calorie foods be analysed separately, without comparing the effects of both stimulus types with an interaction term and without taking into account stimulus position. We found it more appropriate, however, to test both stimulus categories in a single analysis, to be able to draw conclusions about the differences between the two.

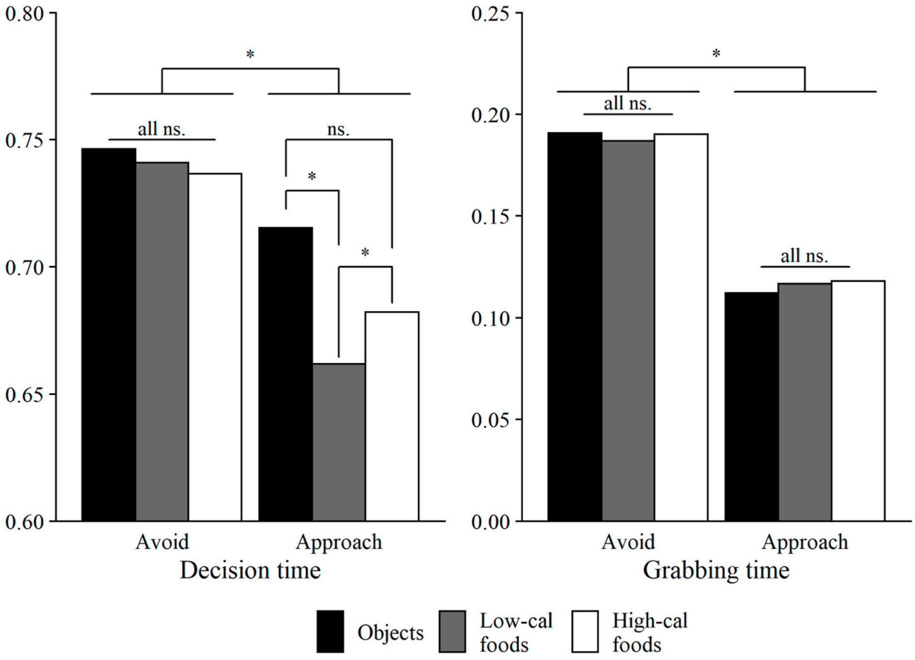

Fig. 4. Means of approach and avoidance RTs dependent on stimulus category.

We explored whether desire-to-eat ratings for specific stimuli predict differences in approach and avoidance decision times for those stimuli. Decision time for food stimuli was predicted using a multilevel model with fixed and random effects of Movement direction, Desire to eat, and their interaction, as well as random intercepts per stimulus, as depicted in Equation (1). The difference between approach and avoidance decision times was larger for stimuli that were more desired, χ^2 (1) = 8.62, p = .003. The relationship between these variables is further elucidated in Fig. 5. We subsequently examined approach and avoidance trials separately using Equation (2), and found that higher Desire to eat is associated with faster approach, χ^2 (1) = 4.32, p = .038, but not with changes in avoidance, χ^2 (1) = 0.21, p = .650.

Because low-calorie foods seem to be more desired on average, we ran separate exploratory analyses with only low-calorie and high-calorie stimuli to disentangle whether the effect of DTE may have been caused by calorie-dependent effects. There was a larger difference between approach and avoidance reaction times to low-calorie foods when they were desired more, χ^2 (1) = 6.92, p = .009, but this was not the case for high-calorie foods, χ^2 (1) = 0.06, p = .800. This may be in part due to lower variance in DTE ratings of high-calorie foods, t (40) = 3.00, p = .002, $\overline{var}_{lowcal} = 4.98$, $\overline{var}_{highcal} = 3.30$.

$$\text{Decisiontime} \sim \text{Movement} * \text{Desire} + (\text{Movement} * \text{Desire} \mid \text{Subject}) + (1 \mid \text{Stimulus}) \quad (1)$$

$$\text{Decisiontime} \sim \text{Desire} + (\text{Desire} \mid \text{Subject}) + (1 \mid \text{Stimulus}) \quad (2)$$

We also examined how palatability affected approach and avoidance decision times to food, as depicted in Fig. 5. Unlike desire, palatability did not affect the difference in decision times between trials where foods need to be approached and trials where foods need to be avoided, χ^2 (1) = 0.82, p = .360. When looking at grabbing time, approach and avoidance speed was not differently affected by desire, χ^2 (1) = 0.61, p = .430, or palatability, χ^2 (1) = 0.12, p = .730.

3.5. Validity: BMI, hunger, trait and state craving

As pre-registered, we computed correlations for state and trait craving on the one hand and double-difference bias scores (decision and grabbing time) for low- and high-calorie foods on the other hand. We further explored correlations of the approach bias scores with state hunger, BMI, and the change in craving and hunger over the course of the experiment, based on findings by Lender et al. (2018). Overall, there was little indication of meaningful and reliable correlations of the bias scores with other variables. Only the correlation between decision time-based approach bias for high-calorie foods and change in hunger across the experiment was significant, $r = 0.33$, $p = .038$, which has to be interpreted with care given the high number of examined correlations (24).

To examine possible reasons for a lack of correlations, we looked at the variance of the criterion variables: There was limited variance in pre- and post-test hunger and craving, as both variables were skewed towards zero. Most participants were not hungry, with a median hunger score of 6 pre-test and post-test (on a scale from 3 to 15).

3.6. Approach bias: Effects of block order

The relevant-feature AAT consists of two blocks; in the congruent block, the target stimulus is approached and the control stimulus is avoided, while in the incongruent block, the target stimulus is avoided and the control stimulus is approached. In the current study, we counterbalanced the order of these blocks; we now sought to analyse whether the two different block-orders produced different results. We conducted a mixed ANOVA predicting median decision times with within-subjects factors Movement and Stimulustype, and between-subjects factor Blockorder (congruent-first, incongruent-first); we confirmed that the congruent-first and incongruent-first versions of the AAT produced different approach and avoidance reaction times in response to foods and objects, F (1, 38) = 10.80, p = .002, $\eta_p^2 = 0.22$. Follow-up analyses revealed that participants who performed the incongruent block first had a larger approach-avoidance reaction time difference for foods than for objects, F (1, 19) = 12.40, p = .002, $\eta_p^2 = 0.40$, unlike participants who performed the congruent block first, F (1, 19) = 0.34, p = .570, $\eta_p^2 = 0.02$. We explored whether this increased average bias score in the incongruent-first task version also resulted in biases that were more reliable. The incongruent-first version of the task was not more reliable than the congruent-first version of the task (incongruent: $r = 0.76$, 95% CI [0.59, 0.89], $p < .001$, $r_{SB} = 0.86$; congruent: $r = 0.61$, 95%CI [0.36, 0.81], $p < .001$, $r_{SB} = 0.75$).

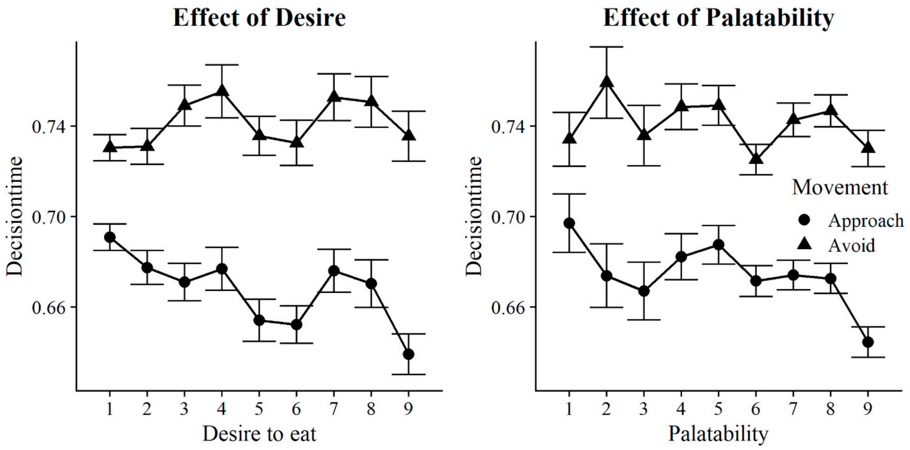

Fig. 5. Means and Standard Errors for Approach and Avoidance Decision Times Dependent on Picture Ratings.
Note. Means are standardized for mean participant reaction time. Both high-calorie and low-calorie stimuli were included.

4. Discussion

In the present study, we developed a touchscreen-based food AAT in which participants slide their hand towards or away from images of food and objects on a touchscreen. The analyses revealed an approach bias towards low-calorie foods, but not to high-calorie foods. Food biases were further related to individual food preferences, but not to hunger levels, BMI, or food craving (with one exception, which was likely a spurious correlation). Reliability for bias scores was high when approach was defined as a distance decrease between the hand and stimulus, but not when approach was defined as a distance change between the hand and body. On the methodological side, reliability remained robust when the number of trials was artificially reduced, but the order of the blocks of the AAT appeared to affect the magnitude of the detected bias. In the following discussion, we will interpret each of these results in the context of the literature before turning to limitations and potential clinical applications.

4.1. Validity: Relevance of calorie content and individual food preferences

4.1.1. Calories and approach bias

We showed that low-calorie foods elicited stronger approach biases than high-calorie foods. On first glance, this is contrary to our hypotheses and to most neuroimaging studies on food cue reactivity, which show that high-calorie foods cause stronger and more widespread activation in the brain, probably due to their relevance for survival in past times of food scarcity (Blechert et al., 2016; Killgore et al., 2003; Mennella et al., 2016; Speakman, 2013). Yet, the stronger approach bias to low-calorie foods in our study may be explained by cognitive and learning-based accounts, which posit that approach bias can be induced by frequent daily-life encounters with the rewarding properties of specific foods, for example through pavlovian-to-instrumental transfer (Watson et al., 2012). While high-calorie foods are assumed to be innately more rewarding, contextual factors and outcome expectations can counteract this effect and enhance the rewarding properties of low-calorie foods instead: two experiments reminded participants of healthy eating behavior by forecasting the long-term positive effects of food intake, and found that this enhanced implicit positive evaluations of low-fat foods in an affective priming task, and reduced attention-related brain activation in response to high-calorie foods (Roefs et al., 2006; Yokum & Stice, 2013). Furthermore, after matching high- and low-calorie foods on subjective liking, both were found to elicit similar activation patterns in the brain when selected in a forced-choice task (Charbonnier, van der Laan, Viergever, & Smeets, 2015). Hence, high calorie density may only marginally influence approach biases when it clashes with health-related beliefs, individual food preferences, or real-life consumption frequency. Accordingly, most previous AAT studies did not find that calorie-density affects approach biases in either direction (Becker et al., 2015; Kahveci, Meule, et al., 2020; Kemps & Tiggemann, 2015; Paslakis et al., 2016), except in anorexia nervosa, which we will discuss further below (Neimeijer, de Jong, & Roefs, 2015). Compared to other research in this area, our results may have been affected by the lack of explicit cognitive coding of the stimuli as high-calorie or low-calorie, allowing other food characteristics such as healthiness to instead affect approach bias. Additionally, approach biases to low-calorie foods may have emerged because our sample contained relatively more restrained eaters who may habitually choose to eat low-calorie foods; this hypothesis is in accordance with the higher desire-to-eat ratings we obtained for these foods.

4.1.2. The effects of desire to eat and palatability

In line with this idea, we found that more desired foods were approached faster than less desired foods. Our findings replicate those of Kahveci, Meule, et al. (2020), who demonstrated a link between desire to eat and approach reaction times in a similar student population. Further analysis in the current study revealed that this effect of desire on approach bias was limited to low-calorie foods. This may reflect a more direct link between desire and approach bias for low-calorie foods than for high-calorie foods, whose consumption is more likely to be preceded by both desire and guilt-related deliberation (Rozin, Bauer, & Catanese, 2003). However, we cannot exclude the possibility that a similar desire effect for high-calorie foods could not be demonstrated because there was a smaller range of desirable and undesirable high-calorie foods in the current study, decreasing statistical power for desire-related analyses this stimulus set.

The demonstrated relationship between desire to eat and approach bias is in line with clinical research, where it has been shown that patients with anorexia nervosa, who have a general low desire to eat foods and a particularly low desire to eat high-calorie foods (Stoner, Fedoroff, Andersen, & Rolls, 1996), also have a reduced approach bias for foods in general (Paslakis et al., 2016) and for high-calorie foods in particular (Neimeijer et al., 2015; Neimeijer, Roefs, Glashouwer, Jonker, & de Jong, 2019). The interplay between food preferences and approach biases in clinical and healthy populations highlights the importance of individualized stimulus sets in intervention studies. Targeting overt symptoms by modifying underlying approach biases is only sensible if the used stimuli actually elicit dysfunctional high or low approach biases (Clarke, Notebaert, & MacLeod, 2014). It is therefore important to retrain approach bias only for those stimuli which are relevant for the individual.

Desire to eat and calorie content affected approach bias despite the fact that the task was focused on distinguishing objects from foods rather than on judging the desirability or calorie content of the stimuli. Lender et al. (2018) found that food-related approach bias effects only occurred when food stimuli were task-relevant, and as such, they suggested that attention toward the stimulus itself is necessary to elicit approach-avoidance tendencies. We extend this hypothesis by suggesting that task-irrelevant aspects of the stimulus (here: calorie content) can affect approach and avoidance reaction times once the stimulus has been evaluated. This occurs in a relevant-feature AAT, but not in the irrelevant-feature AAT, where participants can usually ignore stimulus content completely and attend to peripheral features such as image format and frame color.

4.1.3. *The relationship between BMI, craving, and approach bias*

We did not find a relationship between approach bias and clinically relevant variables like food craving and elevated BMI in this healthy student population. Similarly, previous touchscreen-AAT studies also did not find relationships between approach bias and craving (Kahveci, Meule, et al., 2020; Meule, Richard, et al., 2019), except when the study was specifically focused on chocolate-containing foods (Lender et al., 2018; Meule, Lender, et al., 2019). When paired with the demonstrated relationship between desire to eat and bias scores, these findings suggest that relationships between craving and approach bias occur on a food or flavour-specific level. The lack of a relationship between approach bias and BMI is contrasted by previous findings that BMI correlates positively with impaired avoidance of sweet food (Maas, Woud, et al., 2017). Similarly, Havermans et al. (2011) showed impairments in overweight men during avoidance of high-calorie foods. In both studies, impairments were selectively shown for avoidance, whereas approach to unhealthy foods was not facilitated in comparison to normal weight participants. We therefore speculate that overconsumption and weight gain may only occur when approach tendencies to foods are paired with low self-regulatory capacity reflected by impaired avoidance or poor inhibitory control (Kakoschke, Kemps, & Tiggemann, 2015), which was likely not the case in our current sample with slightly elevated scores on restrained eating. It should also be taken into account that any relationship between approach bias and between-subject variables may have been blurred out by the bias score-distorting influence of block order.

4.2. *Reliability: Relevance of stimulus-relative distance change and evaluative labels*

4.2.1. *Reliability in the current study*

According to guidelines that are routinely applied to questionnaires and psychological tests,[3] the current task achieved very good ($r_{SB} > 0.80$) reliability, indicating it is suitable for comparisons of group data (DeVellis, 2016). Such reliable tasks are relatively rare in the wider field of cognitive bias measurement: most implicit tasks like the irrelevant-feature AAT, dot-probe or affective Simon task have attained low reliabilities, often statistically indistinguishable from zero (Matheson, 2018; Rinck, Dapprich, Lender, Kahveci, & Blechert, in review; Schmukle, 2005; Teige, Schnabel, Banse, & Asendorpf, 2004; Van Bockstaele et al., 2020); it is well-recognized that it is difficult to attain high reliability for scores that rely on subtraction of correlated subcomponents (Lebel & Paunonen, 2011; McNally, 2019). Among the implicit measures, then, the relevant-feature AAT stands out as a test capable of achieving good reliability, attaining reliabilities around $r = 0.80$ in two studies (Krieglmeyer & Deutsch, 2010; Rinck & Becker, 2007). While the currently achieved level of reliability was on-par with these aforementioned relevant-feature joystick-AAT studies, we cannot directly compare them with the current study, as reliability is dependent on many factors, some of which are not shared in common with these previous studies. For example, reliability depends on the size and variability of true underlying bias scores, and none of the aforementioned studies quantified food-related approach bias (Lachin, 2004).

4.2.2. *The role of experiment length*

The reliability of double-difference scores usually increases when more trials are added to the RT task. However, after a certain number of trials has been added, the increase in reliability from adding new trials is minimal. According to Miller and Ulrich (2013) this tipping point depends on known factors such as the effect size but also on unknown factors that must be approximated by theoretical consideration. For example, even though difference scores attempt to average out bias-unspecific processes such as stimulus perception or purely motoric effects, the duration of these processes influences reliability, as higher overall reaction times are related to increased variance in those reaction times, and thus lower reliability. Next to these unspecific processes, reliability is affected by the relationship between cognitive processes specific to one task condition (e.g. approach food) and specific to another task condition (e.g. avoid food). If the durations of cognitive processes specific to contrasted conditions are negatively correlated, fewer trials are needed to achieve reliable difference scores.

We can assume that there is a negative correlation between cognitive processes specific to the conditions of the AAT, as stronger automatic approach responses to food would speed up cognitive processes specific to approach-food trials, but slow down cognitive processes specific to avoid-food trials. Unfortunately, there is no method to separately determine the duration of specific cognitive processes in the overall RT and calculate the relationship between trial number and reliability in the current task set-up. Hence, we instead investigated the effect of trial number on reliability in current task by artificially reducing task length through removal of trials from the end of each block. We found that the length of the task can be reduced by more than 75% before reliability significantly begins to deteriorate, and conversely, adding more trials can be expected to only marginally improve reliability. Further improvements in reliability will therefore have to come from other sources, such as better stimuli and different task instructions.

4.2.3. *The role of evaluative labels*

High reliability was achieved when defining approach and avoidance under the stimulus-relative distance change account ($r_{SB} > 0.8$), but not when defining approach and avoidance under the body-relative distance change account ($r_{SB} = 0$). Under the stimulus-relative distance change account, approach and avoidance were defined as a stimulus-relative distance decreases and increases, respectively. Under the body-relative distance change account, approach and avoidance were instead defined as moving the hand towards and away from oneself, respectively. Two conclusions can be drawn from this reliability difference. First, the participants interpreted approach and avoidance as intended by the task instructions (with respect to the stimulus), while the alternative body-related interpretation did not interfere with the task by introducing perspective ambiguity. Second, because the unreliable body-relative operationalization of approach and avoidance precisely maps onto arm flexion and extension, we can conclude that hard-wired associations between stimulus valence and muscle flexion/extension did not influence approach biases. The conclusions are further supported by our finding that stimulus position (distally vs. proximal) did not affect the magnitude of the approach bias effects.

The different accounts of approach bias produce diverging predictions for what happens when distally presented stimuli are approached. The stimulus-relative distance change account and evaluative coding account predict approach-like reaction times, because the participant moves their hand towards a stimulus or because the movement is labelled as approach, respectively; however, the specific muscle

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[3] These standards are based on Cronbach’s alpha, which is statistically equivalent to the average split-half reliability of all possible splits of the data (Cronbach, 1951), and approximated by our split-half reliability coefficient based on 10,000 splits.

account and body-relative interpretation predict avoidance-like reaction times because the arm is extended and the distance to the body increases. As stimulus position did not influence bias size, we assume that the approach bias to foods is only driven by the evaluative label of the movement and/or distance change with respect to the stimuli, rather than the distance change with respect to the body or specific muscle activations. It should be noted that predictions of the stimulus-relative distance change account overlap completely with predictions of the evaluative coding account in this study, since moving towards a stimulus was labelled as 'approach' and moving away from a stimulus labelled as 'avoidance'. Hence, we cannot currently dissociate their effects. A previous study showed that both the distance change and descriptive labels of movements interact to influence bias effects in a relevant-feature AAT (Krieglmeyer, Deutsch, De Houwer, & De Raedt, 2010); therefore, it may very well be that reliability of the current study was supported by the aforementioned confound of movement labels with stimulus-relative distance change.

4.3. Theoretical implications: Bias in the decision to approach, not in decision to avoid or in the subsequent movement

We demonstrated that the time to initiate a movement was faster when approaching food,[4] especially in the case of low-calorie desired food; in contrast, the actual execution of approach and avoidance movements did not take longer or shorter for food and object stimuli, and was not influenced by food calorie content or desire to eat. These differential effects for movement preparation and movement implementation are in line with previous findings (Rotteveel & Phaf, 2004) that demonstrated the existence of approach bias during movement preparation, but not during movement execution. Basic models of motor control suggest that higher-level motor programs determine the specific action goal, such as approach or avoidance, whereas the motor intelligence of lower-level motor neurons in the brainstem and spinal cord implement the actual movement from start to finish (Stringer, Rolls, & Taylor, 2007). Hence, in line with our findings, we suggest that the actual muscle movements may not carry context-dependent, affective information, but that approach biases are generated during movement goal formation within higher-level movement preparation.

We further demonstrated that the time to initiate approach movements, not avoidance movements, was affected by stimulus category and desire to eat, closely replicating Kahveci, Meule, et al. (2020). Possibly, frequent approach of highly desired foods in everyday life may train an 'approach expertise' for specific food cues, whereas less desired foods are usually only passively avoided, thus not training an active 'avoidance expertise'. Active avoidance may be less practiced in general, since error rates across all stimuli categories were higher for avoidance than approach, as discussed in the Appendix. Future research may investigate whether clearly aversive stimuli do facilitate active avoidance in this variant of the AAT.

4.4. Limitations: The confounding influence of block order

The current task, like every relevant-feature AAT, requires two blocks with different instructions, which makes the task prone to block order effects. In the current study, avoiding food and approaching objects in the first block (bias-incongruent response mapping) led to a significantly larger approach bias to food than avoiding objects and approaching foods in the first block did. Block order was counterbalanced between participants, and therefore introduced artificial bias score differences between participants who performed different versions of the task. This confound needs to be addressed before applying the task in clinical practice, for example, by introducing more frequent instruction switches to reduce the primacy of any single block type (e.g. Van Alebeek, Kahveci, & Blechert, submitted), by using a fixed block order, or, as we will discuss further, by introducing longer practice blocks.

The effect of block order is likely to be a learning effect. This argument is justified by the following observations and assumptions. We observed that desire to eat only influenced approach and not avoidance trial reaction times, and we can assume that participants do not have strong approach or avoidance proclivities towards objects; therefore, food-approach trials were, at least in this study, the main driving force behind the observed approach bias effects. Additionally, the second block yielded faster response times than the first, as well as larger contrasts between reaction times to the two stimulus categories. It therefore appears that participants were still learning the task during the first block, and only during the second block did they produce the fast reaction times needed to reveal the influence of cognitive processes that cause small reaction time differences. The incongruent-first block order therefore likely elicited larger approach bias effects because the bias-carrying food-approach trials appeared in the second block, when participants had already mastered the task and were responding more automatically. This explanation is made more plausible by the fact that the current study involved only a short practice phase using stimuli unrelated to the main task (butterflies and leaves), likely leaving participants insufficiently prepared to perform the main task. This finding contrasts with the common finding in the IAT literature that the congruent block is performed faster if it is administered first (Greenwald, McGhee, & Schwartz, 1998; Greenwald, Nosek, & Banaji, 2003). While Greenwald and colleagues hypothesized that negative transfer reduces performance on the second block, we hypothesize that learning effects (and thus, positive transfer) in the current study may have overpowered any such negative interference. Taken together with the findings that shortening the main task does not significantly affect reliability and that participants respond unusually slowly at the start of each block (see Appendix), the results suggest that the task could be improved by shortening the main task and instead introducing a longer and more task-relevant practice phase before each block. Future studies should investigate whether order effects are still present when these longer practice blocks are added.

4.5. Conclusion

In the current study, we showed that touchscreen-based approach and avoidance movements yield reasonably reliable approach biases to food stimuli in a healthy student population, when approach and avoidance are operationalized as movements toward and away from the stimulus rather than from the body. Methodological findings suggest that the task could further be improved by increasing the number of instruction switches, or by moving trials from the main task into longer practice blocks, to ensure that participants do not have to figure out the task as they perform it. Approach biases were related to individual food preferences and calorie content, with higher biases toward low-calorie foods, especially if they were subjectively more desired. Our findings cast doubt on the commonly held idea that high-calorie foods elicit enhanced approach responses by virtue of being calorie-dense, and instead highlight the importance of individual momentary preferences and the need for future approach bias retraining paradigms to use personalized stimulus sets.

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[4] Unlike the current study, previous studies from our lab demonstrated the presence of approach bias towards food in movement execution, rather than in decision time (Meule, Richard, et al., 2019). We hypothesize that these contradictory effects emerged because these experiments allowed participants to immediately lift their hand from the screen after stimulus onset, only deciding on whether to approach or avoid while already moving. This was not possible in the current task, as participants had to keep their hand on the screen and thus moving the hand in the wrong direction was registered as an error, forcing participants to plan their responses in advance.

Author contributions

Sercan Kahveci: Conceptualization, Formal analysis, Data Curation, Writing - Original Draft, Writing - Review & Editing, Visualization; Hannah van Alebeek: Writing - Original Draft, Writing - Review & Editing, Visualization; Matthias Berking: Writing - Review & Editing; Jens Blechert: Conceptualization, Investigation, Resources, Writing - Review & Editing, Supervision.

Declaration of competing interest

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Appendix A. Other pre-registered and exploratory analyses

Movement repetition effects. As pre-registered, we compared trials where the movement direction (approach, avoid) was the same as in the previous trial, to trials where the movement direction was different, using a multilevel model predicting decision time with fixed and random effects for Movement, Stimulustype, Movement Repetition, and their interactions, as well as random intercepts per stimulus, and fixed and random effects for incorrect reponses. We did not exclude error trials for this analysis. Repetition of the same movement did not affect approach bias magnitude, χ^2 (1) = 2.27, p = .130. Additionally, there was no difference between the reliability of bias scores computed from trials with unrepeated movements ($r_{SB} = 0.66$) and repeated movements ($r_{SB} = 0.64$; $z = 0.15$, $p = .470$).

Temporal trends. Next, we examined temporal trends in the data. We divided the experimental data in 8 sub-blocks, splitting each of the original 4 blocks in half where the location of the stimulus was switched from top to bottom or vice-versa. First, we predicted decision time with fixed and random effects for Trial number (within sub-block); participants significantly sped up over time within blocks, χ^2 (1) = 34.30, $p < .001$. Inspection of plots revealed that the first two trials at the start of each sub-block had very high reaction times compared to the rest, and a multilevel model comparing the initial two trials against all other trials confirms this, χ^2 (1) = 59.50, $p < .001$, $\Delta RT = 103$ ms. After removal of these trials, we predicted effects for Trialnumber as before, and found that participants still sped up over time, though less strongly, χ^2 (1) = 12.60, $p < .001$. To reveal block-specific changes in this speedup effect, we predicted decision time with fixed and random effects for Trialnumber (within sub-block), Sub-blocknumber, and their interaction, with the initial two trials of each sub-block removed. The effect of participants speeding up throughout each sub-block got weaker after each sub-block, χ^2 (1) = 8.15, $p = .004$. Effects of inverse trial number were not modelled due to convergence issues.

Error rates. We also explored the effects of approaching and avoiding foods and objects on error rates, using a multilevel generalized linear model with a negative binomial distribution and fixed and random predictors for Movement, Stimulustype, and their interaction. All participants were included in this analysis, including the ones that were excluded from other analyses due to excessive errors or outliers. There was no interaction between Movement and Stimulustype, χ^2 (1) = 0, $p = 1$. A further analysis with only main effects revealed that there were significantly more errors for avoidance trials than for approach trials, χ^2 (1) = 12.50, $p < .001$, and more errors for objects than for foods, χ^2 (1) = 1, $p = .016$. It must be noted that there were on average only 2.14 errors per cell; therefore, this analysis is underpowered and no further factors, such as calorie content, could be analysed reliably.

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