Competing influences on healthy food choices: mindsetting versus contextual food cues

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Abstract

Food choices are influenced by one's current mindset, suggesting that supporting health (vs. a palatability) mindsets could improve daily food choices. The question rises, however, to what extent internal mindsets still guide choices when people are exposed to external food-context stimuli in an obesogenic environment. To examine these two competing effects we induced health vs. palatability mindsets, and investigated the robustness of the mindset effect by presenting food-context stimuli during a Pavlovian-to-Instrumental-Transfer (PIT) task in two separate cohorts of 102 (76 females) Dutch and 120 (60 females) German participants. For the mindset induction, participants rated food items on visual analogue scales (VAS), based on healthiness and palatability, respectively. In each cohort, half of the participants received a health, the other half a palatability mindset induction. Additionally, we explored whether 'mindset triggers' could be used to further shape behavior. Triggers were established by placing unfamiliar logos at the extreme ends of the VASs used for the mindset inductions.

Independent of the mindset, food-associated stimuli influenced food choices in accordance with the previously learned association in each test phase. Health mindset induction biased food choices towards healthier, palatability mindset towards unhealthier choices in the first cohort, but not in the second. The mindset triggers had a more robust effect. These induced healthier (triggers for healthy and not-palatable) and unhealthier (triggers for unhealthy and palatable) food choices in both cohorts alike. Interestingly, these effects did not tamper with the overall effect of Pavlovian cues and were thus true in the presence and absence of food-context stimuli. Therefore, we show that, in our experimental setting, food-associated mindset triggers can be used to bias food choices towards a healthy snack even in an obesogenic environment.

Keywords: food choice, mindset, instrumental behavior, cue-dependent, Pavlovian-to-Instrumental Transfer

1. Introduction

A choice between a highly palatable, unhealthy food item and a less palatable, but at the same time healthier alternative can give rise to conflict between short-term rewards and long-term health-related goals (Stroebe, van Koningsbruggen, Papies, & Aarts, 2013). It has been suggested that the current mindset of the individual may help to resolve this conflict (Lu, Park, & Nayakankuppam, 2012). Many studies show that experimentally induced 'health' and 'pleasure/palatability' mindsets do indeed influence eating behavior and food choices by focusing attention on either the health or palatability features of food , respectively. For example, in a food choice task, healthy snacks were chosen more frequently when participants were asked to think about healthiness as compared to thinking about the palatability of food (Bhanji & Beer, 2012; Hare, Malmaud, & Rangel, 2011). In a portion size selection task, also the selected portion size was shown to be dependent on the previously induced mindset (fullness, pleasure, health) in both, individuals with healthy-weight and obesity (Hege, et al., 2018; Veit, et al., 2019). Here, participants selected the biggest portion size for fullness, less for pleasure and the lowest for healthiness. An alternative mindset induction by choosing food for a wedding (palatability mindset) vs. for a friend who wants to lose weight (health mindset) attenuated the attentional bias for high-calorie foods particularly in restrained eaters (Werthmann, Jansen, & Roefs, 2016).

However, in real life our food-related choices are not driven purely by internal mindsets, but also by external food-context stimuli. For example, the sign of one's favorite fast food restaurant, reminding of a hamburger, may trigger the action of going to this restaurant. This contextual and thus outcome-specific response priming effect has been studied with the (outcome-specific) Pavlovian-to-instrumental transfer (PIT) paradigm (Cartoni, Balleine, & Baldassarre, 2016). The PIT paradigm was initially used in animal research and has more recently been translated in human research (see for review (Holmes, Marchand, & Coutureau, 2010)). For example, a Pavlovian stimulus associated with chocolate has been shown to lead to a response bias towards chocolate (and reduction in responding for popcorn), relative to a condition where participants are making responses for food outcomes in the absence of any Pavlovian stimuli (Watson, Wiers, Hommel, & de Wit, 2018). The relatively automatic nature of PIT is revealed by (outcome devaluation) studies which show that food-context stimuli will bias food choices towards the signaled food even when participants are already sated on this snack (Holland, 2004; van Steenbergen, Watson, Wiers, Hommel, & de Wit, 2017; Watson, Wiers, Hommel, & de Wit, 2014). In this way, food-context stimuli may contribute to the obesogenic effect of an environment in which palatable, unhealthy food becomes cheaper and more readily available, with food-context stimuli all around us to remind us of this availability (Hill & Peters, 1998; Ng, et al., 2014). Therefore, it is of crucial importance to gain insight into the factors that drive food-related decisions in an obesogenic environment in order to support healthier choices. Based on previous literature using the PIT task (Holmes, et al., 2010; Meemken & Horstmann, 2019; Watson, et al., 2014) we hypothesized that in the presence of Pavlovian cues previously associated with specific snacks (food-context stimuli), participants would increase instrumental responding for those snacks, relative to a baseline (no-cue condition), i.e. outcome-specific PIT effect.

The important question addressed by the current study is to what extent our mindset has a potent effect on our food-related choices in an obesogenic environment. To this end, we investigated the influence of health and palatability mindsets on food choice behavior in the presence versus absence of food-context stimuli. We induced a health mindset by a food picture rating for healthiness and a palatability mindset by food picture rating of palatability on visual analogue scale. We hypothesized that participants receiving a health-mindset induction would reduce instrumental responding for the unhealthy snack relative to participants receiving the palatability-mindset induction. This effect was assumed to be stronger in the absence of the food-context stimuli.

Furthermore, we investigated whether external mindset-associated triggers could also be used to bias food choices. Indirect support for this comes from studies showing that explicit triggers, such as health posters on vending machines, increase purchases of healthy snacks whereas unhealthy snack purchases can be increased by a funfair poster (Stockli, Stampfli, Messner, & Brunner, 2016). Furthermore, verbal health triggers related to health consciousness have been shown to reduce snack purchases among individuals with overweight and obesity (Papies, Potjes, Keesman, Schwinghammer, & van Koningsbruggen, 2014). To prevent previous associative learning about real-life logos (such as junk food logos) from confounding results, we used novel logos in the current study, which functioned as mindset triggers. Participants were exposed to the novel logos during the experiment, whilst making health and palatability ratings. We hypothesized that logos that had been associated with extreme healthiness would subsequently lead participants to reduce responding for unhealthy snacks (relative to a logo associated with extreme unhealthiness). Similarly, we expected participants to increase responding for unhealthy snacks in the presence of a palatability (relative to extreme unpalatability) trigger. These effects were expected to be stronger in the absence of food-context stimuli.

To the best of our knowledge this is the first study to assess mindset induction in combination with mindset triggering. The present study suggests that the controlled experimental setting of the PIT paradigm can be used to study the interaction between internal factors (mindset) and the effect of external factors (triggers, food-context stimuli) on food-related decision making.

2. Methods

We report how we determined our sample size, all data exclusions (if any), all manipulations, and all measures in the study.

2.1 Participants

We conducted this study in two separate cohorts. The second (German) cohort was tested in an attempt to replicate the results of the first Dutch cohort (table 1). For the first cohort (cohort 1) 107 participants were measured. Five participants had to be excluded (for one participant the program crashed in the middle of the experiment, two participants did not press any key in several trials and could thus not be analyzed, two participants remembered the key – snack association incorrectly at the end of the experiment) resulting in a total of 102 Dutch male and female students with 52 participants in the health mindset group (39 female) and 50 participants in the palatability mindset group (37 female). The groups showed no significant differences in mean age and BMI across mindset groups in each gender separately (as indicated by no significant difference using between-groups t-tests; all ps > 0.28). For the second cohort 123 participants were measured. After exclusion of three participants (one participant remembered the key – snack association incorrectly at the end of the experiment, two were excluded in order to match groups for mean age and BMI within each gender) the second cohort consisted of 120 German male and female students (cohort 2) with an equal distribution for both sexes in the two mindset conditions (each n=30). Mean age and BMI were matched in this cohort also (no significant difference between groups, ps > 0.27). None of the participants reported any kind of current or previous eating disorder. All participants were requested to refrain from eating and drinking (except for a glass of water) for at least three hours before the experiment. Participants were reimbursed with 15€ or course credits (Dutch cohort) after completion of the experiment.

All participants gave written informed consent prior to participation and the study was approved by the Ethics Committees of the University of Amsterdam and of the Medical faculty of the University of Tübingen. The study was conducted in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans. The study was registered at clinicaltrial.gov (NCT03255304).

2.2 Power analyses.

We based our power analyses on the mindset induction manipulation since based on the literature, we expected the smallest effect here (as compared to a rather big and robust effect of the Pavlovian-to-Instrumental transfer task as for example shown by Watson et al (2014)). Bhanji et al. (2012), reported comparatively higher healthy food choices after a health mindset induction than after a palatability mindset induction with an effect size of *d*=0.52. With an accepted alpha-error of 5% and the power of 80% for a paired t-test, this results in a required sample size of at least 25 subjects per group.

Table 1

Study cohorts

	cohort 1 (Dutch)		cohort 2 (German)	
	health	**palatability**	**health**	**palatability**
female	n=39 Age=21.8 (18-28) BMI=22.2 (16,85-31.46)	n=37 Age=22.5 (18-34) BMI=22.3 (17.66-27.93)	n=30 Age=22.8 (19-29) BMI=21.1 (17.66-25.55)	n=30 Age=23.0 (20-28) BMI=21.7 (16.70-25.86)
male	n=13 Age=21.5 (19-29) BMI=22.3 (17.74-27.84)	n=13 Age=23.1 (19-33) BMI=23.1 (17.91-28.40)	n=30 Age=24.1 (18-31) BMI=23.1 (18.90-26.67)	n=30 Age=24.3 (20-35) BMI=22.8 (18.73-25.40)

Note: Mean age in years (range) and mean BMI in kg/m² (range) are depicted. Within each cohort and gender, mindset groups did not differ significantly on mean age or BMI (all $p>0.27$).

2.3 Task Procedure and Stimuli

The experimental task was programmed with the Presentation software (neurobs.com) and presented on a stand-alone PC. The food choice task was based on the Pavlovian-instrumental transfer test used in a previous study by Watson et al. (2014) and was combined with a mindset induction and a mindset trigger protocol. Potato chips and raw zucchini were used as snack rewards in the experiment. These two snack outcomes were chosen because they differ in both health and palatability. Those snacks were already successfully used in a previous study (Watson, Wiers, Hommel, Gerdes, & de Wit, 2017). Participants were informed that they would be trained on a computer task how to earn snacks (potato chips and raw zucchini) in a training phase and that they would then perform a task to actually earn 40 pieces of the snacks (test phase) which would be provided to them at the very end of the experiment while they watched a movie. Participants were also told that the proportion of chips and zucchini they would receive at the end would be based on their key press behavior during the test phases. With this procedure we aimed to ensure that the participants knew their key press behavior would have a direct bearing on the rewards they earned. At the beginning of the experiment six pieces of each reward (chips and zucchini) were placed on two plates next to the participants.

2.3.1 VAS 1

The computer task consisted of six main phases and three rating stages (figure 1). Prior to the first phase, participants were asked to rate their subjective hunger, thirst and appetite on a 10-cm visual analog scale (*VAS 1*) with the endpoints “not at all” to “very much”.

2.3.2 Instrumental training phase

In the instrumental training phase, participants learned how to earn chips and zucchini. Between trials, participants were shown a white square in the middle of the computer screen upon a black background (1.5-s ITI). Participants were told that once the white square turned purple a snack would become available, but that its identity (chips or zucchini) was hidden behind the square. Participants were instructed that they could earn the available snack by pressing the correct response key (left or right) several times, but that they had to find out by trial and error which snack was available by pressing the keys until they won something (key–snack relationships were counterbalanced across participants). Once the appropriate key had been pressed a sufficient number of times (variable ratio schedule of between 5 and 10 presses, selected at random) an image of the snack was revealed and remained on screen for one second. In addition, every fourth time that a specific snack picture was presented, participants received an audible (“ding”) signal indicating that they should now eat one piece of that snack (a longer 6-s ITI was used for these consumption trials). Participants were instructed to press the keys with the index finger of their dominant hand (Dutch cohort) or a pen (German cohort) only so as to avoid simultaneous presses of both keys. The instrumental training phase consisted of four blocks in which participants learned the response-outcome (R-O) relationships between the keys and the snacks. Within each block, each snack was available three times in random order (24 trials total). Participants’ knowledge about the R-O associations between the keys and the snack outcomes was tested after the second and after the fourth block.

2.3.3 Pavlovian training phase

During the subsequent Pavlovian training phase, participants learned the stimulus-outcome (S-O) relationships between three Pavlovian cues (three black-and-white colored background patterns which functioned as context stimuli) and three outcomes (chips, zucchini or ‘nothing’; see figure 2A). In this learning phase, participants sat passively in front of the screen and were instructed to pay attention. On each trial the Pavlovian context stimulus was presented as a background for 2 seconds, after which the picture of the according outcome was presented in the middle of the screen for 1 second superimposed on the background. The ITI was 1.5s. Every fourth time that a specific snack picture was presented, participants again received the audible (“ding”) signal indicating that they should now eat one piece of that snack (6-s ITI on these consumption trials). Within each of four blocks, both S-O pairs, as well as the neutral pair (context stimulus – “nothing”) were presented three times in random order (36 trials total). Participants’ knowledge about the S-O associations was not tested at this point, since we wanted to avoid explicitly drawing the attention to these relationships just before the test phases. Instead, the S-O knowledge was tested after the test phases.

2.3.4 VAS 2

Afterwards, participants filled out the second visual analog scale (VAS 2) that questioned them about their hunger and thirst.

2.3.5 Baseline choice test

In the baseline choice test, participants could earn the snack they wished for by pressing the keys previously associated with chips and zucchini as often as possible during each trial. However, they were informed that as in the first phase, they would not know which reward was available on each trial and furthermore, that they would not receive any feedback about the reward that they won but would receive the appropriate number of snacks to eat at the end of the experiment while watching a short movie. Participants were also informed that they would occasionally see background patterns on the screen but that they should ignore these and focus on the purple box as this indicated that they had three seconds within which to win a reward. Each trial began with 1-s presentation of the ITI screen. When the white square turned purple, participants had 3 seconds to press either key as often as they wished to win the available snack. After the instruction, participants received two demo trials. The actual test phase did not begin until they had confirmed that the instructions had been understood. During the test phase, the purple square was presented superimposed on one of four context options (black background or one of the three Pavlovian context stimuli, figure 2A). Participants completed five blocks of eight trials (40 trials total). Therefore, within each block, choice behavior was assessed in the presence of food-context stimuli (when the backgrounds associated with chips and zucchini were presented (cued trials), allowing for outcome-specific Pavlovian-to-instrumental transfer) and in the absence of food-context stimuli (when a black background and the background previously associated with 'nothing' were presented: non-cued trials). With the different backgrounds we aimed to operationalize an external context. Hence, the context can either be food-related cued (cued trials with the context associated with either snack) or non-cued (context not associated with either snack, figure 2A). The four trial types were each presented twice and intermixed in random order within each block.

2.3.6 Mindset induction phase

After the baseline test, during the mindset induction phase, participants rated 40 food pictures (20 high and 20 low calorie) for either healthiness or palatability on a visual analogue scale to induce the corresponding mindset. Participants were assigned to the health or palatability mindset in a pseudorandomized order, with four consecutive participants being attributed to the same mindset. In an initial instruction slide, participants in the health mindset group were instructed to concentrate on the health aspects of the foods (e.g., the consequences of eating the food for their own health, risk for obesity, diabetes or coronary heart disease) whereas those in the palatability group were instructed to rate the palatability of each of the foods (e.g., how pleasant it would be to eat the food right now). At the extreme ends of the VAS scale two neutral unfamiliar logos were inserted to induce an association between the logos and healthy and unhealthy (or palatable and not palatable). These logos were based on a pilot study with eighteen self-created logos which were rated for valence and any previous associations on a 1-9 Likert scale (n=27). The logo pair with the best match (medium valence of 5.29 ± 1.37 SD for logo 1 and 5.42 ± 1.38 SD for logo 2 and low previous associations of 2.83 ± 2.61 SD for logo 1 and 2.83 ± 2.67 SD for logo 2; each t-test not significant) was chosen for the experiment. In the final test phase, these logos were then used as triggers for the mindset extremes (healthy/palatable vs. unhealthy/not palatable). The assignment of the logos to the positive/negative extremes of the scale was counterbalanced between participants.

2.3.7 Mindset induction test

Following the mindset induction, the participants performed the second choice test (the mindset induction test) to establish whether the mindset induction influenced responding for zucchini versus chips, in the presence versus absence of food-context stimuli (i.e., cued versus non-cued trials). This phase was identical to the baseline test phase.

2.3.8 Mindset trigger test

The final choice test phase (mindset trigger test) was also similar to the baseline test, but this time the mindset triggers (logo associated with healthy/palatable and logo associated with unhealthy/not palatable) were added. Thus, we tested whether the logos, first introduced at the extreme ends of the VAS during the mindset induction, could function as triggers for healthy/palatable and unhealthy/not palatable choices. Participants were informed that they would see background patterns and logos during this phase, but that they should ignore them and focus on the purple box indicating that they had three seconds to respond. During the mindset trigger test each of the four context stimuli were used (as in the baseline test) but now one of the two triggers were placed in the middle of the purple box. This test phase therefore contained twice as many trials as the previous test phases (i.e., participants completed five blocks of sixteen trials; each of the four contexts was used twice in combination with each trigger, totaling 80 trials).

2.3.9 VAS 3

Afterwards, participants filled in the third VAS (*VAS 3*) asking for hunger, thirst and appetite. The participants were also asked to rate chips and zucchini for healthiness and palatability.

2.3.10 Snack and mindset ratings

Afterwards, they completed a snack choice rating as to whether they would rather have a few pieces of chips or a few pieces of zucchini to eat right away. In the healthiness rating of zucchini as well as the choice rating between chips and zucchini, only 66 of 120 participants of the second cohort completed the rating due to technical problems (which was only discovered after several testings). Since there were 33 participants in each mindset, the samples were still balanced, and so we decided to include these results.

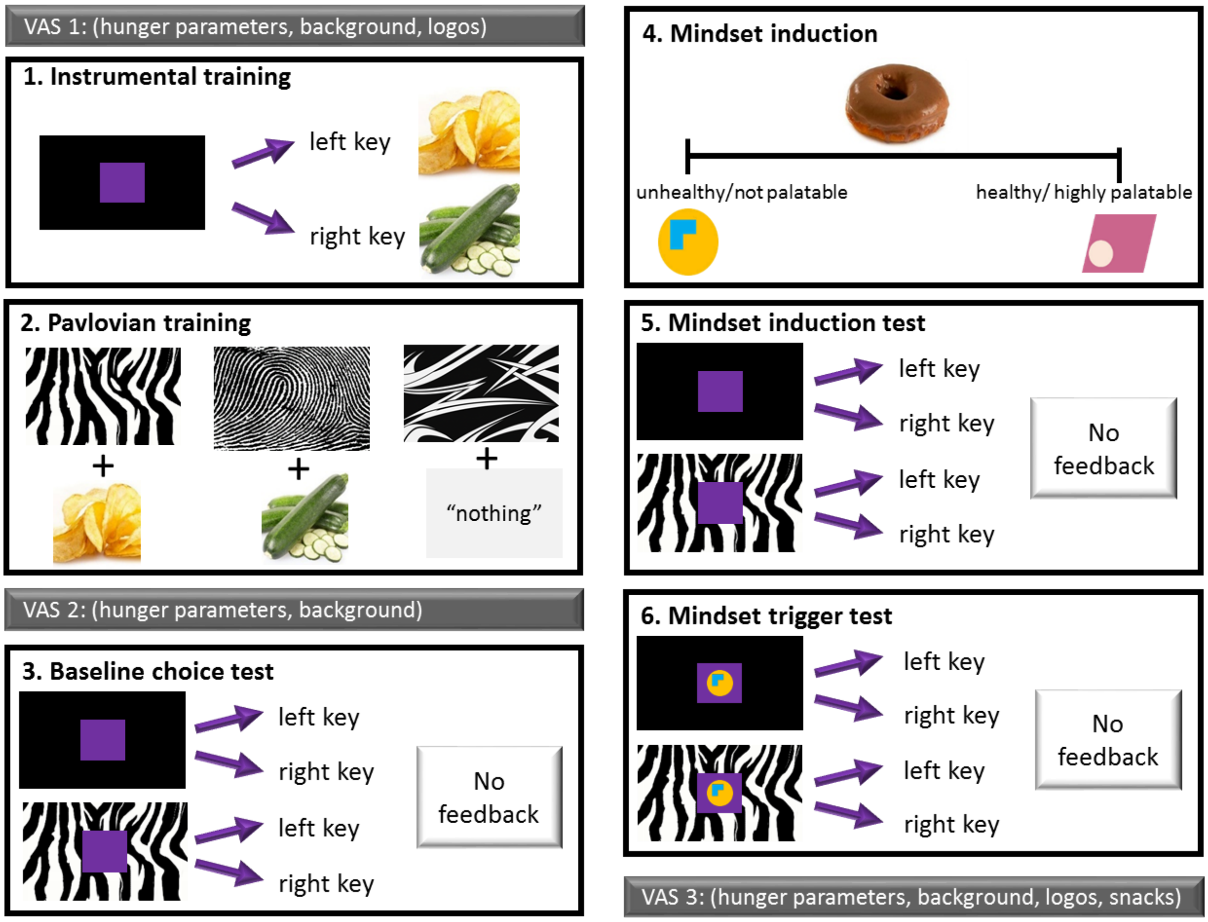
Finally, participants rated two questions on a VAS questionnaire (paper and pencil form) about the general mindset (in detail, (i) what tends to drive their daily food choices on a scale from ‘palatability’ to ‘health aspects’ and (ii) how they would describe their general eating behavior from ‘what I want’ to ‘totally controlled’).

After a further mindset induction according to the previously induced mindset in the two groups, participants rated another set of 20 high-calorie and 20 low-calorie food items for current wanting and general liking on a VAS (“not at all” to “very much”). With these measures, we aimed to test, whether possible differences in ratings of chips and zucchini between the cohorts can be generalized to the broader category of high-calorie and low-calorie food. The mindset induction was repeated beforehand in order to refresh a possible mindset effect for these measures.

After this protocol, participants were asked how high they rated the probability to receive either snack in the presence of each Pavlovian context stimuli and mindset trigger during the choices tests (VAS from “0%” to “100%”). Here, we aimed to examine the ability to explicitly report S-O relationships induced by the Pavlovian training phase (Pavlovian context stimuli) and during the mindset induction (triggers).

All described tests were identical in both cohorts. For the purpose of optimizing the experimental setting for the second cohort, two subtests used in the first cohort were not repeated in the second since they were nation specific or did not prove meaningful. These tests are not reported here but are briefly described in the supplementary material. Subtests were only excluded in case they were scheduled after the main experiment and did thus not tamper the replicability of the study.

Figure 1: Task procedure



*Note. Task design: **VAS 1:** Assessing subjective hunger, thirst and appetite **1. Instrumental training:** Participants learned the relationship between two keys on a keyboard and the snack (chips and zucchini) outcomes. **2. Pavlovian training:** Participants learned about the association of the three black-and-white shaped background patterns with three outcomes (chips, zucchini, and 'nothing'). **VAS 2**: Assessing hunger and thirst. **3. Baseline choice test:** Participants were instructed to try to win chips and/or zucchini. A purple box (indicating the window to respond for 3 seconds) was presented in the presence of four different context conditions, i.e. upon a black background or upon the Pavlovian context stimulus associated with 'nothing' (non-cued behavior) as well as upon the Pavlovian food-context stimuli associated with chips or zucchini (to assess cued behavior). Participants were instructed to ignore the background (context stimuli). **4. Mindset induction:** Forty food pictures were rated for palatability (palatability mindset induction for half of the group) or for healthiness (health mindset induction for the other half). Two hitherto unfamiliar logos were placed at the extreme ends of the VAS scale. These logos were thus associated with unhealthy/not palatable and healthy/palatable, respectively, and used as triggers in the last* *test phase.* ***5. Mindset induction test:*** *Identical to the baseline test, examining the effect of the mindset manipulation on cued and non-cued responding for snack rewards.* ***6. Mindset trigger test:*** *Identical to previous test phases only now the triggers were also presented.* ***VAS 3****: Assessing hunger, thirst and appetite, individual aims to earn specific snacks or snacks in general as well as health and palatability ratings of the snacks. Furthermore, participants were asked whether they would prefer a few pieces of chips or zucchini straight away.*

2.4 Analyses

Statistical analyses were performed using SPSS 24 (IBM®SPSS®, Armonk, NY, USA). Analyses are based on the previously described hypothesis.

2.4.1 Analyses of the three choice tests.

The dependent variable for each analysis of the choice tests was the percentage of chips presses. The following analyses were performed identically for each of the cohorts. To first determine the *overall outcome-specific PIT effect* (effect of context), we aggregated all three choice tests (baseline test, mindset test and mindset trigger test) and calculated the mean percentage of chips presses for each of the four context conditions (Pavlovian context stimulus for chips, zucchini, 'nothing' or black background, figure 2 A). We then conducted a repeated measures ANOVA with the factor 'context' (4 level). We commenced with this analysis as a proof of principle that the task worked and that we were able to manipulate choice preference using Pavlovian context stimuli. Furthermore, we tested the strength of the outcome-specific PIT effect for each snack by calculating an *outcome-specific response priming effect* for either snack. For that, we used presses for chips in trials with the Pavlovian context stimulus associated with chips minus the mean presses for the two non-cued conditions (presses in the presence of the Pavlovian context stimulus for 'nothing' and during the black background). The outcome-specific response priming effect for zucchini was calculated accordingly (presses for zucchini in trials with the Pavlovian context stimulus associated with zucchini minus mean presses for the two non-cued conditions.

Based on the study of Watson et al. (2014), we additionally calculated the *mean priming strength* for each test phase. Here, we used percent presses for the signaled reward above the percent presses of the non-cued trials in order to evaluate whether the mindset induction and/or the inclusion of the triggers alter the influence of the four different context conditions on outcome-specific pressing behavior for the snacks over the course of the experiment.

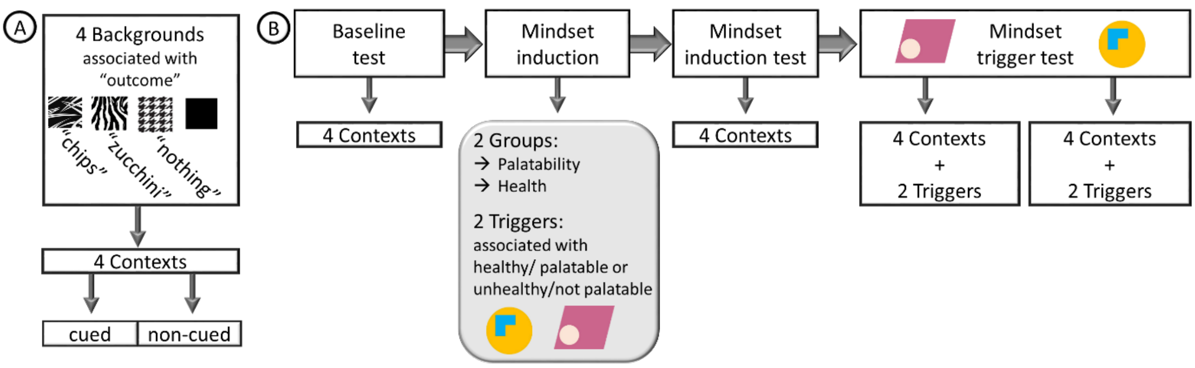
To analyze the *mindset effect* on non-cued and cued choices, we used a linear mixed model design with the repeated factor ‘test type’ (baseline test, mindset induction test), the between factor ‘mindset group’ (palatability, health) and between factor ‘context’ (chips, zucchini, ‘nothing’, black background, figure 2 A, B).

To investigate the *effect of the mindset triggers*, a second linear mixed model design was used with the repeated factor ‘test type’ (baseline test, mindset induction test trigger health/palatable, mindset induction test trigger unhealthy/not palatable), the between factor ‘mindset group’ and between factor ‘context’ (figure 2 A, B). Results were significant with $p<0.05$. In case of significant interaction effects, Bonferroni corrected post hoc tests are reported.

Since only the German cohort was balanced for sex, exploratory analyses were performed for this cohort to investigate sex differences using an additional between factor ‘*sex*’.

The highest-order interactions involving the factors of interest are always reported.

Figure 2: Schematics of factors and stimuli



Note. A: Schematic view of the factors for the Pavlovian-to-Instrumental Transfer (PIT) task: the factor 'context' is operationalized by four backgrounds associated with four different outcomes, reflecting cued and non-cued trials. B: Study design depicting the different phases of the experiments and the factors used in the analyses.

2.4.2 Comparison of the two cohorts.

To determine differences between the cohorts, we calculated t-tests for independent samples for variables age, BMI, (Prasad & Mishra, 2019)current wanting of high-calorie food, current wanting of low-calorie food, general liking of high-calorie food, and general liking of low-calorie food, general mindset as well as aims to gain chips, zucchini or snacks in general and the snack choice rating (i.e. whether they preferred to receive a piece of chips or zucchini right now) and the contingency knowledge about the R-O and the S-O association, asked for at the end of the experiment. Two ANOVAs were used to compare the snack ratings with the between factor 'cohort' and the within factor 'snack' (chips and zucchini) for the health and the palatability rating separately. Furthermore an ANOVA for percent chips presses was used with the between factor 'cohort' and the within factors 'context' and 'test type'. Three further ANOVAs were calculated to investigate differences in hunger, thirst and appetite over the experiment between the cohorts. Results were considered significant with $p<0.05$. In case of significant interaction effects, Bonferroni corrected post hoc tests were performed.

2.4.3 Exploring the role of explicit expectations.

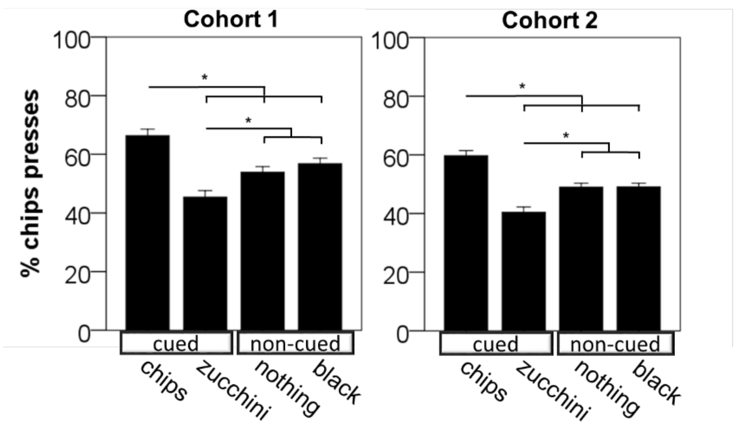
In order to explore whether explicit S-O expectations were related to the magnitude of outcome-specific response priming (PIT) effects (i.e. presses for chips in the presence of the Pavlovian context stimulus associated with chips vs. the presses for zucchini in the presence of the Pavlovian context stimulus associated with zucchini; both variables minus the mean presses for the two non-cued conditions), we performed correlation analyses for the response priming effect for either snack reward, with the strength of the expectations to receive either snack in the presence of the associated Pavlovian context stimulus. Further correlation analyses were performed with the subjective expectation to receive either snack in the presence of the two triggers. These analyses were performed for mindset groups separately. Bonferroni corrected p-values are reported.

3. Results

3.1 Overall PIT effect

Averaged across the three consecutive tests, both cohorts showed the expected outcome-specific *PIT effect* with a response bias for the signaled snack (cohort 1: $F_{(2,173)}$=33.6, p<0.001, cohort 2: $F_{(2,208)}$=30.1, p<0.001). As can be seen in figure 3 (see also figure 2A for schematics), participants made more presses for chips in the presence of the context stimulus associated with chips than on all other trials, and less presses for chips in trials with the zucchini context than on all other trials. This outcome-specific PIT was observed in all of the analyses below represented in the significant factor 'context'.

Figure 3: PIT effect



Note. Mean outcome-specific PIT effect across all choice tests (i.e. shown are the means of % percent chips presses for each context condition across the baseline test, the mindset induction test, and the mindset trigger test). Bar plots represent % chips presses ± SEM. p<0.05*

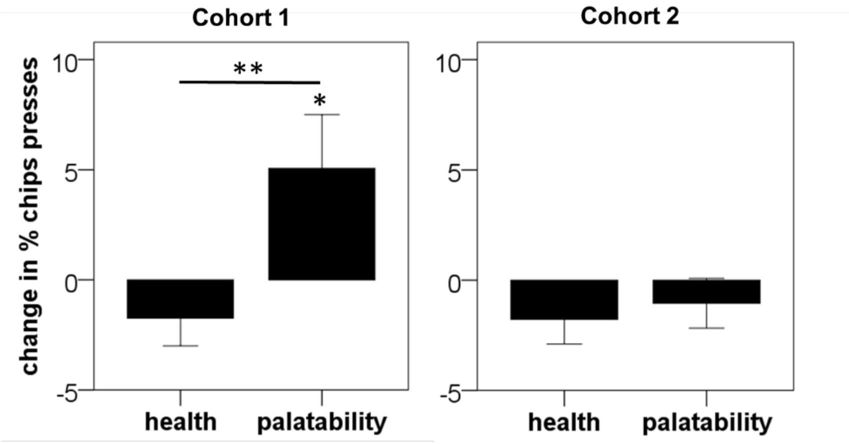
For purposes of a comparison of PIT magnitude between the chips and zucchini cues, the *outcome-specific response priming effect* for each snack was calculated (i.e. comparison of presses for chips during the context stimulus associated with chips vs. presses for zucchini during the context stimulus associated with zucchini; both variables minus the mean value of the two non-cued conditions). These analyses showed no significant differences between the two snacks for both cohorts (cohorts 1: $t_{(101)}$=0.5, p=0.59, cohort 2: $t_{(119)}$=1.0, p=0.3), suggesting that the magnitude of the response priming was not influenced by type of snack.

3.2 Mindset effect

The following analysis was conducted to investigate to what extent food choice behavior was influenced by mindset, and whether this was still the case in the presence of food-context stimuli. The *mindset effect* was tested by analyzing the first two choice tests (baseline test vs. mindset induction test). In the first cohort, the expected interaction between 'test type' and 'mindset group' was significant ($F_{(1,400)}$=9.1, p=0.003). Post hoc test showed that there was no significant difference in percent chips presses in the baseline test ($t_{(100)}$=0.3, p=0.77), but after the mindset induction the percentage of chips presses was higher in the palatability mindset group than in the health mindset group ($t_{(100)}$=2.2, p=0.027, not Bonferroni corrected). Furthermore, the palatability mindset group showed a significant increase in responding for chips, (yet also not Bonferroni corrected with $t_{(100)}$=2.1, p=0.043) which was also significantly different in comparison to the decrease in the health mindset group ($t_{(100)}$=2.5, p=0.014) (figure 2B, figure 4). Furthermore, the 'context' effect was also significant ($F_{(3,400)}$=22.0, p<0.001), reflecting the influence of contextual stimuli on food choices (i.e., outcome-specific PIT) as described above. However, there was no significant 3-way interaction ('test type' x 'mindset group' x 'context': $F_{(3,400)}$=1.8, p=0.15; for detailed depiction of the non-significant 3-way interaction effects for each Pavlovian context, see supplementary material, figure S1).

In the second German cohort, the 'test type' x 'mindset group' interaction effect could not be replicated ($F_{(1,472)}$<0.001, p=0.991, figure 4). The outcome-specific PIT effect (factor 'context') was significant ($F_{(3,472)}$=23.7, p<0.001), and again the 3-way interaction was not significant ($F_{(3,472)}$=0.9, p=0.4).

Figure 4: Mindset effect

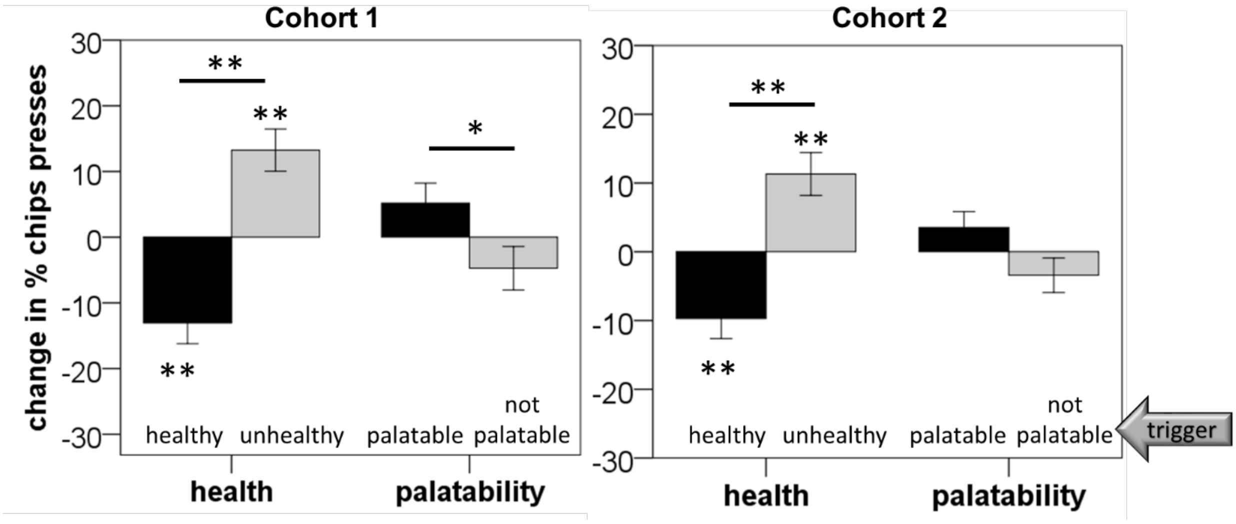


Note. *Effect of mindset induction in both cohorts in a comparison between the baseline test and the mindset induction test. For the purpose of illustration, baseline-corrected data are depicted. Thus, bar plots represent change in % chips presses ± SEM (more precisely: mean percent chips presses collapsed across all 4 context conditions during the mindset induction test minus mean percent chips presses collapsed across all 4 context conditions during the baseline test). The first cohort showed increased presses for chips in the palatability condition, an effect that was not observed in the second cohort. **p<0.02 based on post hoc tests in the event of a significant interaction effect, *p<0.05 based on post hoc tests in the event of a significant interaction effect (not Bonferroni corrected significant).*

3.3 Trigger effect

The *effect of the mindset triggers* was examined by comparing 3 'test types': baseline test, mindset induction test trigger health/palatable, mindset induction test trigger unhealthy/not palatable. As expected, we found significant 'test type' x 'mindset group' interaction effects, and this time in both cohorts (test type x mindset group: cohort 1: $F_{(2,795)}=53.6$, $p<0.001$; cohort 2: $F_{(2,937)}=35.8$, $p<0.001$). As depicted in figure 5, these effects were mainly driven by the triggers in the health mindset groups. Post hoc tests revealed that participants in the health mindset group in both cohorts decreased presses for chips in the presence of the healthy trigger and increased presses for chips in the presence of the unhealthy trigger (cohort 1: $t_{(51)}=4.39$, $p<0.001$; cohort 2: $t_{(59)}=3.97$, $p<0.001$). For the triggers in the palatability mindset groups, the effects were less pronounced; for participants in cohort 1 the palatable trigger significantly increased chips presses relative to the not-palatable trigger ($t_{(49)}=2.11$, $p<0.04$) but not relative to the baseline test (ts<1.8, ps>0.05). For those in the palatability mindset in cohort 2, there were no significant differences in responding for chips as a function of test type (ts<1.2, ps>0.05). In both cohorts, this analysis additionally yielded a significant effect of 'context' (cohort 1: $F_{(3,402)}=14.5$, $p<0.001$; cohort 2: $F_{(3,477)}=25.2$, $p<0.001$) reflecting that participants pushed more often for the signaled reward (outcome-specific PIT effect). Importantly, however, the influence of the mindset triggers on food choices was not altered overall by the presence of the food-context stimuli, as there was no significant three-way interaction in either cohort (3-way interaction: cohort 1: $F_{(6,795)}=1.0$, $p=0.40$; cohort 2: $F_{(6,937)}=0.8$, $p=0.60$; for detailed depiction of the non-significant 3-way interaction effects for each Pavlovian context see supplementary material, figure 2B, figure S2).

Figure 5: Trigger effect



Note. During the mindset trigger test, the mindset triggers associated with the extremes of the healthiness or palatability scales biased responding in both the 'health' and 'palatability' mindset groups. In the health mindset group, the healthy trigger significantly reduced percent chips presses and the unhealthy trigger increased chips responding, relative to the first choice test (baseline test) in both cohorts. Also, the direct comparison of the two triggers within the health mindset group revealed significantly different % changes of chips presses according to the healthy vs. unhealthy trigger for both cohorts. For the palatability mindset group only the direct comparison between the two triggers reached significance in the first (not in the second) cohort, i.e. the palatable trigger significantly increased chips presses relative to the not palatable trigger. For the purpose of illustration, baseline-

*corrected data are depicted, i.e. values are standardized on the first choice test (baseline test). Thus, bar plots represent change in % chips presses ± SEM. **p ≤0.001 based on post hoc tests in the event of a significant interaction effect. *p=0.04 based on post hoc tests in the event of a significant interaction effect (not Bonferroni corrected significant)*

3.4 Effect of mindset and triggers on the mean priming strength

The mean priming strength (mean responding for the signaled outcome above non-cued trials) changed over the sessions with no difference between the baseline test and the mindset induction test, but was reduced in the presence of the triggers (mindset trigger test). This effect was significant for the first ($F_{(2,171)}$=7.4, p=0.002), but only marginal for the second cohort ($F_{(2,210)}$=2.8, p=0.069) (see also figure S2, supplementary material).

3.5 Sex differences

We did not find a sex effect in any of the additional analyses in the second cohort.

3.6 Comparison between the cohorts (for statistics and values see table S1, supplementary material)

There are several indications that the first (Dutch) cohort was more strongly motivated by the chips reward than the second (German) cohort. The first cohort reported a significantly higher aim of gaining chips during the task than the second cohort, while no significant differences were observed in the aim to gain zucchini or snacks in general. Furthermore, when asked whether they would like to receive a few pieces of either snack (snack choice rating after VAS 3), the first cohort showed a stronger preference for chips. This was also represented in an overall higher percentage of presses for chips in the first cohort which was independent of the Pavlovian context or the test phase (no significant 2- and 3 fold interaction of the factors 'context' and 'test type' with 'cohort').

Both cohorts rated chips as less healthy (cohort 1: $t_{(100)}$=31.0, p<0.001, cohort 2: $t_{(65)}$=38.2, p<0.001) and more palatable (cohort1: $t_{(100)}$=9.5, p<0.001, cohort 2: $t_{(119)}$=5.6, p<0.001) with a much stronger differentiation in the healthiness than in the palatability measure. The snack ratings however also revealed differences between the cohorts. Specifically, the second (German) cohort rated chips as less healthy, while its healthiness rating of zucchini was higher than the rating of the first (Dutch) cohort. Additionally, Dutch participants rated chips as more palatable than the German cohort. No difference in the palatability of zucchini was observed. Also in the current wanting and general liking ratings of several food items, German participants rated low-calorie food as more wanted and more liked. No significant differences were observed for the high-calorie category. Also, no differences were observed with regard to BMI, hunger, thirst and appetite parameters or the general mindset. The German cohort was significantly older than the Dutch cohort, yet only 1.3 years.

When analyzing the contingency knowledge of the R-O association, the first cohort showed 99.5% in the health mindset group and 98.5% in the palatability mindset group. The second cohort showed 100% in both groups. For the S-O contingency knowledge, the health mindset groups had an average contingency knowledge of 88.8% (cohort 1) vs. 81.9% (cohort 2). For the palatability mindset groups the contingency knowledge was 92.7% (cohort 1) vs. 86.7% (cohort 2.). None of these differences reached significance.

3.7 Cue specific outcome expectations

The outcome-specific response priming effect for chips correlated positively with the expectation to receive chips in the presence of the Pavlovian context stimulus associated with chips (cohort 1: $r=0.22$, $p=0.024$: not Bonferroni corrected; cohort 2: $r=0.51$, $p<0.001$). Likewise, the outcome-specific response priming effect for zucchini correlated positively with the expectation to receive zucchini in the presence of the Pavlovian context stimulus associated with zucchini (cohort 1: $r=0.24$, $p=0.016$; cohort 2: $r=0.48$, $p<0.001$).

Finally, we wanted to exclude the possibility that the mindset trigger effects were driven by an expectation to receive a snack congruent with the associated mindset value (healthy/unhealthy/palatable/not palatable). For instance, participants may have thought that a healthy mindset trigger signaled that zucchini was more likely to become available than chips. It appears that this was not the case. Correlation analyses between the S-O expectations during the mindset triggers and responding showed no significant Bonferroni-corrected correlations in either cohort ($rs < 0.29$, $ps \geq 0.05$).

4. Discussion

In two cohorts, we aimed to change food choices by the induction of a health vs. a palatability mindset as well as by the presentation of mindset-associated triggers. We report three main findings. Firstly, the pure mindset induction (baseline vs. mindset induction test) yielded a significant difference for the health vs. palatability mindset group in the Dutch cohort. That is, participants in the health mindset pressed less for chips than those in the palatability mindset. However, this effect was not robust as we failed to replicate it in the (second) German cohort. Secondly, we show that external mindset triggers can be used to powerfully boost the effect of a mindset induction. Particularly health mindset triggers had a potent effect that far exceeded that of the simple mindset induction in both the Dutch and the German cohort. Our third and final main finding concerns the role of context and thus environmental stimuli in food choice behavior. We consistently show across all test phases in both cohorts that Pavlovian context stimuli strongly and robustly shifted food choices according to the associated snack. More importantly, food-context stimuli failed to diminish the effect of mindset and mindset triggers. To summarize, our central finding is that particularly mindset triggers associated with a health mindset exert strong replicable effects on food choices, even in the presence of food-context stimuli, suggesting that these could be applied to support healthier choices in our obesogenic environment. In the remainder of the discussion, we will discuss these different findings and their implications in more detail.

The pure mindset induction affected choice behavior in the Dutch cohort. This difference between the cohorts may be related to nationality. Despite the fact that Germany and the Netherlands are neighboring countries, there are still differences in their food culture and population-wide definition of healthy eating (Margetts, et al., 1997). Additionally, according to the OECD, the obesity rate in the Netherlands is lower than in Germany (12.8% vs. 23.6%) (OECD, 2017). Interestingly, we found several differences between the two cohorts, suggesting that health consciousness in the German cohort is generally stronger. German participants rated chips as less healthy and less palatable and zucchini as healthier than their Dutch counterparts, who showed a stronger interest in receiving chips. This was also represented in the higher percentage of chips presses in the Dutch cohort during the experiment as well as lower wanting and liking of low-calorie foods. Nevertheless, when asked about the general mindset (i.e. what tends to drive their daily food choices in terms of healthiness vs. palatability), there were no significant differences between the cohorts. To conclude, further research is required to uncover the cause for the inconsistency in findings regarding the pure mindset induction. Our second central finding is that the mindset trigger associated with healthiness induced a decrease in percentage of chips presses (leading therefore to an increase in zucchini presses), whereas the trigger for unhealthiness increased chips presses (and reduced zucchini presses), relative to baseline. For both cohorts, this effect was more than three times as strong as that of the pure mindset induction in the Dutch cohort. In contrast, the palatability mindset triggers had a relatively small effect (increase on responding for the palatable chips relative to baseline), which was restricted to the Dutch sample. The smaller effect of the palatability mindset and triggers might partly be related to our finding that participants in both cohorts made a much clearer distinction between the snacks in terms of healthiness compared to palatability. While they rated chips as both less healthy and more palatable, the difference in palatability ratings (for chips versus zucchini) was relatively modest. Our findings are in line with a study showing that variance in portion size selection could be predicted on the basis of healthiness ratings only when participants were in a health (vs. pleasure or fullness) mindset (Hege, et al., 2018). Therefore, and in accordance with our results, it seems necessary to make a health mindset salient so as to alter food-associated behavior towards healthier choices.

Thirdly, we also replicated the repeatedly shown outcome-specific PIT effect (Cartoni, et al., 2016; Holmes, et al., 2010), with the food-context stimuli biasing choice behavior towards the signaled food. Importantly, in the Dutch cohort which did display an overall mindset effect, we also show for the first time that mindset can influence food choice independent of contextual food stimuli. These results suggest that internal mindset can have an additive influence on food choice to external food-context stimuli. This interpretation is based on the fact that the health/palatability mindset induction produced a *general* reduction/increase in responding for chips, regardless of the presence of Pavlovian context stimuli in the Dutch cohort. And conversely, external food-context cues (here background patterns) still elicited responding for signaled food rewards (i.e. outcome-specific PIT), despite the induction of the mindset manipulation. This pattern appears similar to what has been observed for the influences of food satiation and external cues (Watson, et al., 2014). To conclude, we speculate that in an obesogenic environment one's current internal mindset – especially when once again triggered - can compete with strong contextual influences in determining food choices.

Furthermore, the presence of food-associated cues did not diminish the mindset trigger effect. On the other hand, the mean priming strength tended to be reduced in the presence of competing external mindset triggers. Therefore, we experimentally demonstrate that food choice behavior can be influenced by environmental stimuli in different ways: the obesogenic, food-associated environment (operationalized as food-associated backgrounds) has the power to shape such food choices; while health mindset triggers can still have a potent effect on top of that. The health mindset trigger effect highlights the potential of using health triggers to support healthy choices in an obesogenic environment.

This study lends support, therefore, for attempts at influencing consumer behavior through environmental stimuli; for example, by applying easy-to-interpret food labels signaling the health status of food (such as a traffic-light system) (Hawley, et al., 2013). Our results suggest that such attempts might not overrule the effect of an obesogenic environment, but may independently bias choice behavior towards healthy food choices.

Of note, in our adult cohorts, the strength of the PIT effect was not significantly different between the snacks. In a previous PIT study investigating (Dutch) adolescent participants, the PIT effect for high-calorie rewards was stronger than that for low-calorie rewards (Watson, et al., 2016). This might suggest that adolescents, but not adults, are more sensitive to contextual cues associated with high-calorie nutritional rewards as opposed to low-calorie foods (i.e. vegetables). Within the PIT literature there is an ongoing discussion about the role of explicit beliefs versus a rather associative character of the response (Mahlberg, et al., 2019; Seabrooke, Hogarth, & Mitchell, 2016; Seabrooke, Wills, Hogarth, & Mitchell, 2019; Watson, et al., 2018). In our study, the expectation about the probability to receive a specific snack outcome correlated with the degree of responding for the outcome signaled by the Pavlovian context stimuli, even though the participants were instructed to ignore these stimuli. However, such a correlation does not necessarily mean that explicit knowledge was the driving force behind the PIT effect. More importantly, the mindset trigger effect was not based on explicit expectations of the availability of a healthy or unhealthy snack in the presence of the trigger for healthiness or unhealthiness. This makes the observed trigger effects even more convincing.

In addition to the strengths of the present study, such as the sample size, the replication design and the strong reproducible effects of the triggers, the limitations should also be mentioned. We did not include a mindset manipulation check since we wanted to avoid drawing attention to the purpose of the manipulation. In retrospect, it would have been useful to include this, especially in the second cohort that failed to show a mindset effect on food choice behavior. It remains unclear why precisely the mindset effect could not be replicated in the German cohort. A way to improve the overall interpretability of the mindset manipulation would be to include a ‘no mindset’ group, to allow comparison of the effectiveness of inducing a health versus palatability mindset. Another limitation is that we included mostly healthy-weight participants and it remains possible that individuals with obesity and/or an eating disorder show different cue-dependent behavior that is more or less likely to be influenced by mindset induction or mindset triggers, depending on the context of the mindset. For example, Veit et al. (2019) showed that individuals with overweight showed stronger responding to a pleasure mindset than normal-weight participants. There are also lines of evidence showing BMI-dependent differences in the sensitivity to food cues. For example, obese adults showed higher response priming rates for palatable, high-calorie foods than for low-calorie foods in a PIT task, an effect which was not observed in healthy-weight individuals (Watson et al., (2017); but see Meemken & Horstmann (2019), who did not replicate this pattern of results. Using an outcome devaluation paradigm, Horstmann et al. (2015) showed reduced behavioral sensitivity to satiation in obese individuals, which could further prompt overeating. Furthermore, as is invariably the case with highly standardized laboratory experiments, caution is warranted in extrapolating the results to real-life settings. In the current study we used novel logos as mindset triggers (and abstract patterns as Pavlovian cues) to show that mindset (trigger) effects persist in a food-associated environment on food seeking. While our experimental allows us to control the associative learning process within the experiment, we should be cautious with generalizing our findings to real-life food seeking. Therefore, further investigation of these processes in realistic, ecologically valid environments is warranted. It remains a question as to how familiarity of logos/cues would modulate these results and the importance of conscious perception when processing external cues (see e.g., (Gaillet, Sulmont-Rosse, Issanchou, Chabanet, & Chambaron, 2013; Prasad & Mishra, 2019)).

Conclusion: In support of the notion that our obesogenic environment contributes to a gap between intentions and behavior, we show that external food-context stimuli strongly bias food choice behavior also after a mindset induction and even in the presence of mindset induced triggers. Furthermore, we show that external mindset triggers can be used to strongly bias food choice behavior towards a healthy snack (in both cohorts). Our study therefore emphasizes the possible benefit of population-wide food labeling initiatives such as a traffic light labeling of food products that is currently under discussion.

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Author contributions

SFP, SdW, HP developed the study design; AV, PW contributed to the study design and programmed the experiment; Testing and data collection was performed by SFP and SS; SFP performed data analyses; all authors contributed to results interpretation; SFP drafted the initial manuscript; all authors provided critical revisions; all authors approved the final version of the manuscript for submission.

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