Top-down expectation effects of food labels on motivation

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ABSTRACT

Labels on food packages inform our beliefs, shaping our expectations of food properties, such as its expected taste and healthiness. These beliefs can influence the processing of caloric rewards beyond objective sensory properties and have the potential to impact decision making. However, no studies, within or beyond the food domain, have assessed how written information, such as food labels, affect implicit motivation to obtain rewards, even though choices in daily life might be strongly driven by implicit motivational biases. We investigated how written information affects implicit motivation to obtain caloric rewards in healthy young adults. We used food labels (high- and low-calorie), associated with an identical fruit-flavored sugar-sweetened beverage, to study motivation for caloric rewards during fMRI. In a joystick task, hungry participants (N = 31) were instructed to make fast approach or avoid movements to earn the cued beverages. Behaviorally, we found a general approach bias, which was stronger for the beverage that was most preferred during a subsequent choice test, i.e., the one labeled as low-calorie. This behavioral effect was accompanied by increased BOLD signal in the sensorimotor cortex during the response phase of the task for the preferred, low-calorie beverage compared with the non-preferred, high-calorie beverage. During the anticipation phase, the non-preferred, high-calorie beverage label elicited stronger fMRI signal in the right ventral anterior insula, a region associated with aversion and taste intensity, than the preferred, low-calorie label. Together, these data suggest that high-calorie labeling can increase avoidance of beverages and reduce neural activity in brain regions associated with motor control. In conclusion, we show effects of food labeling on fMRI responses during anticipation and subsequent motivated action and on behavior, in the absence of objective taste differences, demonstrating the influence of written information on implicit biases. These findings contribute to our understanding of implicit biases in real-life eating behavior.

Introduction

We know how to behave not only through experience, but also through top-down information, such as by instructions. Instructions can control behavior by altering the value of actions, even when such behavior leads to sub-optimal outcomes. For example, misleading information, such as product claims made in marketing, can influence reward-based learning and decision making - and associated neural processes - beyond experience or actual value (Biele et al., 2009; Doll et al., 2011; Doll et al., 2009; Engelmann et al., 2009; Hayes, 1989; Li et al., 2011; Nickerson, 1998). Similarly, misleading information can strongly influence the processing of caloric rewards. Previous studies have found influences of semantic framing of foods (de Araujo et al., 2005; Veldhuizen et al., 2013), price labels (Plassmann, O'Doherty,

Shiv and Rangel, 2008), healthiness of foods (Grabenhorst et al., 2013; Hare et al., 2011; van der Laan et al., 2012), and "organic" labels (Linder et al., 2010) on neural processing of passively tasted foods or on explicit choice and valuation measures such as liking and willingness-to-pay. Interestingly, the top-down influences of food labels impacts explicit motivation in children (Enax et al., 2015) and can even act on low levels in the gut-brain axis, such as secretion of the gut peptide ghrelin, which signals hunger state to the brain (Crum et al., 2011). However, no studies within or beyond the food domain, have assessed how written information, such as food labels, affect the implicit motivation to obtain rewards, as well as underlying neural processes. This is relevant as behavior is motivated not only by explicit goals that people set for themselves, but also by implicit biases that do not necessarily contribute to adaptive, optimized behavior. Approach

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biases, defined as an automatic behavioral inclination to approach rather than avoid certain stimuli, can lead to unwanted behavior with negative consequences, such as drug-seeking behavior in addiction (Watson et al., 2012). Here, we assess the degree to which written information affects approach bias towards caloric rewards in healthy participants.

Approach biases have been demonstrated by having participants make approach (towards their body) versus avoid (away from their body) movements with a joystick upon stimulus presentation, such as pictures (Rinck and Becker, 2007; Watson et al., 2012). This paradigm has also been successfully applied to study approach biases in the food domain. Obese relative to lean subjects showed enhanced approach biases towards food cues (Havermans et al., 2011; Kemps and Tiggemann, 2015). Furthermore, approach biases to food stimuli were observed when people were food deprived (Seibt et al., 2006), and when food stimuli were appealing rather than disgusting (Piquer-as-Fiszman et al., 2014). However, whether behavioral approach biases are affected by written labels is unclear, as well as the neural mechanisms underlying this effect. Specifically, it is unknown whether the neural counterpart of top-down label effects on approach-avoidance can be expected in regions involved in taste processing (Woods et al., 2011), motivational processing (Cousijn et al., 2012; Doll et al., 2009) or motor control (Mogenson et al., 1980; Radke et al., 2016; Salamone and Correa, 2012). To investigate which brain areas are involved in the effect of written information on the actual motivation to obtain rewards, the present fMRI study examined how approach biases are affected by beliefs. These beliefs were induced by cueing an identical beverage as 'low-calorie' or 'high-calorie', as perceived healthiness of food exerts a strong influence on behavior (Chandon and Wansink, 2012). We employed a variant of an approach-avoidance task in which hungry participants worked to actually obtain these differently labeled beverages during fMRI. Specifically, participants were cued with the beverage labels informing them which beverage they were working for. Affective stimuli have been shown to facilitate or suppress instrumental responses (Geurts et al., 2013; Guitart-Masip et al., 2014; Talmi et al., 2008), even in priming studies, i.e., when the affective stimulus preceded the target instructing a response (Ly et al., 2016; Ly et al., 2014). Following a brief delay, participants responded to label-independent approach (i.e., pull joystick) and avoid (i.e., push joystick) instructions. This paradigm allowed us to disentangle label-based anticipatory caloric reward processes from instrumental action processes in the brain.

Because participants responded in the motivational context of action-dependent outcomes that were given shortly after working for them within the scanner, this task has a high degree of ecological validity. Given that affective stimuli can modulate instrumental behavior, we expected labeling to modulate approach-versus avoid-related behavioral and brain responses. Specifically, we predicted to observe a stronger approach bias for the label people preferred, i.e., a tendency to pull the joystick towards the body relative to pushing it away, as expressed in either faster reaction times or decreased error rates when making a pull versus a push movement, and associated neural effects. As mentioned above, we expected neural approach bias effects in regions involved in taste processing (Woods et al., 2011), motivational processing (Cousijn et al., 2012; Doll et al., 2009) or motor control (Mogenson et al., 1980; Radke et al., 2016; Salamone and Correa, 2012). In addition to assessing neural responses at the moment people worked for the differently labeled beverages, we also assessed BOLD responses during the preceding anticipation phase, i.e., when the low- or high-calorie label was presented. We hypothesized that if participants form different beliefs about the caloric content of the beverage, this would be reflected in differential activation, for instance in regions encoding stimulus properties such as taste intensity or reward.

Materials and methods

Participants

Our sample consisted of 31 right handed, neurologically and psychologically healthy participants (15 men, mean age = 24, age range = 20–32, mean BMI = 23.1, BMI range 20.3–28.1). Exclusion criteria were: a BMI <18.5 or >30 kg/m2, problems with chewing or swallowing, stomach or bowel diseases, diabetes, thyroid disease or any other endocrine disorder, gaining or losing more than 5 kg during the last six months, an energy restricting diet during the past 6 months, having a current alcohol consumption of >28 units per week, being allergic and/or intolerant for products under study or having any contra-indication for MRI scanning. We invited 34 participants; data of three participants were discarded because of technical problems. Recruitment took place via a student forum and the subject database of the Radboud University (radboud.sona-systems.com). Participants were compensated for participation, and gave written informed consent in a manner approved by the local ethics committee on research involving human participants (CMO region Arnhem-Nijmegen, The Netherlands).

Experimental procedure

Training session

Participants were instructed to fast for at least 6 h prior to the experiment (no food, only water) and were either tested in the morning, around 10:30, or between 15:00–19:00 h in the afternoon. Participants were told that they would be working to earn different beverage rewards by making correct and fast responses on a joystick task. Inside the scanner, the experiment started with a training session in which participants were familiarised with the experiment and learned the label-taste pairings (Fig. 1). The training session started and ended with participants indicating their feeling of hunger, thirst, and fullness ("How hungry/thirsty/full do you feel right now?") on a continuous visual analog scale (VAS, ranging from a score of 0 -"Not hungry/thirsty/full at all" to 10 -"Very hungry/thirsty/full"). Then, the training started with three blocks of 24 trials in which the response requirements of the task (see below) were practiced. Then, a VAS for hunger, fullness and thirst was administered again, followed by trials in which the labels were paired with tastes. The labels 'low-calorie', 'neutral' and 'high-calorie' were presented in that order, followed by the presentation of a taste after the participant moved the joystick. The neutral label was paired with demineralized water. Unbeknownst to the participants, both the 'low-calorie' and 'high-calorie' labels were paired with the same fruit-flavored sugar-sweetened beverage (Karvan Cévitam grenadine, 120 g syrup dissolved in 700 g of demineralized water; the mixture contained 385 kcal/l). This allowed us to investigate the effects of labelling in the absence of objective taste differences. Each label with the paired beverage was delivered three times in 1.5 mL (duration: 3s) quantities, together with a picture indicating the receipt of that beverage (a blue drop for the neutral beverage, a lighter red for the beverage labeled low-calorie and a darker red for the beverage labeled high-calorie Directly after receiving each beverage for the first and third time, participants indicated their liking ("How pleasant do you find the taste of this beverage?") on a continuous VAS scale. Liking ratings were collected on a continuous VAS (ranging from a score of 0 -"Very unpleasant"- to 10 -"Very pleasant"). In the final block of training, participants practiced the full task: working to obtain the beverage that was cued at the start of the trial by responding to the cue that indicated which was the appropriate response. This block included 12 trials. After the sixth trial, a wanting VAS was answered for each of the labeled beverages in the form of the question: "How much do you want to drink this beverage at this moment?" (ranging from a score of 0 – "Not at all" – to 10 – "Very much"). At the end of the block, participants received
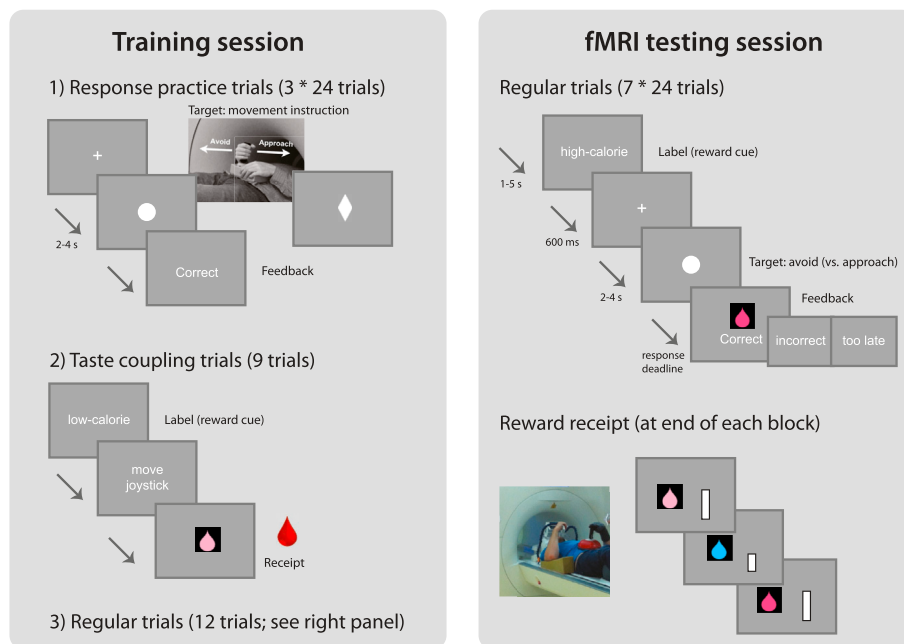
Fig. 1. Experimental design. Left panel: Training session. 1) Response practice trials: training started with three blocks of 24 trials in which the response requirements of the task were practiced. 2) Taste coupling trials: the labels 'low-calorie', 'neutral' and 'high-calorie' were presented in that order, followed by the presentation of a taste after the participant moved the joystick. 3) Finally, 12 full trials were completed, followed by reward receipt (see right panel). Right panel: Example trial in the approach bias paradigm. The presentation of one of the reward cue labels (neutral/low-calorie/high-calorie) indicated which reward could be earned during the trial. After a variable delay, the response target appeared on the screen. For each shape, participants were trained to make either an approach movement (pull joystick towards their body) or an avoid movement (push joystick away from their body). After the response deadline, feedback was given (correct/incorrect/too late). Caloric rewards were only received at the end of each experimental block. The earned amount of beverage was delivered at 30 mL/min (continuous infusion). A vertical bar that decreased in size during drink administration indicated how much of the beverage was still to come.

the earned amount of each labeled beverage, as they would in the actual experiment.

Throughout the experiment, beverages were administered with the use of three identical programmable membrane-liquid pumps (KNF Stepdos FEM03.18RC, KNF Verder, Vleuten, The Netherlands; 0.030–30.0 mL/min) into the participant mouth at a rate of 30 mL/min. Each of the three labeled beverages was administered through a separate tube, but the beverages labeled low-calorie and high-calorie were connected to the same bottle filled with fruit-flavored beverage. However, upon entering the scanner area, participants saw a tube running into another bottle. The tube was placed into the same bottle as the other tube once the experiment started, such that the two differently labeled beverages were in reality the same beverage. The three tubes reached the head of the subjects via a plastic arm and went through a plastic holder. The final parts of the tubes were bundled together and held in place by a tape. Participants held the end of the three tubes between their lips.

fMRI test session

Participants were scanned while performing an instrumental approach-avoidance task in which they worked to obtain caloric rewards (Fig. 1). In order to earn the reward cued by the label, participants had to follow the response instructions, i.e., approach (pull towards their body) or avoid (push away from their body). Because our participants were hungry, we expected them to show an implicit approach bias towards appetitive food stimuli. Trials started with a reward cue (i.e., one of the labels: neutral/low-calorie/high-calorie), which predicted the beverage reward for correct performance. The interval between the reward cue and the response target was jittered with a variable delay between 2 and 6 s. The target to which participants responded was one of four shapes. For two of the shapes, they had to pull the joystick towards their body (approach), for the other two shapes they had to push the joystick away from their body (avoid). These instructions, with emphasis on the responses relative to their body, were given to them before the start of the scan session and were repeated when they received the joystick while lying on the scanner bed before the start of the experiment. During the experiment, joystick displacements of 80% of the maximal displacement achievable along the sagittal plane were counted as valid responses. To enhance automatic tendencies, responses had to be made within a response deadline, which was adaptive during the experiment: a correct

response resulted in a lowering of the deadline with 20 ms, failure to respond within the deadline resulted in an increment of 25 ms. Separate deadlines for each beverage cue and each response (approach/avoid) were used. The response deadlines from the end of the practice trials were used as the initial deadlines for the actual experiment. At the time of the response deadline, participants received feedback ("correct", "incorrect" or "too late"). Feedback "correct" was accompanied by a picture indicating the earned reward. With each correct response, participants earned 0.5 mL of the cued beverage. Rewards were not received immediately, but participants received the total amount of liquid they had earned for each beverage during each experimental block of 24 trials at the end of that block. This was done to avoid sensory-specific satiety (Rolls et al., 1981), which occurs faster when the same amount of food is received in smaller portions (Weijzen et al., 2009). First, a message was presented that indicated that participants would receive the beverages, then the beverage rewards were given in the order: low-calorie, neutral and high-calorie. Beverages were given in one uninterrupted flow; a vertical bar that decreased in size with beverage exposure indicated how much of the beverage was still to come. All participants were instructed to refrain from swallowing until instructed to swallow on the screen. Then, liking ratings for the received taste were collected via a VAS (see above). After the earned amounts of beverages were presented, 0.75 mL of demineralized water was given to rinse. In total, 7 experimental blocks of 24 trials each were presented, making a total of 28 trials per combination of reward cue and response requirement (approach/avoid). Trial sequences were randomly generated per participant per block, with an equal number of trials for each combination of reward cue label and response target shape. A VAS for hunger, fullness and thirst was completed before the start of the experimental session, before block 3 and block 5 and after the last trial. A wanting VAS for each beverage (see above) was administered halfway through each block (after trial 12). After leaving the scanner, performing an unrelated task for about an hour, and completing questionnaires (see below), participants had to choose one of two 0.5 l bottles to take home. The bottles were filled with the fruit-flavored sugar-sweetened beverage they received during the experiment and looked identical, except for their labels: "'low-calorie'" and "high-calorie".

In the context of a larger project, we collected participants' responses to the Dutch Eating Behavior Questionnaire (DEBQ; Van Strien, Frijters, Bergers and Defares, 1986), the BIS/BAS (Carver and White, 1994), the

Table 1
Participant characteristics.

Age, *M(SD)*	24.06 (3.26)
Sex N (%) female	31 (51.6%)
BMI, *M(SD)*	23.1 (1.77)
DEBQ restrained, *M(SD)*	2.33 (0.66)
HTAS general health interest, *M(SD)*	4.7 (1.13)
HTAS light product interest, *M(SD)*	3.17 (1.02)

BIS-11(Barratt, 2006), the Health and Taste Attitude scale (HTAS; Roi-ninen et al., 2001), the Kirby delay discounting test (Kirby et al., 1999) and the Food Neophobia scale (Pliner and Hobden, 1992). Participant characteristics deemed potentially relevant for this study are reported in Table 1. To determine whether these characteristics could predict beverage choice at the end of the experiment, we ran a binary logistic regression in SPSS Statistics (Version 21; IBM, Armonk, NY), which also included sex, (z-scored) BMI and the difference between wanting scores for the beverage labeled high-calorie and for the one labeled low-calorie directly after the first taste as predictors. Note that liking scores were not included in this regression analysis because of their correlation with the wanting scores.

Behavioral data analysis

Behavioral data were preprocessed in Matlab 8.4 (Mathworks, Natick, MA). To obtain a precise measure of the movement onset (reaction time; RT), joystick movements were reconstructed for each trial using the joystick displacement measurements. Movement onsets (RTs) were constrained by several criteria: the joystick needed to be close to the movement onset position (at least < 25% of the maximum deviation [2 cm]) for at least 100 ms prior to onset time, and, subsequently, a sustained deviation for at least 150 ms had to be made. Furthermore, the velocity needed to be significant and sustained (>0.01 cm/s and peaking to 5 cm/s in the following 100 ms). When these constraints were met, the movement onset was defined as the time-point with the lowest velocity. Criteria for movement offset were defined as: the joystick being close to the maximum offset position (>80% of the maximum deviation), and at the end of a ballistic movement showing a decreasing velocity (>5 cm/s in a time window 50-20 ms prior to offset time). Movement time (MT) was defined as the time difference between movement onset and movement offset. We excluded trials in which no response was made (4.6% of trials), trials that showed extreme RTs (<150 ms or >1000 ms; 0.06% of trials with a response), RTs and MTs >3 SD from the mean (2.4% of trials with a response). For RT analysis, trials in which a response in the wrong direction was made were also excluded. Following Baayen and Milin (2010), we employed minimal a priori data trimming (3 SDs from the mean, see above), combined with model critique on log-transformed RTs. Model critique was implemented by fitting the mixed-effects RT model (see below) and trimming at 2.5 SDs was then conducted on the scaled residuals produced from this model. These processes led to the removal of 1.5% of the remaining trials. For the accuracy analysis, we started with the data of all trials that were responded to (i.e., without misses) and applied the same trimming: extreme response times plus response times more than 3 SDs from the mean were removed. RTs and accuracy were analyzed with mixed-level models using the lme4 package in R (lme4 1.1–13; Bates et al., 2015; R 3.2.2; R Core Team, 2013). This allowed us to account for within-subject variability in addition to between-subject variability. Factors Action (approach, avoid) and anticipated Labeled beverage were within-subject factors, for which main effects and their interaction were included. We also added the main effect of trial number as a within-subject covariate (Baayen and Milin, 2010), as well as the fixed effect of BMI as a between-subject covariate of no interest. All models contained a full random effects structure for the effects of interest, plus a random slope for trial number. P-values are obtained by type II Wald chi-square tests

from the car package (version 2.1–5; Fox and Weisberg, 2011). Given our experimental aim, we focus on the main contrast of interest between low-calorie and high-calorie labels. For comparison, we also performed analyses that included the neutral label. We calculated error rates per condition, which were defined as the amount of errors divided by the total amount of trials for that condition (excluding misses), times 100 to obtain a percentage, for display purposes and for performing paired T-tests in case interactions were observed.

Subjective ratings for liking and wanting of each taste were analyzed with mixed-level models using the lme4 package in R (see above). For both wanting and liking ratings, we created models with fixed factors Labeled beverage and Total amount consumed, indicating for each rating observation how much had already been consumed (cumulatively, in mL) of the label under question. Models for the analysis of hunger, thirst and fullness contained Time Since Start of the Training as fixed factor. Models of subjective ratings contained a full random effects structure for the fixed effects.

FMRI data analysis

Data acquisition

Whole-brain functional images were acquired on a 3T Siemens Skyra MRI scanner (Siemens Medical system, Erlangen, Germany) using a 32-channel coil. A multi-echo echo-planar imaging (EPI) sequence was used to acquire 34 axial slices per functional volume (voxel size 3.5 × 3.5 × 3 mm; repetition time 2070 ms; echo times: 9 ms, 19.25 ms, 29.5 ms, and 39.75 ms; flip angle = 90°; field of view = 224 mm). This type of multi-echo acquisition sequence for functional images reduces motion and susceptibility artifacts (Poser et al., 2006). After the acquisition of functional images, a high-resolution anatomical scan was acquired (T_1-weighted MPRAGE, voxel size 1 × 1 × 1 mm, TR 2300 ms, TE 3.03 ms, 192 sagittal slices, 1 mm thick, FoV 256 mm).

Image processing

Data were analyzed using SPM8 (www.fil.ion.ucl.ac.uk/spm). The volumes for each echo time were realigned to correct for motion artifacts (estimation of the realignment parameters was done for the first echo and then copied to the other echoes). The four echo images were combined into a single MR volume based on 30 volumes acquired before the actual experiment started using an optimized echo weighting method (Poser et al., 2006). Combined functional images were slice-time corrected. Structural and functional data were then co-registered and spatially normalized to standard stereotactic space (Montreal Neurological Institute (MNI) space). After segmentation of the structural images, using a unified segmentation approach, the mean of the functional images was spatially coregistered to the bias-corrected structural images. The transformation matrix resulting from segmentation was then used to normalize the final functional images into MNI space (resampled at voxel size 2 × 2 × 2 mm). Finally, the normalized functional images were spatially smoothed using an isotropic 8 mm full-width at half-maximum Gaussian kernel.

GLM analyses

Statistical analyzes were performed in the context of the general linear model in SPM8. Our first level model contained 9 regressors of interest: 3 regressors for the reward cue labels (neutral, low-calorie, high-calorie) and 6 regressors for the response cues after which a correct response was made (Labeled beverage × Action). All regressors of interest were modeled as an impulse response function (duration = 0) convolved with a canonical hemodynamic response function. Furthermore, experiment-related regressors of no interest were included for the response cues to which an incorrect response was made (collapsed over preceding labels), the outcomes (receipt of each type of beverage), VAS

scales and for rinse and swallow instructions. In addition, we included six motion parameters, their first-order derivatives and global signal changes (as indexed by segmented white matter, cerebral spinal fluid and out-of-brain voxels). Statistical analysis included high-pass filtering (cutoff: 128 s) to remove low-frequency confounds such as scanner drifts and correction for serial correlations using an autoregressive AR(1) model.

Contrast images from the first level were entered into second level random-effects analyses to test for consistent effects over participants. We performed different one-sample T-tests based on the following contrasts calculated on the first level: low-calorie vs. high-calorie labels during anticipation. To assess signal during motivated action (approach versus avoid), we calculated the contrast between all approach (pull) instructions > all avoid (push) instructions. Furthermore, to investigate whether implicit biases were affected by the misleading information, we tested for interactions between Labeled beverage and Action using the contrast images for the approach bias: (approach vs. avoid) in low-vs. high-calorie labeled trials. Given that BMI has been found to influence neuronal responses to food cues (Janssen et al., 2016; Ng et al., 2011; Stice et al., 2008; Veldhuizen et al., 2013), we have included BMI as a covariate of no interest in our second level fMRI analyses. The results of all random effects fMRI analyses were thresholded at P < 0.001 (uncorrected) and statistical inference was performed at the cluster level, family-wise- error-corrected (P_{FWE}<0.05) for multiple comparisons over the search volume (the whole brain).

Results

Subjective measures

We analyzed subjective liking and wanting of the differently labeled beverages using mixed-level models that included the cumulative consumed amount of each beverage at the time of the rating as a measure of consumption progress (see Materials and Methods). For liking, there was a trending main effect of the labels ($\chi^2(2) = 5.61$, P = 0.061; $M_{low\text{-}calorie,initial}$(SD) = 5.96(1.95); $M_{high\text{-}calorie,initial}$(SD) = 5.71(1.88); $M_{neutral,initial}$(SD) = 5.26(1.76); $M_{low\text{-}calorie,end}$(SD) = 5.81(2.43); $M_{high\text{-}calorie,end}$(SD) = 5.75(2.68); $M_{neutral,end}$(SD) = 5.60(2.26)). To investigate this trend further, we compared the labels with each other: high-calorie vs. low-calorie ($t(30) = 0.945$,P = 0.352), and high-calorie vs. neutral ($t(30) = -0.49$,P = 0.63). The main effect of Amount consumed ($\chi^2(1) = 0.11$,P = .742) or the interaction between amount consumed and the labels ($\chi^2(2) = 1.89$,P = 0.389) were both not significant. Overall wanting for beverages decreased with increased consumption (main effect of Amount consumed: $\chi^2(1) = 10.33$,P = 0.013; $M_{low\text{-}calorie,initial}$(SD) = 6.39(2.19); $M_{high\text{-}calorie,initial}$(SD) = 6.36(2.41); $M_{neutral,initial}$(SD) = 6.27(2.02); $M_{low\text{-}calorie,end}$(SD) = 5.53(2.69); $M_{high\text{-}calorie,end}$(SD) = 5.03(3.05); $M_{neutral,end}$(SD) = 5.30(2.56)). The main effect of Labeled beverage ($\chi^2(2) = 1.28$,P = 0.53) was not significant, nor was the interaction between Labeled beverage and Amount consumed ($\chi^2(2) = 2.503$,P = 0.29).

At the end of the experiment, participants were presented with the choice to take home a 0.5 L beverage bottle with identical fruit-flavored sugar-sweetened beverage content, labeled as either the low-calorie or the high-calorie beverage. Of the 30 participants presented with this choice (for one participant, time constraints prevented this), twenty-three (76.7%) participants chose the bottle with the low-calorie label ($\chi^2(1) = 14.226$, P < .001). Therefore, we interpret the low-calorie label as being the preferred label. To determine whether the beverage choice could be predicted by participant characteristics, we ran a binary logistic regression with Beverage choice as dependent variable, and sex, BMI, wanting score differences between the high and low-labeled beverages upon first tasting, and these questionnaire subscales: the restrained eating subscale of the DEBQ, and the general health interest and light product interest subscales of the HTAS (see Materials and Methods). The omnibus test for this regression model shows that it is significant ($\chi^2(6) = 17.0$, P < 0.01; Nagelkerke's $R^2 = 0.653$). Within the model, the

wanting score differences between the high and low-labeled beverages upon first tasting was the only significant (positive) predictor of choosing the beverage labeled high-caloric over the low-caloric at the end of the experiment (P = 0.044). Furthermore, trends were observed for (z-scored) BMI as a positive predictor of high-calorie label choice (P = 0.062) and light product interest as a negative predictor of high-calorie label choice (P = 0.056), all other predictors were not significant (Ps > 0.4).

Given that the difference in initial wanting between the differentially labeled but identical beverages was a significant predictor of choice, we added the between-subject factor Beverage choice at the end of the experiment as well as the factor Amount consumed (i.e., indicating time passed) to a wanting model with wanting scores for the low- and high-calorie Label. This revealed, besides the same main effect of consumption seen before, an interaction between Labeled beverage and Beverage choice in wanting ratings ($\chi^2(2) = 6.543$,P = 0.038), but no other interactions (Ps > 0.127). Breaking down the Labeled beverage × Drink choice interaction by running separate models for each Drink choice group revealed that, in the group choosing the beverage labeled low-calorie, there was a trending main effect of Labeled beverage ($\chi^2(1) = 3.719$,P = 0.054; $M_{high} = 5.64$,$M_{low} = 6.27$), and an Amount consumed effect ($\chi^2(1) = 7.36$,P < 0.01), but no interaction between the two. No further main effects or interactions were observed (Ps > 0.38). In the group choosing the beverage labeled high-calorie, no effect of Labeled beverage or Amount consumed was observed (Ps > .22), but a Labeled beverage × Amount consumed interaction was observed ($\chi^2(1) = 5.535$,P = 0.018). Breaking down this interaction, there was a significant negative correlation between Amount consumed and wanting rating for the beverage labeled high-calorie (rho = −.271,P = 0.043), whereas this was not observed for the beverage labeled low-calorie (rho = −0.07,P = 0.62).

To test whether the instructed knowledge manipulation worked, we asked participants to describe the difference between the beverages labeled as low-calorie and those labeled as high-calorie. Of the 30 participants who filled out this question, 26 reported that they had consistently tasted a difference ($\chi^2(1) = 16.133$, P < .001). Of these 26 participants, 22 described the beverage labeled high-calorie as being sweeter/more intense, 3 described the beverage labeled low-calorie as being sweeter/more intense, and 1 did not specify which one was perceived as such (label described as sweeter: $\chi^2(1) = 14.440$, P < .001).

Finally, we assessed how the subjective ratings of hunger, thirst and fullness changed over the course of the experiment. Thirst decreased significantly during the course of the experiment ($\chi^2(1) = 11.189$,P=<0.001; first rating: M = 6.22, SD = 2.46; last rating: M = 4.64,SD = 2.44; t(30) = 4.67, P < .001), whereas this effect was not significant for their hunger ratings ($\chi^2(1) = 2.61$,P = 0.11; first rating: M = 7.11, SD = 2.27; last rating: M = 6.68, SD = 2.56, t(30) = 1.13; P = .267). For fullness, the increase was also significant across the course of the experiment ($\chi^2(1) = 6.28$,P = 0.01; first rating: M = 2.41, SD = 1.51; last rating: 2.82, SD = 1.56).

In sum, a choice test indicated that the low-calorie label was preferred over the high-calorie label, a preference predicted mainly by the relative wanting scores between the two labels at the first tasting. With increased beverage consumption over the course of the experiment, thirst decreased, subjective fullness increased, and overall wanting for the beverages decreased. Importantly, the relative liking and wanting scores for the labeled beverages did not seem to change over the course of the experiment.

Behavioral results

First, we assessed accuracy and reaction times (RTs) of the approach (i.e., pull towards the body) and avoid (i.e., push away from the body) joystick actions depended on the preceding reward cues (i.e., neutral, or high or low-calorie label). Overall, participants made fewer errors when instructed to make approach versus avoid actions (main effect of Action

Table 2
Behavioral results. RTs (in milliseconds) and error rates (in percentages) for each combination of reward cue label and instructed movement.

Labeled beverage	Action	RTs in milliseconds (SD)	Error rates in percentage (SD)
Low-calorie	Approach	443.7 (55.3)	10.88 (8.6)
Low-calorie	Avoid	450.0 (63.4)	22.40 (13.17)
High-calorie	Approach	450.2 (66.7)	14.35 (7.80)
High-calorie	Avoid	441.1 (53.4)	18.12 (13.50)
Neutral	Approach	444.0 (56.0)	11.55 (8.36)
Neutral	**Avoid**	**444.1 (57.4)**	**22.32 (14.62)**

$\chi^2(1) = 18.36$, P < .001). Importantly, this approach bias depended on the anticipated label (Labeled beverage × Action $\chi^2(2) = 13.405$, P = .001; Table 2). Breakdown of this interaction showed a significant approach bias for the low-calorie (T(30) = 2.8, P < .001) and neutral (T(30) = 4.013,P < .001) labels and a marginally significant effect for the high-calorie label (T(30) = 1.965,P = .059). Simple main effects analyses revealed that, after approach instructions, significantly fewer errors were made on low-than high-calorie trials (T(30) = 3.445,P < .001). There was a trend towards fewer errors on neutral than high-calorie trials (T(30) = 1.838,P = .076), and no difference between low-calorie and neutral trials (T(30) = .461,P > .6). After avoid instructions, significantly more errors were made on low-calorie than high-calorie trials (T(30) = 2.867,P < .01) and on neutral than high-calorie trials (T(30) = 2.815,P < .01), whereas no difference was observed between neutral and low-calorie trials (T(30) = .045, P > .9). Thus, the Labeled beverage × Action interaction was driven primarily by greater approach bias for the preferred (low-calorie) versus non-preferred (high-calorie) labels (Fig. 2). Effects of Trial number (P = 0.12) and BMI (P = 0.74) were insignificant. To substantiate the interpretation that the low-calorie label was preferred on the behavioral level, we performed a post-hoc analysis within the subgroup of participants that all chose (i.e., preferred) the beverage labeled low-calorie at the end of the experiment (n = 23). Within this group, we observed the same main effect of Action (χ2(1) = 13.01,P < 0.001), as well as the Labeled beverage × Action interaction over all three Labeled beverages (χ2(2) = 9.927,P < .01). Simple main effects in this group confirmed that significantly fewer errors were made on low- (preferred) than high-calorie (non-preferred) trials (T(22) = 2.833,P = .01), whereas no difference was observed

between neutral and either low or high calorie labels (Ps > .29). After avoid instructions, this subgroup also made significantly more errors on low-calorie (preferred) than high-calorie (non-preferred) trials (T(22) = 2.454,P = .022) and on neutral than high-calorie trials (T(22) = 3.008,P < .01), whereas no difference was observed between neutral and low-calorie trials (T(22) = .167,P > .8). Given our main contrast of interest was between the calorie labels, we confirmed the findings above in a model without the neutral label: main effects of Action (χ2(1) = 15.61,P < 0.001) and Labeled beverage × Action interaction (χ2(2) = 10.12,P = 0.001). No other effects were significant (Ps > 0.20). Note that adding trial number as an interaction with Action and Labeled beverage to the model did not show a significant Labeled beverage × Action*Trial number interaction (χ2(2) = 2.57; P = 0.11).

The model of RTs to all beverage labels did not show any Labeled beverage × Action interaction ($\chi^2(2) = 4.60$, P = .101), nor any main effect (all other P > .4). Given our main contrast of interest was between the calorie labels, we proceeded without the neutral label. In this statistical model, RTs for approach versus avoid actions differed depending on the cued reward label (Labeled beverage × Action: $\chi^2(1) = 4.57$, P = .033; see Table 2). This was due to slower avoid actions after a low-versus high-calorie label (T(30) = 2.298, P = .028), but no difference in RTs for approach actions after low-versus high-calorie labels (T(30) = -0.938, P = .356). No main effects of Labeled beverage, Action, Trial Number or BMI were observed for the RTs (all P > .3). Adding Trial number as an interaction with the other fixed effects only resulted in a trend towards an Action × Trial number interaction ($\chi^2(1) = 3.207$, P = .073), and no other interactions. We again performed a post-hoc analysis within the subgroup of participants that all chose (i.e., preferred) the beverage labeled low-calorie at the end of the experiment (n = 23) to support the interpretation that the low-calorie label was preferred on the behavioral level. Again, we did not see a significant Labeled beverage × Action interaction (χ2(2) = 4.085, P = .130), nor any main effect (Ps > 0.5). When disregarding the neutral label as before, we find a significant Labeled beverage × Action interaction (χ2(1) = 4.0326,P = .045). This effect was driven by slower avoid actions after a low-versus high-calorie label (T(22) = 2.212, P = .038), whereas no difference in RTs for approach actions after low-versus high-calorie labels was observed (T(22) = 1.13, P = .271).

In sum, behavioral approach tendencies and choices depended on the labels of the beverage, despite the absence of any objective value differences (i.e., same fruit-flavored sugar-sweetened beverage). Specifically, we observed a greater approach bias (i.e., more approach than avoid movements despite an equal amount of approach and avoid instructions) for the preferred (low-calorie) than non-preferred (high-calorie) label. This effect was paralleled by slower RTs when having to make an avoid movement for the preferred (low-calorie) than non-preferred (high-calorie) label. These behavioral results are therefore in line with preferences, indicated by choices for labeled beverages made after the experiment. The link with subject preference is supported by subgroup analyses based on these choices.

fMRI results

Anticipation effects of label

To identify the brain regions involved in label-related anticipation, we compared BOLD responses to high-calorie labels with that during low-calorie labels. This comparison showed significant clusters in left middle temporal gyrus, left superior temporal pole and a cluster overlapping the right temporal pole and the right ventral anterior insula (Fig. 3 and Table 3a). No significant clusters were found for the contrast low-calorie label > high-calorie label. Both the low-calorie > neutral and high-calorie > neutral comparisons yielded responses in occipitotemporal cortex, which could be due to the larger visual input associated with the longer labels (i.e., words) or, alternatively, due to greater arousal (Phan et al., 2002). No results were found in other regions or for the reverse contrasts.
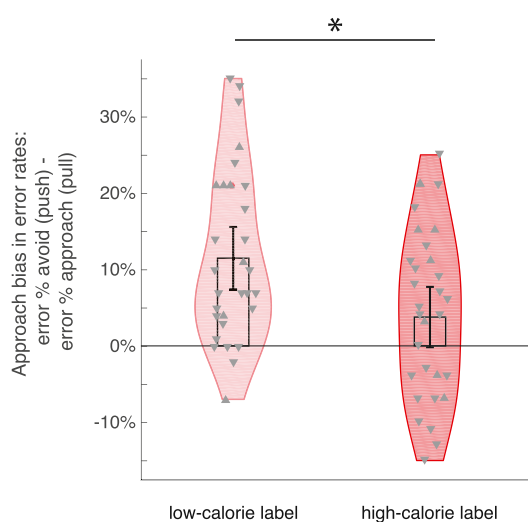

Fig. 2. Approach bias in error rates: error percentages for avoid (push away from the body) minus approach (pull towards the body) instructions, made during working for the low-calorie and high-calorie labeled beverages. Markers indicate whether participants chose the beverage labeled low-calorie (▼) or high-calorie (▲) at the end of the experiment (see Materials and Methods). Bars represent means (±SEM).
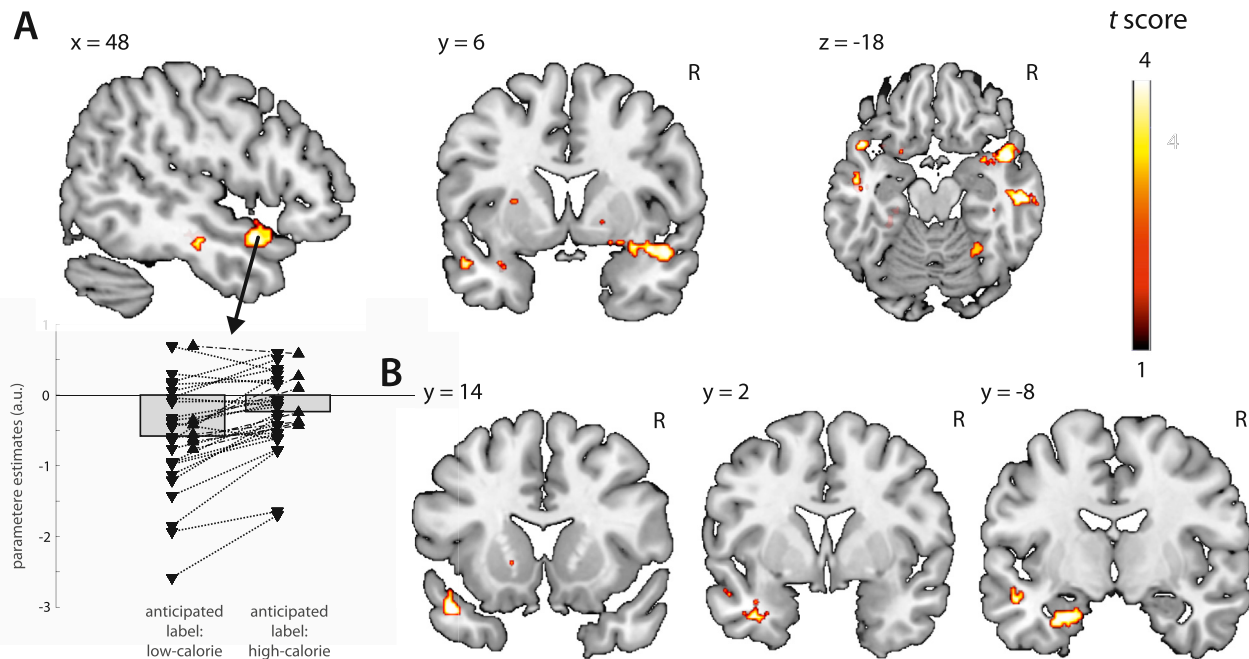
Fig. 3. Anticipation-related brain responses as a function of beverage label. **A)** High-calorie > low-calorie in the whole sample (N = 31). Insert: parameter estimates for anticipation of the low-calorie and high-calorie labels in the activated right ventral insula/superior temporal pole region. Bars indicate mean response across participants, points indicate individual participants. Markers indicate whether participants chose the beverage labeled low-calorie (▼) or high-calorie (▲) at the end of the experiment (see Materials and Methods). **B)** Non-preferred (high-calorie) > preferred (low-calorie) within the subgroup of participants that all chose (i.e., preferred) the beverage labeled low-calorie at the end of the experiment (n = 23). Activations shown at P < .001, k>10. For coordinates and which activations survive $P_{FWE} < 0.05$ at the cluster level (*), see Tables 3a and 3b.

Given that the insula is involved in taste processing and food rewards (Dalenberg et al., 2015; Sescousse et al., 2013; van der Laan et al., 2011; Woods et al., 2011) but also in processing aversive stimuli (Bermú-dez-Rattoni, 2014; Nitschke et al., 2006a; Wicker et al., 2003), we performed a post-hoc contrast on the anticipated labels in the subgroup of participants that all chose (i.e., preferred) the beverage labeled low-calorie at the end of the experiment (n = 23; cluster-defining threshold P<0.001; k>10). In this subgroup, the contrast high-calorie (non-preferred) label > low-calorie (preferred) label yielded whole-brain significant (P_{FWE}<.05) clusters in left anterior temporal cortex and left medial temporal lobe, overlapping hippocampus and amygdala, as well as (uncorrected; P<.001, k>10) activations in other temporal regions and putamen (Table 3b).

Effects of top-down labeling on neural signaling during motivated action

We first assessed the main effect of motivated action, that is the

difference between approach and avoid actions. Signal was reduced during approach versus avoid actions in the cerebellum and a cluster in left sensorimotor cortex (postcentral gyrus), in line with responding with their right hand (Table 4a; Fig. 4). Next, we assessed the degree to which neural signals during motivated action were modified by top-down beverage labeling. The left sensorimotor cortex (in the postcentral gyrus, not overlapping the cluster in left sensorimotor cortex observed in the main avoid > approach contrast), as well as the left superior parietal cortex exhibited a Labeled beverage × Action interaction, due to stronger approach versus avoid responses after the low-calorie label versus the high-calorie label (Table 4a; Fig. 4). For the reverse interaction (approach > avoid after high-calorie > low-calorie label), we observed a

Table 3a
Brain regions showing significant response during the anticipation phase of trials (*$P_{FWE} < 0.05$ at the whole-brain corrected cluster level; cluster-defining threshold: P < .001).

Contrast/Region	Cluster size (voxels)	x	y	z	peak t
Anticipation high-calorie > low-calorie label					
L middle temporal gyrus	139	−52	−14	−10	5.31*
R superior temporal pole	155	48	6	−18	4.52*
R ventral insula		38	6	−16	
R inferior/middle temporal gyrus	108	54	−20	−18	4.52*
Anticipation low-calorie > neutral label					
L/R occipitotemporal cortex	4712	−16	−86	−10	8.61*
Anticipation high-calorie > neutral label					
L occipitotemporal cortex	4437	−16	−88	−10	8.81*
R occipitotemporal cortex	**730**	**18**	**−90**	**−4**	**7.86***

Table 3b
Brain regions showing significant response during the anticipation phase of trials within the subgroup of participants that all chose (i.e., preferred) the beverage labeled low-calorie at the end of the experiment (n = 23; threshold: P < .001, k>10; *$P_{FWE} < 0.05$ at the whole-brain corrected cluster level) [+]$P_{FWE} < 0.1$ at the whole-brain corrected cluster level).

Contrast/Region	Cluster size (voxels)	x	y	z	peak t
Anticipation high-calorie (non-preferred) > low-calorie (preferred) label in subgroup that chose low-calorie beverage (n=23)					
L anterior temporal lobe	225	−46	14	−24	4.91*
L middle temporal cortex		−52	−14	−10	
R fusiform gyrus/ hippocampus	80	36	−28	−18	4.84
R parahippocampal gyrus		26	−26	−20	
L anterior hippocampus/ amygdala	92	−30	−8	−28	4.51[+]
R medial temporal lobe	33	46	−12	−24	4.34
L putamen	69	−26	8	8	4.33
R putamen	12	48	8	−18	3.96
Anticipation low-calorie (preferred) > high-calorie (non-preferred) label in subgroup that chose low-calorie beverage (n=23)					
R rolandic operculum	10	50	2	18	4.11

Table 4a
Brain regions showing signification responses during the response phase of trials (*$P_{FWE} < 0.05$ at the whole-brain corrected cluster level; cluster-defining threshold: $P < .001$).

Contrast/Region	Cluster size (voxels)	x	y	z	peak t
Avoid > approach action					
Cerebellum	819	10	−64	−28	5.74*
L postcentral gyrus	178	−58	−16	14	4.61*
L Heschl's gyrus		−32	−26	14	
Approach > avoid action					
L frontal white matter	158	−24	−6	30	4.74*
Approach > avoid: low-calorie > high-calorie					
Postcentral gyrus	166	−40	−18	40	4.55*
L supramarginal gyrus		−58	−24	36	
L superior parietal cortex	166	−22	−46	60	4.35*
L postcentral gyrus		−34	−40	58	
Approach > avoid: non-preferred (high-calorie) > preferred (low-calorie) label					
L/R occipitotemporal cortex	389	−22	−96	0	4.76*
Approach > avoid: low-calorie > neutral label					
L postcentral gyrus	315	−44	−36	54	4.76*
L inferior parietal cortex		−42	−46	54	

Table 4b
Brain regions showing signification responses during the response phase of trials within the subgroup of participants that all chose (i.e., preferred) the beverage labeled low-calorie at the end of the experiment (n = 23; threshold: $P < .001$, k>10; *$P_{FWE} < 0.05$ at the whole-brain corrected cluster level).

Contrast/Region	Cluster size (voxels)	x	y	z	peak t
Approach > avoid: preferred (low-calorie) > non-preferred (high-calorie) in subgroup that chose low-calorie beverage (n=23)					
L mid cingulate cortex	64	−12	−30	46	6.03
L postcentral gyrus		−8	−30	54	
L postcentral gyrus	71	−40	−16	40	4.82
L sup frontal cortex	19	−14	−42	30	4.61
R cerebellum	29	30	−40	−32	4.56
L postcentral gyrus	57	−22	−46	60	4.46
R postcentral gyrus	10	36	−34	64	3.96
L supramarginal gyrus	15	−58	−26	36	3.85
Approach > avoid: non-preferred (high-calorie) > preferred (low-calorie) in subgroup that chose low-calorie beverage (n=23)					
L inf/mid occipital cortex	551	−30	−80	−4	5.59*
R inf/mid occipital cortex	57	34	−70	−8	5.14
R sup/mid occipital cortex	65	16	−86	20	4.81
R inf frontal gyrus	45	34	24	28	4.72
L fusiform gyrus	23	−44	−60	−20	4.72
L mid occipital cortex	30	−16	−82	14	4.33
R lingual gyrus	27	14	−84	4	4.08
R fusiform gyrus	11	26	−66	−6	3.90

cluster in bilateral occipitotemporal cortex. In keeping with the Labeled beverage (low vs high) x Action contrast, a comparison between the low-calorie trials with the neutral label trials also revealed a Labeled beverage × Action interaction in the postcentral gyrus: approach versus avoid signal in this region was greater for low-calorie label trials than for neutral trials. There were no main effects of Labeled beverage irrespective of Action during the response phase. To assess the degree to which these results are driven by the preference of participants, we performed a post-hoc contrast on the Labeled beverage × Action interaction in the subgroup of participants that all chose (i.e., preferred) the beverage labeled low-calorie at the end of the experiment (n = 23; cluster-defining threshold P<0.001; k>10). In this subgroup, approach > avoid after low-calorie (preferred) label > high-calorie (non-preferred), we did not find whole-brain significant ($P_{FWE}<.05$) clusters, but we did find activations in similar sensorimotor regions as those observed in the whole sample uncorrected at the whole-brain level (P < 0.001, k>10; Table 4b). For the reverse interaction (approach > avoid after high-calorie > low-calorie label), we observed a range of occipitotemporal visual regions, as we did in the entire sample.

In sum, our subjects demonstrated a greater approach bias behaviorally when anticipating the preferred (low-calorie) versus non-preferred (high-calorie) labeled beverage, which was also chosen in more than 75% of the time when given the option between the two differently labeled (but identical) beverages after the experiment. At the neural level, the written information led to anticipation differences in a set of regions including the insula. During motivated action, the preferred beverage elicited greater signal in the sensorimotor cortex during approach versus avoid actions relative to the non-preferred beverage.

Discussion

The present fMRI study examined the effects of induced beliefs - elicited by different labels on otherwise identical drinks - on neural responses during both the anticipation and response phase of a motivated action task. We found that induced beliefs can exert influence on approach bias in brain and behavior, by labeling identical beverages as either 'low-calorie'
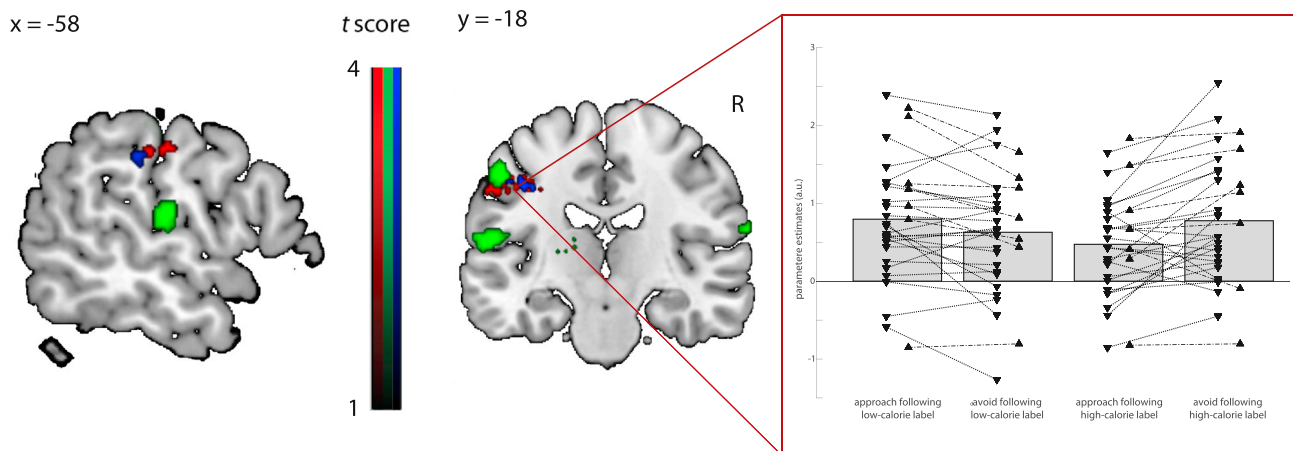

Fig. 4. Motivated action-related brain responses. The Labeled beverage × Action interaction (approach > avoid: low-calorie > high-calorie) is shown in red (N = 31). The contrast of all avoid (push) > approach (pull) actions is shown in green (N = 31). The Labeled beverage × Action interaction (approach > avoid: preferred (low-calorie) > non-preferred (high-calorie) within the subgroup of participants that all chose (i.e., preferred) the beverage labeled low-calorie at the end of the experiment (n = 23) is shown in blue. Insert: parameter estimates for conditions in the Labeled beverage × Action interaction in the activated postcentral region (red clusters). Bars indicate mean response across participants, points indicate individual participants. Markers indicate whether participants chose the beverage labeled low-calorie (▼) or high-calorie (▲) at the end of the experiment (see Materials and Methods). Activations shown at P < .001, k>10. For coordinates and which activations survive P_{FWE} < 0.05 at the cluster level (*), see Tables 4a and 4b.

or 'high-calorie'. Although the liking scores did not differ between the labeled beverages, the vast majority of participants chose the beverage labeled 'low-calorie' when given the option, which we interpret as a general preference for this label. The behavioral results are in line with this interpretation, as we observed an approach bias – tendency to move joystick towards the body compared to pushing it away from the body – when anticipating the preferred beverage (labeled as low-calorie) in both behavioral accuracy and reaction times. This interpretation was substantiated in a subgroup analysis in the participants that all chose the low-calorie beverage. Our results are in line with a previous study that used similar joystick instructions (towards or away from the body), which showed automatic tendencies to approach appetitive foods (i.e., fruit) pictures and to avoid aversive pictures (i.e., rotten fruit; Piqueras-Fiszman et al., 2014). However, in our task, as in real life, approach behaviors towards food could result in more or less favorable outcomes. Our results extend the findings from a study in children, demonstrating that explicit motivation (i.e., grip force) was related to preferred food packaging of objectively identical products (Enax et al., 2015). Here, we show effects of labeling in an implicit, and perhaps more ecologically valid, way in adults, along with underlying neural mechanisms.

The absence of main behavioral effects of label indicates that the preferred beverage did not become more salient overall, nor did participants generally perform better (i.e., became more goal-directed) for the beverage they preferred. Instead, the labels affected the magnitude of the approach bias. We interpret our results in terms of approach bias because evaluative meaning attributed to the instructed joystick movement, namely 'pull towards yourself' and 'push away from yourself', is associated with approach and avoidance movements, respectively (Eder and Rothermund, 2008; Neumann and Strack, 2000). Experimental support for this interpretation comes from a study in which participants that had to make a joystick pull movement to healthy targets and a push movement to tasty targets made more healthy choices when choosing between foods at the end of the experiment than participants with the reverse configuration (Fishbach and Shah, 2006). It has been suggested that both instrumental (e.g. habitual) and Pavlovian mechanisms contribute to the approach bias effect (Watson et al., 2012). For instance, cues with conditioned (Pavlovian) value can affect the vigor of instrumentally trained responses; an effect that emerges in the absence of a formal association between Pavlovian and instrumental contingencies (Talmi et al., 2008). In our instrumental version of the task, approach bias effects for the preferred, low-calorie labeled beverage (i.e., errors for avoid actions) reflect an inability to inhibit an approach response, despite being rewarded with the actual preferred stimulus for a correct avoid response. Thus, our data show that participants were more motivated to approach the preferred stimulus and to avoid the less preferred stimulus, despite these automatic tendencies directly counteracting someone's ability to obtain the associated, preferred reward. Top-down information could thus affect goal-directed control in hungry participants. Whether this label-specific decrease in goal-directed control is driven mostly by Pavlovian effects or by habitual, outcome-independent, instrumental responses remains unclear and could for example be investigated by using this instrumental version of the task before and after an outcome devaluation manipulation. Future research should also assess how our instrumental (and perhaps more ecologically valid) task relates to earlier findings of (non-instrumental) approach bias effects to food cues as a function of individual differences in eating behavior, e.g. health interest (Brignell et al., 2009; Havermans et al., 2011; van Rijn et al., 2016; Veenstra and de Jong, 2010), as well as whether our instrumental task can be utilized for approach bias modification, which has been found to reduce unhealthy (food) consumption behaviour (Fishbach and Shah, 2006; Kakoschke et al., 2017).

The beverage choice at the end of the experiment could have reflected social desirability or a specific decrease in wanting over time for the – what was thought to be - more concentrated drink. However, analyses on the change in wanting of the two differentially labeled beverages revealed no differential decrease over time (i.e., as a function of amount

consumed), also not in an interaction with drink choice. The preference for the beverage labeled as low-caloric seems to be established immediately after seeing the label and tasting the beverage, as initial wanting differences between the beverage labels was the only significant predictor for beverage choice at the end of the experiment. Most importantly, we observed behavioral approach bias effects elicited by labels alone, i.e., in otherwise identical beverages, which remained stable across the experiment, as we controlled for trial number in our analyses.

Parallel to the behavioral effects, a stronger neural approach bias was observed when working for the preferred (low-calorie labeled) beverage relative to the non-preferred (high-calorie labeled) beverage in postcentral gyrus and superior parietal cortex. Tentative support for this interpretation comes from a subgroup analysis using the same interaction contrast in the participants that all preferred the beverage labeled 'low-calorie' also yielded neural responses in a range of sensorimotor regions, although these findings were not significant after a whole-brain correction for multiple comparisons ($P_{FWE} < .05$). This is possibly due to a loss of power in the smaller subgroup (n = 23 vs. N = 31). This neural counterpart in sensorimotor cortex of the error rate effect therefore seems to reflect the greater efficiency with which the approach actions are executed when working for the preferred label. The finding that appetitive cues, such as food cues, can increase one's propensity to act prior to the moment at which an instrumental response is required can underlie this effect, by increasing motor system excitability (Chiu et al., 2014; Freeman et al., 2014; Gupta and Aron, 2011). An alternative explanation would be that sensorimotor cortex is involved in the exertion of avoid-related effort. A separate region, but overlapping the left postcentral gyrus, was more strongly involved in avoid-relative to approach actions made with the right hand, similar to findings of a recent approach bias study (Radke et al., 2016). Interpreted in this way, the interaction between label and action found in neighboring (non-overlapping) sensorimotor and parietal cortices would reflect additional motor resource recruitment to overcome automatic approach biases for the non-preferred beverage (Chong et al., 2017; Harris and Lim, 2016). The importance of cue- (or label-)induced motor responses is highlighted by studies in which motor responses toward or away from specific food cues were trained, which suggest that the motor component of approach biases towards foods can affect choice behavior (Stice et al., 2016). Similar to our findings, these previous motor system excitability and behavioral training studies point towards a strong role of the motor system in approach tendencies towards food.

Mere manipulation by word labels did not only result in behavioral and neural differences during approach and avoidance responses, but also in neural differences during presentation of the labels preceding the response. Specifically, anticipation of the non-preferred high-calorie versus the preferred low-calorie labeled beverages activated several temporal regions and the right ventral anterior insula. The (ventral) anterior insula is well-known for processing food rewards (Sescousse et al., 2013; van der Laan et al., 2011), taste pleasantness (Dalenberg et al., 2017; Small, 2010) and (anticipating previously experienced) taste differences (Dalenberg et al., 2015; Woods et al., 2011), but it is also associated with experiencing aversive smells (Wicker et al., 2003), anticipation of aversive stimuli (Nitschke, Sarinopoulos, Mackiewicz, Schaefer and Davidson, 2006b) and (aversive) taste learning (Bermúdez-Rattoni, 2014). Indeed, meta-analyses have shown the anterior insula to be responsive to (anticipation of) outcomes with both positive and negative subjective values (Bartra et al., 2013; Knutson and Greer, 2008). To dissociate between the interpretations of anticipated taste differences and aversive anticipation, we performed a subgroup analysis in the participants that all chose the beverage labeled 'low-calorie' at the end of the experiment. This analysis revealed clusters in left anterior temporal cortex and left medial temporal lobe regions, including hippocampus and amygdala. These regions are involved in anticipatory memory processes for aversive events (Mackiewicz et al., 2006; Mechias et al., 2010). Therefore, we hypothesize that, in this subgroup, the anticipatory activations for the high-calorie vs the low-calorie

anticipation is driven by a relatively larger aversive anticipation. Given that the insula results do not seem to be driven by the subgroup of participants that chose the beverage with the label 'low-calorie' and that 22 of the 26 participants who reported that they had consistently tasted a difference between them describe the beverage labelled 'high-calorie' as sweeter/more intense, we interpret the anticipatory insula responses across the whole group in terms of anticipated taste intensity (Woods et al., 2011). This appears to be a cognitive effect; beverages containing more calories are apparently expected to be sweeter than drinks with less calories. Note that when we would do a preference-based contrast (i.e., reversing the direction of the contrast for the subgroup that preferred the high-calorie labeled beverage), preference would go opposite to expected calories/sweetness for this subgroup, making interpretation of the results of that analysis problematic. It is unclear why we did not find increased responses for the reverse contrast (preferred > non-preferred label) in reward anticipation regions, such as the ventral striatum (Knutson et al., 2001). Perhaps the contrast was not strong enough to show this effect because of the identical objective, e.g. caloric, properties of the beverages. Indeed, the ventral striatum has been found to represent caloric values of foods independent of preference, whereas the insula was sensitive to differences in subjective properties (de Araujo et al., 2013).

Previous research on the neural basis of instructed beliefs point strongly towards a role for the prefrontal cortex in interpreting evidence in line with existing beliefs (Small, 2010) – across learning, decision and valuation processes (Biele et al., 2011; Doll et al., 2009, 2011; Engelmann et al., 2009; Li et al., 2011; Plassmann et al., 2008). We failed to observe prefrontal involvement in this study, which might be explained by the different task used here. In contrast to many of these previous studies, here we contrasted differently labeled beverages instead of contrasting the 'actual' with the believed truth, as one label was not more correct in relation to the actual sensory experience than the other. Also, here the actual sensory evidence was obtained during only 7 reward receipts following each block (the small number precludes analysis) instead of the many trials in the cited studies. Finally, participants in many of the previous studies had time for some deliberation on their responses, whereas the adaptive response deadline used here forces people to make immediate responses. Therefore, we might have tapped into faster, implicit processes rather than more deliberate control processes by the prefrontal cortex.

We observed an approach bias when anticipating a preferred, low-calorie label in both behavioral accuracy and reaction times and in sensorimotor cortex, despite the fact that our joystick task differed from most other approach-avoidance tasks in two important ways. First, as mentioned above, automatic tendencies to approach anticipated desired food stimuli directly counteracted someone's motivation to obtain them in our instrumental task. Second, our task contained an (incentive) delay period between the stimulus to which a bias might exists and the moment of response, whereas usually the stimulus is shown at the time the response needs to be made (Rinck and Becker, 2007; Watson et al., 2012), but see Ly et al. (2014), who show an effect of a social prime on a following instrumental approach-avoid task. Nevertheless, our task was sensitive enough to detect differences caused by the food labels, showing that written information can influence task performance at a later point in time and despite contradicting participant's (goal-directed) motivations. These findings suggest that approach-avoidance paradigms can be robust to time delays between cue and response and that future studies with this paradigm can attain increased ecological validity, by applying it in the motivational context of action-dependent outcomes.

The effect of misleading information on motivated action was consistent in brain and behavior. Conversely, responses after the neutral label resulted in a different pattern in brain and behavior. In contrast to the caloric beverages, the neutral beverage was a different beverage (water) that did not differ from the other beverages in subjective liking or wanting, making comparisons to the neutral label hard to interpret in terms of mere beliefs versus sensory or reward differences.

There is strong evidence that labels can influence food choices or subjective valuation, like willingness to pay, in experimental setups (Chandon and Wansink, 2012; Enax and Weber, 2015; Olson and Dover, 1978; Piqueras-Fiszman and Spence, 2015). However, in daily life, food choice might be more driven by implicit biases than in experimental environments. Here, we demonstrate that labels can indeed affect such implicit biases. Future research should investigate whether our behavioral and neural label effects are accompanied by altered food choice in daily life, in a wider range of products and labels.

Conclusion

We report that written information in the form of food labels can lead to different approach tendencies behaviorally as well as in sensorimotor cortex for the preferred labeled beverage. The subtle manipulation of written information led to approach bias effects that were strong enough to override goal-directed, instrumental responses to obtain the reward outcomes. These findings enhance our understanding of how expectancies caused by food labels affect motivational processes.

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