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Using functional near-infrared spectroscopy to examine consumer stated liking and neuronal responses to regular and light variants of coke and potato chips

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ABSTRACT

This study examined differences in stated liking and prefrontal brain activation between regular and light versions of coke and potato chips using functional near-infrared spectroscopy (fNIRS). Thirty-one participants completed blind tastings of both variants, with water as a control. Stated liking was rated on a 7-point scale (before the tasting), and neuronal activation was analyzed with a General Linear Model at $p < 0.10$ (Bonferroni-corrected). Regular products received significantly higher liking scores than light variants ($p < 0.05$). Both types evoked distinct prefrontal activation patterns compared to water, but no significant group-level neural differences appeared between regular and light versions ($p > 0.10$). Subgroup analyses showed stronger activation in the dorsolateral and ventrolateral prefrontal cortex for likers of the respective product ($p < 0.10$). Caloric reduction did not markedly alter cortical responses but influenced general evaluation, highlighting how fNIRS can reveal neural correlates of consumer preference for healthier foods.

1. Introduction

Growing consumer awareness of the health risks associated with high sugar, salt, and fat intake has intensified the demand for healthier foods and beverages (Andarwulan et al., 2021). Manufacturers have responded by reformulating popular products to reduce caloric content while maintaining palatability (Grunert, 2017; Hunter et al., 2019). Soft drinks and snack foods, particularly Coke and potato chips, exemplify this shift, now available in "light" or "zero" variants using low-calorie sweeteners or reduced fat (Roberts et al., 2020; Tiwari et al., 2018).

Although these alternatives align with public health goals, consumer preference often remains higher for the original products due to differences in taste, texture, and satiety (Bolhuis & Keast, 2015; Lee & Lee, 2020). Traditional sensory evaluation captures such differences via hedonic ratings but cannot fully explain the underlying cognitive and emotional processes that drive preference. Since food choice involves both conscious and subconscious responses, integrating neuroscientific tools might offer a deeper understanding of consumer behavior beyond self-report measures.

Functional near-infrared spectroscopy (fNIRS) has emerged as a powerful and ecologically valid method to study the neural basis of sensory perception. It measures changes in oxygenated and deoxygenated hemoglobin in cortical regions, enabling non-invasive monitoring of brain activity associated with evaluation and decision-making (Scholkmann et al., 2014; Balconi & Sansone, 2021). Unlike functional magnetic resonance imaging (fMRI), fNIRS allows natural tasting without physical constraints, making it particularly suitable for food research (Chen et al., 2020). Recent studies have shown that fNIRS effectively detects brain responses to sweetness, taste pleasantness, and cross-modal sensory cues during food consumption (Eremenko et al., 2025; Jezierska et al., 2025). However, most research has focused on single product types or taste qualities, leaving little understanding of how calorie-reduced and regular versions of familiar products are processed neurally.

Previous neuroimaging studies using fMRI or EEG have shown that caloric content influences activity in reward-related brain regions such as the orbitofrontal cortex and striatum (Frank et al., 2008; Burger & Stice, 2014; Smeets et al., 2011). Yet, few have applied fNIRS to compare regular and light variants of both beverages and snacks under blind tasting conditions, where expectations are minimized. Likewise, the

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interaction between stated liking and neural activation remains underexplored, despite evidence that habitual consumption and hedonic orientation can shape brain responses (Green & Murphy, 2012; Rudenga & Small, 2012). Addressing these gaps is crucial to understanding how stated liking and neural valuation jointly determine consumer preference for low-calorie products.

This study therefore introduces a novel approach by applying fNIRS to examine real-time neuronal responses and stated liking across two product categories—Coke and potato chips—each tested in regular and light variants. The experiment was conducted under naturalistic, blind tasting conditions to isolate genuine sensory and neural effects from brand or labeling influences. The focus on the prefrontal cortex (PFC), including the dorsolateral and ventrolateral regions, stems from their established role in reward processing, decision-making, and hedonic evaluation (Kringelbach et al., 2003; Okamoto et al., 2006). Monitoring this region enables assessment of how the brain integrates sensory and affective information during food choice.

The novelty of the present work lies in combining stated liking and fNIRS-based neuroimaging to investigate calorie-related differences in both beverages and snacks within a single, ecologically valid framework. To our knowledge, this is the first study to simultaneously compare regular and light products across categories while considering individual preference differences. By linking subjective stated liking with cortical activation patterns, this research advances consumer neuroscience and offers practical implications for product reformulation strategies.

Understanding whether reduced-calorie products evoke distinct neural responses provides valuable insight for food developers aiming to balance health considerations with consumer satisfaction. This integrative neuro-sensory approach supports evidence-based design of healthier, appealing products and contributes to the growing field of neuromarketing in food science.

In summary, this study addresses a key gap by exploring how the brain, subjective experience, and stated preferences jointly respond to regular and light product variants. Functional near-infrared spectroscopy allows investigation of taste-related cortical dynamics during realistic consumption, linking neural responses to consumer stated liking.

Accordingly, the following hypotheses were proposed: (1) Regular products (Coke and chips) will be rated higher in stated liking than their light counterparts. (2) Both regular and light products will elicit significant prefrontal activation compared with the neutral control (water). (3) Likers and dislikers of each product type will show distinct patterns of prefrontal activation, reflecting individual differences in stated liking.

2. Methods

2.1. Participants

The study included a total of 34 healthy participants (17 women and 17 men) aged between 18 and 60 years, recruited from the student and staff population of the University of Applied Sciences, Hamburg. After applying exclusion criteria—including left-handedness (which can influence hemispheric activation patterns), unstable fNIRS signals, and motion-related artifacts—31 participants (16 women, 15 men) were included in the final analysis. All participants self-reported no known food allergies or intolerances and confirmed regular consumption of carbonated beverages and snack foods, ensuring familiarity with the test products. Participants with neurological or psychiatric conditions, impaired taste or smell, or those under medication affecting cognitive or sensory processing were excluded. While demographic characteristics such as age and gender were documented, racial classification was not included, in accordance with German research ethics and legal norms. In Germany, race is not routinely recorded in scientific studies due to historical, legal, and ethical considerations; instead, emphasis is placed on individual health, education, and cultural factors to ensure participant diversity and non-discrimination.

The sample size of 31 participants was selected based on established empirical precedent for neuroimaging studies using within-subject designs in the field of sensory and food science. A systematic assessment of gustatory neuroimaging literature reported a median sample size of 24.0 and a mean of 33.9 for relevant studies, placing our cohort size well within the typical range (Yeung et al., 2020). Furthermore, recent functional near-infrared spectroscopy (fNIRS) investigations into basic taste perception and hedonic food evaluation have successfully demonstrated robust and interpretable neural correlates using similar sample sizes of between 32 and 36 participants (Mai et al., 2025; Meyerding et al., 2024). Given our repeated-measures, within-subject design, this sample size provides sufficient statistical power to detect the anticipated differences in prefrontal cortex activity between the tested conditions.

All procedures performed in this study involving human participants were in accordance with the ethical standards of the institutional research committee of the University of Applied Sciences, Hamburg (2020–09). Informed verbal and written consent was obtained from all individual participants included in the study. All participants provided informed consent for their anonymized data to be used for research and publication purposes. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors. The authors would like to thank the participants and the sensory laboratory staff at the University of Applied Sciences, Hamburg, for their support and assistance during the study.

2.2. Stimuli

The samples used in this study were water, commercially available regular coke (water, sugar, carbonic acid, caramel color, acidulant, phosphoric acid, and natural flavors), zero coke (water, carbonic acid, caramel color, phosphoric acid, sweeteners sodium cyclamate, acesulfame potassium, aspartame, natural aroma, aroma caffeine, and sodium citrate) from the same brand (Coca Cola and Coca Cola Zero, The Coca-Cola Company, USA), commercially purchased regular potato chips with salty flavor (potato, corn, sunflower, canola oil, and salt), and light potato chips (potato, sunflower oil, and salt) from the same brand (Lay's Gesalzen and Lays Light Chips Gesalzen, PepsiCo, USA). All products were bought in Hamburg, Germany.

While it may seem intuitive that hedonic and neural responses to flavored stimuli would differ from water, the inclusion of water as a control condition is essential in fNIRS paradigms to establish a physiological baseline and isolate taste-related activation. This approach allows for more precise spatial localization and interpretation of cortical hemodynamic responses and is widely adopted in both fMRI and fNIRS protocols investigating taste and preference (Frank et al., 2008; Okamoto et al., 2006; Laves et al., 2022).

Regular coke is a soft drink with added sugars. In zero coke, sugar is substituted with sweeteners such as acesulfame potassium and aspartame. The difference between regular and zero coke lies mainly in the sweetener used and therefore in the caloric value. A 100 ml (milliliter) of regular coke contains 180 kJ (kilojoule) of energy or 42 kcal

Table 1
Nutritional composition of regular and zero coke.

Regular coke (100 ml)		Zero coke (100 ml)	
Energy	180.0 kJ/42 kcal	Energy	0.9 kJ/0.2 kcal
Carbohydrate	10.6 g	Carbohydrate	0.0 g
		Salt	0.02 g

Note. Data are taken from manufacturers' product labels. Nutrient values are expressed per 100 ml for beverages. "Regular" and "Zero" refer to full-sugar and reduced-sugar formulations, respectively. Energy values are reported in kcal.

(kilocalorie), while the same amount of zero coke contains only 0.9 kJ or 0.2 kcal (see Table 1). Another coke product has a low-calorie content (light coke). The difference between zero and light coke is the caloric value and the sweetener. A 100 ml light coke contains 1.4 kJ or 0.3 kcal.

A new bottle of coke that was chilled in the refrigerator was opened every experimental day to reduce the precipitation of CO_2 (Burger & Stice, 2014). Coca-Cola was chosen because it is the most sold coke brand (Burger & Stice, 2014). The water sample was filtered through tap water obtained from the sensory lab using a Britta filter.

Light potato chips were claimed to have 33% less fat compared to regular potato chips (see Table 2). They came from the same company (PepsiCo) and had the same labeled flavors (salty) as the used regular chips. Chips and water samples were stored at room temperature.

The stimuli were placed on the right side of the screen and made as easy as possible to reach by the participants. These stimuli were chosen because sweet and savory tastes are the most attractive (Zhao et al., 2003).

2.3. Procedure

The experiment was conducted in the sensory lab of the University of Applied Science, Hamburg between August 08th and 30th of August 2022. The temperature and light conditions were kept constant to ensure the same environmental conditions for all participants. The room was kept quiet with a minimum level of noise.

Each participant was asked to remain focused and sit on a comfortable chair in a relaxed state in front of a computer screen approximately 50 cm away, which displayed the presentation of the experimental task (using PsychoPy, Version 2023.2.3, Open Science Tools Ltd., UK). The fNIRS headband (NIRSport 2 System, NIRx Medical Technologies, USA), including seven detectors and eight emitters, was then placed over the forehead.

Before the experiment, the participants were asked to restrain intense and abrupt head movement during the data recording to get appropriate fNIRS data quality and prevent strong movement artifacts (Krampe et al., 2018).

To classify participants based on product preference, the value of their stated liking was obtained from each individual (for regular coke, zero coke, regular chips, and light chips) before the tasting. The value represents their stated liking on a 7-point scale (ranging from 1 = "dislike extremely" to 7 = "like extremely") given by each participant per product type. Participants with a rating of 5.0 or higher were grouped as likers, and those with a rating of less than 4.0 were categorized as dislikers. Participants whose scores fell within the neutral range (4.0) were excluded from later group analysis to avoid interpretive ambiguity.

The signal quality was calibrated, and the data quality was checked using the Aurora Software (Version 2023.9, NIRx Medical Technologies, USA) before the recording started. Participants followed the instructions provided on the monitor display.

In this study, five experimental conditions ("taste" conditions for regular coke, zero coke, regular potato chips, and light potato chips, and one control condition (water as a tasteless solution) were used. Both coke and chips samples were blindly provided. The participants knew they would taste two types of coke and chips but did not know which one was regular or zero, or regular and light. Each participant had to drink 2 cl (centiliter) of water, then 2 cl of regular coke, 2 cl of zero coke, and eat one piece (1 g) of regular potato chips and one piece (1 g) of light potato chips for each trial (see Table 3).

In total, each of the five samples was tested five times. For water, regular coke, and zero coke stimuli, the participants held and raised the small cup to their mouth (take a sample, 8 s), and then the word "swallow" appeared on the screen for five seconds. Next, the word "taste" appeared on the screen for 20 s, and "neutralize" to rinse out any previous flavors (see Fig. 1). For chips samples, participants took a piece of chips into their mouth (take a sample, 8 s), taste (20 s), swallow (5 s), and neutralize (25 s) (see Fig. 2).

Participants were instructed not to swallow until the screen with the "swallow" instruction. Water was provided to neutralize the taste buds. The taste section of the chips was chosen directly after placing the sample in the mouth because it required chewing.

All food and beverage samples were handled under standardized hygienic and sensory conditions. Beverages were chilled to 6–8°C and chips were stored and served at room temperature (~21°C) to simulate typical consumer experience. Participants were tested individually, and data collection was conducted over a period of four weeks, with no more than three participants per day to allow for equipment calibration and stable signal acquisition.

All participants received the samples in the same fixed order across conditions. A fully randomized or counterbalanced design is generally the gold standard in sensory neuroimaging studies to eliminate fixed sequence effects. However, two critical control measures were implemented to mitigate the influence of order bias. First, a mandatory 25-second rinse period with neutral water was administered immediately after the ingestion of each stimulus. This robust rinse procedure was specifically utilized to provide a sufficient washout phase and prevent sensory carryover effects between trials, a necessity in gustatory evaluation protocols. Second, the primary statistical focus was on within-subject comparisons—specifically comparing the activation of test products against the neutral water control and comparing activity between the hedonic variants (regular vs. light). Given the fixed sequence was identical for all participants, any residual order effect would be systematically consistent across the cohort, allowing for valid comparisons of the core experimental differences.

Functional near-infrared spectroscopy (fNIRS) was used to monitor cortical hemodynamic responses associated with tasting. The method detects relative changes in oxygenated (O_2Hb) and deoxygenated hemoglobin (HHb) as indirect indicators of neural activity (Jöbsis, 1977; Scholkmann et al., 2014). Near-infrared light (650–950 nm) was emitted and detected through optodes placed on the forehead, allowing continuous, non-invasive assessment of prefrontal cortex (PFC) activity (Fig. 3).

The optical array followed standard fNIRS principles, where emitter–detector distances (~30 mm) ensure optimal signal quality. In this study, the NIRSport 2 System (NIRx Medical Technologies, USA) with dual wavelengths of 760 and 850 nm, eight light sources, and seven detectors yielded 22 channels covering the PFC (Fig. 4) in combination with the Aurora fNIRS software (version 2021.9) was used. Relative concentration changes in O_2Hb, HHb, and total hemoglobin (totHb) were recorded at a 8.7 Hz sampling rate with a maximum source power

Table 2
Nutritional composition of regular and light potato chips.

Regular potato chips (100 g)		Light potato chips with 33% less fat (100 g)	
Energy	2289 kJ/549 kcal	Energy	2050 kJ/490 kcal
Fat	34.0 g	Fat	22.0 g
Carbohydrate	53.0 g	Carbohydrate	64.0 g
Fiber	4.4 g	Fiber	4.5 g
Protein	6.1 g	Protein	7.0 g
Salt	1.1 g	Salt	1.4 g

Note: Data are taken from manufacturers' product labels. Nutrient values are expressed per 100 g for potato chips. "Regular" and "Light" refer to full-fat and reduced-fat formulations, respectively. Energy values are reported in kcal.

Table 3
Experimental conditions for each trial.

Tasting Condition	Amount
1. Water	20 ml
2. Coke regular	20 ml
3. Coke zero	20 ml
4. Chips regular	One piece (1 g)
5. Chips light	One piece (1 g)

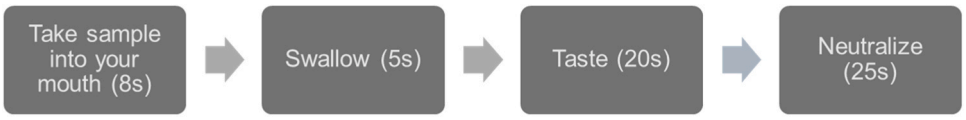

Fig. 1. Schematic of experimental design for water, coke regular, and coke zero.

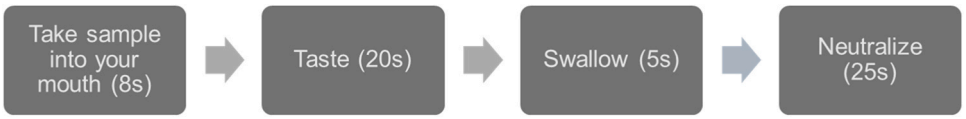

Fig. 2. Schematic of experimental design for chips regular and chips light., Note: The figures illustrate the trial sequence for each tasting condition. Each trial consisted of a 20 s tasting phase and a 25 s rest period. Because beverages need to be swallowed before they can be tasted and foods need to be tasted and then swallowed, the order differed between the product categories.

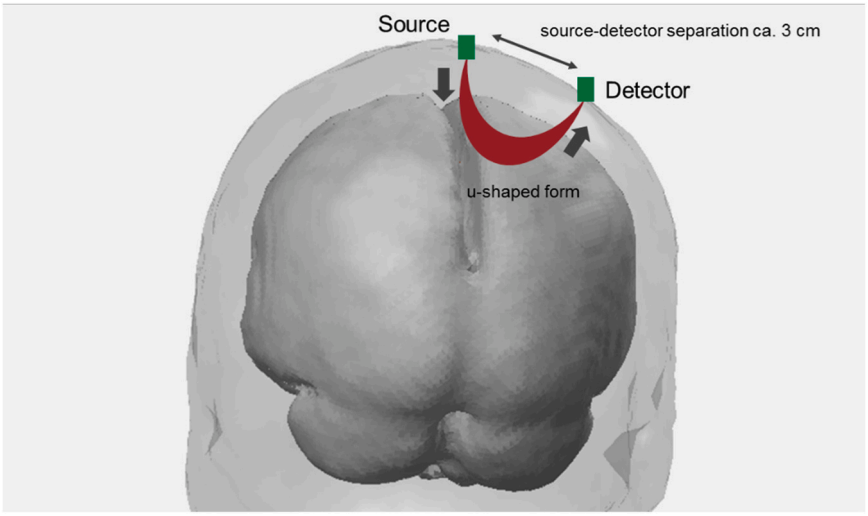

Fig. 3. Method of fNIRS measurement (adapted from Meyerding & Risius, 2018).

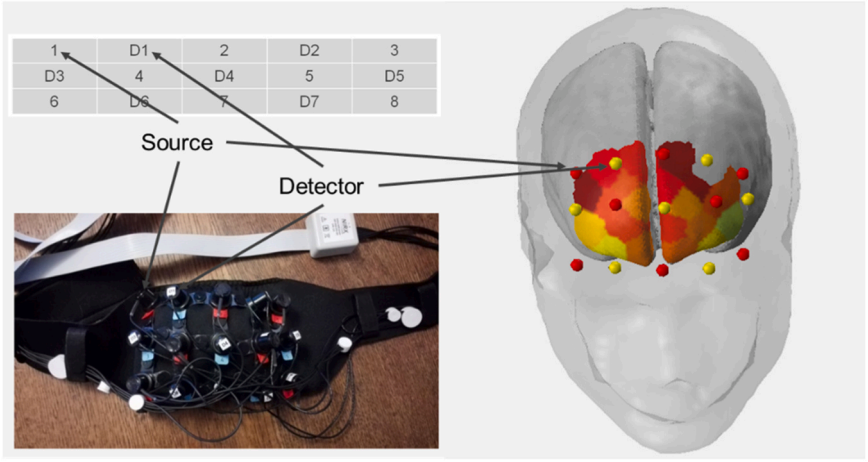

Fig. 4. Topographical layout for the prefrontal cortex measurement (adapted from Meyerding & Risius, 2018). Note: Source (red) and detector (yellow) optodes were arranged over the prefrontal cortex following the international 10–20 system. The resulting 22 measurement channels covered dorsolateral and frontopolar regions. The layout corresponds to the default probe configuration in Aurora.

of 25 mW per wavelength (eye-safe, Laser Class I) and a detector sensitivity of < 1 pW. Prior to data acquisition, the system underwent automated signal optimization, during which the NIRSport2 incrementally adjusted LED source brightness until optimal detector signal amplitude was achieved across all channels. Calibration typically lasted ~60 s and ensured signal levels above 0.5 mV and dark noise below device-specific thresholds. The total recording duration was approximately 25 min per participant. The system's time-multiplexed illumination pattern activated sources sequentially to minimize cross-talk between channels. All configurations, including source–detector layout,

sampling rate, and illumination pattern, were kept constant across participants to ensure measurement reliability.

The analysis focused on oxygenated hemoglobin changes because they exhibit higher signal-to-noise ratios and stronger correlations with functional MRI measures (Strangman et al., 2002; Hoshi et al., 2021). The prefrontal regions assessed—including dorsolateral and frontopolar cortices—are known to underlie reward, evaluation, and decision processes during food consumption (Kringelbach et al., 2003; Okamoto et al., 2006).

2.4. Analysis

Each participant's data recording was loaded into NIRSLab and registered to the probe information file corresponding to the topographical layout shown in Fig. 4. Event markers were configured with a stimulus duration of 20 s for each of the five experimental conditions (taste task in Figs. 1 and 2). In the preprocessing stage, signal quality was visually inspected; no truncation, interpolation, discontinuity removal, or spike artifact removal algorithms were applied to the raw data at this point. To convert optical density to hemodynamic states, we utilized the modified Beer-Lambert law with the W.B. Gratzer extinction coefficient spectrum. A baseline correction was applied using the entire duration of the recording (frames 1 to i.e. 13,780) to normalize the data. The parameters for this computation included a total hemoglobin (totHb) concentration of 75 μM, muscle oxygen saturation (MVO2Sat) of 70%, and differential pathlength factors (DPF) of 7.25 for 760 nm and 6.38 for 850 nm.

For the statistical analysis, a general linear model (GLM) was estimated for each participant (SPM Level 1) focusing on oxygenated hemoglobin (oxyHb). The model specification used frames as the unit of design and included pre-whitening with an autoregressive model (AR (n)) to account for temporal autocorrelation. The canonical hemodynamic response function (HRF) was employed as the basis function with standard parameter specifications (delay of response: 6; delay of undershoot: 16; dispersion of response: 1; dispersion of undershoot: 1; ratio of response to undershoot: 6; onset: 0; length of kernel: 32). To remove low-frequency drift, temporal filtering was applied using a discrete cosine transform (DCT) with a high-pass period cutoff of 128 s. Finally, the GLM coefficients were estimated to generate the statistical parametric maps. The fNIRS data analysis consisted of statistical parametric mapping (SPM) 1 and 2. First, all data from each participant were analyzed individually at SPM Level 1, and then for all participants within the group at SPM level 2. All statistical results were corrected for multiple comparisons using the Bonferroni method across the 22 prefrontal channels at both the subject-level (SPM Level 1) and group-level (SPM Level 2) analyses.

NIRSlab generates statistical parametric maps based on a GLM but does not compute or export descriptive statistics (means, SDs) or standardized effect sizes. Consequently, group-level results are presented in terms of significant activation patterns and associated *p*-values rather than descriptive numerical summaries.

At the group level, one-sample *t*-tests were used to identify significant differences in neuronal activation between conditions. The significance level was set at 10% ($p < 0.10$). Given that a threshold of $p < 0.10$ is more liberal than the conventional alpha level of 0.05, the present analyses should be considered exploratory in nature. While this approach increases sensitivity to potentially meaningful neural trends in relatively small samples, it also elevates the probability of Type I error. Therefore, statistically significant findings reported at this level should be interpreted as indicative rather than confirmatory and require replication in larger, adequately powered studies. This more liberal threshold was intentionally chosen due to the exploratory nature of the study and the relatively small sample size, which can reduce statistical power. Setting the threshold at 10% allows for the detection of subtle trends in neural activation that might be overlooked at the stricter 5% level, thereby supporting hypothesis generation for future, more powered studies. Furthermore, prior fNIRS research in naturalistic and taste-related contexts has also adopted this threshold when aiming to identify initial patterns of neural activity (e.g., Laves et al., 2022). The modified Beer-Lambert law algorithm was used, and Bonferroni correction was performed.

Stated liking was analyzed Using Microsoft Excel (Microsoft 365, Microsoft, USA). Analysis of variance (ANOVA) was performed using SPSS (Version 29.0.0.0 (241), IBM, USA) to examine the potential differences in stated liking between groups.

In this study, oxyhemoglobin data were chosen because 1) it correlates more with cerebral blood volume (Hoshi et al., 2021); 2) it has a better signal-to-noise ratio; and 3) it has a stronger correlation with fMRI results than deoxygenated hemoglobin (Strangman et al., 2002).

While the sample size of 31 participants may appear modest, it aligns with standard practices in exploratory neuroimaging research using functional near-infrared spectroscopy (fNIRS), particularly within naturalistic consumer behavior and sensory studies (Meyerding & Mehlhose, 2020; Laves et al., 2022). Given the non-invasive, real-time nature of fNIRS and its ability to detect subtle prefrontal activation differences in small samples, a sample size of 30 + is often considered sufficient for exploratory purposes. Nevertheless, statistical power increases with larger samples, and therefore, the findings of the present study should be interpreted as indicative rather than definitive.

3. Results

A total of 34 consumers ranging in age from 18 to 67 years participated in this study. Before the experiment, the participants were verbally and written informed about the experimental procedure. All participants provided verbal and written consent before starting the study. All the participants were right-handed. This criterion is essential to reduce the hemispheric dominance difference (Qing et al., 2021). However, three participants were excluded because of poor data quality and errors during data recording.

3.1. Stated liking results

All participants rated the likeability of each product under investigation before the fNIRS experiment on a 7-point scale (1 = "dislike extremely," 7 = "like extremely"), where 4 indicated neutrality (see Table 4). Participants whose ratings were neutral (score = 4) were excluded from subsequent analyses to maintain clearly polarized preference groups (likers ≥ 5; dislikers ≤ 3). This approach follows established practices in sensory and affective neuroscience to enhance contrast in neural activation patterns (Minematsu et al., 2018; Qing et al., 2021).

As shown in Table 4, participants generally preferred the regular over the light versions for both Coke and potato chips. ANOVA confirmed significant differences in stated liking between product types,

Table 4
Stated liking rating of the products.

Group	Name	Frequency	Mean	SD
1	Regular coke disliker	5	2.40	0.69
2	Regular coke liker	26	5.62	0.65
3	Zero coke disliker	10	2.78	0.68
4	Zero coke liker	19	5.46	0.69
5	Regular chips disliker	4	3.50	0.38
6	Regular chips liker	26	5.66	0.70
7	Light chips disliker	7	3.00	0.49
8	Light chips liker	22	5.89	0.68

Note. Mean values reflect the average of the 7-point scale ratings for each product type in that group. Participants with neutral scores (4) were excluded from group analysis, explaining why the total does not equal 31. ANOVA revealed statistically significant differences in liking between groups ($p < 0.05$ for all product types).

supporting the expected preference hierarchy of regular over light.

3.2. Neuronal activation of different stated liking groups of coke

To examine whether individual preferences influenced cortical activation during tasting, participants were categorized into four distinct groups according to their stated liking ratings for regular and zero Coke (see Table 4). Groups 1 and 2 comprised regular Coke dislikers and likers, respectively, whereas Groups 3 and 4 consisted of zero Coke dislikers and likers. Functional near-infrared spectroscopy (fNIRS) data were analyzed across 22 prefrontal cortex (PFC) channels corresponding to standard 10–20 system electrode positions, allowing for fine-grained localization of activation patterns across dorsolateral and frontopolar cortical areas (Okamoto et al., 2006).

Table 5 summarizes the fNIRS channels that exhibited significantly increased oxygenated hemoglobin (OxyHb) levels in likers compared with dislikers during the tasting of the respective Coke variants. The table presents statistically significant contrasts corrected for multiple comparisons using Bonferroni adjustment ($p < 0.10$).

As indicated in Table 5, distinct activation differences were observed between likers and dislikers for both regular and zero Coke. It should be noted that all reported neural activation differences were identified using an exploratory threshold of $p < 0.10$. Consequently, these findings should be interpreted with caution and regarded as preliminary evidence of potential neural effects rather than definitive proof of condition-specific activation. Fig. 5a and 5b visualize these differences for the regular Coke condition, while Fig. 6a, 6b, and 6c depict the corresponding results for the zero Coke condition. Fig. 5a shows the cortical topography of significant activation differences, and Fig. 5b presents the time course of OxyHb concentration changes for channel 15 during regular Coke tasting. Similarly, Fig. 6a–6c illustrate the activation patterns and OxyHb trajectories for channels 2 and 6 during zero Coke tasting. These figures collectively display how cortical oxygenation varied between stated liking groups during beverage consumption, emphasizing the localized prefrontal activation patterns identified by the GLM analysis.

When drinking regular Coke, regular Coke likers exhibited significantly higher activation in fNIRS channel 15 (EEG 10–5: AF3) compared with regular Coke dislikers (Table 5; Fig. 5a and 5b). Channel 15 corresponds to the left frontopolar cortex (Brodmann area 9), a region implicated in evaluative and hedonic processing (Kringelbach et al., 2003). As shown in Figure 5b, OxyHb levels actually decreased for regular Coke dislikers in channel 15 during tasting, whereas an increase was observed for likers.

When drinking zero Coke, zero Coke likers showed significantly higher activation in fNIRS channels 2 (EEG 10–5: F4) and 6 (EEG 10–5: F3h/FFC3h) compared with zero Coke dislikers (Table 5; Fig. 6a–6c). Channel 2 primarily covers the right middle frontal gyrus (Brodmann area 9), and channel 6 extends over the left dorsolateral prefrontal region (Brodmann areas 6/8), both regions commonly associated with sensory evaluation and attention to gustatory stimuli (Minematsu et al., 2018; Balconi & Sansone, 2021). As visible in Fig. 6b and 6c, OxyHb decreased for zero Coke dislikers in these channels, while an increase was observed for zero Coke likers during tasting.

Table 5
fNIRS channels showing significant increased activation for coke product likers compared to dislikers when tasting the respective product.

Comparisons	fNIRS Channels with increased OxyHb	*p*-Value
Regular coke liker > Regular coke disliker	15	$p < 0.10$
Zero coke liker > Zero coke disliker	2 & 6	$p < 0.10$

Note: Listed channels with significantly increased OxyHb are derived from the NIRSlab general linear model (GLM) analysis, corrected for multiple comparisons (Bonferroni-adjusted across 22 prefrontal channels). Channels correspond to the standard NIRx 10–20 montage positions.

3.3. Neuronal activation of different stated liking groups of chips

To further investigate how stated liking influences cortical activation during the consumption of savory stimuli, participants were divided into four groups based on their liking ratings for the potato chip samples (see Table 4). Groups 5 and 6 consisted of regular chips dislikers and likers, respectively, while Groups 7 and 8 included light chips dislikers and likers. Functional near-infrared spectroscopy (fNIRS) data were again analyzed across 22 prefrontal cortex (PFC) channels using the standardized 10–20 electrode placement system, enabling spatially resolved detection of oxygenated hemoglobin (OxyHb) changes during tasting (Okamoto et al., 2006; Kringelbach et al., 2003).

Table 6 summarizes the fNIRS channels that showed significant differences in OxyHb concentration between likers and dislikers when eating regular and light potato chips. Bonferroni correction was applied across all 22 prefrontal channels, and results were considered significant at $p < 0.10$.

As shown in Table 6, distinct activation differences were observed between liking groups for both regular and light chips. Fig. 7a and 7b visualize these differences for the regular chips condition, while Figures 8a through 8e display the activation contrasts for the light chips condition. Specifically, Fig. 7a depicts the topographical representation of differential activation for regular chips, and Fig. 7b illustrates the time course of OxyHb changes for channel 4 during tasting. Similarly, Fig. 8a–8e present the cortical activation maps and OxyHb concentration changes for channels 2, 6, 12, and 17 during the consumption of light chips. Together, these figures illustrate the localized prefrontal hemodynamic responses corresponding to hedonic preference during snack consumption, providing a spatial overview of significant activation patterns derived from the GLM analysis.

When eating regular chips, regular chips likers showed a significantly lower activation of fNIRS channel 4 (EEG 10–5: F1h) compared to regular chips dislikers (Table 6; Figures 7a and 7b). Channel 4 corresponds to the superior frontal gyrus (Brodmann area 6), a region involved in attention and sensory integration (Balconi & Sansone, 2021; Minematsu et al., 2018). As shown in Figure 7b, OxyHb increased for regular chips dislikers in channel 4 during tasting, whereas regular chips likers displayed a reduction in OxyHb.

When eating light chips, light chips likers exhibited significantly higher activation in fNIRS channels 2 (EEG 10–5: F4), 6 (EEG 10–5: F3h/FFC3h), 12 (EEG 10–5: AFF3h), and 17 (EEG 10–5: AF6) compared with light chips dislikers (Table 6; Fig. 8a–8e). These channels are associated with regions of the dorsolateral and frontopolar prefrontal cortex, areas commonly implicated in evaluative and hedonic food processing (Balconi & Sansone, 2021; Minematsu et al., 2018). As can be seen in Fig. 8b–8e, OxyHb decreased for light chips dislikers across channels 2, 6, 12, and 17 during tasting. An exception was observed in channel 2, where OxyHb increased for light chips likers while decreasing for dislikers (Fig. 8b).

3.4. Neuronal activation of the experimental conditions compared to the control condition (water)

To identify the cortical responses specifically associated with tasting the different product types, neuronal activation during each experimental condition (regular Coke, zero Coke, and regular chips) was compared to the control condition (water). Water served as a neutral baseline to isolate taste-related prefrontal activity from general sensorimotor or swallowing-related activation. This methodological approach follows established fNIRS research protocols that employ tasteless solutions as baselines to enhance interpretability of hemodynamic contrasts in gustatory experiments (Okamoto et al., 2006; Frank et al., 2008; Smeets et al., 2011).

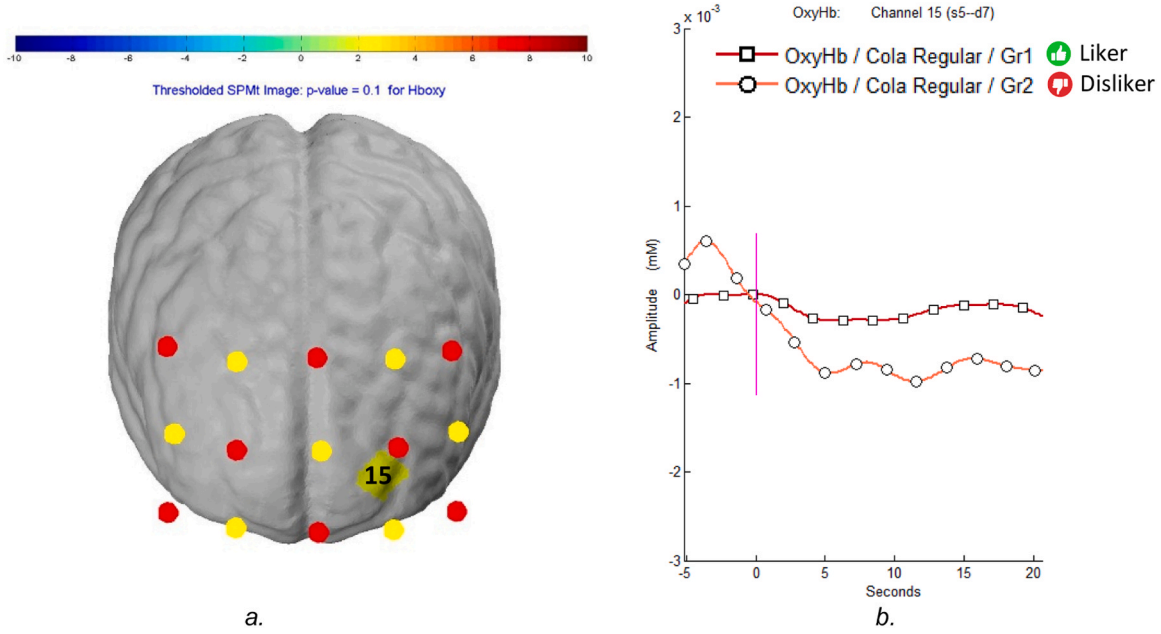

Fig. 5. a. Increased neuronal activity of the coke regular groups likers vs. dislikers.Fig. 5b. OxHb regular coke likers vs. dislikers for channel 15 during tasting (20 s) of regular coke. Note: Channel 15 corresponds to EEG 10–20 electrode: AF3, percentage underlying brain regions: frontal pole (100%), Brodmann area nearest mean electrode position: left BA9 (Scrivener & Reader, 2022).

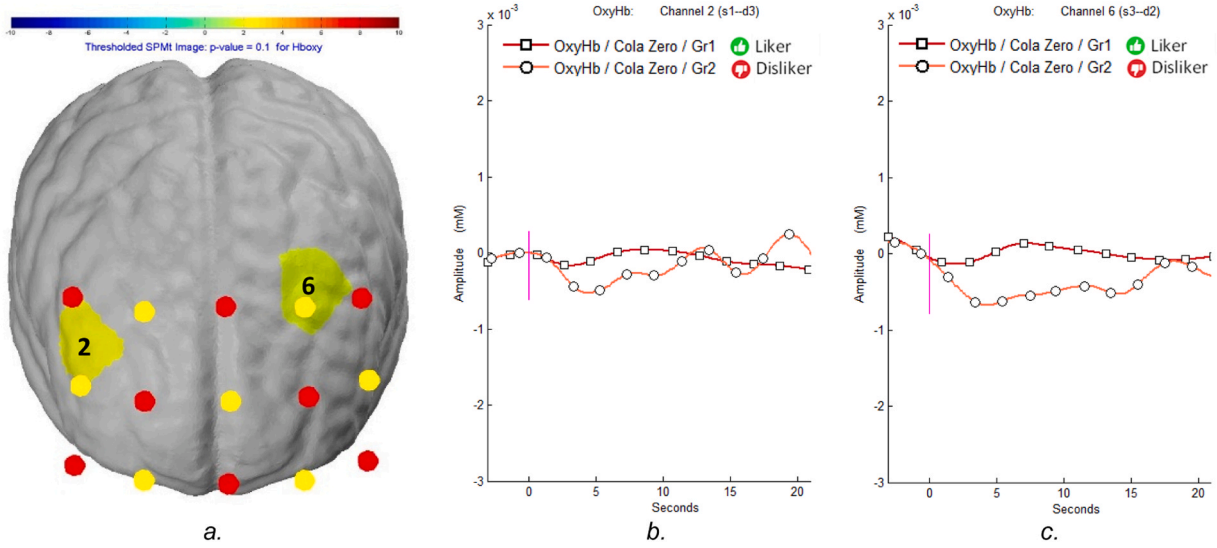

Fig. 6. a. Increased neuronal activity of the zero coke groups likers vs. dislikers. Fig. 6b. OxHb zero coke likers vs. dislikers for channel 2 during tasting (20 s) of zero coke. Fig. 6c. OxHb zero coke likers vs. dislikers for channel 6 during tasting (20 s) of zero coke. Note: Channel 2 corresponds to EEG 10–20 electrode: F4, percentage underlying brain regions: frontal pole (53%), middle frontal gyrus (47%), Brodmann area nearest mean electrode position: right BA9; Channel 6 corresponds to EEG 10–20 electrode: F1 (FFC3h), percentage underlying brain regions: superior temporal gyrus (71%), frontal pole (29%), Brodmann area nearest mean electrode position: left BA6/BA8 (Scrivener & Reader, 2022).

Table 7 presents the fNIRS channels that exhibited statistically significant increases or decreases in oxygenated hemoglobin (OxyHb) during tasting of the test products compared to water. Each channel corresponds to standard EEG 10–5 positions, mapped to cortical regions within the prefrontal cortex (PFC). As shown in earlier sensory neuroimaging work, decreased OxyHb in specific prefrontal channels can reflect reduced cortical activation relative to a neutral baseline (Hoshi et al., 2021; Laves et al., 2022). The significance threshold for all comparisons was set at $p < 0.10$ (Bonferroni-corrected across 22 channels), consistent with exploratory neuroimaging standards in food and sensory research.

As shown in Table 7, several channels demonstrated significant changes in OxyHb concentration between the tasting conditions and the water control. For the whole sample, drinking regular Coke was associated with decreased neuronal activation in fNIRS channel 5 (EEG 10–5: AFFz) and channel 12 (EEG 10–5: AFF3h) relative to water. Drinking zero Coke also decreased activation in channel 5 (EEG 10–5: AFFz) but, in contrast, increased activation in channel 21 (EEG 10–5: AFF5) compared with water. Finally, eating regular chips decreased activation in channel 12 (EEG 10–5: AFF3h) relative to the control condition (Table 7).

Fig. 9 provides a spatial and graphical visualization of these results, showing the cortical topographies and channel-wise OxyHb differences for the three contrasts (regular Coke vs. water, zero Coke vs. water, and

Table 6
fNIRS channels showing significant increased or decreased activation for chips product likers compared to dislikers when tasting the respective product.

Comparisons	fNIRS Channels with increased OxyHb	fNIRS Channels with decreased OxyHb	*p*-Value
Regular chips liker > Regular chips disliker	-	4	$p < 0.10$
Light chips liker > Light chips disliker	2, 6, 12, & 17	-	$p < 0.10$

Note: Listed channels with significantly increased/decreased OxyHb are derived from the NIRSlab general linear model (GLM) analysis, corrected for multiple comparisons (Bonferroni-adjusted across 22 prefrontal channels). Channels correspond to the standard NIRx 10–20 montage positions.

regular chips vs. water). Each subpanel (A–C) corresponds to one of the experimental conditions, indicating the respective areas of increased or decreased neuronal activity within the prefrontal cortex.

As illustrated in Fig. 9(A), tasting regular Coke produced a clear reduction in OxyHb in channels 5 and 12, indicating decreased prefrontal activation compared with water. Similarly, Fig. 9(B) shows that zero Coke also reduced OxyHb in channel 5, while concurrently increasing it in channel 21, reflecting localized differences in cortical engagement across the right and left anterior prefrontal regions. Finally, Fig. 9(C) displays that consuming regular chips led to a reduction in OxyHb in channel 12, consistent with a lower level of activation relative to the neutral baseline. For the stimuli light chips, no significant difference compared to water have been found. Across all conditions, the observed activation and deactivation patterns correspond to dorsomedial and frontopolar cortical areas, regions typically implicated in the evaluation of gustatory stimuli (Okamoto et al., 2006).

3.5. Neuronal activation differences between regular and light products

For the coke taste test experiment, statistical parametric mapping at the group level (SPM level 2) was performed, but it did not yield any significant results. No significant differences of neural activation in the PFC were detected during "taste" conditions of regular coke vs. zero coke. Comparing neural processing during regular intake with light chips, also no significant differences in activation were found.

4. Discussion

The study aimed to test three hypotheses concerning stated liking and neural activation patterns for regular and light variants of Coke and potato chips. Behavioral results supported Hypothesis 1, revealing that regular products were rated significantly higher in stated liking than light variants, consistent with prior sensory research emphasizing the role of caloric content and expected sweetness in hedonic preference (Bolhuis & Keast, 2015; Lee & Lee, 2020). Hypothesis 2 was partially supported: both regular and light stimuli evoked distinct prefrontal cortical activation compared to water, indicating that even calorie-reduced products elicit measurable neuronal responses during tasting. Hypothesis 3 was strongly supported, showing differential activation between likers and dislikers across specific prefrontal cortex (PFC) channels—particularly AF3 (left frontopolar cortex), F4 (right middle frontal gyrus), and F3h (left dorsolateral PFC). These regions are known to mediate hedonic valuation and reward monitoring (Mai et al., 2025). The pattern of increased OxyHb among likers and decreased OxyHb among dislikers aligns with recent fNIRS and fMRI findings that higher subjective pleasantness correlates with stronger prefrontal activation during taste evaluation (Eremenko et al., 2025). Together, the behavioral and neuronal data confirm that stated liking is reflected in prefrontal hemodynamic activity, supporting the study's integrative neuro-sensory framework. However, given that neural effects were detected at an exploratory significance level of $p < 0.10$, these results should be interpreted as preliminary indications of differential prefrontal engagement rather than conclusive evidence of robust hedonic encoding.

4.1. Stated liking of regular and light variants

The stated liking ratings in this study were collected prior to tasting, reflecting participants' general attitudes and habitual preferences

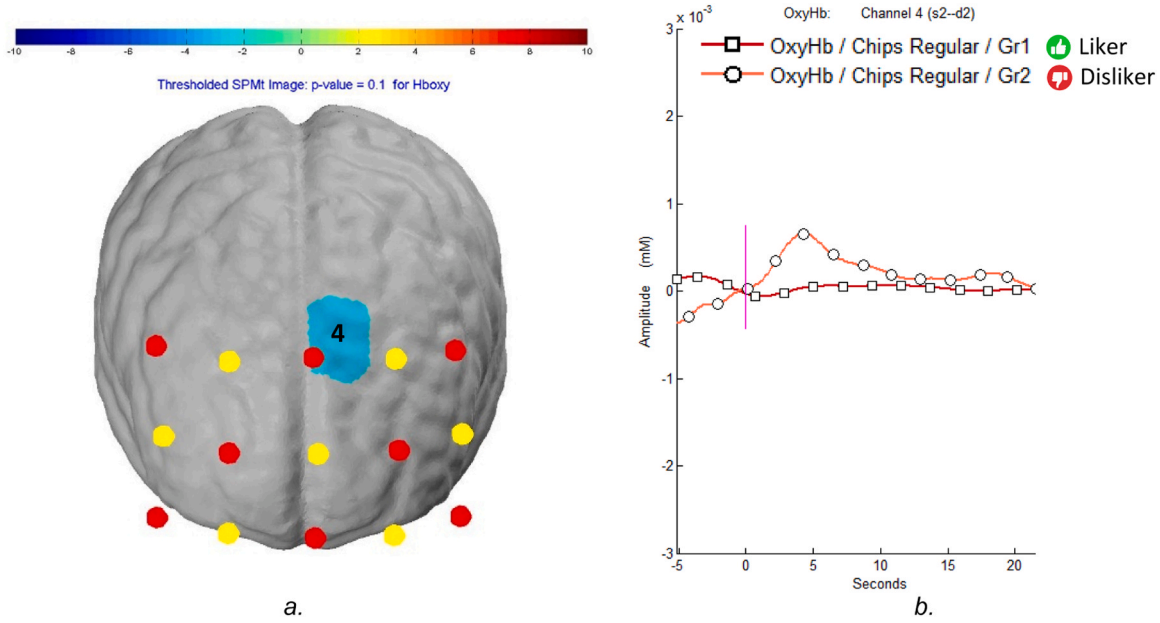

Fig. 7. a. Deceased neuronal activity of the regular chips groups likers vs. dislikers.Figure 7b. OxHb regular chips likers vs. dislikers for channel 4 during tasting (20 s) of regular chips. Note: Channel 4 corresponds to EEG 10–20 electrode: Fz, F1 (FFC1h), Fz: percentage underlying brain regions: superior frontal gyrus (100%), Brodmann area nearest mean electrode position: left BA6, F1: percentage underlying brain regions: superior temporal gyrus (71%), frontal pole (29%), Brodmann area nearest mean electrode position: left BA6/BA8 (Scrivener & Reader, 2022).

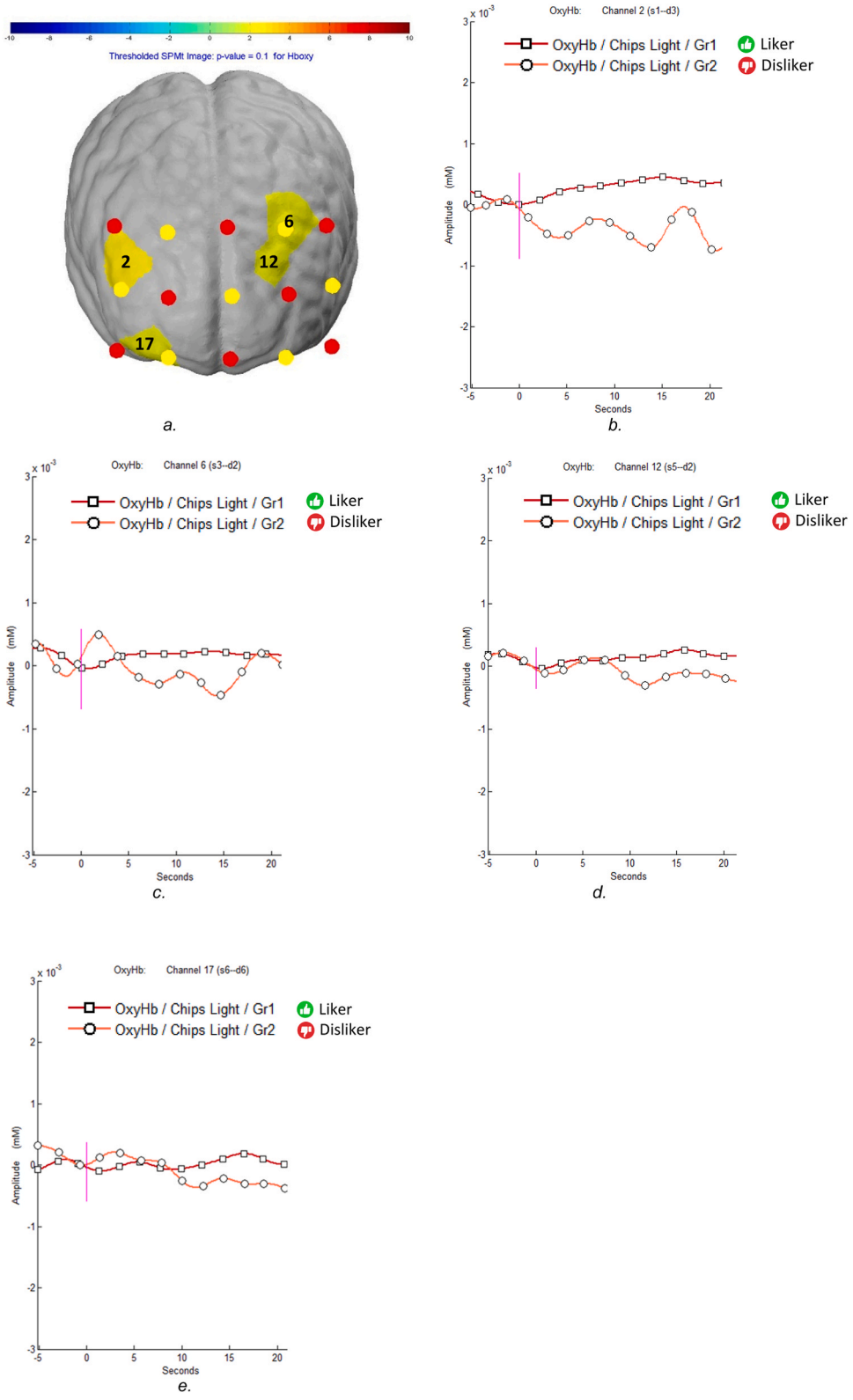

Fig 8. a. Increased neuronal activity of the light chips groups likers vs. dislikers. Fig. 8b. OxHb Light chips likers vs. dislikers for channel 2 during tasting (20 s) of light chips.Note: Channel 2 corresponds to EEG 10–20 electrode: F4, percentage underlying brain regions: frontal pole (53%), middle frontal gyrus (47%), Brodmann area nearest mean electrode position: right BA9; Channel 6 corresponds to EEG 10–20 electrode: F1 (FFC3h), percentage underlying brain regions: superior temporal gyrus (71%), frontal pole (29%), Brodmann area nearest mean electrode position: left BA6/BA8; Channel 12 EEG 10–20 electrode: F1 (AFF1), percentage underlying brain regions: superior temporal gyrus (71%), frontal pole (29%), Brodmann area nearest mean electrode position: left BA6/BA8; Channel 17 EEG 10–20 electrode: AF8 (Fp2), percentage underlying brain regions: frontal pole (100%), Brodmann area nearest mean electrode position: right BA10 (Scrivener & Reader, 2022).Fig. 8c. OxHb Light chips likers vs. dislikers for channel 6 during tasting (20 s) of light chips, Fig. 8d. OxHb Light chips likers vs. dislikers for channel 6 during tasting (20 s) of light chips, Fig. 8e. OxHb Light chips likers vs. dislikers for channel 17 during tasting (20 s) of light chips.

Table 7
fNIRS channels showing significant increased/decreased activation for the main effects of the experimental conditions compared with the control condition water.

Comparisons	fNIRS Channels with increased OxyHb	fNIRS Channels with decreased OxyHb	*p*-Value
Regular Coke > Water	-	5 & 12	$p < 0.10$
Zero Coke > Water	21	5	$p < 0.10$
Regular Chips > Water	-	12	$p < 0.10$

Note: Listed channels with significantly increased/decreased OxyHb are derived from the NIRSlab general linear model (GLM) analysis, corrected for multiple comparisons (Bonferroni-adjusted across 22 prefrontal channels). Channels correspond to the standard NIRx 10–20 montage positions.

toward the products rather than direct sensory impressions during the experiment. The significantly higher liking for regular Coke and regular chips compared to their light counterparts therefore illustrates pre-existing cognitive, sensory, and experiential biases rather than immediate hedonic responses. Such biases are strongly influenced by familiarity, prior exposure, and learned reward associations, which shape both expectation and memory-based evaluation (Van Opstal, et al., 2021; Melios et al., 2025).

From a sensory and reward-learning perspective, repeated exposure to regular products containing sugar and fat strengthens flavor-calorie associations through dopaminergic reinforcement pathways (Van Opstal et al., 2021). This conditioning results in a lasting preference for the original formulations, even in the absence of actual tasting. Conversely, low-calorie sweeteners or reduced-fat formulations—such as those used in light variants—often fail to deliver the expected post-ingestive reward, leading to weaker learned associations and reduced hedonic expectation (Moriconi, et al., 2020; Yang et al., 2021). Studies show that the mere anticipation of caloric sweetness activates reward-related regions such as the orbitofrontal and dorsolateral prefrontal cortices more strongly than non-caloric alternatives (Van Opstal et al., 2021; Yang et al., 2021).

Psychological mechanisms, particularly expectancy and familiarity, further reinforce these patterns. Consumers who habitually consume sugar-sweetened beverages or full-fat snacks develop stable cognitive schemas of "authentic" flavor, which influence liking judgments even before tasting (Melios et al., 2025; Hong, 2025). The sensory characteristics of light products—such as thinner mouthfeel or artificial sweetness—are often perceived as deviations from these prototypes, triggering expectation mismatches and reducing pre-tasting liking (Navarré, et al., 2025; Saito & Misaka, 2025).

From a product development standpoint, these findings emphasize that stated liking is not purely a reflection of sensory performance but a cognitive construct shaped by prior experience. Consequently, reformulation strategies should target both sensory quality and cognitive framing—leveraging cues like branding, packaging, and messaging to adjust expectations and increase acceptance of calorie-reduced variants (Navarré et al., 2025; Saad & Weinbach, 2026).

4.2. Neuronal activation differences between coke likers and dislikers

The functional near-infrared spectroscopy (fNIRS) results demonstrated significantly higher activation in specific prefrontal cortex (PFC) channels among Coke likers compared with dislikers, namely channel AF3 (left frontopolar cortex, Brodmann area 9), and channels F4 and F3h (right middle frontal gyrus and left dorsolateral PFC, Brodmann areas 6/8). These regions play critical roles in reward valuation, hedonic processing, and cognitive appraisal of sensory stimuli (Kringelbach et al., 2003). Increased oxygenated hemoglobin (OxyHb) concentrations in these areas suggest that participants who reported generally liking Coke experienced greater engagement of reward-related neural circuits during tasting, even under blind conditions.

The left frontopolar cortex (AF3, BA9) is implicated in subjective pleasantness evaluation and the integration of affective and cognitive components of reward (Rolls, 2012). Its heightened activation among likers likely reflects enhanced hedonic appraisal and memory retrieval of positive taste experiences. In contrast, the right middle frontal gyrus (F4, BA9) and left dorsolateral PFC (F3h, BA6/8) are associated with attentional control and decision-related processing, indicating stronger motivational salience and reward anticipation in likers (Balconi & Sansone, 2021; Mai et al., 2025). Such activation patterns align with prior fNIRS findings showing that higher perceived pleasantness of sweet stimuli is accompanied by increased PFC oxygenation, representing a neurophysiological correlate of liking (Eremenko et al., 2025).

Conversely, dislikers exhibited decreased OxyHb in these same regions, consistent with reduced reward value and negative affective evaluation. Deactivation in the PFC may reflect either lower engagement of reward networks or active inhibitory processes during aversive or mismatched sensory experiences. This is in line with the reward mismatch hypothesis, which posits that when the expected caloric reward does not match sensory input—such as tasting a sweet but non-

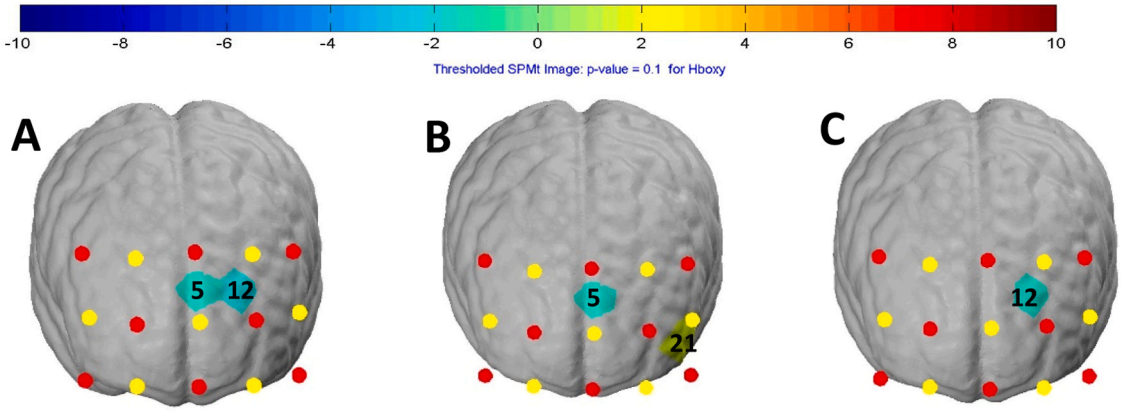

Fig. 9. Significantly decreased neuronal PFC activity for the contrast between the A: "regular coke taste", B: "zero coke taste" and C: "regular chips taste" compared to "water taste" as a control condition. Note: Channel 5 corresponds to EEG 10–20 electrode: Fz, AFz, Fz: percentage underlying brain regions: superior frontal gyrus (100%), Brodmann area nearest mean electrode position: left BA6, AFz: percentage underlying brain regions: frontal pole (62.5%), superior frontal gyrus (37.5%), Brodmann area nearest mean electrode position: left BA9; Channel 12 corresponds to EEG 10–20 electrode: F1 (AFF1), percentage underlying brain regions: superior temporal gyrus (71%), frontal pole (29%), Brodmann area nearest mean electrode position: left BA6/BA8; Channel 21 corresponds to EEG 10–20 electrode: AF3 (AFF5h), percentage underlying brain regions: frontal pole (100%), Brodmann area nearest mean electrode position: left BA9 (Scrivener & Reader, 2022).

caloric beverage—neural prediction errors occur in reward circuits, leading to attenuated PFC activation (Coccurello, 2025; Van Opstal et al., 2021). fMRI studies confirm that artificial sweeteners like aspartame and acesulfame K elicit weaker responses in the ventromedial PFC and orbitofrontal cortex than sucrose, corresponding to lower subjective pleasantness (Mouillot, et al., 2020; Steinglass, et al., 2024).

Moreover, cognitive dissonance may also contribute to reduced activation among dislikers. Individuals who habitually avoid sweetened drinks may experience a conflict between sensory input and personal preference, resulting in dampened neural response and negative affect (Saad & Weinbach, 2026; Rodrigues, et al., 2025). Together, these findings indicate that prefrontal activation patterns faithfully mirror individual hedonic orientation, capturing both reward-driven liking and aversion-related inhibition in the cortical processing of sweet beverages.

4.3. Neuronal activation differences between chips likers and dislikers

The analysis of cortical activation during chip consumption revealed a distinct pattern between regular and light variants. When eating regular chips, likers exhibited lower oxygenated hemoglobin (OxyHb) in channel F1h (superior frontal gyrus, Brodmann area 6) compared with dislikers, suggesting reduced prefrontal engagement despite positive hedonic evaluation. This deactivation pattern aligns with previous fNIRS findings showing that pleasurable and familiar stimuli may require less cognitive effort or attentional control, reflecting an efficient neural encoding of reward (Balconi & Sansone, 2021). Conversely, dislikers displayed increased activation, possibly indicating greater evaluative or attentional processing toward less-preferred sensory input—a phenomenon often associated with attentional conflict or sensory incongruity (Rodrigues et al., 2025; Balconi & Sansone, 2021).

For light chips, however, likers demonstrated higher OxyHb in multiple channels—F4 (right middle frontal gyrus, BA9), F3h (left dorsolateral PFC, BA6/8), AFF3h (frontopolar region, BA10), and AF6 (right anterior prefrontal cortex, BA10)—than dislikers. These findings suggest stronger recruitment of neural circuits linked to reward evaluation, attentional control, and gustatory integration when participants positively appraised the reduced-fat chips. Activation in these regions is consistent with enhanced cognitive appraisal and attentional modulation, reflecting the effort to reconcile reduced-fat sensory cues with a rewarding eating experience (Rolls, 2012). The involvement of the dorsolateral and frontopolar PFC supports the notion that liking for light chips may depend more on cognitive-emotional regulation and expectation adjustment than on pure sensory pleasure.

Neuroimaging literature on fat perception and texture processing provides further insight into this differential activation. High-fat foods are known to elicit strong responses in subcortical reward areas (e.g., striatum, orbitofrontal cortex), while lower-fat foods engage prefrontal regions more heavily, reflecting top-down modulation of hedonic appraisal (Liu, et al., 2025; Steinglass et al., 2024). In the present study, light-chip likers' increased prefrontal activation may represent compensatory neural processing—maintaining perceived pleasure despite reduced fat-induced orosensory stimulation. In contrast, the lower activation in regular-chip likers could indicate automatic, low-effort hedonic responses resulting from familiar and gratifying sensory input.

These findings highlight how texture and fat content influence cortical reward processing and suggest that positive evaluations of reduced-fat foods may require greater cognitive-emotional integration. From an applied perspective, this emphasizes the importance of enhancing cross-modal cues (e.g., crunchiness, aroma, saltiness) to preserve sensory pleasure and satiety in reformulated snack products, supporting consumer acceptance while promoting healthier consumption behaviors.

4.4. Neural responses compared to control (water)

Compared with the water control condition, the tasting of both Coke and chips led to localized decreases in oxygenated hemoglobin (OxyHb) within specific prefrontal channels (AFFz, AFF3h, and related sites). Rather than indicating an absence of neural activity, such deactivation patterns can represent efficient or inhibitory neural processing during gustatory evaluation. In fNIRS and fMRI studies, water baselines are typically used to isolate taste-related responses, and reductions in prefrontal activity relative to water have been interpreted as adaptive modulation of attentional or predictive networks (Okamoto et al., 2006; Laves et al., 2022).

One possible mechanism is attentional modulation, where repetitive and predictable sensory input—such as tasting familiar stimuli—requires less cognitive engagement than neutral baseline stimuli, leading to attenuated PFC activation (Rodrigues et al., 2025; Balconi & Sansone, 2021). Similarly, gustatory habituation may occur when exposure to palatable stimuli over multiple trials dampens cortical responses, reflecting neural efficiency rather than disengagement (Smeets et al., 2011). Decreased OxyHb can thus reflect refined top-down control within the prefrontal cortex, which regulates hedonic appraisal and integrates reward prediction with sensory feedback (Rolls, 2012).

Another explanation involves predictive coding mechanisms, wherein the brain minimizes prediction errors between expected and actual sensory outcomes. As water provides a neutral sensory baseline, more complex taste stimuli may elicit transient suppression of prefrontal activity due to predictive accuracy—an active inhibitory process optimizing gustatory information flow (Coccurello, 2025; Van Opstal et al., 2021). Therefore, the observed decreases in OxyHb during tasting likely represent not reduced engagement but rather optimized cortical efficiency, consistent with contemporary neurocognitive models of sensory valuation.

4.5. Regular and light products: integrative interpretation

Despite clear behavioral differences in stated liking between regular and light variants, the fNIRS data revealed no significant neural differences between these product categories during tasting. This apparent dissociation between subjective preference and measured cortical activation can be explained through a combination of physiological, cognitive, and psychophysical factors.

From a physiological standpoint, one limitation of fNIRS is its restricted penetration depth—it primarily measures hemodynamic changes in superficial cortical layers, particularly within the dorsolateral and frontopolar regions. Deeper limbic and subcortical structures such as the orbitofrontal cortex (OFC), insula, and striatum, which play central roles in reward and satiety processing, remain largely inaccessible to surface-level optical imaging (Liu et al., 2025; Steinglass et al., 2024). Thus, although regular and light products may have elicited different activations in these deeper areas, fNIRS may not have captured them, masking underlying neural distinctions.

Cognitively, the absence of differences could be due to reward habituation and expectancy normalization. Participants familiar with both product types might have formed stable cognitive templates of "cola" or "chips," reducing neural contrast between caloric and non-caloric variants (Navarré et al., 2025; Van Opstal et al., 2021). When sensory and cognitive representations converge, prefrontal activation becomes less sensitive to subtle changes in caloric density or fat content (Navarré et al., 2025; Van Opstal et al., 2021). Furthermore, sweetness–calorie dissociation, observed when sweet taste cues are not followed by expected metabolic rewards, may attenuate prefrontal response through adaptive recalibration of the brain's reward prediction system (Coccurello, 2025; Van Opstal et al., 2021). This effect can lead to similar cortical activation for regular and light versions despite differences in subjective liking.

Psychophysically, the sensory design of modern light products has

narrowed perceptual differences with their regular counterparts. Advances in sweetener blending and fat-mimicking technologies have improved sensory congruence, allowing reduced-calorie products to mimic the temporal and textural dynamics of full-calorie items (Nourmohammadi, et al., 2023; Ramsey, et al., 2025). This sensory compensation likely contributes to equivalent cortical responses across variants, as the brain's initial perceptual coding emphasizes immediate sensory input rather than long-term metabolic implications.

Overall, the convergence of cortical responses suggests that the prefrontal cortex encodes hedonic processing in a relative, not absolute, manner, integrating expectation, familiarity, and sensory cues more strongly than metabolic content. From an applied perspective, this finding offers a positive implication for healthy product design: if sensory and cognitive cues are properly aligned, reduced-calorie foods can achieve similar neural engagement as their regular counterparts. Such insights can inform consumer neuroscience approaches to reformulation, emphasizing perceptual fidelity and expectation management over pure nutritional mimicry. Beyond the absence of statistically significant neural differences, the comparative pattern between regular and light variants suggests a more nuanced interpretation of caloric valuation. Although regular products received higher stated liking scores, both regular and light variants elicited comparable prefrontal engagement during blind tasting. This indicates that, under conditions where branding and labeling cues are minimized, immediate sensory processing in the dorsolateral and frontopolar prefrontal cortex may rely more strongly on perceptual similarity than on metabolic content. Previous neuroimaging studies have shown that caloric sugars can activate reward-related regions more robustly than artificial sweeteners, particularly within orbitofrontal and striatal circuits (Frank et al., 2008; Van Opstal et al., 2021). However, such subcortical differences may not be fully captured by fNIRS due to its cortical measurement depth (Liu et al., 2025; Steinglass et al., 2024). At the cortical level, especially within the PFC, value integration appears to depend heavily on cognitive appraisal, expectancy, and learned associations (Kringelbach et al., 2003; Rolls, 2012). If modern light products successfully approximate the sensory profile of their regular counterparts—as suggested by advances in sweetener blending and fat-mimetic technologies (Nourmohammadi et al., 2023; Ramsey et al., 2025)—then cortical evaluation processes may converge despite differences in caloric density. Thus, the comparative findings imply that while metabolic reward signals may differ at deeper neural levels, the conscious evaluative stage reflected in prefrontal activation can remain similar when sensory congruence is preserved.

4.6. Limitations, industrial applicability, and future research

Several methodological and interpretive limitations should be considered when contextualizing the findings of this study. First, the sample size was modest, which limits statistical power and the generalizability of the results. A larger and more demographically diverse participant pool would strengthen future analyses and enable subgroup comparisons, such as by gender, age, or habitual consumption patterns. Second, the fixed stimulus order may have introduced potential order effects or habituation biases. Future research should employ fully randomized or counterbalanced designs to control for sequence-related neural adaptation and expectation effects (Gemmerich et al., 2025).

A third limitation involves that the fNIRS technology inherently measures only superficial cortical regions, particularly the dorsolateral and frontopolar prefrontal cortex. This limited spatial depth restricts access to deeper reward-processing regions such as the orbitofrontal cortex, insula, and ventral striatum, which are critically involved in gustatory reward and emotional valuation (Liu et al., 2025; Steinglass et al., 2024). Future studies should combine fNIRS with fMRI or EEG to achieve multimodal spatial–temporal resolution and gain a more comprehensive understanding of cortical–subcortical interactions during food perception.

Another limitation of this study was the high number of repetitions for each sample. Repeated exposure to the same food leads to a decrease in hedonic food ratings (Temple, 2014). It should be considered that frequent repetition of drinking, especially with the five repetitions performed in this experiment, can lead to taste overlap and sensory fatigue.

A primary methodological consideration in the current study is the use of a fixed sequence for the presentation of tasting stimuli. While this approach was chosen to maintain strict standardization across all participants and was mitigated by a 25-second water rinse protocol between samples, it introduces the potential for systematic order effects or carryover bias. Although our within-subject comparisons against the water control condition are less susceptible to this bias, future research should incorporate a fully randomized or counterbalanced design (e.g., a latin square design). This would provide an even more robust methodological foundation by eliminating the risk of a consistent fixed sequence influencing the hedonic ratings and fNIRS response patterns for later-presented products.

A key limitation of the present study involves the statistical threshold used for identifying significant neuronal activation differences. Specifically, a significance level of $p < 0.10$ was employed for our exploratory analyses of the fNIRS results. While this less conservative threshold can be justified in initial studies to detect potential, yet subtle, neural patterns in a complex neuroimaging paradigm, we acknowledge that it increases the susceptibility to Type I errors (false positives). Consequently, the neuronal findings associated with $p < 0.10$ should be interpreted cautiously as tentative findings and serve primarily as a guide for future, confirmatory studies.

A further methodological limitation concerns the absence of a direct correlation analysis between individual hedonic ratings and neural activation. In the present study, participants were categorized into likers and dislikers based on their pre-tasting stated liking, and group-level differences in prefrontal oxygenated hemoglobin (OxyHb) were examined. While this categorical approach enhances contrast between preference groups and is consistent with prior sensory-neuroscientific paradigms (Minematsu et al., 2018; Qing et al., 2021), it does not allow for the assessment of linear associations between the magnitude of subjective liking and the intensity of cortical activation across individuals. Previous neuroimaging research has demonstrated that perceived pleasantness and reward value can scale parametrically with activity in prefrontal and orbitofrontal regions (Frank et al., 2008; Kringelbach et al., 2003; Rolls, 2012). Similarly, fNIRS studies have reported associations between subjective hedonic evaluation and OxyHb changes within the dorsolateral prefrontal cortex (Eremenko et al., 2025; Hu et al., 2014). Without a channel-wise correlation analysis, it remains unclear whether the observed activation differences reflect graded neural encoding of liking or primarily categorical contrasts between polarized groups. Future studies should therefore incorporate regression-based approaches linking continuous hedonic ratings to hemodynamic responses, enabling a more fine-grained characterization of the neural valuation processes underlying food preference.

The findings of this study offer practical insights for the food industry, particularly in the development and optimization of health-conscious food and beverage products. The observed neural responses during blind tasting of regular versus light variants of coke and potato chips reveal that consumer preference/stated liking is tied to distinct patterns of prefrontal cortex activation. Importantly, while stated liking scores were generally favorable for both regular and light products, the differences in neuronal activation between likers and dislikers underscore the relevance of individualized taste responsivity in product formulation. These results highlight the potential of using functional near-infrared spectroscopy (fNIRS) in early-stage product design and neuromarketing to assess consumer response beyond self-reported liking. For manufacturers aiming to reformulate existing high-calorie snacks and beverages, this approach can support the reduction of sugar or fat without compromising hedonic experience—a key challenge

in product optimization (Burger & Stice, 2014; Van Opstal et al., 2021). Moreover, as fNIRS enables real-time, in situ testing under natural consumption conditions, it provides a scalable and cost-effective tool for rapid prototyping and sensory validation in R&D pipelines (Chen et al., 2020). In this context, neurocognitive data can complement traditional sensory panels, contributing to more nuanced and consumer-aligned innovations in functional food development and production engineering.

From an applied standpoint, the present findings underscore the potential of fNIRS as a tool for industrial and neuromarketing applications. Its portability and non-invasive nature allow for in-situ measurements of consumers' implicit responses during product testing, bridging the gap between sensory evaluation and emotional engagement (Kühn et al., 2022). Recent research demonstrates how neuroimaging measures can identify latent affective drivers of product preference, offering manufacturers valuable insights into how sweetness, texture, and branding interact to influence consumer choice (Mai et al., 2025; Zhao, et al., 2024).

In the context of low-calorie or reformulated products, fNIRS could help optimize multisensory profiles by mapping which perceptual cues—such as carbonation dynamics, aroma complexity, or crunch intensity—best maintain reward-related activation despite reduced caloric content. Integrating such neurophysiological feedback with traditional sensory methods and consumer segmentation models may accelerate the development of healthier yet appealing food products. Future work should therefore aim to establish standardized protocols for applying fNIRS in sensory-driven reformulation and marketing research, promoting evidence-based innovation within the food industry.

5. Conclusions

This study shows that functional near-infrared spectroscopy (fNIRS) can capture neural correlates of consumer preference during the tasting of regular and light Coke and potato chips. Regular variants received higher liking scores, yet neural activation patterns did not differ significantly between regular and light products, indicating comparable cortical engagement despite caloric reduction. Distinct prefrontal activation among likers and dislikers suggests that hedonic orientation may be reflected in cortical response; however, these effects should be interpreted cautiously given the exploratory statistical threshold applied. Methodologically, fNIRS proved effective for ecological tasting studies but remains limited to cortical regions; larger, randomized, and multimodal studies are recommended. Practically, these findings suggest that maintaining sensory and cognitive congruence allows healthier, reformulated products to sustain consumer appeal. Integrating fNIRS into product design may thus help the food industry align sensory pleasure with nutritional goals.

Ethics statement

This study adhered to stringent ethical guidelines to ensure the protection and welfare of all participants. Informed Consent: All participants were fully informed about the purpose of the study, the procedures involved, their rights as participants, and any potential risks. Informed consent was obtained from each participant before their involvement in the study. Confidentiality: The privacy and confidentiality of all participants were strictly maintained. Personal data were anonymized to ensure that individuals could not be identified from the information provided. Data were stored securely and accessed only by the research team. Voluntary Participation: Participation in the study was entirely voluntary. Participants had the right to withdraw from the study at any time without any penalty. Ethical Approval: The study protocol was reviewed and approved by the HAW Hamburg Ethics Committee (2020–09), ensuring that it met all ethical standards and guidelines for research involving human subjects. Transparency and Honesty: The research team was committed to conducting the study with the highest level of integrity and transparency. Participants were provided with accurate and honest information about the study's objectives and procedures. Beneficence and Non-maleficence: The principle of beneficence was upheld, ensuring that the study aimed to contribute positively to the understanding of consumer preferences and sensory acceptance.

CRediT authorship contribution statement

Fauziah Fahrudin: Writing – original draft, Investigation, Formal analysis, Data curation, Conceptualization. **Andrea Bauer:** Methodology, Conceptualization. **Stephan G.H. Meyerding:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Conceptualization.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) used ChatGPT based on GPT-4, specifically the Multimodal version with vision capabilities (also called GPT-4-turbo) and the customized version called ScholarGPT, designed for advanced academic research, critical reading, data analysis, and scholarly writing to improve the readability and language of the manuscript. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix

Table 1A
General acceptance of the products without tasting

	Acceptance regular coke		Acceptance coke zero		Acceptance regular chips		Acceptance light chips	
	N	%	*N*	%	*N*	%	*N*	%
I dislike it extremely	1	3.2%	2	6.5%	1	3.2%	2	6.5%
I rather dislike it	1	3.2%	6	19.4%	1	3.2%	2	6.5%
I dislike it a bit	3	9.7%	4	12.9%	5	16.1%	1	3.2%
Neither like nor dislike	5	16.1%	3	9.7%	5	16.1%	8	25.8%

(*continued on next page*)

Table 1A (*continued*)

	Acceptance regular coke		Acceptance coke zero		Acceptance regular chips		Acceptance light chips	
I like it a bit	6	19.4%	5	16.1%	5	16.1%	11	35.5%
I quite like it	12	38.7%	8	25.8%	6	19.4%	2	6.5%
I like it extremely	3	9.7%	3	9.7%	8	25.8%	5	16.1%

Note. Rating on a scale from 1 = I dislike it extremely to 7 = I like it extremely

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