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Insect-Based Food: The Role of Consumer Neuroscience in Exploring Consumer Behavior

Andreia C. B. Ferreira[1], Ricardo Gouveia Rodrigues[1], Ana R. Gouveia[1, 2, 3], Oliva M. D. Martins[4], Hugo A. Ferreira[2], João Pereira[1], and Paulo Duarte[1]

[1] Department of Management and Economics, Núcleo de Estudos em Ciências Empresariais, da Universidade da Beira Interior

[2] Faculdade de Ciências, Instituto de Biofísica e Engenharia Biomédica, Universidade de Lisboa

[3] Faculdade de Ciências da Saúde, Universidade da Beira Interior

[4] Tomar School of Management, Instituto Politécnico de Bragança, Bragança, Portugal and Transdisciplinary Research Center on Education and Development

Insect-based food, a potential solution for the escalating global food demand, faces consumer acceptance challenges in some regions. This article aims to understand the physiological reactions to an insect bar to assess its potential acceptance, thereby fostering the quest for sustainable food sources. An experiment was conducted with participants aged 18–55 years, who first completed a preexposure survey to assess their awareness of insect-based foods. Next, physiologic responses, including brain electrical activity (electroencephalography) and cardiac electrical activity (electrocardiography), were recorded while participants consumed an insect bar. After the consumption, a postexposure questionnaire was conducted to assess the bar's preference. The results highlight the need for improved communication about insect-based food and its advantages, given limited awareness. Still, when people are informed about it, they are more likely to accept it. Consuming the insect bar led to a more attentive state and higher electrophysiological activity, with participants self-reporting a preference for the insect bar. These findings suggest that the processed insect-based product should be enhanced to increase its acceptance and that marketing strategies such as free samples and tasting experiments could be effective in promoting this new alternative. This study is a pioneer in using electroencephalography and electrocardiography to assess insect-based food consumption. The mixed methods approach (survey plus physiologic signals) produces more sound findings.

Keywords: insect-based food, electroencephalography, electrocardiography, consumer neuroscience

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Katsunori Yamada served as action editor.

Andreia C. B. Ferreira https://orcid.org/0000-0002-6966-1638

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All authors have read and agree to the published version of the article and contributed to the conceptualization, methodology, validation, formal analysis, investigation, data curation, writing-original draft preparation, writing-review and editing, supervision, project administration, and synthesis of the literature reviewed.

Andreia C. B. Ferreira played a lead role in conceptualization, data curation, investigation, methodology, writing–original draft, and writing–review and editing. Ricardo Gouveia Rodrigues played a lead role in supervision. Ana R. Gouveia played a supporting role in data curation

continued

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The global population is projected to surpass nine billion by 2050, presenting challenges to food security and risks to human survival due to the anticipated nearly doubling of food demand (Steinfeld et al., 2006; Wendin & Nyberg, 2021).

At the core of this demand is protein, an essential nutrient critical to human health and survival whose deficiency can lead to severe health conditions, like Kwashiorkor, a form of severe protein malnutrition marked by peripheral pitting edema (Benjamin & Lappin, 2023) or marasmus, characterized by energy deficiency (Vanbergen & Appleton, 2012).

Among the emerging alternatives to animal protein sources are insects (Aiking, 2011). They have gained attention in the past few years due to regulatory approval in Europe, granted in 2018 (Siddiqui et al., 2023).

Anthropo-entomophagy, the consumption of insects by humans, is an ancient practice (Ramos-Elorduy, 2009) that may offer a sustainable solution to the growing demand for protein (van Huis et al., 2013). It is considered more sustainable when compared to animal protein (Govorushko, 2019; van Huis et al., 2013; Wendin & Nyberg, 2021), as they emit less pressure on natural resources and require less land to produce, justified by their size, as they are smaller (Simion et al., 2019; Wendin & Nyberg, 2021). Specifically, environmental and climate sustainability are promoted because insect-based food products generate fewer greenhouse gases (Govorushko, 2019; Simion et al., 2019) than meat production, which, in contrast, is a significant emitter (Tjärnemo & Södahl, 2015). Sikora et al. (2023) noted that insects also cause less water pollution (Kim et al., 2020), resulting in a low footprint (Sikora et al., 2023; van Huis & Rumpold, 2023). In summary, insects have a smaller impact on climate change (Sikora et al., 2023) while meeting high-quality nutritional needs (Wendin & Nyberg, 2021) and supplementing human food needs (Food and Agriculture Organization of the United Nations, 2017). Insects also provide high-quality, digestible proteins, relevant fat values (e.g., essential fatty acids and unsaturated fats), mineral substances, vitamins, and carbohydrates (Belluco et al., 2013; Payne et al., 2016). They are consumed whole (e.g., fried snacks), in their immature stages (e.g., eggs, larvae, pupae, and nymphs), or in their adult state, as well as in processed forms (e.g., made into powder or pasta) and as isolated protein (e.g., through insect extracts; Klunder et al., 2012; Sikora et al., 2023). Compared to other protein sources, insect-based foods have lower fat content and higher levels of calcium, iron, and zinc (Simion et al., 2019; van Huis et al., 2013).

Regardless of all the advantages of the novel protein alternative and being recognized as a promising and complementary protein source, meeting the rising demand for novel, sustainable proteins (S. Mancini et al., 2019), the acceptance of insects as food in Europe was identified as a challenge (Dagevos, 2020; Goncikowska et al., 2023; Piha et al., 2018), especially when the insect is visible in food products (Dagevos, 2020; Martins et al., 2022) due to adverse emotional reactions associated with disgust and neophobia, meaning the fear or rejection of novel food, which play an essential role (Bourke et al., 2024) and influence the acceptance (Caparros Megido et al., 2016; Hémar-Nicolas et al., 2022; La Barbera et al., 2018; Lammers et al., 2019; Padulo et al., 2022; Wendin & Nyberg, 2021) in cultures without anthropo-entomophagy tradition or habits (da Silva et al., 2023; Hémar-Nicolas et al., 2022; Koch et al., 2021).

Research in the field is needed as there is a gap in understanding how to enhance the acceptance of insect-based foods in Europe using consumer neuroscience techniques such as electroencephalography (EEG) and electrocardiography (ECG) to improve consumer behavior research on insect-based foods (Harris et al., 2018). To the best of our knowledge, only one study has evaluated emotion during the cooking and tasting of insect-based foods, comparing chicken and mealworms. The findings reveal high arousal and low valence for mealworms, due to anxiety and implicit escape behavior (Brouwer et al., 2017). The authors called for future research to use consumer

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Correspondence concerning this article should be addressed to Andreia C. B. Ferreira, Department of Management and Economics, Núcleo de Estudos em Ciências Empresariais, da Universidade da Beira Interior, Estrada do Sineiro, s/n, 6200-209 Covilhã, Portugal. Email: andreia.cristina.ferreira@ubi.pt

neuroscience techniques to enhance its capability to measure valence and emotions toward food.

Consumer neuroscience methods and tools enable researchers to analyze thoughts, feelings, nonconscious intentions, and decision-making processes (Harris et al., 2018) when consumers are confronted with a marketing stimulus (Ohme et al., 2011). The general neuroscience, cognitive psychology, and biomedical sciences tools (Dumitrescu & Dumitrescu, 2021; Harris et al., 2018) were classified into three different categories, considering their function: The first is the record of the brain metabolic activity, including the measurement and identification of the response of the consumer's brain to a marketing stimulus; the second is the recording of the electrical activity of the brain, and the third is the record of other physiologic responses (without brain activity registration) to find a physiologic correlation with the behavior (Nyoni & Bonga, 2017). Two main tools that deserve to be highlighted and chosen for this research are EEG and ECG.

EEG was chosen because it is one of the most used neuroscience tools to measure brain activity (Alwitt, 1985; Morin, 2011; Panda et al., 2023; Songsamoe et al., 2019) and allows for the assessment of the brain areas that are activated when exposed to a marketing stimulus (Oostenveld & Praamstra, 2001; Songsamoe et al., 2019), through the bioelectrical changes in the cerebral cortex (Nadanyiova, 2017; Oostenveld & Praamstra, 2001), recording electrical potential differences in real time, before, during, and after the stimulation (Oostenveld & Praamstra, 2001; Songsamoe et al., 2019). The variations in electrical frequency are categorized into low and high values and then into brain waves (Alwitt, 1985; Dumitrescu & Dumitrescu, 2021; Songsamoe et al., 2019): Delta waves (0.5–4 Hz) are more pronounced during deep sleep status; theta wave (4–8 Hz) activity is more pronounced during sleep, meditation, or reduced conscious status; alpha wave activity (8–12 Hz) is related to physically and mentally relaxed mood, an awaken but sleepy status; beta waves (13–30 Hz) are associated with an awake, conscious, and alert status; and, finally, gamma waves (above 30 Hz) are more pronounced during learning, memory, and information processing (Morin, 2011; Songsamoe et al., 2019).

ECG is another consumer neuroscience tool, and the interest in using it in marketing and consumer behavior research is related to the cardiac system that reports to the central nervous system, resulting in a heart rate (HR) reflection when there are behavioral or emotional changes, identifying levels of arousal (Palomba et al., 1997), as emotions reflect nervous and physical responses to specific events (Xu et al., 2023). Lindstrom (2009) also argued that the HR is an excellent proxy for an emotional scale because it is related to peripheral nervous system activation.

ECG records the heart's electrical activity to measure parameters such as HR by detecting voltage differences between electrodes placed on the skin (Van Mieghem et al., 2004). These signals are time variable, as are the heartbeat intervals (De Chazal et al., 2004). Through them, several parameters can be measured, including HR variability, which is derived from the variation in the occurrence of heartbeats (Lang et al., 1998).

Neuroscience, coupled with marketing and consumer behavior, reinforces the relevance of emotions to the human cognitive process and consumption decision making (Hamelin et al., 2017). Combined with conventional methods, the results offer a more in-depth understanding of consumer food choices (Ares & Vidal, 2021).

For these reasons, this research is an essential first step toward identifying strategies for promoting insect-based foods as viable alternatives to animal protein, in a context where attitudes, environmental concerns, motivation (Hanan et al., 2024), and familiarity (Bourke et al., 2024) are known to influence consumer behavior toward novel food products, highlighting the importance of a targeted approach in understanding and promoting consumer acceptance of insect-based foods (Hanan et al., 2024).

This study assessed consumers' perceptions and electrophysiological (ECG and EEG) responses, including arousal, attention, and engagement, to a category of insect-based food products, specifically when exposed to an insect protein bar. The research, which employed traditional and consumer neuroscience methods, was divided into sequential phases. Initially, a preexposure survey was administered to participants before consumption to assess their opinions and awareness of insect-based food. During the consumption phase, participants' electrophysiological responses were recorded as the researcher indicated they were about to consume a protein bar. Finally, a postexposure interview

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was conducted to assess participants' preferences and the insect-based bar's likability.

The described research contributes to the field of insect-based food acceptance in Europe as well as to consumer neuroscience research within food research, offering an enhancement on the understanding of consumer behavior toward insect-based food, using psychophysiological measures to assess emotions (Lajante & Ladhari, 2019), which, as stated by Herrando et al. (2022), has a low adoption rate.

Method

The research was conducted in Portugal and was authorized by an ethics committee, with a sample that met the specific inclusion criteria: participants aged 18 to 65 who had never tried insect-based foods. Previous insect consumption was confirmed by questioning whether the person had tried insect-based food. The exclusion criteria are enumerated: patients with neurological, psychiatric, cardiovascular, or immunological disorders, as well as those with pacemakers.

While the intended sample size was 40 participants, we collected data from 45 participants. Because participants were initially allowed to chew and talk, ECG and EEG data acquisition yielded abnormal signals, resulting in the exclusion of data from seven participants.

The participants (n = 38) were randomly divided into four subgroups, as described in Table 1, according to two criteria: First is the presence or absence of manipulation in the presentation of bars. Participants in the "with manipulation" condition consumed the insect bar, thinking it was a cereal bar. Conversely, in the "without manipulation" condition, the type of bar disclosed to participants was the correct one. Second is the consumption order (i.e., which type of cereal bar the participant tasted first).

The experiment was conducted as described: Before the consumption/exposure phase, a survey was used to analyze the levels of awareness of insect-based foods, potential readiness for future consumption, the sample's demographic characteristics, and other variables (Table 2). Chi-square tests (α = .05) were performed to examine the relationships among the variables.

Data acquisition (i.e., recording of EEG and ECG signals) began when the bar (insect or cereal; Figures 1 and 2) was presented.

The bars (insect or cereal) had a similar flavor (apple and cinnamon).

Figure 3 shows the experiment montage.

The EEG data were recorded using the Unicorn Hybrid Black (from g.tec medical engineering GmbH), a headset with eight channels/electrodes positioned over the frontal {Fz; C3; Cz; C4}, parietal {Pz}, and occipital {PO7; Oz; PO8} lobes during consumption/exposure, per bar (see Figure 4).

The signal was decomposed on delta, theta, alpha, low beta (12–20 Hz), high beta (20–30 Hz), and gamma relative wave power (i.e., the relative of a wave over the sum of all the waves) using a toolbox—cross-wavelet and wavelet coherence (Grinsted, 2024)—and mean Hz values per wave were found. For each wave, the bar (insect vs. cereal), manipulation (presence or absence of bar manipulation), and subgroup (segmentation of groups by order and manipulation) for each of the eight EEG channels were tested by analyzing whether there were significant differences in the results. The analysis was focused on the channels from the right hemisphere (C3, PO7) and the most frontal channel (Fz). Data acquisition and further analysis were divided into Bar 1 and Bar 2.

Electrical brain activity was compared across bars within subgroups and across channels to assess whether there were significant differences. Boxplots were used to assess significant differences, and Wilcoxon tests were performed. For

Table 1
Characterization of the Subgroups According to the Existence of Manipulation and Order of Presentation

Subgroup	Sample size (N)	w/o man.	w/ man.	Order: insect –cereal	Order: cereal–insect
N1	9	✓		✓	
N2	10		✓	✓	
N3	10	✓			✓
N4	9		✓		✓

Note. w/ = with; w/o = without; man. = manipulation.

Table 2
Survey Variables and Scales/Response Format

Variable	Question	Scale/response format
Concern for sustainability	How important is sustainability to you?	5-point scale (*not important* to *extremely important*)
Diet	Which of the following best describes your diet?	Multiple choice (omnivorous, vegetarian, or vegan)
Flexitarianism	Do you practice flexitarianism?	Dichotomic (Yes/No)
Purchase awareness	Did you know that it is now possible to buy insect-based foods in Portuguese stores?	Dichotomic (Yes/No)
Product found	Have you seen insect-based foods for sale in supermarkets?	Dichotomic (Yes/No)
Curiosity	Were you curious to try it?	Dichotomic (Yes/No)
Previous experience	Have you ever tried insect-based products?	Dichotomic (Yes/No)
Product availability consciousness	Do you know which types of insects are authorized for sale in Portugal?	Dichotomic (Yes/No)
Emotions	How do you feel when people talk to you about insect-based foods?	Multiple choice (disgust, surprise, fear, happiness, sadness, anger)
Valence	How positive is that emotion you feel?	5-point scale (*extremely negative* to *extremely positive*)
Arousal	How intense is this emotion you feel?	5-point scale (*not intense* to *very intense*)
Likelihood for future consumption	Do you see yourself eating this type of food in the future?	Dichotomic (Yes/No)
Gender		Dichotomic (male/female)
Age		Open ended
Education		Multiple choice
Place of birth		Open ended

the analysis, a significance level of $\alpha = .05$ was established.

Additionally, the engagement beta/(alpha + theta) ratio and attention provide information about cognitive and attentional activity (Clarke et al., 2019) and were calculated according to the guidelines of Pope et al. (1995).

To assess these metrics, power spectral density was computed at each electrode, and then band powers were aggregated: {Fz; C3; Cz; C4} as the frontal; {Pz} as the parietal; and {PO7; Oz; PO8} as the occipital lobes, according to Mcmahan et al. (2015).

Moreover, ECG data were acquired with BITalino (PLUX – Wireless Biosignals & S. A., 2020) and processed with OpenSignals (PLUX – Wireless Biosignals & S. A., 2019). Then, the graphical interpretation of electrocardiogram data was segmented into moments before, during, and after consumption/exposure. HR in beats per minute (BPM) was recorded for each participant, and an F test was used to test for the equality of variances.

The ECG analysis was performed by comparing mean values at various moments during the bar experiment, including before, during, and

Figure 1
Insect Bar

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Figure 2
Cereal Bar

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after consumption/exposure. Before consumption refers to the moment when the bar is presented to the participant, during consumption refers to the "masticating" moment, and after consumption refers to the moment that begins when chewing ends. The analysis was conducted and divided according to the subgroups identified in Table 1, that is, by the bar tested, the presentation order, and the manipulation states. Means were compared using a 95% confidence interval ($\alpha = .05$) and a two-sided test for equality of means.

After the consumption phase, participants were asked to identify their preferred bar among the ones they had consumed. Figure 5 represents the descriptive schema of the experimental design, including stages and duration.

Sample

The pseudorandom sample was initially predicted to be $N = 40$, and although data were collected from 45 participants, incomplete data (e.g., ECG recording started late) or abnormal data (e.g., chewing, talking) led us to filter the heterogeneous sample to $N = 38$.

A summary of the sample's ($n = 38$) demographic characteristics is presented in Table 3,

Figure 3
Experiment Montage

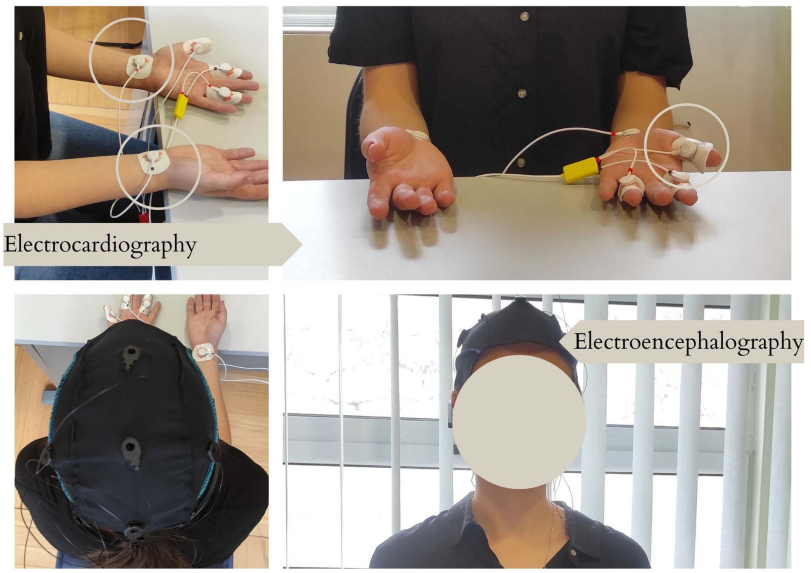

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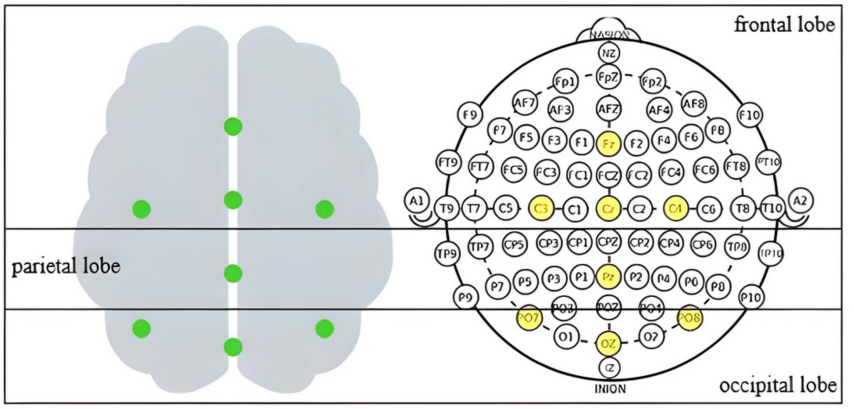
Figure 4
Electrode Position



Note. Adapted From "Unicorn: The Brain Interface, 2022". See the online article for the color version of this figure.

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including age group, sex, level of education, and nationality.

The sample's heterogeneity and adherence to the sample sizes suggested in consumer neuroscience studies, which range from 20 to 30 individuals (Plassmann et al., 2015), enabled us to consider the results relevant to improving the field.

Results

The results are presented according to the experimental schema: preexposure survey, EEG, ECG, and postexposure questionnaire.

Preexposure Survey

Based on the responses to the preexposure survey, it was possible to conclude that sustainability is a significant topic and has been gaining prominence among the public. That is also noticeable in people's efforts to change eating habits. In the sample, 84% of the participants were omnivorous, and only 16% were vegetarian (refused to eat meat or seafood). More than half of those with a meat-based diet admit to reducing meat consumption by practicing flexitarianism (reducing meat and seafood consumption).

The participant's level of awareness of anthropo-entomophagy was assessed. The results show that almost half of the participants (47%) were already aware that insect-based foods could be bought or sold in Portuguese shops and 67% expressed curiosity about trying insect products. However, only 8% of these have ever found such products on sale. When asked about the legally and commercially accepted species, only 3% of participants admitted knowing them, and the insect most easily identified was the grasshopper. These results suggest that awareness remains limited.

The survey also focused on participants' self-reported emotions when considering insect-based food. In descending order of selection percentage, the emotions of surprise, fear, happiness, and disgust were mentioned. Regarding emotions, the evidence indicated a predominance of barriers (the participants tended to select disgust and fear) over favorable aspects (happiness), which is consistent with the fact that these foods are not yet part of the country's gastronomic culture. On the other hand, the evidence also suggested some degree of openness to experimentation and consumption. According to the questionnaires, 71% of participants see themselves as future consumers of insect-based foods.

To statistically validate the survey results, the statistical significance of the association between the variable "future consumption intention" and three other variables, such as sustainability concerns, emotions, and sex, was computed. There is evidence of a statistically significant association (chi-square test) between emotions and future insect-based food consumption intention (p = .005). The individuals who said they would not

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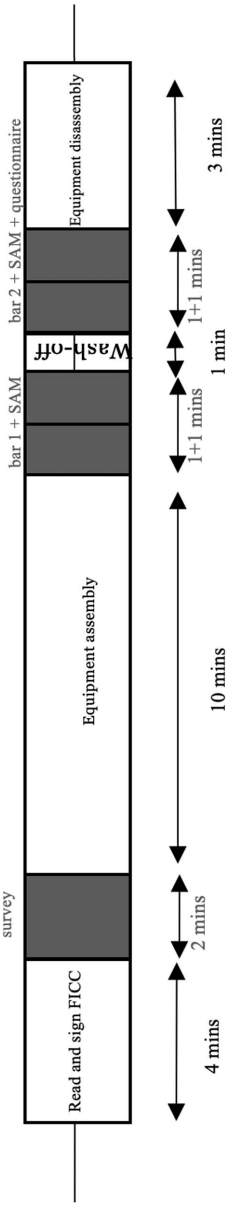

Figure 5
Schema of the Insect-Based Food Experimental Design

Note. Source: own elaboration. SAM = Self-Assessment Manikin; FICC = free and informed consent.

consume insects selected "surprise" as the emotion they named first when thinking about insect-based food. In contrast, sustainability concerns are not significantly associated with future consumption intention ($p = .283$). No evidence suggests that higher sustainability concern leads to a greater acceptance of insect-based food.

Surprise, characterized by Ekman (2022) as a startle reaction triggered by unexpected or sudden situations, is a spontaneous reaction that does not influence long-term outcomes. In turn, disgust, as described by Ekman (1999) as a feeling of aversion to something offensive, can effectively influence future decision making.

There is evidence of a significant association between sex and future consumption intention ($p = .128$). It was noted that males tend to exhibit a higher tendency toward future consumption intention. However, there is no evidence of a significant association between age group and future consumption intention ($p = .994$).

EEG

Table 4 summarizes the results of the boxplot analysis conducted to identify differences between the means (95% confidence interval), considering the eight EEG channels and each of the variables (see further details, per channel, in Supplemental Appendices A–F).

The bar reflected higher delta wave activity for the insect bar at the Fz, PO8, and Oz electrodes; higher theta wave activity at Oz and PO8; higher alpha wave activity at Pz; and higher gamma wave activity at C3. Manipulation produced differences in mean values, influencing arousal and valence, as reported by Ferreira and Saraiva (2019).

The medians between bars within subgroups and channels were compared (see Supplemental Material G). Significant differences were found in alpha wave for subgroup N1 in C4 frontal lobe electrode ($p = .047$); in low beta wave for subgroup N4 in C3 frontal lobe electrode ($p = .045$); in high beta wave for subgroup N2, in Oz occipital lobe electrode ($p = .045$); and in gamma wave for subgroup N1 in Fz frontal lobe electrode ($p = .03$) and for subgroup N2 in Oz and PO8 occipital lobe electrodes ($p = .005$; $p = .04$).

A Wilcoxon test complemented the analysis and supported the validation of results, considering the channels and their integration into the brain lobes, as detailed in the Methods section.

Table 3
Demographic Characterization of the Experiment Sample

% Age	% Sex	% Level of education	Nationality
From 18 to 25 years old—53%	Male—37%	Basic education—16%	Switzerland—3%
From 26 to 35 years old—29%	Female—63%	Higher education—84%	Spain—4%
From 36 to 45 years old—8%			France—4%
From 46 to 55 years old—10%			Brazil—8%
			Portugal—81%

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The full table is provided in Supplemental Material L.

The results show a significant marginal difference in low beta activity in the frontal lobe for subgroup N4 ($Z = -1.960, p = .05$), with superior activity for the insect bar. On the occipital lobe, gamma waves ($Z = -2.497$, $p = .013$) must be highlighted, as there was a marginally significant difference between bars that tend to be higher for the insect bar in subgroup N2.

Likewise, a comparison between means (paired sample *t* test) was made to assess which bar (insect bar or cereal bar) had higher mean values (a complete analysis is provided in Supplemental Material G). The results are presented in Table 5, considering the type of bar presented (with or without manipulation). The goal was to understand which bars elicit higher brain electrical activity. For interpretation, the characteristics of the subgroups must be considered.

Channels of the right hemisphere (C3, PO7) in the delta wave tend to be higher (with or without manipulation). The findings provide preliminary evidence of a slight elevation in arousal in response to the insect bar. We also observed increased mean theta activity. The findings suggest increased attentional engagement and positive valence toward the insect bar (whether they were genuinely consuming it or being misled/manipulated).

Furthermore, to interpret the means-comparison results, the position of the Unicorn Hybrid Black electrodes was identified based on the cerebral Brodmann areas (Brodmann & Garey, 2006) and their MNI coordinates using the MRIcroGL software (Table 6), as recommended by Scrivener and Reader (2022). This identification allows us to interpret higher mean values per wave and Brodmann areas.

Taken together, Tables 5 and 6 provide evidence of increased beta wave activity during insect bar consumption, consistent with heightened attentional and visual engagement. Higher occipital gamma activity was also observed in the insect bar, suggesting increased visual processing demands. In contrast, no significant differences were detected in frontal/parietal regions responsible for motor function. Engagement and attention metrics are shown in Table 7.

The results in Table 7 support the findings of the previous analysis and provide evidence of increased attentional engagement in sensorimotor and visual areas. However, the cereal bar shows a tendency toward higher engagement.

Table 4
Summary of the Influence of the Variables Bar, Manipulation, and Subgroup on the Wave Activity

	Variable		
Wave	Bar	Manipulation	Subgroup
Delta	✗	✓	✓
Theta	✗	✓	✗
Alpha	✗	✓	✓
Low beta	✗	✓	✗
High beta	✗	✓	✓
Gamma	✗	✓	✓

Note. ✗ means there are no significant differences and ✓ means there are significant differences.

ECG

ECG results: the mean difference and standard deviation between HR (in BPM values) are shown in Table 8.

Based on the data in Table 8 and starting with the subgroup N1, the results suggest, with 95% confidence interval, that a difference exists between the HR means at the moments before and during insect bar consumption ($p = .010$). In addition, by analyzing the column mean difference, it is possible to argue that the mean of the

Table 5
Summary of Identification of Higher Mean Values per Wave and Channel

			Brain lobe/channel							
			Frontal				Parietal	Occipital		
Wave	w/ or w/o manipulation	Subgroup	Fz	C3	Cz	C4	Pz	PO7	Oz	PO8
Delta	w/o man.	N1	cB	iB	cB	iB	cB	iB	cB	iB
		N3			iB			cB		cB
	w/ man.	N2	cB	cB		iB	cB		iB	
		N4	iB	iB			iB			
Theta	w/o man.	N1	iB	cB	iB	iB		iB		
		N3		iB						
	w/ man.	N2		iB	cB					
		N4			iB					
Alpha	w/o man.	N1	cB		cB		cB		cB	
		N3	iB				iB		iB	
	w/ man.	N2		cB			cB	iB	iB	cB
		N4						cB		iB
Low beta	w/o man.	N1					cB			
		N3								
	w/ man.	N2		iB		cB	iB		cB	
		N4				iB			iB	
High beta	w/o man.	N1	iB		iB		iB	iB	iB	
		N3			cB			cB		
	w/ man.	N2					cB			
		N4					iB			
Gamma	w/o man.	N1	iB		iB		iB	iB	iB	
		N3			cB			cB		
	w/ man.	N2					cB			
		N4					iB			

Note. w/= with; w/o= without; man. = manipulation; cB = cereal bar; iB = insect bar.

"during" moment was significantly higher than that of the "before" moment. It was also observed that the tendency increased from the moment "before" to the moment "during" and "after" as the HR (in BPM) tended to decrease.

In subgroup N2, a significant difference was found between the moments "before" and "after" the insect bar was consumed ($p = .039$). In subgroup N4, significant differences in HR were found between the moments "before" and "during" and between the moments "before" and "after" cereal bar consumption. Even so, in column mean difference, it was possible to see a tendency for an increase in HR (in BPM) from the moment before to the moment after.

In summary, in the subgroups where the bar variable was manipulated, especially in subgroup N2, a higher HR was noted during the consumption of the manipulated cereal bar (insect bar without knowing. After that moment, HR decreased. "After" the consumption of the manipulated insect bar, HR was higher than before, although not by much. In turn, the subgroup N4, which experimented with the cereal bar followed by the insect bar, with manipulation, exhibited HR oscillations, with a lower HR before than after consuming the bar).

The HR during the consumption of the bars tends to be higher than during the "before" and "after" moments, where no consumption is observed. We can also suggest that the HR was higher when the individuals consumed the insect bar than when they consumed the cereal bar.

Postexposure Questionnaire

At the end of the consumption experience, a final question was asked to assess which bar the participant liked the most: "the insect or the cereal?" Despite the question's simplicity, some participants insisted on providing their opinion about the experience rather than just answering the question, selecting either the insect bar, the cereal bar, or both. The most relevant responses will be described below.

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Table 6

Unicorn Hybrid Black Channels' Brodmann Areas Correspondence (Brodmann & Garey, 2006; Scrivener & Reader, 2022)

Unicorn Hybrid Black Channel	Mean and *SD* MNI cortex coordinates (in mm)			Coordinates (X, Y, Z) Brodmann/ROI	What does the ROI identified represent?
	X	Y	Z		
Fz	0.88 (3.46)	34.43 (5.64)	62.21 (4.84)	(3, 34, 60) ROI 8	Brodmann's area 8 is part of the human frontal cortex. This area plays an important role in controlling complex movements, including those originating in the eye.
C3	−50.88 (4.53)	−21.18 (6.81)	59.95 (3.47)	(−51, −21, 60) ROI 3	Brodmann's area 3 integrates Areas 3, 2, and 1 by convention and is located in the primary somatosensory cortex. It is responsible for processing sensorial information, such as localization of touch, sensory perception, and motor learning.
Cz	−0.47 (3.61)	−24.64 (6.88)	80.16 (3.89)	(2, −24, 77) ROI 4	Brodmann's area 4 is part of the primary motor cortex and is involved in motor control.
C4	50.78 (4.61)	−23.18 (6.17)	63.58 (4.78)	(50, −23.18, 61) ROI 3	Brodmann's area 3 integrates Areas 3, 2, and 1 by convention and is part of the primary somatosensory cortex. It is responsible for processing sensory processes such as touch localization, sensory perception, and motor learning.
Pz	−1.94 (5.31)	−69.12 (7.17)	66.04 (4.54)	(−3, −69, 66.04) ROI 7	Brodmann's area 7 belongs to Brodmann's cytologically defined brain regions, as the precuneus and the superior parietal lobule. Its function is to localize objects in space.
PO7	−46.45 (3.26)	−86.74 (3.80)	3.87 (9.43)	(−43, −83, 2) ROI 19	Brodmann's area 19 is situated on the occipital lobe's associative visual cortex (V3, V4, and V5). It is responsible for processing visual information.
Oz	−2.49 (4.97)	−102.67 (3.09)	9.10 (10.31)	(−6, −103, 9.1) ROI 17	Brodmann's area 17 is in the primary visual cortex of the brain's occipital lobe, corresponding to ROI 18. In this area, the brain processes the visual information received by the eyes.
PO8	42.78 (4.03)	−88.05 (3.60)	7.87 (9.83)	(39, −88, 7.87) ROI 18	Brodmann's area 18 is in the secondary visual cortex (V2) on the occipital lobe. In the area, the first stage of visual processing proceeds.

Note. ROI = region of interest.

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Table 7
Engagement and Attention Ratio Values per Cerebral Lobe and Bar

		Cerebral lobe		
Metric	Bar	Frontal {Fz; C3; Cz; C4}	Parietal {Pz}	Occipital {PO7; Oz; PO8}
Engagement	iB	.28	.29	.28
	cB	.29	.30	.32
Attention	iB	2.33	2.15	2.24
	cB	2.17	2.00	1.90

First, in subgroup N1, 89% of the members preferred the insect bar. In subgroup N2, 20% of participants could not identify a preferred bar, stating that they liked both bars equally and did not distinguish between the flavors; 10% preferred the manipulated cereal bar (insect). The remaining 70% of the participants identified the manipulated insect bar as their favorite (cereal). In subgroup N3, 20% of participants did not identify a preferred bar, 50% preferred the insect bar, and the remaining 30% preferred the cereal bar. The subgroup N4 had the following results: 89% identified the insect bar as their favorite, but only 11% said they liked the cereal bar better, when in fact it was the insect bar.

In summary, individuals preferred the insect bar to the cereal bar. Some participants also mentioned that they consider it essential to introduce more alternative protein bars to the market and increase the offerings of insect-based bars.

Discussion

While marketing evaluates both rational and emotional responses, consumer neuroscience examines the less conscious responses and processes

Table 8
Mean Difference (MD) and Standard Deviation (SD) Between HR (in BPM Values), Between Bars, per Subgroup

					Significance	
Subgroup	Means comparison	*MD*	*SD*	Tobs[a]	Unilateral *p*	Bilateral *p*
N1	iB before–iB during	−16.00	12.80	−3.53	.005	.010
	iB before–iB after	−5.50	18.60	−0.84	.215	.431
	iB during–iB after	10.50	16.38	1.81	.056	.113
	cB before–cB during	−5.25	11.97	−1.24	.127	.255
	cB before–cB after	−5.88	20.15	−0.83	.218	.437
	cB during–cB after	−0.63	24.23	−0.07	.472	.944
N2	cB before–cB during	−3.90	11.35	−1.09	.153	.305
	cB before–cB after	4.60	12.55	1.16	.138	.276
	cB during–cB after	8.50	16.35	1.64	.067	.135
	iB before–iB during	15.50	22.05	2.22	.027	.053
	iB before–iB after	18.50	24.30	2.41	.020	.039
	iB during–iB after	3.00	13.56	0.70	.251	.502
N3	cB before–cB during	−4.33	21.30	−0.61	.279	.559
	cB before–cB after	−1.78	23.78	−0.22	.414	.828
	cB during–cB after	2.56	11.43	0.67	.261	.521
	iB before–iB during	−7.56	24.08	−0.94	.187	.374
	iB before–iB after	0.67	26.75	0.08	.471	.942
	iB during–iB after	8.22	12.23	2.02	.039	.078
N4	iB before–iB during	−11.33	11.82	−2.88	.010	.021
	iB before–iB after	−12.33	9.07	−4.08	.002	.004
	iB during–iB after	−1.00	11.30	−0.27	.399	.797
	cB before–cB during	−12.67	21.10	−1.80	.055	.109
	cB before–cB after	−4.11	17.63	−0.70	.252	.504
	cB during–cB after	8.56	12.77	2.01	.040	.079

Note. HR = heart rate; BPM = beats per minute.
[a] Tobs = *t* observed.

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(Arieli & Berns, 2010) by measuring physiological and neural correlates of evaluation (Xu et al., 2023). As a result, the results of neuroscience tools are sometimes inconsistent with those from questionnaires/surveys (Lin et al., 2024). In the present study, participants' prior perceptions of insect-based food were primarily assessed on a pretasting survey.

The results from the Portuguese context contradict those from prior evidence reported in Germany (Lammers et al., 2019) and Italy (Iannuzzi et al., 2019), with more informed and aware consumers. This highlights the need to inform potential Portuguese customers about this novel food alternative and its sustainable benefits, which can influence perception and enhance the acceptance of insects as a food source, as stated by Simeone and Scarpato (2022), in contrast to the findings of Liu and Kim (2024). Segmenting consumers for effective targeting will enhance acceptance (Possidónio et al., 2021), such as among the youngest generations (Bourke et al., 2024).

For all, it is critical to state the sustainable and nutritional advantages of insect consumption (Koch et al., 2021; Liu & Kim, 2024) because people, in particular, were found to have increased worries about the environment and environmental issues (Moser, 2016) and, in general, are misinformed about the sustainability of this source of protein, both about its characteristics, the packaging, or the production systems (Groth et al., 2023) and the nutritional value of products (Balzan et al., 2016; Koch et al., 2021).

Considering the barriers to acceptance, the current findings led us to conclude that, contrary to what Lammers et al. (2019), Dupont and Fiebelkorn (2020), Tuccillo et al. (2020), Wendin and Nyberg (2021), and Padulo et al. (2022) indicate, disgust is not the main emotional factor for insect-based food nonacceptance, even though it is triggered right before consumption, validating La Barbera et al.'s (2018) previous findings. The current findings suggest that surprise is more determinant due to a lack of awareness regarding this novel alternative. According to Caparros Megido et al. (2016), awareness of insect-based food increases its acceptance. The vast majority of participants who envision themselves consuming insect-based food in the future (almost 70%) agree with the previous findings (Balzan et al., 2016; Niva & Vainio, 2021), thereby strengthening the argument that contradicts the notion of disgust.

Regarding product presentation, another unexpected result was the impact of manipulation. With or without manipulation, individuals preferred the insect to the cereal bar. This result contradicts Bourke et al. (2024), Lammers et al. (2019), Padulo et al. (2022), and Wendin and Nyberg (2021), who stated that food neophobia was also an emotional factor responsible for nonacceptance. Participants would not choose insects as a preferred bar but would opt for cereal if neophobia were present.

The evidence on insect-based product characteristics suggests consumers prefer processed insects rather than having insects visible in the products (Caparros Megido et al., 2016; Pozharliev et al., 2023), such as bars. This study reinforces that integrating them into familiar flavors, textures, and contexts can increase exposure and positive experiences, growing their potential for acceptance (Nyberg et al., 2021; Wendin & Nyberg, 2021). Another argument relies on the product category—protein bars—as it is described as an easy-to-think and easy-to-choose food item and can be a driver of the acceptance of insect-based food products (Stocchi et al., 2021).

Moreover, the self-reported and the nonconscious reactions to insect-based bars during consumption (measured with ECG and EEG) and before (with a survey) enable us to draw several conclusions. People tend to be more enthusiastic as they speed up their HR (arousal) in the presence of an insect bar and during its consumption. In addition, a tendency toward increased attentiveness and improved visual processing was observed, along with a tendency to lower engagement levels with the insect bar. However, when asked about their preferred bar, they answered "insect." The results from ECG and EEG align and support Xu et al. (2023), who argue that consumer neuroscience reveals consumption intentions when what people say may differ from what they actually feel.

Our results, in agreement with Caparros Megido et al. (2016), suggest that acceptance of insect-based food can be promoted through tasting experiments, especially in consumer settings. Hémar-Nicolas et al. (2022) added that acceptance strategies must be targeted to children (peer group), incorporate fun activities for children, and add fun to those experiment sessions to impact their families. Overall, the results align with those of Raheem et al. (2019) and

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Govorushko (2019), who argue that insect-based food has a promising future in Europe.

Conclusions

The research advances the emerging field of insect-based food consumption and its acceptance in Europe, which has been identified as a promising alternative to animal protein (Kozlu et al., 2024).

Instead of viewing acceptance as an assertive outcome, our study explores how participants react when faced with insect-based food stimuli, differentiating between responses observed during conscious and nonconscious exposure conditions. The first critical insight from this research concerns participants' awareness of insect-based foods and their limited familiarity with them. It was concluded that awareness of insect-based foods remains low, as participants reported being surprised when confronted with this food alternative, suggesting that awareness and prior exposure are comparatively low in the sample. Importantly, surprise did not appear as a single, isolated reaction; instead, it co-occurred with a mixed affective outline overlapping with fear and disgust, as well as positive arousal (e.g., happiness and attention). Surprise is interpreted as a reaction to novelty and uncertainty rather than a positive or negative appraisal. Accordingly, our conclusions are framed as evidence of a complex, ambivalent initial response to insect-based food.

From a practical point of view, the findings reveal a need to increase communication about insect-based foods as alternatives and novelties in the European market. Specifically, communication should not only position insect-based food as "new" but also clearly state its potential nutritional and sustainability-related advantages compared with other protein alternatives (Pozharliev et al., 2023). Given the low familiarity in our sample, this communication should primarily aim to reduce novelty-driven reactions and support informed evaluation rather than relying solely on persuasion.

We therefore suggest a staged approach. At the first level, educational communication led by public institutions, insect-focused associations, and other credible entities can focus on basic knowledge, for example, safety, production standards, nutritional profile, and environmental implications, to build awareness (Goncikowska et al., 2023). At a second level, commercial communication by insect-focused companies can build on this foundation, emphasizing product-specific benefits, usage occasions, and taste/culinary integration. Increasing familiarity is particularly relevant for overcoming surprise and the low intention to consume insects, as repeated exposure may reduce the initial surprise response.

Furthermore, fear and disgust were repeatedly reported by participants and should be considered in the design of communication and marketing strategies. In particular, disgust, frequently identified as a barrier to the acceptance of insect-based foods, may reduce willingness to try or adopt these products. Our results also show that negative reactions can occur alongside curiosity: Even when participants reported disgust, many still expressed interest in trying the novel product when it was presented as a sample.

We have organized the consumption-stage findings based on what our results support. During the tasting experience, participants displayed patterns of increased attention and arousal (as reflected in self-reports and/or EEG indices analyzed), indicating engagement with the stimulus rather than immediate avoidance. We interpret these findings to suggest that, in this specific context, exposure to the insect bar triggered attentive processing and interest, even among participants who initially reported feelings of aversion. Accordingly, the results highlight the importance of interventions that diminish disgust-related judgments while fostering curiosity, especially through product exposure and information that enhances familiarity and perceived safety.

In the consumption experience/product exposure, participants evaluated the insect bar more favorably than the cereal bar on our preference measures. This result suggests that, under the conditions of this study, processed insect-based formats can achieve product acceptance levels competitive with familiar alternatives. From a practical perspective, these findings support the use of tasting experiences (e.g., free sampling or in-store trials) as a strategy to shift from curiosity to experience/consumption, thereby reducing uncertainty.

From a product perspective, the results reinforce the relevance of processed insect-based products, particularly bars, as an alternative worth exploring to drive broader adoption. A processed format without insects as an identifiable ingredient may lessen initial aversive reactions (e.g., disgust and fear). This interpretation aligns with previous evidence that supports acceptance of

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familiar product forms (Caparros Megido et al., 2016; Pozharliev et al., 2023). Consequently, we suggest that future research and market development focus on processed products beyond bars, such as insect-based flour or flour products, snacks, cookies, and pasta, especially since several of these are already commercially available and could provide different ways to increase familiarity and normalize insect-based foods.

Furthermore, regarding targeting strategies, a key market segment has been acknowledged and must be explored: sustainability-minded consumers, whose concern with environmental impact has gained prominence. This segment, characterized by the efforts to reduce meat or seafood consumption, is more open minded to finding novel, sustainable alternatives. For these consumers, it is suggested that the advantages of insect-based foods be emphasized, with a focus on their sustainability benefits (Michel & Begho, 2023). This is because individuals need to be informed to make sustainable choices (Groth et al., 2023) and because they influence acceptance. This warning was previously noted by P. Mancini et al. (2017), who suggested that the government should inform consumers to select sustainable products consciously, and by Bourke et al. (2024), who also attributed a role to the media.

The potential of this market can be leveraged through social marketing, which is responsible for conceptualizing, implementing, and controlling marketing programs aimed at addressing social issues (Kotler & Zaltman, 1971).

To conclude, this research has some limitations, and future research proposals should be added.

Limitations and Future Research Avenues

Some limitations and challenges of the research should be disclosed. First, while consumer neuroscience tools such as the Unicorn Hybrid Black or the BITalino (used in the research) ease operation through signal filtering and sampling, they were shown to be recording sensitive when compared with 128- or 256-channel options. Successful data registration required avoiding actions such as talking or moving too much, which were not initially cautioned against, leading us to reduce the sample from 45 to 38 participants. Also, according to Scrivener and Reader (2022), there is an intersubject variability in the mapping of electrodes to specific cerebral regions, which may slightly bias EEG results.

It should also be noted that although the two bars were the same in flavor (apple and cinnamon), they differed in texture, suggesting that variables such as the sweetness of the bars may have influenced the results. This difference, unrelated to insects, must be avoided in future research. It is recommended to replicate the protocol using personalized bars from the same provider, with similar sensory characteristics for the insect and cereal bar versions. Alternatively, conducting a prestudy blind sensory test comparing sweetness, flavor intensity, texture, and other relevant attributes to verify their equivalence beforehand can be useful prior to the main experiment.

Moreover, to assess whether pleasurable consumption experiences motivate future consumption, individuals could be asked, after trying insect-based food, whether they are optimistic about incorporating it into their diets.

Future research replicating this method with larger samples in other countries or regions is suggested to draw robust conclusions, especially those obtained by consumer neuroscience tools. Additionally, other insect-based food categories (such as dehydrated grasshoppers, mealworms, or insect-based pasta) already available on the market could be considered, with an evaluation and comparison of consumer acceptance differences between less-processed and nonprocessed insect-based food products.

Furthermore, given Hémar-Nicolas et al.'s (2022) assumption that children must drive acceptance strategies, these strategies must be considered when designing future research.

Finally, by focusing on developing consumer neuroscience research and leveraging the data gathered through this research (i.e., data obtained from two different techniques per individual), it becomes possible to assess the differences between what people feel and what they report feeling. This approach allows a coherent evaluation of the results obtained for each technique and of whether individuals' self-perceived feelings toward the insect-based product correspond to the physiological data recorded.

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