A NEUROECONOMIC INVESTIGATION OF CONSUMER WILLINGNESS-TO-PAY IN DECAFFEINATED COFFEE MARKET: EVIDENCE FROM NEURAL MECHANISMS *

Gong Xi
Pennsylvania State University
xigong@psu.edu

Chen Gao
Universität Zürich
gaochen@uzh.ch

Peng Yifeng
The University of Hong Kong (Shenzhen)
yifengpeng@cuhk.edu.cn

ABSTRACT

This study delves into the concept of Willingness to Pay (WTP) within the theoretical framework of neuroeconomics, with a particular focus on the decaffeinated coffee market. The paper posits that incorporating cognitive neural activities as a key determinant of consumer WTP is essential. The research underscores the importance of including neurobiological factors among the predictors of WTP. Subsequently, a neuroeconomic experiment was conducted using Electroencephalogram (EEG) technology to empirically analyze the neurobiological indicators that play a decisive role in the WTP decision-making process. Through regression and factor analysis of the experimental data, the study assessed consumers' WTP for decaffeinated coffee. The findings reveal that cognitive neural activities and the activity of the prefrontal cortex play a crucial role in the WTP decision-making process. This study makes unique contributions both theoretically and practically. On the one hand, it deepens our understanding of how brain activities constitute additional predictors of WTP, providing new explanatory perspectives for the WTP model of decaffeinated coffee. On the other hand, the results offer valuable insights for researchers, industry professionals, manufacturers, marketing strategists, and consumers in designing effective marketing strategies and making informed WTP decisions.

***K*eywords** Willingness to Pay · Neuroeconomics · Decaffeinated Coffee · EGG

1 Introduction

With the deepening of research on brain activity and human behavior, there has been a rapid surge in international scientific interest in the use of brain activity analysis methods under different contexts in recent years, a trend evidenced by the publication data of researchers. From 2000 to 2023, the number of scientific papers in the Scopus database containing the keywords "neuroscience" or "neuromethods" has increased more than fivefold.

The use of neuroscientific tools to address traditional economic issues has given rise to a new interdisciplinary field known as neuroeconomics. The primary objective of neuroeconomics is to enhance our understanding of economic decision-making processes in human society by integrating knowledge from both economics and neurobiology [1]. Traditional economic research primarily explains behavior through the constructs of utility and preferences, whereas neurobiology focuses on various physiological variables that influence decision-making. As a fusion of these two research domains, neuroeconomics posits an empirical hypothesis that understanding the relevant neural and physiological processes is crucial for explaining human behavior. Consequently, researchers have the opportunity to investigate the neural predictors of human behavior in economic decision-making.

In the field of neuroeconomics, a central economic concept currently under active exploration is Willingness to Pay (WTP), which is defined as the maximum price a consumer is willing to pay for a single unit of a good or service [2]. The study of WTP has been widely applied to address issues across various market domains, including but not limited to the food market [3], the sustainable energy market [4], the mobile gaming market [5], and the health and wellness market [6]. Researchers' interest is primarily driven by market-specific factors that directly influence the formation of consumers' WTP for particular goods and services. For instance, in the food market, consumers' purchasing decisions are influenced by both sensory and non-sensory factors [7] [8].

The methodology of neuroeconomics demonstrates unique advantages in elucidating the concept of willingness to pay, as it extends the range of factors determining consumers' willingness to pay for goods or services by capturing neural activities. As demonstrated in empirical studies by Khushaba et al. [9] and Alsmadi & Hailat [10], consumers' preferences and consumption behaviors can be reflected through the activity levels of different brain regions. Incorporating such data into econometric models significantly enhances the accuracy of predicting consumer behavior [11]. However, in the current field of food market research, particularly in the study of decaffeinated coffee markets, the exploration of factors from a neuroeconomic perspective remains insufficient. The interrelationships between these factors and those that have been extensively studied (such as taste, product texture, brand, etc.) have not yet been adequately understood and explored.

One of the unique advantages of neuroeconomic approaches in the field of WTP is their enrichment of the set of tools available to researchers. The most common WTP research tools include questionnaire surveys, interviews, conjoint analysis, and behavioral experiments [12]. Overall, these methods can quantify the overall economic value of goods or services, including their utility, determine the possible range of WTP, and reveal the core factors influencing consumers' WTP. However, these methods still have certain methodological limitations, such as difficulties in handling hypothetical biases or accurately assessing price elasticity, particularly for low-priced goods [13]. A potential reason for these issues is that traditional WTP research methods and tools are primarily designed to address the explicit cognitive components of the decision-making process, overlooking the fact that a significant portion of decision-making is actually driven by subconscious processes [14] [15]. Therefore, it is particularly important to adopt methods and tools that can incorporate these implicit or latent subconscious processes into the WTP assessment model, as this can significantly enhance the accuracy and quality of the model.

Therefore, the advancements in neuroeconomics have demonstrated the potential to consider and further utilize brain bioelectric activity as a proxy variable for unobserved processes in purchasing decisions. However, a literature review reveals that current neuroeconomic research is fraught with controversies. For instance, the question of which neural indicators can serve as the optimal proxy variables remains unanswered. Additionally, researchers have yet to reach a consensus on what type of process the decision-making regarding willingness to pay entails. Some studies link willingness to pay, or related concepts, to enhanced brain activity in the occipitotemporal region, interpreting this as a relatively simple, fundamental-level process: consumers are willing to pay because they have developed specific likes or dislikes for certain sensory characteristics of goods [16]. In contrast, other studies indicate that willingness to pay is associated with the frontal and prefrontal regions, suggesting that the evaluation of willingness to pay is a complex affective-cognitive process [17] [18].

The purpose of this study is to empirically analyze and validate the applicability of neuroeconometric techniques in reflecting consumer willingness to pay in the coffee market. Firstly, this paper explores, at a theoretical level, cognitive neuroresponses as a novel factor influencing consumers' willingness to pay in the coffee market, thereby enriching the prediction of consumer behavior to include not only individual intrinsic factors but also sensory and non-sensory factors. Secondly, this paper provides a systematic overview of the application of neuroindicators and their role in specific brain regions during the decision-making process of willingness to pay, through a neuroeconomic research framework. Ultimately, a series of neuroeconomic experiments were conducted using electroencephalography (EEG) technology to collect experimental data, which were then used to conduct in-depth factor analysis and regression analysis on the influencing factors of consumers' willingness to pay in the coffee market.

2 Research Review on WTP & Neurobiological Tool

2.1 Willingness to Pay in the Food Market

From the perspective of economic theory, food is regarded as a common commodity, typically categorized alongside goods and services such as clothing, entertainment, transportation services, and household appliances. However, observations of consumer behavior reveal that food is placed in a distinct category due to its unique sensory attributes (e.g., taste, smell, shape), which directly influence consumers' purchasing decisions. For instance, Stroebele et al. identified a series of specific factors affecting food consumption, including the color, smell, and temperature of the food, the temperature and lighting of the dining environment, the presence and number of people around, and ambient sounds [19]. These factors are aptly termed "consumption contexts," which directly impact consumers' purchasing decisions and serve as unique determinants of food's distinct categorization as a commodity.

Reviewing existing literature on food consumption tendencies, it is common for researchers to categorize the factors that may influence consumer choice behavior into multiple groups. The presence or absence of these factors largely depends on the type of product being studied. For instance, in the case of fresh foods (such as fresh meat, fruits, or vegetables), sensory attributes (including color, aroma, and shape) are critical considerations [20] [21]. Conversely, for products such as candies, snacks, or carbonated beverages, marketing attributes (like packaging design and brand image) play a decisive role [22] [23].

After summarizing and analyzing various categorization methods of factors influencing willingness to pay in the food market, we have identified the following groups of willingness to pay factors, which are most relevant to the coffee products under study (see Table 1):

Table 1: Determinants of Consumer Willingness to Pay in Food Markets

Factor Classification	Factor	Representative Studies
Personal Characteristics	Gender	Gracia et al [24]; López-Mosquera [25]
	Age	Kremer et al [26]; Alsubhi et al [27]
	Family Condition	Xu & Wu [28]; Nocella et al [3]
	Menstrual Cycle	Bowen & Grunberg [29]; Gong et al [30]
Sensory Characteristics	Taste	Stefani et al [8]; Plasek & Temesi [31]
	Color	McCluskey & Loureiro [32]; Gluchowski et al [33]
	Sweetness	Drewnowski et al [34]
	Texture	Kampfer et al [35]
	Aroma	de Wijk et al [36]
Non-sensory Characteristics	Price	Binesh et al [37]
	Brand	Ares et al [38]
	Origin	Hwang et al [39]
	Nutrition	Viana et al [40]
Perception Factors	Emotional Reaction	Desmet & Schifferstein [41]; Jiang et al [42]
	Mood Condition	Köster & Mojet [43]
	Neural Reaction	Bugdjo et al [44]; Semenova et al [45]

Note: This comprehensive classification is derived from systematic literature review and meta-analysis of consumer behavior studies in food markets.

This study further delves into the role and significance of the final set of factors. In the existing literature on consumers' WTP in food markets, the question of how and through which mechanisms the perception of individuals towards goods or services can be most effectively mapped remains unanswered. Some scholars argue that individual perception can be integrated with the "Attitude—Behavior—Context" model [3] [46], while others believe that perception is related to emotional and affective responses [47] [48]. In this research, we propose a new perspective, which involves exploring individuals' implicit physiological responses, particularly brain activity, to approximate perception. Furthermore, we suggest considering cognitive neuroresponses as an important factor influencing consumers' willingness to pay.

Recent neurobiological research has clearly demonstrated that the moment an individual makes a decision regarding willingness to pay can be reflected through the activity of specific brain regions, which can be recorded using neurobiological tools [16] [49]. When modeling consumer behavior and assessing willingness to pay, it is reasonable to use these neural responses as additional proxy factors for subconscious processes. This factor can objectively reflect consumers' reactions to food on one hand, and on the other hand, it can complement individual, sensory, and non-sensory consumer behavior predictive variables.

2.2 Neurobiological Tools Assessment of WTP Factors

Among the neurobiological tools used for recording brain activity, the most commonly employed include: functional magnetic resonance imaging (fMRI), electroencephalography (EEG), magnetoencephalography (MEG), positron emission tomography (PET), diffusion tensor imaging (DTI), and functional near-infrared spectroscopy (fNIRS). These tools enable the observation of the sequence of brain region activations in individuals during decision-making or in response to specific stimuli.

In the study of WTP, EEG stands out as one of the most popular neurobiological tools. EEG is a non-invasive, relatively inexpensive, and effective method for assessing neurophysiological responses. Due to these and other advantages, the method has been widely adopted in neuroeconomics and neuromarketing research. For instance, Songsamoe et al.

[50] utilized EEG to uncover correlations between activity in the occipito-parietal region of the brain and the hedonic ratings of food, which, under certain conditions, can serve as a proxy for willingness to pay. Ramsøy et al. [18] identified a link between willingness to pay and asymmetries in gamma-band signals in the prefrontal cortex through EEG, a metric closely related to willingness to pay and the actual decision-making phase. Parnaz et al. [51] discovered statistically significant associations between purchasing decisions and brain activity recorded by frontal and central parietal electrodes in a series of EEG experiments.

However, despite the growing population benefiting from electroencephalography (EEG) research, its limitations remain evident, such as limited spatial resolution, difficulties in signal interpretation, and the complexity of conducting experiments outside the laboratory. In recent years, functional near-infrared spectroscopy (fNIRS) has emerged as a novel neuroimaging technique, with its application in consumer behavior research gradually increasing, although its widespread use is still relatively low. For instance, Murat et al. conducted pioneering explorations into the applicability of this tool in the field of neuromarketing, while K. Kawabata et al. successfully utilized it to assess consumers' willingness to pay for cosmetics. Subsequently, in 2021, Hirabayashi et al. further refined the original model by introducing a series of control variables, which included sensory characteristics of the products, such as the color and texture of lipsticks.

In the field of neuroeconomics, foundational research on the determinants of willingness to pay is widely regarded to have originated from the work of G. Plassmann et al. in 2007 [16]. This research team utilized functional magnetic resonance imaging (fMRI) technology to uncover statistically significant correlations between consumers' willingness to pay and the activity levels in the right ventromedial prefrontal cortex (vmPFC) and the right dorsolateral prefrontal cortex (dlPFC). However, as the authors of the study emphasized, the specific functional roles of the orbitofrontal and dorsolateral regions in the decision-making process of willingness to pay remain unclear. To gain deeper insights into this issue, further research is needed to refine the structure and mechanisms of these neural networks, enabling them to be integrated as functional units into economic models of willingness to pay. This study systematically synthesizes the findings of research efforts aimed at constructing proxies for brain activity—referred to as neurometrics—that reflect an individual's willingness to pay during decision-making processes. It is important to note that the neurometric studies listed are not limited to the food product domain, as the number of relevant studies within this area is quite limited.

In a groundbreaking study, Van Bochove et al. introduced a novel neural metric termed the "parieto-occipital EEG asymmetry index," which demonstrated significant correlations with hedonic food evaluation and reward sensitivity across both alpha (8-12 Hz) and beta (13-20 Hz) frequency bands. Subsequently, Ramsøy et al. [18] identified another promising neural measure: the prefrontal electrode asymmetry in the gamma band (30-80 Hz), which exhibited strong associations with willingness to pay and decision-making phases. Their research revealed statistically significant correlations between willingness to pay and neural activity at specific electrode sites: AF4, F3, F4, O2, and P8 in the alpha band; F3, P7, and T8 in the beta band; and AF3, F3, F7, F8, FC6, O1, and P8 in the gamma band. Further advancing this field, Golnar-Nik et al. [51] established significant correlations between purchase decisions and brain activity recorded through frontal and centro-parietal electrodes (Fp1, Cp3, Cpz), providing additional insights into the neural mechanisms underlying consumer decision-making processes.

Therefore, existing research on the neural metrics of WTP shows discrepancies in both the neural metrics and the corresponding brain activity that may be associated with WTP decisions. These discrepancies may arise from several factors: firstly, differences in the temporal and spatial resolution of various research methods; secondly, the specificity of the samples and the products analyzed. Additionally, the discrepancies may be related to the design characteristics of WTP assessment studies, such as whether the product was tasted before the WTP question was asked, whether the evaluated product was compared with other products, and whether consumers were required to spend real money. To gain a more comprehensive understanding of the relationship between neural metrics and WTP, it is necessary to conduct more studies with rigorous control over the primary methodological factors. Furthermore, it is important to consider the different contexts and conditions under which WTP decisions occur. This will help establish more accurate connections and identify the most effective neural metrics for studying WTP.

In the next section of this study, we assess consumers' willingness to pay for decaffeinated coffee through a series of laboratory EEG experiments, identifying neural metrics that significantly influence willingness to pay in the chocolate market. Subsequently, considering the complexity of interpreting individual neural metrics, we conduct factor analysis to integrate these metrics into larger constructs, which broadly correspond to brain regions. We then perform regression analysis to evaluate consumers' willingness to pay for decaffeinated coffee, incorporating not only traditional explanatory variables of personal and sensory characteristics but also neural metrics from individual electrodes and factors representing specific brain region activity derived from the factor analysis.

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3 Experiment and Methodology

Experiment Setup This study recruited a total of 50 healthy volunteers (25 males and 25 females), aged between 17 and 29 years (mean age 21.5 ± 4.5 years). This number of participants is typical for experiments utilizing neurobiological tools, as seen in the willingness-to-pay studies mentioned in Table 2, where the number of participants ranged from 16 (Ramsøy et al., 2018; Golnar-Nik et al., 2019) to 36 (Van Bochove et al., 2016). All participants were recruited through social media invitations and voluntary sign-ups. The necessary conditions for participation included: no food allergies or other medical contraindications, and regular consumption (at least once a week) of desserts. To minimize errors in the assessment of willingness to pay due to differences in hunger levels, each participant was asked to evaluate their hunger on a 5-point Likert Scale before the experiment began. The results showed that no participants felt hungry before the experimental session started. We also required all participants to avoid consuming coffee, tea, tobacco, and alcohol for at least 4 hours before the experiment to prevent any potential interference that could affect sensory experiences and EEG signals. The experimental procedure was approved by the ethics committee, and each participant signed a written informed consent form before the experimental session began.

In our experiment, we tested five brands of decaffeinated black coffee-flavored desserts. We intentionally selected samples with as similar ingredients as possible to eliminate the influence of other components on the perceived taste evaluation. The samples provided for tasting varied in price and brand recognition, including: A) an unknown, inexpensive decaffeinated black coffee; B) a well-known, mid-range decaffeinated black coffee; C) an expensive, high-end decaffeinated black coffee; D) a "healthy" decaffeinated black coffee with fructose substituted for sucrose; and E) a decaffeinated black coffee based on carob, devoid of cocoa products. Table 2 presents the market average prices, the average consumer willingness to pay, and the average taste ratings for each brand of decaffeinated black coffee. The market average prices were derived by averaging the prices of each brand of decaffeinated black coffee across multiple e-commerce platforms (the experiment was conducted in September 2024).

The average WTP for each brand is calculated using the following formula, where $\sum WTP_{iM}$ represents the total amount all participants are willing to pay for brand M's decaffeinated black coffee, and n represents the number of participants:

$$\text{Average WTP} = \frac{\sum WTP_{iM}}{n} \tag{1}$$

The average taste score for each brand's chocolate is calculated using the following formula, where $\sum \text{taste}_{iM}$ represents the sum of perceived taste scores from all participants for brand M's chocolate, and n represents the number of participants:

$$\text{Average Taste Score} = \frac{\sum \text{taste}_{iM}}{n} \tag{2}$$

The perceived flavor comparison of decaffeinated black coffee from different brands under "blind test" conditions was conducted using the Wilcoxon test, while the comparison of willingness to pay for different brands was performed using the paired t-test. All statistical analyses were carried out in the Rstudio statistical environment (R v4.1.2) using the rstatix package.

The experimental sessions were conducted as follows: Participants were comfortably seated in front of a display screen, which showed all necessary instructions and questions. Each experimental participant was asked to blindly test 10 coffee samples (two samples from each analyzed brand), which were provided to the participants in a random order. Each sample was approximately 10 milliliters in size, sufficient to determine the taste characteristics of the sample while allowing for quick swallowing in the mouth, which helped to minimize accompanying noise when recording electroencephalogram (EEG) signals. After tasting each sample, participants were required to answer three questions: 1) How enjoyable was the coffee they just tasted (rated on a scale from 1 to 5); 2) How much they would be willing to pay for this coffee; 3) What they believed the price of this coffee to be in stores. Between tasting different samples, participants were allowed to drink as much still water as needed.

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Throughout the experimental process, a portable wireless 24-channel electroencephalogram (EEG) system, "NeuroPolygraph," was used to record EEG signals. The sampling frequency was set at 500 Hz, and all other parameters were configured according to the manufacturer's instructions. After all experiments were completed, the EEG data were filtered within the range of 0.1–100 Hz and exported in CSV format for subsequent analysis. Further analysis included the removal of blink and muscle artifacts, as well as the calculation of the power in the α (8–12 Hz) and β (15–30 Hz) frequency bands of EEG signals recorded from the frontal (F3, F4), prefrontal (Fp1, Fp2), parietal (P3, P4), and occipital (O3, O4) electrodes (Figure 2) during the tasting of each chocolate sample. These power values were calculated over representative 1-second time intervals.

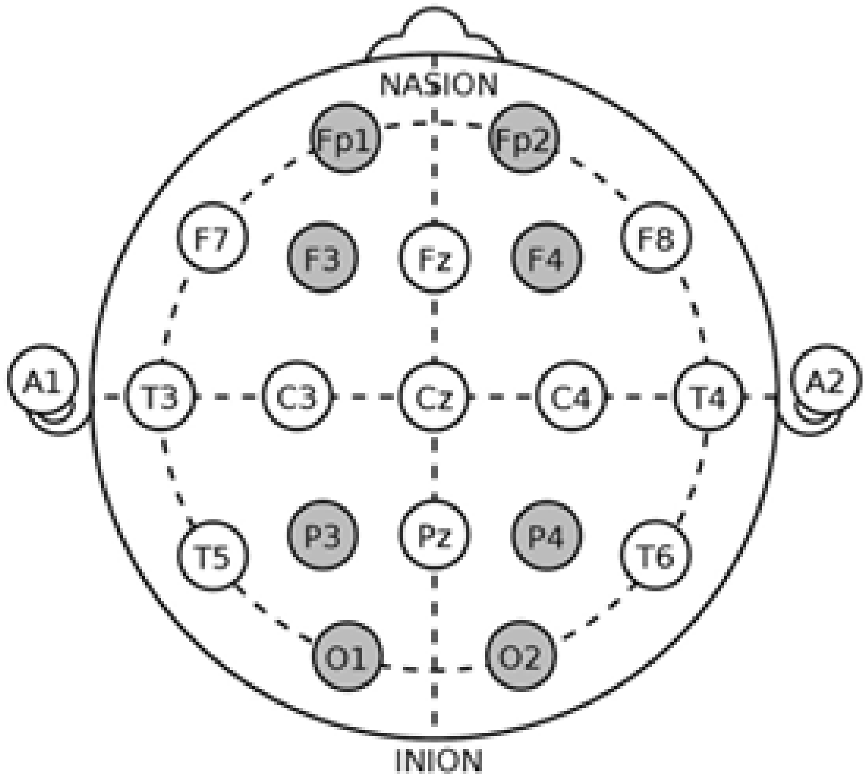

Figure 1: Schematic diagram of EEG electrode placement on the subject's head. The electrodes used for subsequent power analysis are highlighted in dark color.

Regression Analysis Based on the categorization of factors influencing willingness to pay in the food market as presented in the first part of this paper (see Table 1), we constructed several linear regression models, incorporating one or more factors from the subgroups of "Personal Characteristics" and "Product Sensory Attributes." Additionally, as a proxy variable for the "Perception" factor group, we included neurophysiological measurements of willingness to pay in the models. In the models evaluating willingness to pay, consumers' willingness to pay for a particular brand of chocolate they tasted served as the dependent variable; the independent variables selected were the subjects' gender and age, their subjective taste evaluation of the specific brand of chocolate, and the neurophysiological measurements. According to the literature analysis presented earlier, the most common predictors of willingness to pay are neurophysiological measurements from the frontal, parietal, occipital, and temporal lobes. Therefore, in this study, we incorporated the corresponding neurophysiological measurements from these regions, specifically the transformed power of electrodes F3, F4 (frontal lobe), Fp1, Fp2 (prefrontal lobe), P3, P4 (parietal lobe), and O3, O4 (occipital lobe).

In general form, the econometric model for analysis can be expressed as follows:

- WTP_{im}: Represents the willingness to pay of consumer i for chocolate sample m.
- $Personal\_characteristics_i$: Represents individual characteristics, particularly gender (a dummy variable where 1 indicates male and 0 indicates female) and age (in full years) of respondent i.
- $Sensory\_characteristics_{im}$: Represents the sensory characteristics of the product, especially consumer i's subjective taste evaluation for chocolate sample m.
- $Perception_{im}$: Represents the individual's perception of the product, using the EEG power signal recorded from specific electrodes when individual i evaluates sample m.

- ε_{im}: Represents the random error term.

Factors Analysis A review of the literature on neural measures of willingness to pay revealed issues with the interpretation of these measures, which are derived from the power converted from individual electrodes. Due to volume conduction of currents generated in different brain regions, signals from closely spaced electrodes may be highly correlated, making the interpretation of results and the selection of the best neural measures challenging. To address this issue, it was decided to combine individual neural measures into factors through factor analysis, which could serve as proxies for activity in specific brain regions. To determine the number of factors, the "Very Simple Structure" (VSS) method was employed. This method compares a series of factor analyses to the extent of their match with a "simplified" loading matrix by eliminating all but the c largest loadings, where c is a measure of factor complexity.

During the implementation phase of factor analysis, the "generalized least squares" method was applied to extract neural measurement data (power transformed from electrodes Fp1, Fp2, F3, F4, P3, P4, O3, and O4 in the α and β frequency bands), and the "varimax" rotation method was used to maximize variance. The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy was 0.846. The Bartlett's test of sphericity yielded a result of (χ^2=6676) with 120 degrees of freedom (df) and p < 0.001, which sufficiently ensures the quality of the model for subsequent data processing. The results indicated that all the included neuro-measurement indicators were consolidated into two factors, accounting for a total explained variance proportion of 72%. The Cronbach's α coefficients for the formed factors were 0.94 and 0.93, respectively (see Table 2).

Table 2: Factor Analysis Results for Neurometrics

Factor Name	Indicators	Loadings	Cronbach's Alpha
Neurometrics of the Occipital-Parietal Brain Area	F3-alpha	0.85	
	F3-beta	0.91	
	O3-alpha	0.82	
	O3-beta	0.64	
	O4-alpha	0.52	
	O4-beta	0.51	
	P3-alpha	0.75	
	P3-beta	0.63	
	P4-alpha	0.71	
	P4-beta	0.68	0.91
Neurometrics of the Frontal Brain Area	Fp1-alpha	0.80	
	Fp1-beta	0.83	
	Fp2-alpha	0.68	
	Fp2-beta	0.75	
	F4-alpha	0.77	
	F4-beta	0.64	0.89

The factors obtained can be described as follows:

1. Neural measurement indices of the parieto-occipital brain regions. These include neural measures approximating the power of α and β band EEG signals recorded from parietal ($P3, P4$) and occipital ($O3, O4$) electrodes. This factor also encompasses neural measures from the frontal electrode $F3$ in the α and β bands.

2. Neural measurement indices of the frontal brain regions. These include neural measures approximating the power of α (8–12 Hz) and β (15–30 Hz) band EEG signals recorded from prefrontal ($F4$) and frontal ($Fp1, Fp2$) electrodes.

Table 4 presents the least squares estimation results of the linear regression models: the model without neuroimaging measures (Model 0), the model with neuroimaging measures (Model 1), and the model incorporating factor analysis results (Model 2). The results indicate that for each additional point in the perceived taste rating, the willingness to pay increases by an average of 3.5$, accounting for 29.2% of the average willingness to pay. Men are willing to pay an additional 2.5$ for the same coffee on average, while each additional year of age results in a decrease of 0.35$ in the willingness to pay.

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In the model that includes neural measurement indices (Table 4, Model 1), several neural measurement indices are statistically significant: $F3$ and $F4$ (both α and β bands), $Fp2$ (in the β band), and $P3$ (in the β band). Among these, $F4$ in the β band significantly enhances the explanatory power of the model including neural measurement indices, increasing the adjusted coefficient of determination (R^2_{adj}) from 0.39 (Model 0) to 0.483 (Model 1). It is important to note that we use the adjusted coefficient of determination (R^2_{adj}) to compare model quality because R^2_{adj} accounts for penalties related to the number of independent variables, making it more suitable for comparing models with different numbers of variables.

Regarding the model including factors (Model 2), focusing on factors of neural measurement indices at a 1% significance level reveals statistical significance. The explanatory power of the model including factors increases, with the adjusted coefficient of determination (R^2_{adj}) rising from 0.396 (Model 0) to 0.416 (Model 2). The stability of this model was tested with two random samples, showing consistent performance across samples and aligning with results based on complete data.

Discussion of Factor Analysis and Regression Analysis Results. Through factor analysis of neurophysiological measurements, two factors were identified: "Occipito-Parietal Neurophysiological Measurements" and "Frontal Neurophysiological Measurements." An intriguing and worthy of further investigation phenomenon is that the frontal neurophysiological measurement F3 was categorized into the first factor. This could be related to asymmetrical effects (e.g., Ramsøy et al., [18]; Semenova et al.,[45]), as well as the contrasting contributions of different hemispheres during the process of purchasing decisions.

Since some studies have linked activity in the parietal posterior region to "like/dislike" type decisions, the activity of electrodes in this area during the process of determining willingness to pay may indicate that this process is simple and automatic for the individual. Regarding frontal region neuroimaging metrics, activity in this part of the brain is associated with the planning of complex cognitive behaviors, decision-making, regulation of social behaviors , and emotional regulation . Therefore, high electrical activity in this region during the process of determining willingness to pay may indicate that this process is complex and emotionally taxing for the individual. Consequently, we have identified two factors, each characterizing the decision-making process of willingness to pay: one that is simple, automatic, and requires almost no effort (the "parieto-occipital neuroimaging metrics" factor), and another that is complex and requires conscious intellectual and emotional engagement (the "frontal region neuroimaging metrics" factor). In the regression analysis incorporating these factors (Table 4, Model 2), we found that the "frontal region neuroimaging metrics" factor was statistically significant, indicating that the decision-making process of willingness to pay is complex and requires emotional investment from the individual.

4 Conclusion

In this study, the concept of WTP is explored within the context of neuroeconomics. Specifically, the paper theoretically argues for the inclusion of cognitive neural responses as additional factors influencing consumers' WTP in the decaffeinated coffee market, beyond the known individual, sensory, and non-sensory predictors of consumer behavior. Furthermore, the paper analyzes and systematizes neuroeconomic research that employs neuro-measurement indicators, which play a crucial role in the decision-making process of WTP.

To achieve the set objectives and tasks, this research conducted a series of neuroeconomic experiments on a specific product—decaffeinated coffee—using electroencephalography (EEG) technology. The data obtained served as the basis for regression and factor analysis to evaluate the determinants of consumer WTP. Through regression analysis, we confirmed the significance of cognitive neural responses as additional factors in WTP. Additionally, we demonstrated that cognitive neural response variables could be either individual electrode signals from the alpha and beta wave bands, consistent with other findings on WTP , or neuro-measurement factors formed through factor analysis, which serve as proxies for specific brain region activity. Notably, we identified a factor approximating frontal brain activity that significantly influenced the decision-making process of WTP, allowing us to describe this process as cognitively complex and emotionally taxing for individuals.

Therefore, we believe that the main contribution of this study is the enhancement of understanding how brain activity serves as an additional factor in determining willingness to pay, with these activities approximated through individuals' implicit physiological responses to the product's perception. Furthermore, we not only specified the neural measures of willingness to pay for decaffeinated coffee but also addressed the issue of the difficulty in interpreting individual neural measures by integrating them into factors, demonstrating the importance of frontal brain activity in the decision-making process of willingness to pay. By combining traditional explanatory variables of personal and sensory characteristics with neural measures, we also improved the explanatory power of the willingness-to-pay assessment model.

Several limitations that could affect the interpretation of the results should be considered. Firstly, it must be noted that coffee tasting conducted under laboratory conditions is not equivalent to its consumption in natural environments, a fact that could potentially impact the results. Secondly, due to the small sample size, not all potentially interesting factors of willingness to pay identified were included in the regression analysis. Finally, caution should be exercised when generalizing the findings to other foods.

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