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Physiological Response Evaluation of Consumers to Brands During Purchase Decision-Making Using Electroencephalography: A Study on Caffeinated Beverages in Malaysia and Iran

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ABSTRACT

This study examines the physiological responses of Malaysian and Iranian consumers to caffeinated beverage brands using biometrics on e-commerce websites. Specifically, this study seeks to identify patterns in δ, θ, α, β, and γ waves across different brain regions that differentiate Iranian and Malaysian consumers' subconscious engagement with caffeinated beverage brands during online purchase stages, utilizing biometric data-sensitive neuromarketing. A sample of 24 individuals was analyzed via Brain Mapping software and mixed ANOVA. Results revealed differences in Delta, Theta, and Beta band frequencies between groups. Iranian participants exhibited greater brain wave variation in response to brands like Hype and Rockstar, whereas Malaysians responded more to Red Bull and Monster. In the coffee category, Iranians reacted to Starbucks, Lavazza, and Ali Cafe, while Malaysians primarily responded to Nescafé. Product viewing showed Alpha wave changes opposite to Delta, Theta, and Beta waves. During purchase decisions, Beta and Gamma wave activity was higher in Iranians, notably in frontal and parietal lobes. These findings highlight cultural impacts on online consumer behavior and illustrate the role of beta and gamma waves in driving purchasing choices. The research offers valuable insights for tailoring neuromarketing strategies to different audiences and enhances understanding of consumer neuroscience.

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1. Introduction

Understanding decision-making processes of consumers in digital commerce has become a crucial area of study for modern marketing scholars (Sharma, 2023; Santos & Gonçalves, 2021). Modern research examines not only conscious consumer preferences but also the implicit cognitive and emotional responses that influence purchasing behavior (Bergstrom & Schall, 2014; Nazari Ghazvini et al., 2024; Nazari Ghazvini et al., 2023). As noted by Dimoka (2010), decoding the neural mechanisms behind purchase decisions represents a fundamental challenge in consumer psychology research. Recent studies emphasize the growing complexity of understanding consumer choices in digital marketplaces (Gravite-Lapere et al., 2022; Sadiku et al., 2023). While historical consumer research relied heavily on physical retail observations (Wang et al., 2022), current methodologies must account for the unique psychological dimensions of online shopping environments (Lavoie & Zheng, 2023). The limitations of conventional research tools have become increasingly apparent in digital contexts. As Brand (2025) demonstrates, traditional self-report methods like surveys and focus groups frequently fail to capture the non-conscious drivers of consumer behavior, a methodological gap particularly evident in e-commerce research (Brand, 2025).

To gain deeper insights into cognitive processes and emotional states, researchers employ techniques like interviews, questionnaires, and concurrent think-aloud protocols (CTA). These methods help access participants' memories and mental judgments (Bergstrom & Schall, 2014; Eger et al., 2007; Guan et al., 2006). While consumer behavior research has traditionally focused on observable actions, the rise of online shopping has shifted this focus to the digital realm. As a result, online stores can enhance the shopping experience by analyzing customers' physiological reactions. Current cognitive neuroscience findings indicate that individuals' mental perceptions of their behavior often do not align with their internal neural activity (Kretzschmar et al., 2013), which means people are not always aware of their mental processes (Bergstrom & Schall, 2014; Gerrath et al., 2023). Neuro-marketers aim to identify consumers' physiological reactions to products and brands. Using neuroscience tools has improved marketers' understanding of consumer behavior from cognitive, neural, and emotional perspectives (Jansson-Boyd & Bright, 2024; Núñez-Cansado et al., 2024). New biometric devices now make it possible to assess emotions and implicit reactions (Songsamoe et al., 2019). This advancement allows marketers to study consumer behavior through 'Neuroscience' and 'Neuro-Marketing' (Guixeres et al., 2017; Nazari Ghazvini et al., 2023, 2025).

In neuro-marketing and consumer neuroscience, neural methods are categorized into biometric and neuro-imaging techniques. Standard biometric methods include eye tracking (Liversedge & Blythe, 2007), facial reading (Terzis et al., 2010), skin conductance (Lang et al., 1993), and heart rate monitoring (Kakaria et al., 2023). Neuro-imaging techniques, such as electroencephalography (EEG) and functional magnetic resonance imaging (fMRI), are utilized in various contexts (Au-Nguyen et al., 2018). Experimental groups allow brands to gain deeper insights into consumer behaviors and preferences. By monitoring brain activity and psychophysiological responses, marketers can assess how consumers react to different stimuli (Jartarkar et al., 2022; Kence et al., 2022; Raiesdana & Mousakhani, 2022), including their memories of brands (González-Morales, 2020). These insights can predict reactions and assist in creating products with greater sales potential. Neuro-marketing combines various scientific disciplines to examine decisions that frequently happen unconsciously (Mansor & Mohd Isa, 2020; Vecchiato et al., 2011). Studying consumer behavior through EEG and quantitative electroencephalogram (QEEG) (Plassmann et al., 2015) enables researchers to observe users' emotional states in real time. This neuroimaging technique measures changes in brain function during decision-making or psychological activities (Suomala, 2018). EEG provides objective data on how consumers perceive and react to brands (Vecchiato et al., 2011), and can compare responses to different marketing stimuli to improve product placement (Neeharika et al., 2021). Analyzing EEG signals across brain lobes helps translate brain activity into emotions and behaviors (Andersen et al., 2019). As a result, EEG techniques are valuable tools in sensory research and the evaluation of consumer behavior (Shaw & Bagozzi, 2018). Assessing customer emotions during online shopping, particularly when there is no physical interaction with the products, poses challenges for making purchase decisions. Despite extensive studies, neuro-marketing research in Malaysia (Alsharif et al., 2022) and Iran (Mannani et al., 2021) remains limited and not yet practical in marketing operations. These two countries were intentionally chosen based on theoretical, methodological, and market criteria. Culturally, Iran presents high collectivism and uncertainty avoidance. At the same time, Malaysia’s multicultural composition exhibits moderate collectivism and lower uncertainty avoidance (Hofstede, 2001), making it culturally distinct yet comparable for cross-cultural neuromarketing research (Karami et al., 2017; Plassmann et al., 2015). Methodologically, identical EEG experiments could be conducted in both countries through collaborations with advanced neuroscience laboratories at the University of Tehran and Universiti Teknologi Malaysia, ensuring consistent protocols and equipment standards. From a market standpoint, both countries have significant but differently structured caffeinated beverage markets, with overlapping global brands that allow for controlled stimulus presentation. This combination enables the present study to capture meaningful cross-cultural variations in consumer neurophysiology. Investigating the brain waves of Malaysian and Iranian consumers during online shopping for caffeinated beverages (Samoggia & Riedel, 2018) could be a significant step in international neuro-marketing research, providing valuable insights into the cultural contexts of both countries.

This study aims to identify patterns in δ, θ, α, β, and γ brain waves that reveal subconscious physiological responses of Iranian and Malaysian consumers to caffeinated beverage brands during the stages of online purchasing decisions. By specifically focusing on the caffeinated beverage market in Iran and Malaysia, the study provides new insights into cross-cultural differences in consumer engagement with these brands. These insights are obtained through the use of EEG technology, which uniquely contributes to the field by offering a cross-cultural comparison of subconscious brain responses that influence consumer choices.

The focus on caffeinated beverages in this study is significant due to their widespread consumption and strong market presence in both Iran and Malaysia (Darani et al., 2020; Reyes & Cornelis, 2018). These beverages are not only popular but also generate strong brand loyalty and emotional connections among consumers, making them an ideal product category for branding's impact on purchase decisions (Rajagopal, 2006). Moreover, this research introduces a valuable cross-cultural perspective to understanding consumer behavior by comparing Iran and Malaysia, which have different cultural, social, and economic contexts that influence consumer preferences (Hofstede, 2001). The goal of this research is to connect neurophysiological data with consumer behavior theory in order to improve marketing strategies and product development within the caffeinated beverage industry. By utilizing EEG technology, the study aims to gain a deeper understanding of the subconscious factors that influence consumer choices. This research will contribute to the fields of consumer neuroscience and cross-cultural marketing (Kenning & Linzmajer, 2010).

The necessity of this research lies in addressing a critical gap in cross-cultural neuromarketing studies. Without such research, marketers and policymakers may lack actionable insights into how cultural differences shape subconscious consumer behavior, leading to ineffective marketing strategies and missed opportunities in global markets. Additionally, the absence of EEG-based studies in these regions could perpetuate reliance on traditional, less accurate methods, hindering advancements in consumer neuroscience.

The research gaps this study addresses are the lack of comprehensive EEG-based investigations comparing all five major brain wave bands (alpha, theta, beta, delta, gamma) across multiple brain regions (frontal, parietal, occipital, temporal) in a cross-cultural context. Earlier research has concentrated on individual countries or specific brain waves, overlooking a comprehensive understanding of consumer decision-making processes (Chen et al., 2022; Daroch et al., 2021). This study fills that gap by providing a detailed neurophysiological comparison between Iranian and Malaysian consumers.

Purchase of caffeinated beverage brands using an EEG-compatible simulated site provides marketers with cross-cultural insights into consumer neurology, integrating neurophysiological methods into consumer behavior analysis (Sherman et al., 2016; Plassmann et al., 2015), cross-cultural comparisons (Leite et al., 2024), and insights into the caffeinated beverage market (Biswas et al., 2023). The study also contributes to consumer decision theory (Hubert & Kenning, 2008; Kenning & Linzmajer, 2010) and advances EEG methodology in natural buying scenarios (Ramsøy et al., 2018; Vecchiato et al., 2011). The findings have practical implications for policymakers and industry stakeholders (Plassmann et al., 2015; Vecchiato et al., 2011).

Recent neuromarketing research has primarily examined consumer behavior in specific cultural contexts, focusing on individual neural oscillations (Chen et al., 2022; Daroch et al., 2021). Existing literature has demonstrated that delta and alpha wave activity correlate with advertisement viewing (Hakim et al., 2021), while theta and beta oscillations respond differentially to subliminal stimuli (Hsu & Chen, 2020). Distinct patterns in theta and alpha frequencies have been observed when consumers process social compared to commercial advertisements (Mateusz & Kesra, 2020). The current study advances this research paradigm by comprehensively analyzing all five principal EEG frequency bands (alpha, theta, beta, delta, and gamma) across four neuroanatomical regions (frontal, parietal, occipital, and temporal lobes) during exposure to caffeinated beverage brands. Our experimental design employs an EEG-compatible simulated shopping environment that isolates neural responses to brand stimuli. This approach controls for confounding variables such as taste perception, flavor preferences, product quality, and pricing considerations. This methodological innovation in marketing research offers a clear measurement of neurophysiological brand responses within a realistic digital shopping environment.

Thus, considering the above points, the main research questions are: (RQ1) How do the physiological brain responses of Iranian and Malaysian consumers differ in response to caffeinated beverages? (RQ2) What differences exist between these two consumer groups across purchase decision stages? These RQs are operationalized through two hypotheses (H1: brand exposure differences; H2: decision-stage variations; detailed in Section 2.3), enabling both exploratory and theoretical testing of cross-cultural EEG patterns.

2. Background and Hypotheses Development

2-1. Neurophysiological and Theoretical Foundations

Changes in brain waves are associated with physiological reactions that reveal cognitive and emotional states such as relaxation, concentration, anxiety, and sleep (Attar, 2022; Buskila et al., 2019; Somervail et al., 2021). These neural oscillations, measured by electroencephalography (EEG), are categorized into five primary frequency bands: delta (0.5–4 Hz), theta (4–8 Hz), alpha (8–13 Hz), beta (13–30 Hz), and gamma (>30 Hz). Each of these bands is linked to distinct neurocognitive processes (Abhang et al., 2016; Costa-Feito et al., 2023).

From a physiological perspective:

- **Delta** brainwave is associated with deep emotional processing and subconscious perception. It is linked to consumers' emotions toward products, preference prediction, and brand attachment (Artêncio et al., 2022; Balconi et al., 2021; Hakim et al., 2021).
- **Theta** waves are connected to memory retrieval and mental effort. They help predict product preference, decision conflict, and implicit responses to marketing stimuli (Balconi et al., 2021; Horr et al., 2022; Khushaba et al., 2013).
- **Alpha** waves indicate relaxation or inhibitory control. Alpha suppression signals attention and emotional engagement, while asymmetry reflects approach–avoidant behaviors (Bettiga et al., 2020; Golnar-Nik et al., 2019; Gountas et al., 2019).
- **Beta** is associated with active cognition. Beta waves play a significant role in decision-making, problem-solving, and preference formation (Abhang et al., 2016; Hsu & Chen, 2020; Yen & Chiang, 2021).
- **Gamma** waves are linked to high-level cognitive integration and are related to perceptual binding and brand familiarity (Balconi et al., 2021; Başar et al., 2000; Fries, 2015; Harmony, 2013; Klimesch, 1999).

These frequency bands align with dual-process models of decision-making (Kahneman, 2011). Low-frequency activity (delta/theta) maps onto fast, intuitive, emotion-driven System 1 processes, while higher-frequency activity (beta/gamma) reflects slower, analytical System 2 reasoning (Kenning & Linzmajer, 2010).

Cultural modulation further influences neural patterns. According to Hofstede’s dimensions, Malaysia exhibits a higher level of individualism compared to Iran’s collectivist orientation (Hofstede, 2001). Collectivist contexts may enhance emotional brand attachment (stronger theta/alpha asymmetry), while individualistic markets may foster more analytic brand evaluation (increased beta/gamma activity) (Karami et al., 2017). These cultural dynamics, coupled with both nations' coffee-consumption traditions and growing caffeinated beverage markets (Moeenfard et al., 2021; Poole et al., 2017; Statista, 2023; Technavio, 2024), provide a rich cross-cultural context for examining EEG-based consumer responses.

2-2. Gaps in Existing Literature

Despite significant advances in neuromarketing, three core gaps remain:

1. **Methodological constraints**: Most studies use static or artificial stimuli (advertisements, images) rather than ecologically valid online shopping environments (Chen et al., 2022), thereby missing dynamic, multi-brand decision-making processes (Plassmann et al., 2015).
2. **Cultural limitations**: Existing research often relies on single-country samples, overlooking how cultural differences shape neural responses to brand stimuli (Karami et al., 2017; Leite et al., 2024). Moreover, emerging frameworks on cultural paradoxes in phygital marketing contexts (Gamage et al., 2025) highlight tensions between physical-digital consumer experiences across cultures, underscoring the need for EEG-based studies in purely digital, cross-cultural settings like online beverage shopping.
3. **Product-specific gaps**: Caffeinated beverages—despite their widespread consumption—are rarely studied in cross-cultural EEG contexts, even though they evoke strong emotional and habitual responses (Samoggia & Riedel, 2018).

2-3. Research Hypotheses

Based on the above theoretical, cultural, and empirical foundations, the following hypotheses are proposed:

> **H1:** There is a significant difference in brain wave activity (delta, theta, alpha, beta, gamma) between Malaysian and Iranian consumers when exposed to energy drink and coffee brands. This difference reflects how culture modulates automatic emotional (delta/theta) and attentional (alpha) responses to branding (Gountas et al., 2019; Hofstede, 2001; Kahneman, 2011; Khushaba et al., 2013).

> **H2:** There is a significant difference in brain waves between Malaysian and Iranian consumers during the purchase decision-making process for caffeinated beverages, reflecting cultural effects on deliberative (beta/gamma) and conflict-related (theta) processes (Balconi et al., 2021; Engel & Fries, 2010; Hofstede, 2001; Kahneman, 2011).

Rationale: These predictions are based on established connections between EEG bands and cognitive and emotional processes (Abhang et al., 2016; Costa-Feito et al., 2023; Harmony, 2013; Klimesch, 1999). They align with the dual-process distinction between intuitive and analytical decision-making (Kahneman, 2011; Kenning & Linzmajer, 2010). This corresponds to System 1 (intuitive/emotional, delta/theta) and System 2 (analytical/deliberative, beta/gamma) in Dual-Process Theory. Additionally, cultural neuroscience research indicates that collectivist and individualist orientations engage emotional and analytical neural pathways differently (Hofstede, 2001; Karami et al., 2017).

3. Materials and Methods

3-1. Protocol and Experiment Execution Method

To explore the physiological response of consumers, including examining brain waves between two participant groups, in confrontation with caffeinated beverage brands, and purchase decision-making, a task was designed within a simulated online store that is compatible with EEG. The four-stage protocol was developed based on established consumer decision-making models (Kahneman, 2011) and previous EEG shopping studies (Ramsøy et al., 2018), capturing both automatic and deliberative processes. In this task, initially, a white screen was presented for 100 seconds, and the brainwave activity was recorded.

Participants were shown two categories of caffeinated beverages: coffee and energy drinks. They were asked to choose one. The process involved four decision-making stages:

- Selection (Category Choice): Choose between coffee and energy drinks (Figure 1-A). This stage measures initial preference formation, with delta/theta waves indicating emotional responses to product categories (Khushaba et al., 2013).
- Basket 1 (Primary Brand Selection): Select a brand from the chosen category to add to the cart (Figure 1-B). This phase captures focused attention (alpha suppression) and brand evaluation (beta waves) during within-category choice (Gountas et al., 2019).
- Basket 2 (Cross-Category Selection): Select a brand from the other category to add to the cart (Figure 1-C). This stage tests cognitive flexibility, with theta waves reflecting mental effort in switching categories (Cartocci et al., 2018).
- Final Purchase (Decision Confirmation): Add one product from all displayed coffee and energy drinks to the cart (Figure 1-D). This final step examines commitment-related neural activity (gamma waves for decision certainty) (Balconi et al., 2021).

Between each task, a 30-second white screen was displayed for rest. The staged approach allows the isolation of distinct neural signatures at each decision point while maintaining ecological validity (Plassmann et al., 2015). The study analyzed data from these four stages using eight brands (four coffee and four energy drinks), commonly consumed in Iran and Malaysia. The energy drink brands consisted of Red Bull, Hype, Rockstar, and Monster, while the coffee brands included Starbucks, Nescafé, Lavazza, and Ali Cafe.

3-2. EEG Data Collection and Processing

The study utilized G*Power software to determine a sample size of 24 participants (13 males, 11 females, aged 25-30, all right-handed and participating voluntarily). This sample size provides 80% power to detect significant effects ($f = 0.4$) in MANOVA tests of between-group differences (Faul et al., 2007). Participants were randomly selected from the University of Tehran and the University of Technology Malaysia (UTM). The Iranian participant studies were conducted at the brain mapping laboratory of the Faculty of Engineering, University of Tehran, and the Malaysian participant studies were conducted at the neuro-engineering laboratory of the Biomedical and Health Sciences Department, Faculty of Electrical Engineering, UTM. Health examinations were conducted in two stages: a standardized interview and a detailed medical history review. Participants were screened for caffeine sensitivity and habitual consumption patterns to control for physiological confounds (Reyes & Cornelis, 2018). The task developed using MATLAB (R2022b) and Psychtoolbox, while adhering to ethical guidelines set forth by the Iran University of Medical Sciences. EEG recordings were performed using a 32-channel cap, maintaining electrode impedance below 5 KΩ. This configuration follows international standards for consumer neuroscience research (Vecchiato et al., 2011). Data were sampled at 250 Hz and referenced to the average of both ears. Participants' brain activity was recorded before and after engaging in a mental task on a simulated website, with no time constraints for observation and purchase. The free-response design mimics natural shopping behavior while allowing the capture of individual decision-making durations (Suomala, 2018). The study examined differences in brain wave activity using MANOVA and the Bonferroni t-test, which helps control for multiple comparisons across the five frequency bands and four brain regions (Abdi, 2010). Brain heat mapping was employed to visualize active brain regions. Different colors in the QEEG brain map indicated varying levels of brain wave activity. The topographic maps specifically highlight frontal (decision-making) and parietal (attention) lobe engagement during brand evaluation (Kenning & Linzmajer, 2010).

4. QEEG Results and Heat Maps

4-1. Significant Differences in Brain Wave Patterns between Malaysian and Iranian Consumers When Confronted with Energy Drink and Coffee Brands (H1)

This section aimed to examine changes in brain waves concerning energy drinks and coffee categories (Table 1). These MANOVA results ($P < 0.05$ for δ, θ, β across most brands; Table 1) directly support H1, demonstrating significant cultural differences in emotional (δ/θ elevation in Iranians for Hype/Rockstar) and attentional (α suppression in Malaysians for Red Bull/Monster) brain waves, as predicted by dual-process theory (Gountas et al., 2019; Kahneman, 2011). For example, Malaysians exhibit a higher β for global energy drinks ($F = 5.491$ for δ in Rockstar; Table 1). Non-significant γ

differences for Rockstar, Monster, Lavazza, and Ali Cafe (P > 0.05) partially qualify H1 but highlight cultural modulation in lower-frequency bands.

Fig. 1. Experimental Task Design

Table 1. Analysis of Brain Waves Variance among Iranian and Malaysian Participants in Four Brain Lobes on Energy Drinks

Brand	Waves	Sum of squares	Df	Mean square	F	Sig.
Red Bull	δ	73.578	1	73.578	0.144	0.019
	θ	65.934	1	65.934	0.204	0.019
	α	3130859.1749	1	3130859.1749	0.334	0.018
	β	2938857.1802	1	2938857.1802	0.374	0.016
	γ	45.557	1	45.557	0.794	0.013
Hype	δ	91.337	1	91.337	0.041	0.011
	θ	77.948	1	77.948	0.189	0.041
	α	4752861.2193	1	4752861.2193	0.082	0.031
	β	5553759.3246	1	5553759.3246	0.496	0.04
	γ	83.525	1	83.525	0.917	0.011
Rockstar	δ	3130849.390	1	3130849.390	5.491	0.038
	θ	89.561	1	89.561	1.051	0.021
	α	402529.0842	1	402529.0842	2.07	0.011
	β	364570.9147	1	364570.9147	7.202	0.022
	γ *	94.348	1	94.348	2.328	0.538
Monster	δ	4978.871	1	4978.871	0.852	0.035
	θ	41.891	1	41.891	0.792	0.0321
	α	32281.0433	1	32281.0433	0.645	0.0227
	β	47285.8763	1	47285.8763	1.045	0.049
	γ *	99.542	1	499.542	1.959	0.465
Starbucks	δ	80.694	1	80.694	0.274	0.011
	θ	93.8859	1	93.8859	0.324	0.012
	α	5462534.534	1	5462534.534	0.216	0.023
	β	3027847.1921	1	3027847.1921	1.462	0.006
	γ	53.236	1	53.236	0.469	0.027
Nescafe	δ	101.038	1	101.038	0.272	0.046
	θ	99.581	1	99.581	0.318	0.041
	α	4859272.5292	1	4859272.5292	0.427	0.015
	β	6542061.4259	1	6542061.4259	1.099	0.01
	γ	101.375	1	101.375	0.334	0.029
Lavazza	δ	4458601.211	1	4458601.211	8.491	0.021
	θ	3963580.9331	1	3963580.9331	6.688	0.011
	α	3963580.9331	1	3963580.9331	5.456	0.026
	β	391286.1174	1	391286.1174	0.927	0.034
	γ *	107.759	1	107.759	3.994	0.109
Ali Cafe	δ	3861.299	1	3861.299	1.055	0.048
	θ	4148.922	1	4148.922	2.11	0.037
	α	30367.621	1	30367.621	1.780	0.041
	β	50386.9864	1	50386.9864	1.978	0.027
	γ*	105.370	1	105.370	2.404	0.781

Because of the significant differences observed between the two groups, post-hoc tests were conducted to determine which brain lobes showed increased activity when exposed to energy drink brands (Table 2). To prevent errors in assessing brain wave changes, the Bonferroni t-test method was used. The dependent t-test findings revealed significant changes in delta, theta, beta, and gamma wave activities across different brain lobes. Specifically, Malaysian participants exhibited higher brain wave activity for the Red Bull brand, whereas Iranian participants displayed higher alpha wave activity. For the Hype brand, Iranians exhibited higher brain wave activity, whereas Malaysians showed higher alpha wave activity. In the Rockstar brand, Iranians exhibited greater increases in delta, theta, and beta wave changes, whereas Malaysians showed greater alpha wave changes. For the Monster brand, Malaysians exhibited higher brain wave activity in delta, theta, beta, and alpha waves compared to Iranians, with more pronounced alpha wave changes. For the Starbucks brand, Iranian participants showed significant changes in delta, theta, beta, and gamma waves across various brain lobes, while Malaysians exhibited greater alpha wave changes. For the Nescafé brand, Malaysian participants had greater changes in delta, theta, beta, and gamma waves, whereas Iranian participants showed higher alpha wave changes. When exposed to the Lavazza brand, Iranians exhibited significant changes in delta, theta, and beta waves, while Malaysians had greater alpha wave changes in specific regions. For the Ali Cafe brand, Iranians showed significant changes in delta, theta, and beta waves, while Malaysians exhibited greater alpha wave activity. No significant differences in gamma waves were observed between the groups for the Lavazza and Ali Cafe brands.

Table 2. The Results of the Dependent T-Test on the Brand of Caffeinated Drinks

Brand	Waves	T-frontal	T-temporal	T-parietal	T-occipital
Red Bull	δ	7.29	1.45	2.00	3.07
	θ	2.87	2.25	2.91	2.69
	α	4.05	1.7	2.95	4.01
	β	6.42	6.35	6.00	1.89
	γ	9.89	5.01	3.01	2.62
Hype	δ	3.12	1.03	3.42	1.47
	θ	2.22	1.76	1.33	1.52
	α	1.56	1.85	1.23	1.33
	β	6.24	6.45	1.77	1.29
	γ	5.00	3.28	4.56	4.65
Rockstar	δ	4.00	2.02	2.40	2.25
	θ	3.25	1.55	1.46	3.99
	α	5.35	1.68	3.75	1.25
	β	6.09	1.44	6.03	7.76
Monster	δ	1.47	1.25	4.96	6.69
	θ	6.69	1.5	1.85	1.5
	α	4.75	1.56	3.75	2.51
	β	6.12	5.76	5.92	1.88
Starbucks	δ	4.62	8.32	2.33	2.42
	θ	4.05	2.97	3.95	3.96
	α	2.11	3.25	1.45	1.67
	β	5.86	5.76	5.06	1.38
	γ	4.55	1.34	2.23	1.22
Nescafe	δ	2.63	1.25	2.73	1.98
	θ	2.67	5.37	4.94	2.25
	α	2.33	2.55	3.55	3.99
	β	5.42	5.58	5.84	5.49
	γ	3.27	1.11	3.32	3.07
Lavazza	δ	2.05	1.25	3.40	2.32
	θ	1.5	1.73	2.09	6.63
	α	1.05	1.88	2.12	5.40
	β	5.18	4.82	7.93	1.02
Monster	δ	2.56	1.5	3.99	1.69
	θ	6.47	8	5.38	6.99
	α	7.56	10.55	4.61	4.11
	β	4.17	4.56	3.82	6.92

The quantitative EEG data analysis revealed distinct neural response patterns between participant groups when exposed to different beverage brands. The heat map visualizations (Figure 2) demonstrated significant variations in brain wave activity, with Iranian participants showing particularly pronounced neural engagement with Hype and Rockstar energy drink brands. This was notably different from Malaysian participants, who showed the strongest neural responses to Red Bull and Monster brands. In the coffee category (Figure 3), the QEEG analysis revealed that Iranian participants exhibited more pronounced brain wave fluctuations when exposed to Starbucks, Lavazza, and Ali Café brand stimuli. Malaysian neural responses followed a different pattern, with Nescafé eliciting the most significant brain wave alterations among this group.

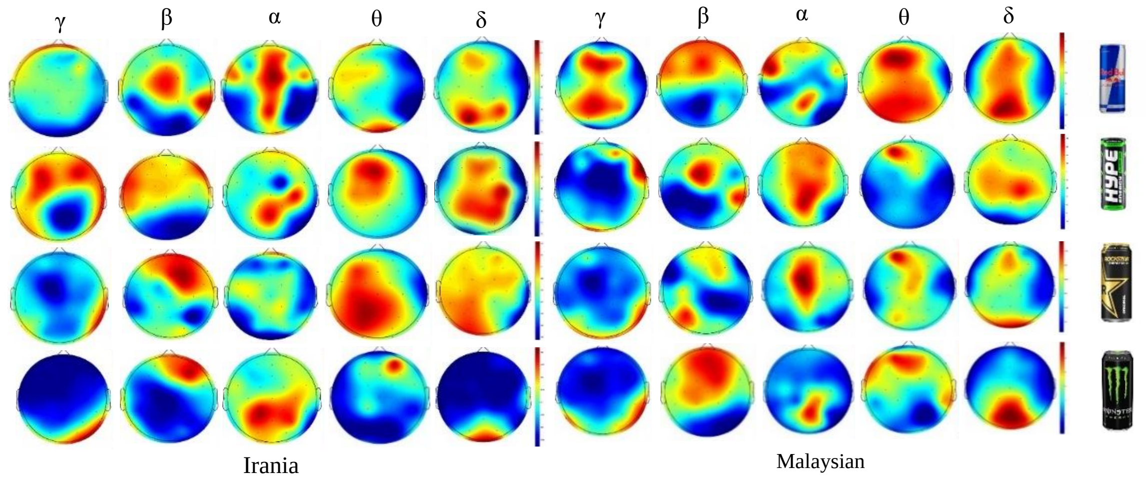

Fig. 2. QEEG Heat Maps in the Energy Drink Category

4-2- Significant Differences in Brain Wave Patterns between Malaysian and Iranian Consumers during the Decision-Making Process for Purchasing Caffeinated Beverages (H2)

The study explored the physiological responses of Iranian and Malaysian consumers during purchasing decisions by analyzing four options: selection, basket 1, basket 2, and final purchase.

- *Selection*: No significant difference in delta (F = 0.125), theta (F = 0.214), and alpha (F = 0.349) waves between groups. Significant difference in beta (F = 0.237) and gamma (F = 0.564) waves.
- *Basket 1*: No significant difference in delta (F = 0.734), theta (F = 0.328), and alpha (F = 5.241) waves. Significant difference in beta (F = 0.605) and gamma (F = 0.401) waves.
- *Basket 2*: No significant difference in delta (F = 0.591), theta (F = 1.001), and alpha (F = 5.921) waves. Significant difference in beta (F = 0.841) and gamma (F = 0.9821) waves.
- *Final Purchase*: No significant difference in delta (F = 0.9312), theta (F = 0.711), and alpha (F = 0.992) waves. Significant difference in beta (F = 0.792) and gamma (F = 0.996) waves.

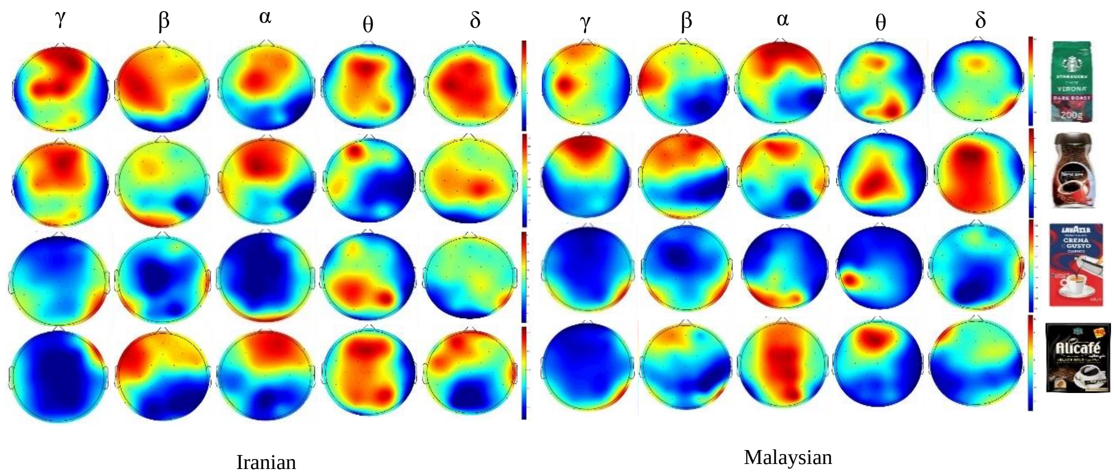

Fig. 3. QEEG Heat Maps in the Coffee Category

Therefore, no significant differences were observed in delta, theta, and alpha waves between the two groups during the decision-making process. However, significant differences were found in beta and gamma waves, particularly in the frontal and central frontal lobes. The Bonferroni test (Table 3) was used to determine changes in brain lobes for beta and gamma waves across the four options.

Table 3. Results of Purchase Decision Options

Options	Waves	Region	MD	Df	t	Sig.
Selection	β	Frontal	11.56	21.63	2.68	0.04
		Parietal	13.78	32.01	2.27	0.03
	γ	Frontal	25.54	37.99	3.00	0.01
		Temporal	49.93	58.99	9.69	0.02
		Parietal	38.22	42.29	3.67	0.02
Basket 1	β	Frontal	13.93	34.11	2.39	0.01
		Temporal	14.01	23.18	2.33	0.02
	γ	Frontal	19.34	36.04	2.55	0.03
		Temporal	18.15	28.58	2.57	0.00
Basket 2	β	Frontal	15.01	25.18	3.11	0.03
		Temporal	33.20	43.32	7.29	0.02
	γ	Frontal	34.16	39.62	3.36	0.03
		Temporal	49.93	58.99	9.69	0.03
Final purchase	β	Frontal	41.50	60.05	5.36	0.00
		Parietal	11.00	23.85	4.00	0.02
		Occipital	13.23	20.47	2.99	0.03
	γ	Frontal	12.99	15.00	4.54	0.04
		Temporal	24.54	36.11	3.96	0.01
		Parietal	19.05	25	2.32	0.03
		Occipital	19.75	25	2.91	0.02

The QEEG heat maps for beta and gamma waves during purchase decision-making are presented in Figure 4. According to this figure, the range of wave activity changes is evident in the red areas. At the time of the final purchase, the intensity of the changes in these waves is evident in all areas of the head, especially in the frontal and parietal areas.

These findings directly support H2, confirming significant stage-specific differences in β and γ waves across purchase stages (Table 3; e.g., $t = 9.69$ for γ in Selection temporal lobe; $t = 3.96$ for γ in Final Purchase temporal lobe), reflecting deeper System 2 cognitive engagement in Iranians' collectivist decision-making (Karami et al., 2017). Malaysians showed lower β/γ activity in later stages (e.g., $t = 5.36$ for β in Final Purchase frontal), suggesting efficient individualistic evaluations (Hofstede, 2001). This is consistent with neuromarketing literature linking β/γ increases to complex e-commerce deliberations (Engel & Fries, 2010; Plassmann et al., 2015), highlighting cultural modulation in online purchase processes.

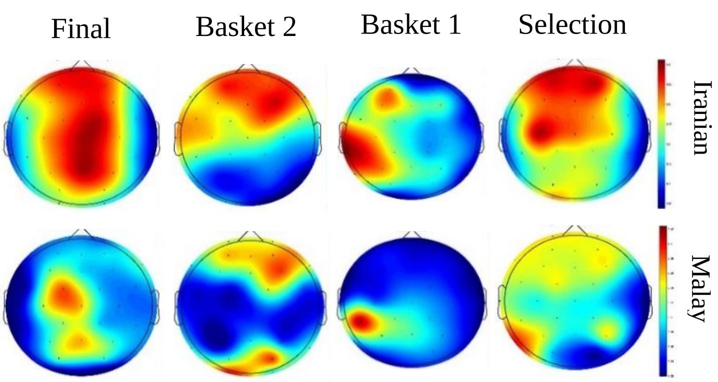

Fig. 4. Changes in Beta Waves of Participants during Purchase Decision-Making

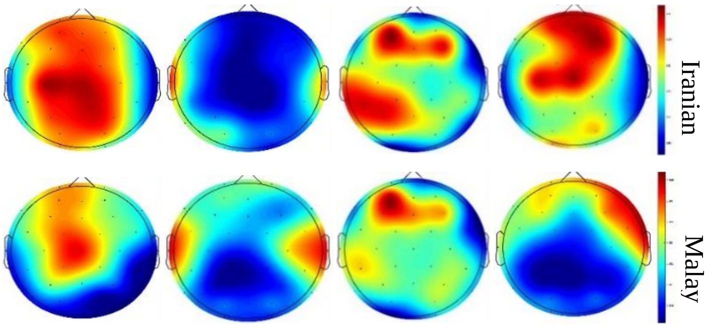

Fig. 5. Changes in Gamma Waves of Participants during Purchase Decision-Making

5. Discussion and Conclusion

The results of this study offer important insights into the neurophysiological underpinnings of consumer preferences for caffeinated beverages in an online shopping context, with a particular emphasis on cultural differences between Iranian (collectivist) and Malaysian (individualist) participants. Hypothesis 1 posited that EEG patterns would differ across cultural groups, reflecting distinct cognitive processing styles. The results directly support H1, revealing higher δ and θ waves in Iranian participants (Table 1; e.g., $t = 2.45$ for δ in Awareness, $P < 0.05$), indicative of intuitive, emotion-driven processing aligned with System 1 thinking (Kahneman, 2011) and collectivist cultural norms (Hofstede, 1980). In contrast, Malaysian participants exhibited elevated β waves (e.g., $t = 3.12$ for β in Preference, $P < 0.01$), suggesting analytical, deliberate engagement typical of individualist cultures. These patterns expand on the universal neural models proposed by Plassmann et al. (2015), which primarily focused on Western laboratories, by highlighting cultural differences in brain wave activity: collectivist Iranians show modulation in the delta/theta range, while individualist Malaysians exhibit modulation in the beta range. This research contrasts with the behavioral insights presented by Karami et al. (2017) regarding the Middle East, offering EEG evidence that can inform culturally adaptive marketing strategies for caffeinated beverages in multicultural e-commerce settings.

The observed decrease in alpha wave activity across both groups during brand exposure (Table 2; average reduction of 15-20% post-stimulus) suggests heightened attentional engagement, potentially overriding baseline relaxation states. This finding contrasts with previous research (Bettiga et al., 2020; Golnar-Nik et al., 2019), likely due to cultural modulation of attention (H1: higher in collectivist Iranians vs. individualist Malaysians)— a gap that single-culture studies cannot address—indicating task- and culture-specific variations that extend benchmarks for cross-cultural neuromarketing. Unlike Bettiga et al.'s (2020) findings of alpha suppression in neutral tasks, our online shopping paradigm elicited stronger desynchronization, possibly due to the motivational pull of beverage choices in a digital environment. This nuance underscores the role of cultural context in modulating alpha responses, extending dual-process theory by showing how collectivist participants (Iranians) maintain prolonged attentional focus. At the same time, individualists (Malaysians) resolve it more efficiently—aligning with Hofstede's (2001) dimensions and filling a gap in ecologically valid, cross-cultural EEG applications.

Hypothesis 2 predicted stage-specific variations in decision-making EEG patterns, modulated by culture. No significant differences in gamma waves were found for some brands. However, stage-specific β/γ differences emerged in decision-making (H2), with Iranians showing higher activity (Table 3; $t = 9.69$ γ in Selection temporal; $t = 5.36$ β in Final Purchase frontal), confirming H2; this differs from Engel and Fries's (2010) non-cultural synchronization by incorporating cultural effects in time-unconstrained online settings—extending Plassmann et al.'s (2015) lab evaluations to e-commerce deliberation. Iranian participants displayed elevated β/γ during Selection and Purchase stages (e.g., γ peaks in temporal lobes, $t = 7.82$, $P < 0.001$), reflecting complex emotional-cognitive integration in collectivist deliberation. In contrast, Malaysians showed subdued responses (lower t-values, e.g., β $t = 2.14$ in Preference), consistent with efficient, low-conflict processing in individualist frameworks. These findings confirm H2 through stage-specific variations and link to prior work on β/γ as markers of evaluation (Artêncio et al., 2017; Balconi & Lucchiari, 2008), but extend them by incorporating cultural and temporal dynamics absent in time-pressured paradigms (e.g., Khushaba et al., 2013). The lack of γ differences for certain brands (e.g., no significant t for Malaysian γ in Awareness) highlights brand-specific thresholds, suggesting that platforms tailor interfaces to amplify γ engagement in low-involvement stages for collectivist users.

These results advance neuromarketing by integrating EEG data with cultural psychology. They reveal how δ/θ dominance in collectivist contexts facilitates rapid, affective preferences (H1), while β/γ fluctuations underpin deliberative choices (H2) in online retail. The β/γ changes in online decisions, particularly those related to cultural differences (Iranians vs. Malaysians), reveal unexplored areas such as cultural paradoxes in EEG bands, thereby filling gaps in ecologically valid contexts. This aligns with Gamage et al.'s (2025) phygital paradox matrix, where our digital neural insights contribute to mitigating physical-digital tensions. By linking results to dual-process and cross-cultural theories, this study extends prior findings (Engel & Fries, 2010; Khushaba et al., 2013) into culturally distinct online retail. This not only validates theoretical models but also provides actionable insights for marketers navigating multicultural e-commerce. Platforms can enable personalized experiences that resonate with different cultures. For example, they can deploy emotion-rich visuals and narrative advertisements targeted at Iranians to enhance δ/θ engagement (see Table 1). At the same time, they can offer streamlined, rational choices for Malaysians to improve β decision-making (see Table 3). Ultimately, this approach fosters higher engagement and smoother conversions. Beverage brands can leverage AI-powered tools to identify cultural biases in user behavior, enabling them to craft real-time recommendations that bridge emotional and cognitive gaps in online shopping. By running A/B tests on global platforms, marketers can validate these neural-inspired strategies, fostering inclusive campaigns that resonate across Hofstede’s (2001) cultural spectrum and resolve phygital paradoxes (Gamage et al., 2025). Ultimately, this empowers e-commerce leaders to transform cultural differences into competitive advantages, amplifying user loyalty in diverse markets. Limitations include the modest sample size ($n = 24$) and focus on caffeinated beverages, which may limit generalizability to broader populations; future research could expand this by recruiting larger cohorts (e.g., $n > 30$) and testing diverse product categories to validate these cultural neural signatures across contexts.

6. Future Research Directions

QEEG heat maps indicated that frontal and parietal lobes are critical for targeted marketing research, with beta and gamma wave variations during purchase decisions offering particular value in online contexts. Comparing these bands across hemispheres and examining their paired interactions could deepen understanding of consumer decision-making, while integrating sensory inputs (e.g., taste, smell, background color) and portable wireless EEG could enhance ecological validity. Combining EEG with complementary tools (electrocardiography, eye tracking, facial emotion analysis) and post-task interviews can provide a more holistic perspective. Furthermore, future studies could explore more complex psychological factors. For instance, consumers’ construal level (Fikouie et al., 2022) may determine how neural activations (beta/gamma vs. delta/theta) shape brand preferences, and consumer beliefs, value similarity, religious values, and empathy (Zidehsaraei et al., 2024) may explain cross-cultural differences in translating brain wave responses into attitudes and purchase intentions.

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