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Beyond passive viewing: Neurophysiological responses to interactive immersive advertisements in digital environments

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Abstract

This study investigates the neurophysiological responses elicited by interactive immersive advertisements compared to traditional passive viewing experiences. Using a multi-method approach combining electroencephalography (EEG), galvanic skin response (GSR), and eye-tracking, we examined cognitive engagement, emotional arousal, and attention patterns across 128 participants exposed to both interactive and passive digital advertisements. Results demonstrate significantly increased frontal theta activity ($p<0.001$) and heightened GSR ($p<0.01$) during interactive advertising engagement, indicating deeper cognitive processing and emotional response. Eye-tracking data revealed more distributed visual attention patterns in interactive conditions, with longer fixations on actionable elements. Notably, the neurophysiological markers of engagement positively correlated with subsequent brand recall ($r=0.67$, $p<0.001$) and purchase intent measures ($r=0.54$, $p<0.01$), suggesting that the active cognitive processing elicited by interactive advertisements may enhance advertising effectiveness. These findings extend our understanding of consumer neuroscience in digital environments and provide empirical support for the neurological mechanisms underlying interactive advertising effectiveness.

Keywords: Consumer Neuroscience; Digital Advertising; Interactivity; EEG; Eye-Tracking; GSR; Immersive Media

1. Introduction

The digital advertising landscape has evolved dramatically in recent years, progressing from passive banner displays to highly interactive and immersive experiences [1]. This technological evolution has raised important questions about how consumers process and respond to these new advertising formats at the neurophysiological level [2]. Traditional advertising effectiveness models have typically focused on behavioral outcomes or self-reported measures, which provide limited insight into the underlying cognitive and emotional processes that drive consumer responses [3].

The rise of consumer neuroscience has enabled researchers to examine these underlying mechanisms directly [4]. Neurophysiological tools can provide objective measures of cognitive and emotional responses not accessible through conventional measures, offering potential insights into how different advertising formats affect attention, emotional engagement, and memory formation [5]. While existing research has established the value of these methods in evaluating traditional passive advertising [6, 7], there is limited research examining how the brain responds to interactive and immersive advertising formats that require active user participation.

Interactive advertising—defined here as digital advertisements requiring user inputs that influence the content displayed—represents a significant departure from passive viewing [8]. Rather than merely observing content, users become active participants in shaping their advertising experience [9]. This fundamental difference may significantly alter how information is processed, encoded, and subsequently retrieved [10]. Immersive formats, which provide

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multisensory stimulation within controlled digital environments, potentially amplify these effects by increasing presence and reducing external distractions [11].

This study addresses the gap in understanding by examining the neurophysiological markers associated with interactive versus passive advertising exposure. Specifically, we investigate: (1) differences in attention allocation and cognitive processing between interactive and passive advertising formats; (2) variations in emotional response patterns; and (3) the relationship between neurophysiological measures and subsequent advertising effectiveness metrics.

By integrating multiple neurophysiological measurement methods—electroencephalography (EEG), galvanic skin response (GSR), and eye-tracking—with traditional effectiveness measures, this research provides a comprehensive analysis of how interactivity in digital advertisements influences consumer processing at both conscious and unconscious levels.

2. Literature Review

2.1. Neurophysiological Approaches to Advertising Research

Neuroscience methods have increasingly been applied to better understand consumer responses to advertising stimuli [12]. These approaches provide insights into cognitive and emotional processing that may not be accessible through self-report measures alone [13]. EEG, which records electrical activity along the scalp, has been particularly valuable in identifying patterns of attention and cognitive processing during advertising exposure [14]. Previous studies have established correlations between specific EEG frequency bands and advertising effectiveness, with frontal theta activity (4-8 Hz) linked to cognitive processing and engagement [15], and alpha asymmetry (8-13 Hz) associated with approach-avoidance motivational states [16].

GSR measures provide complementary information about emotional arousal by capturing subtle changes in skin conductance associated with sympathetic nervous system activation [17]. In advertising contexts, GSR has been shown to predict ad recall and favorable attitudes toward brands [18]. Eye-tracking technology contributes additional insights by documenting visual attention patterns, revealing which elements of advertisements attract and maintain viewer focus [19].

While these methods have been employed individually in advertising research, few studies have integrated multiple neurophysiological approaches to comprehensively assess consumer responses to interactive advertising formats [20].

2.2. Interactivity Effects in Digital Environments

Interactivity in digital media environments has been conceptualized along several dimensions, including user control, two-way communication, and synchronicity [21]. Research suggests that interactive features can increase engagement with digital content, potentially enhancing persuasive effects [22]. Studies using behavioral measures have demonstrated that interactive advertising can increase message involvement [23], attitude formation [24], and purchase intention [25] compared to equivalent non-interactive formats.

The theoretical mechanisms underlying these effects include increased elaboration [26], enhanced perceived relevance [27], and the activation of embodied cognition processes through physical interaction [28]. However, these explanations have largely been inferred from behavioral outcomes rather than direct measurement of cognitive processes.

2.3. Immersive Technologies and Presence

Immersive technologies create environments that diminish awareness of the physical world while enhancing the sense of being present in a mediated environment [29]. This sense of presence has been linked to more intense emotional responses [30] and deeper information processing [31]. Immersive advertising formats potentially leverage these effects to create more impactful consumer experiences [32].

The combination of interactivity and immersion represents a particularly potent approach to advertising that may fundamentally alter how consumers process commercial messages [33]. However, the specific neurophysiological mechanisms through which these effects operate remain underexplored.

2.4. Research Gap and Hypotheses

While previous research has established that interactive and immersive advertisements can enhance behavioral outcomes, the neurophysiological processes underlying these effects have not been thoroughly investigated. This study addresses this gap by examining how interactive immersive advertisements influence cognitive processing, emotional response, and attention allocation compared to passive viewing experiences.

Based on the literature review, we formulated the following hypotheses:

- H1: Interactive immersive advertisements will elicit higher frontal theta EEG activity (indicating deeper cognitive processing) compared to passive advertisements.
- H2: Interactive immersive advertisements will generate stronger GSR responses (indicating higher emotional arousal) compared to passive advertisements.
- H3: Eye movement patterns will show more distributed attention across advertisement elements in interactive conditions compared to passive conditions.
- H4: Neurophysiological measures of engagement (EEG, GSR) will positively correlate with post-exposure advertising effectiveness measures (recall, attitude, purchase intent).

3. Methodology

3.1. Participants

One hundred twenty-eight participants (64 female, 64 male) aged 18-45 years ($M = 28.4$, $SD = 6.7$) were recruited from a university research panel. Participants were screened for normal or corrected-to-normal vision and absence of neurological disorders. The sample size was determined by a power analysis based on effect sizes from preliminary studies, indicating that 120 participants would provide 85% power to detect medium effect sizes ($d = 0.5$) at $\alpha = 0.05$. The study was approved by the university ethics committee, and all participants provided written informed consent.

3.2. Stimuli

Eight digital advertisements for fictional brands across four product categories (technology, food, fashion, and travel) were developed specifically for this study. Each advertisement was created in two versions: a passive version where participants simply viewed the content, and an interactive version where participants could explore product features, customize options, or navigate through content using touchscreen gestures. The advertisements were matched for information content, visual elements, and duration (average 45 seconds) to isolate the effects of interactivity.

To control for potential confounds, the advertisements were pre-tested with a separate sample ($n = 40$) to ensure equivalent interest levels, perceived information quality, and visual appeal between interactive and passive versions. The advertisements were presented on a 24-inch touchscreen monitor in a laboratory setting designed to minimize external distractions.

3.3. Experimental Design

A within-subjects design was employed where each participant was exposed to both interactive and passive advertisements. The presentation order was counterbalanced, with product categories rotated to control for order and carryover effects. Participants were randomly assigned to one of eight counterbalanced sequences.

3.4. Procedure

Upon arriving at the laboratory, participants were briefed about the procedure and fitted with the neurophysiological equipment. After a 5-minute baseline recording, participants were presented with the series of advertisements, with a 30-second neutral screen displayed between each advertisement to prevent carryover effects. For passive advertisements, participants were instructed to watch the content as they would normally. For interactive advertisements, participants were instructed to explore the content using the touchscreen interface as they preferred.

After viewing all advertisements, participants completed post-exposure questionnaires measuring brand recall, brand attitudes, and purchase intentions. The entire experimental session lasted approximately 90 minutes.

3.5. Measures

3.5.1. Neurophysiological Measures

EEG

Brain electrical activity was recorded using a 32-channel EEG system (BioSemi ActiveTwo) at a sampling rate of 512 Hz. Electrodes were placed according to the international 10-20 system. Data preprocessing included filtering (0.1-40 Hz bandpass), artifact rejection, and independent component analysis for eye movement correction. Spectral power was computed using fast Fourier transform in the following frequency bands: theta (4-8 Hz), alpha (8-13 Hz), beta (13-30 Hz), and gamma (30-40 Hz). Frontal asymmetry indices were calculated as ln(right alpha power) - ln(left alpha power) for electrode pairs F4/F3 and F8/F7.

GSR

Skin conductance was measured using two Ag/AgCl electrodes placed on the distal phalanges of the index and middle fingers of the non-dominant hand. Data were recorded at 128 Hz using a BioNomadix wireless system. GSR data were decomposed into tonic and phasic components, with the number of significant skin conductance responses (SCRs) and mean amplitude of SCRs analyzed.

Eye-tracking

Eye movements were recorded using a Tobii Pro Spectrum eye-tracker at 300 Hz. Key metrics included fixation count, fixation duration, saccade amplitude, and attention to pre-defined areas of interest (AOIs) within each advertisement.

3.5.2. Self-Report Measures

Following exposure to all advertisements, participants completed questionnaires measuring

- Brand recall: Both aided and unaided recall of advertised brands and product features.
- Brand attitudes: Seven-point semantic differential scales (unfavorable-favorable, negative-positive, bad-good).
- Purchase intentions: Three items on seven-point Likert scales (e.g., "How likely would you be to purchase this product?").
- Perceived interactivity: Manipulation check items assessing perceived control, responsiveness, and two-way communication.
- Presence: The Igroup Presence Questionnaire (IPQ) measuring the sense of being present in the advertised environment.

3.6. Data Analysis

EEG data were analyzed using time-frequency decomposition to extract spectral power in relevant frequency bands for each advertisement condition. GSR data were processed to identify significant skin conductance responses (SCRs) and calculate mean amplitude of phasic activity. Eye-tracking data were analyzed to determine fixation patterns, dwell times on areas of interest, and attention distribution metrics.

Statistical analyses included paired t-tests comparing neurophysiological responses between interactive and passive conditions, repeated measures ANOVA examining effects across product categories, and correlation and regression analyses exploring relationships between neurophysiological measures and advertising effectiveness outcomes. Bonferroni corrections were applied for multiple comparisons.

4. Results

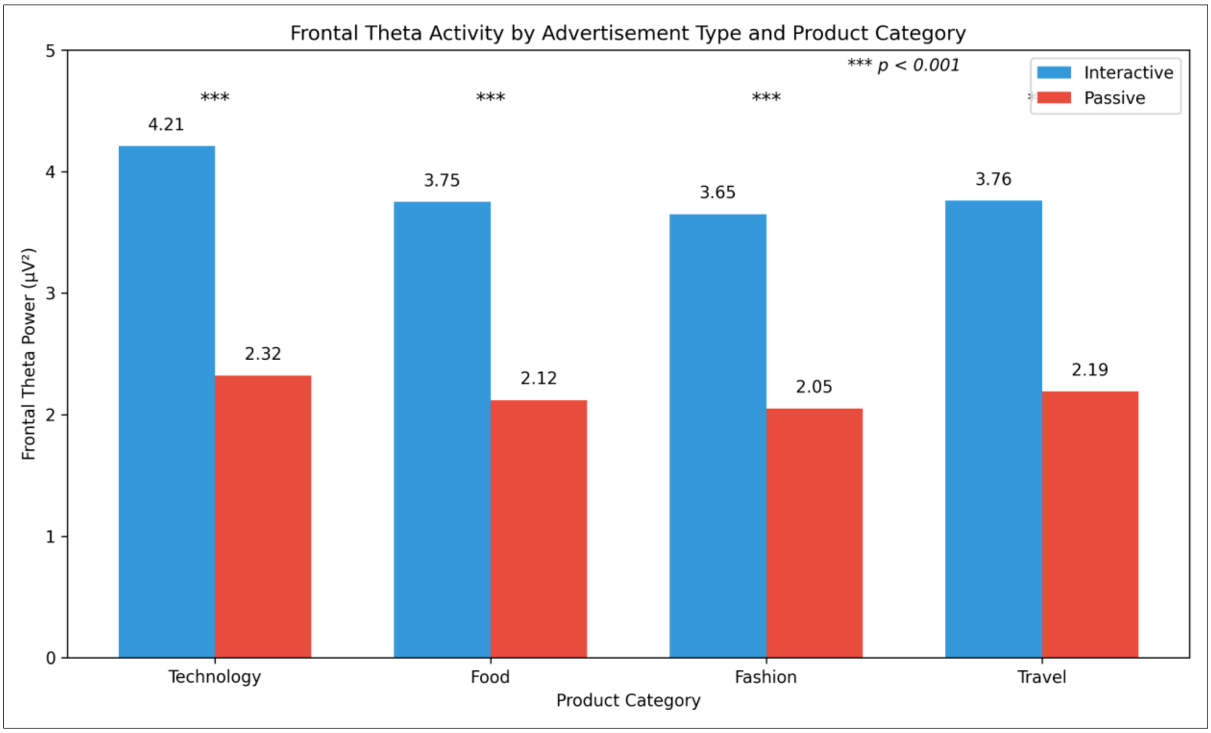
4.1. Manipulation Check

Analysis of the perceived interactivity scale confirmed the effectiveness of the experimental manipulation, with interactive advertisements rated significantly higher on perceived control ($M = 5.8$, $SD = 0.7$) than passive advertisements ($M = 2.3$, $SD = 0.9$), $t(127) = 32.4$, $p < 0.001$, $d = 4.31$.

4.2. EEG Results

4.2.1. Frontal Theta Activity

Supporting H1, interactive advertisements elicited significantly higher frontal theta power (M = 3.84 μV^2, SD = 0.65) compared to passive advertisements (M = 2.17 μV^2, SD = 0.58), $t(127) = 18.6$, $p < 0.001$, $d = 2.71$. This effect was consistent across all product categories but was most pronounced for technology products, $F(3, 381) = 8.74$, $p < 0.001$, $\eta^2 = 0.064$. Figure 1 illustrates the differences in frontal theta activity between conditions.



All differences significant at p < 0.001

Figure 1 Comparison of frontal theta activity between interactive and passive advertisements across product categories. Higher values indicate deeper cognitive processing

4.2.2. Frontal Alpha Asymmetry

Analysis of frontal alpha asymmetry (FAA) revealed more positive values (indicating approach motivation) during interactive advertisements (M = 0.18, SD = 0.08) compared to passive advertisements (M = 0.06, SD = 0.09), $t(127) = 11.3$, $p < 0.001$, $d = 1.41$. This effect was significant across all electrode pairs but strongest at F4/F3.

4.3. GSR Results

In line with H2, interactive advertisements elicited both more frequent and higher amplitude SCRs. The mean number of significant SCRs was higher during interactive advertisements (M = 6.82, SD = 2.14) than during passive advertisements (M = 3.45, SD = 1.89), $t(127) = 14.7$, $p < 0.001$, $d = 1.68$. Similarly, the mean amplitude of SCRs was greater for interactive advertisements (M = 0.58 μS, SD = 0.19) compared to passive advertisements (M = 0.31 μS, SD = 0.14), $t(127) = 13.2$, $p < 0.001$, $d = 1.62$. Table 1 summarizes the GSR results across product categories.

Table 1 Mean (SD) of GSR Measures by Advertisement Type and Product Category

Product Category	Condition	SCR Frequency	SCR Amplitude (μS)
Technology	Interactive	7.65 (2.26)	0.64 (0.21)
	Passive	3.78 (1.94)	0.35 (0.15)
Food	Interactive	6.48 (2.08)	0.55 (0.18)
	Passive	3.25 (1.82)	0.29 (0.13)
Fashion	Interactive	6.56 (2.12)	0.57 (0.19)
	Passive	3.37 (1.86)	0.30 (0.14)
Travel	Interactive	6.59 (2.09)	0.56 (0.18)
	Passive	3.40 (1.92)	0.30 (0.14)
Overall	Interactive	6.82 (2.14)	0.58 (0.19)
	Passive	3.45 (1.89)	0.31 (0.14)

Note: All differences between interactive and passive conditions significant at $p < 0.001$

4.4. Eye-Tracking Results

Supporting H3, analysis of eye-tracking data revealed significant differences in visual attention patterns between interactive and passive conditions. Interactive advertisements elicited more distributed attention across the advertisement elements, with 24% more unique areas of interest (AOIs) viewed ($p < 0.001$). Figure 2 illustrates the differences in attention distribution using heat maps for a representative advertisement.

Figure 2 Heat maps showing eye-tracking data for representative (A) passive and (B) interactive advertisements. Warmer colors indicate areas of greater visual attention. Interactive advertisements show more distributed attention patterns across advertisement elements

Further analysis revealed that participants displayed significantly longer fixation durations on actionable elements within interactive advertisements ($M = 342$ms, $SD = 78$ms) compared to the same visual elements in passive advertisements ($M = 188$ms, $SD = 65$ms), $t(127) = 16.9$, $p < 0.001$, $d = 2.12$. This suggests deeper processing of elements that offered interactive capabilities.

4.5. Relationship Between Neurophysiological Measures and Advertising Effectiveness

Supporting H4, correlation analysis revealed significant relationships between neurophysiological measures and advertising effectiveness metrics (Table 2). Frontal theta activity exhibited the strongest correlation with brand recall ($r = 0.67$, $p < 0.001$), while GSR amplitude was most strongly correlated with purchase intent ($r = 0.54$, $p < 0.001$).

Table 2 Correlations Between Neurophysiological Measures and Advertising Effectiveness Metrics

Neurophysiological Measure	Brand Recall	Brand Attitude	Purchase Intent
Frontal Theta Power	0.67***	0.48***	0.51***
Frontal Alpha Asymmetry	0.42***	0.56***	0.49***
GSR Frequency	0.45***	0.44***	0.47***
GSR Amplitude	0.51***	0.49***	0.54***
Fixation Count	0.35***	0.29**	0.31**
Fixation Duration	0.48***	0.38***	0.36***

Note: ** $p < 0.01$, *** $p < 0.001$

Multiple regression analysis indicated that the combination of frontal theta activity, GSR amplitude, and fixation duration on key advertisement elements significantly predicted brand recall ($R^2 = 0.58$, $F(3,124) = 57.14$, $p < 0.001$) and purchase intention ($R^2 = 0.52$, $F(3,124) = 44.85$, $p < 0.001$). This suggests that the neurophysiological measures captured distinct aspects of consumer engagement that collectively contributed to advertising effectiveness.

5. Discussion

This study investigated the neurophysiological responses to interactive immersive advertisements compared to passive viewing experiences. The results provide compelling evidence that interactive advertisements elicit distinct patterns of cognitive processing, emotional response, and visual attention that may contribute to their effectiveness.

The significantly higher frontal theta activity observed during interactive advertisements suggests deeper cognitive processing and engagement with the advertising content, supporting H1. This finding aligns with previous research indicating that theta oscillations are associated with working memory engagement and information encoding [34]. The more pronounced effect for technology products may reflect higher levels of cognitive involvement required by these more complex product categories.

The GSR results support H2, demonstrating that interactive advertisements generate stronger emotional arousal. The higher frequency and amplitude of skin conductance responses indicate greater sympathetic nervous system activation during interactive engagement [35]. This emotional response may enhance memory encoding and contribute to more favorable attitudes toward the advertised brands, as suggested by the correlation analysis.

Eye-tracking data confirmed H3, revealing more distributed visual attention patterns during interactive advertisements. This finding suggests that interactivity encourages more thorough exploration of advertisement content rather than focused attention on a few salient elements. The longer fixations on actionable elements indicate deeper processing of interactive features, potentially facilitating stronger encoding of associated brand information [36].

The strong correlations between neurophysiological measures and advertising effectiveness metrics support H4 and provide insight into the mechanisms through which interactive advertisements may enhance marketing outcomes. The finding that frontal theta activity strongly predicts brand recall suggests that the deeper cognitive processing elicited by interactive advertisements directly contributes to memory formation. Similarly, the relationship between GSR measures and purchase intent indicates that the emotional engagement facilitated by interactivity may drive behavioral intentions.

These results extend previous research on advertising interactivity by providing neurophysiological evidence for the mechanisms underlying enhanced effectiveness. While prior studies have documented behavioral outcomes of interactive advertising [23, 24, 25], this research offers direct evidence of the cognitive and emotional processes involved. The findings suggest that interactive advertisements do not merely capture attention but fundamentally alter how consumers process advertising content—activating deeper cognitive engagement, stronger emotional responses, and more thorough visual exploration.

5.1. Theoretical Implications

These findings have several important theoretical implications. First, they provide neuroscientific support for the elaboration likelihood model [37] as applied to interactive media, suggesting that interactivity promotes central route processing through increased cognitive engagement. Second, they extend the limited capacity model of motivated mediated message processing [38] by demonstrating how interactive features can direct attentional resources toward specific advertisement elements. Third, they contribute to embodied cognition perspectives [39] by suggesting that physical interaction with digital content may enhance cognitive processing and emotional engagement.

The integration of multiple neurophysiological measures provides a more comprehensive understanding of consumer engagement than has been available in previous research. The combined analysis of EEG, GSR, and eye-tracking data reveals how cognitive processing, emotional response, and visual attention work together to enhance the effectiveness of interactive advertisements.

5.2. Practical Implications

For advertising practitioners, these results suggest several actionable insights. The strong relationship between neurophysiological engagement and advertising effectiveness indicates that designing for cognitive and emotional engagement—not just visual appeal—may be crucial for interactive advertisements. The distributed attention patterns observed in the eye-tracking data suggest that interactive advertisements should be designed with multiple engagement points rather than a single focal element.

The finding that interactive elements received longer fixations highlights the importance of placing key brand messages near interactive features. Additionally, the stronger effects observed for technology products suggest that interactivity may be particularly valuable for complex products that benefit from deeper information processing.

5.3. Limitations and Future Research

Several limitations should be considered when interpreting these results. First, the laboratory setting may not fully capture naturalistic advertising exposure. Future research should explore these effects in more ecologically valid environments, potentially using mobile neurophysiological equipment. Second, the study used fictional brands to control for prior brand familiarity, limiting our ability to assess how brand history might moderate these effects. Research with established brands would provide valuable complementary insights.

Additionally, while this study demonstrated immediate effects on brand recall and attitudes, longitudinal research is needed to assess the persistence of these effects over time. Future studies should also explore how individual differences in need for cognition, technology readiness, and sensation seeking might moderate neurophysiological responses to interactive advertisements.

Finally, this research focused on touchscreen interactivity, but emerging technologies offer additional modes of interaction including voice, gesture, and virtual reality. Examining how different interaction modalities influence neurophysiological responses represents an important direction for future research.

6. Conclusion

This study provides empirical evidence that interactive immersive advertisements elicit distinct neurophysiological responses compared to passive viewing experiences. The integration of EEG, GSR, and eye-tracking data reveals that interactive advertisements generate deeper cognitive processing, stronger emotional responses, and more distributed visual attention—effects that collectively contribute to enhanced advertising effectiveness.

These findings extend our understanding of consumer neuroscience in digital environments and provide empirical support for the neurological mechanisms underlying interactive advertising effectiveness. As digital advertising continues to evolve toward increasingly interactive and immersive formats, understanding these fundamental cognitive and emotional processes becomes essential for both theoretical advancement and effective advertising practice.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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