GLOBAL ACADEMIC TRENDS OF METABOLIC AND ELECTRICAL BIOMEDICAL TOOLS IN MARKETING

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Abstract. This study employs a comprehensive bibliometric analysis, adhering to the PRISMA protocol, to systematically review and map global academic trends in neuroimaging tools for neuromarketing research. Utilising data from the Scopus database spanning January 2007 to July 2023, 104 documents were subjected to analysis, revealing a discernible upward trajectory in publications. The findings revealed that the United States emerges as the predominant contributor, with 19 papers, while influential authors such as Balconi, M., and the most-cited article, "The Neural Mechanisms Underlying the Influence of Pavlovian Cues on Human Decision Making," signify pivotal contributions to the field. A keyword analysis reveals the prominence of key themes, including "emotion," "attention," and "advertising," offering valuable theoretical insights into the field of neuromarketing research. The journal Frontiers in Human Neuroscience is identified as the most productive, with 11 papers published. This comprehensive bibliometric analysis offers insights into the current landscape of neuroimaging tools in neuromarketing, as well as providing a foundation for future research directions. The implications of these findings extend to theoretical advancements, which provide guidance to researchers in refining frameworks and offering insights for strategic decision-making in the use of neuroscientific approaches for effective marketing strategies.

Keywords: neuromarketing, VOSviewer, R Studio, neuroimaging tools, Scopus database.

JEL Classification: M00, M31, M37

1. Introduction

The intersection of marketing, neuroscience, and psychology has seen a surge of interest in neuromarketing, which has the potential to elucidate the complex neural processes underlying consumer behaviour (Ahmed, 2023; Ahmed et al., 2023b; Ariely & Berns, 2010; Halsharif et al., 2022; Pilelienė et al., 2022; Solomon, 2018). As a hybrid field, it employs sophisticated technologies to investigate the neuroscientific underpinnings of decision-making in the context of marketing (Ababkova & Leontieva, 2018; Ahmed et al., 2023c; Al Fauzi & Widyarini, 2023). Ramsoy (2015) categorised neuromarketing technologies into four distinct groups: (a) neuroimaging tools, including functional magnetic resonance imaging (fMRI), positron emission tomography (PET), functional near-infrared spectroscopy (fNIRS), electroencephalography (EEG), magnetoencephalography (MEG), steady-state topography (SST), and single-photon emission tomography (SPET), (b) physiological tools, including eye tracking (ET), electromyography (EMG), galvanic skin response (GSR), and electrocardiogram (ECG), (c) self-report methods, such as surveys, interviews, focus groups, and observations, and (d) behavioural measures, such as the implicit association test (IAT) (Alsharif et al., 2022b; Alvino et al., 2020). Furthermore, Bercea (2012) proposed a classification of NM methods comprising three categories: (a) metabolic tools, which include fMRI and PET; (b) electrical tools, which encompass fMRI, PET, and EEG, TMS, SST, MEG; and (c) non-brain tools, which include ECG, ET, GSR, EMG, FACS, and IAT. According to the above classifications, this study proposed new NM classifications, which are divided into four classifications as: (a) metabolic tools (e.g., fMRI, PET, and fNIRS), (b) electrical tools (e.g., EEG, MEG, SST, and TMS), (c) non-brain tools (e.g., ET, ECG, EMG, GSR, and IAT), and (d) self-report methods

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(e.g., questionnaires, observations, interviews, and focus groups). These technological avenues provide researchers with a comprehensive toolkit to investigate the complex interplay between cognitive, emotional, and physiological factors that influence consumer responses. This marks a significant advancement in the authors' understanding of the relationship between neuroscience and marketing strategies (Agarwal & Dutta, 2015; Alsharif et al., 2021c; Pileliene et al., 2022).

Neuroimaging tools are a critical arsenal for unravelling the intricacies of brain function and cognitive-emotional processes in response to marketing stimuli, including advertising and brands (Ahmed et al., 2022b; Alsharif et al., 2024; Bakalash & Riemer, 2013). Each tool provides unique insights into the neural underpinnings of consumer behaviour. For example, fMRI uses changes in blood oxygen levels to map brain activity, revealing specific regions involved in cognitive tasks (Morin, 2011). PET uses radioactive tracers to measure metabolic activity, allowing visualisation of brain function and neurochemical processes (Muehllehner & Karp, 2006; Sebastian, 2014). EEG records electrical activity in real time, providing valuable information about brain rhythms and event-related potentials (Bazzani et al., 2020; Yang et al., 2015). MEG provides high temporal resolution and localisation of brain activity by measuring magnetic fields generated by neural currents (Crease, 1991; Kumar, 2015; Vecchiato et al., 2011). As a non-invasive tool, fNIRS uses near-infrared light to infer brain activity, particularly in the cortex (Krampe et al., 2018). TMS, which uses magnetic fields, non-invasively stimulates specific brain regions, facilitating the investigation of causal relationships between brain areas and behaviour (Jang & Seo, 2019; Stewart & Walsh, 2006). SST, another non-invasive tool, analyses changes in the brain's electrical responses to visual or auditory stimuli, providing insight into cognitive processing (Halsharif et al., 2020a; Silberstein & Nield, 2008; Silberstein & Nield, 2012). The aforementioned tools, when considered collectively, form an indispensable array, which enables researchers to decode the neural signatures that underlie consumer responses. Furthermore, this array enhances the understanding of the cognitive and emotional aspects associated with marketing stimuli.

Several studies analysing the scientific production of neuromarketing have already been published, indicating the growing interest in neuromarketing (Ahmed et al., 2021; Alsharif et al., 2023a; Alsharif et al., 2021a; 2021b; Alsharif et al., 2021e; Alvino et al., 2020; Cherubino et al., 2019; Halsharif et al., 2021a; Sánchez-Fernández et al., 2021). However, no prior research has been conducted to map the production of "neuromarketing, consumer neuroscience, fMRI, PET, EEG, fNIRS, MEG, SST, TMS" research in the Scopus database. As a result, this study differs from others that focus on global academic research trends of studies in the Scopus database that used fMRI, PET, EEG, MEG, fNIRS, TMS and SST tools in neuromarketing or consumer neuroscience research between 2007 and July 2023. To this end, this research aims to fill a gap in the scientific literature. This research aims to provide a comprehensive bibliometric analysis, including the most prolific countries, academic institutions, authors and journals. It will also identify the articles with the most citations, the co-citation network of authors and papers, and the hot keywords with occurrences. Below are the main materials and stages of this bibliometric analysis study:

1. To provide an overview of neuroimaging tools commonly used in marketing research.
2. To determine the annual growth of scientific publications based on journal issues.
3. To identify common indicators such as prominent countries, academic institutions, journals and authors.
4. To identify the most prominent themes/keywords.
5. To determine the most cited review articles and articles that should be considered for future research.

The research structure is as follows: the study's literature review is presented in Section 2; Section 3 describes the methodology used in this study; Section 4 is devoted to bibliometric analysis of relevant literature; Section 5 discusses the paper's findings; Section 6 contains succinct conclusions; finally, Section 7 discusses the study's limitations as well as possible future directions.

2. Literature Review of Suggested Neuromarketing Tools

Functional magnetic resonance imaging (fMRI) is a widely employed tool in the field of neuromarketing research, particularly for the investigation of consumer behaviour and decision-making processes (Alsharif et al., 2023b; Alvino et al., 2020; Cherubino et al., 2019). Although its usage is less frequent in comparison to other neuroscientific tools, such as EEG and ET, fMRI is a commonly employed technique when consumers are presented with product images and prompted to make purchase decisions (Ahmed et al., 2023b; Rawnaque et al., 2020; Sánchez-Fernández & Casado-Aranda, 2021). This non-invasive technique enables researchers to estimate neural activity at high spatial resolution within seconds, thereby facilitating the investigation of the neural correlates of consumer behaviour (Alvino et al., 2020; Wang et al., 2015). Functional magnetic resonance imaging has been employed to differentiate between various types of decision-making processes, identify cerebral regions that exert influence over financial decisions, and examine brain activations associated with personal involvement (Hsieh & Chang, 2021;

Plassmann et al., 2015; Schaefer et al., 2015). Its popularity can be attributed to its distinctive insights into brain functions, capacity to identify brain mechanisms, comprehension of individual differences, and enhancement of behavioural prediction in neuromarketing (Halsharif et al., 2021b; Hubert et al., 2018). Despite its widespread use, the high cost and large equipment requirements may prove to be a significant barrier to its practical application in neuromarketing studies (Kim et al., 2016). Nevertheless, fMRI's high sensitivity to brain responses renders it a potent technique for investigating consumer psychology with regard to branding and decision-making processes (Al-Kwifi et al., 2020; Al-Kwifi, 2016).

Electroencephalography. EEG has been extensively employed in neuromarketing research to categorise consumer preferences and identify consumer responses (Lin et al., 2018). It serves to bridge the gap between conventional marketing studies and EEG-based brain-computer interface research (Aldayel et al., 2021; Alsharif et al., 2022b). EEG is a dominant instrument in the field of neuromarketing research (Alsharif & Khraiwish, 2024; Alsharif et al., 2022a; Siddique et al., 2023), employed to quantify neural arousal in response to advertisements and evaluate its correlation with advertising efficacy (Eijlers et al., 2020). Furthermore, it provides insights into consumers' implicit brain activity, offering a deeper understanding of the cognitive processes and emotional mechanisms that underlie consumer behaviour (Balconi et al., 2019). EEG-based methods, such as support vector machines, have been demonstrated to be effective in detecting consumer preferences (Aldayel et al., 2020; Ammar Ali et al., 2022). Furthermore, EEG has been employed to discern the cognitive processing of advertising and evaluate the influence of narrative on product preference (Daugherty et al., 2018; Wang et al., 2016). The temporal and spectral dynamics of electroencephalograms have been identified as reliable indicators of participants' immediate internal responses to video commercials. This demonstrates the capability of EEGs to capture real-time cognitive states during exposure to marketing stimuli (Wang et al., 2018).

Functional near-infrared spectroscopy. It has become an important tool in neuromarketing, providing insights into consumer behaviour and decision-making processes (Alsharif et al., 2023b). Studies have shown that fNIRS can be used to understand neural responses to marketing stimuli and consumer preferences. For example, fNIRS has been used to investigate gender differences in brand purchase decisions (Duan et al., 2021), investigate the neural correlates of purchase behaviour (Cakir et al., 2018), and predict impulse purchase behaviour (Bak et al., 2022). Furthermore, the utilisation of mobile fNIRS has expanded the domain of neuromarketing research, facilitating investigations in naturalistic contexts such as shopping malls (Krampe et al., 2018). This method has been demonstrated to yield valid insights into neural activation in relation to consumer behaviour, thereby enhancing the ecological validity of neuromarketing studies (Zhang et al., 2023). Moreover, fNIRS has been employed to evaluate the pleasure-displeasure effect of diverse products, including lipsticks, substantiating its efficacy in assessing consumer responses to specific stimuli (Tanida et al., 2017). Additionally, the viability of mobile fNIRS for neuromarketing has been established, underscoring its capacity to complement conventional marketing research techniques (Meyerding & Risius, 2018).

Positron emission tomography. PET studies, a metabolic brain technique, have been used in neuromarketing research (Ahmed et al., 2023b), along with other methods such as fMRI, EEG, MEG and fNIRS (Jesus et al., 2022). However, PET studies involve the invasive administration of a radioactive substance, which has limited its use in neuromarketing research (Du Plessis, 2011; Harris et al., 2018). Despite this limitation, neuromarketing aims to assess consumers' cognitive and emotional responses to marketing stimuli, integrating different psychophysiological variables to understand economically relevant behaviour (Cuesta et al., 2018; Dursun & Goker, 2019).

Magnetoencephalography. It is a neurophysiological technique that measures the magnetic fields associated with neuronal activity in the brain (Hegazy & Gavvala, 2022). In the context of neuromarketing, MEG, in conjunction with other neuroimaging techniques such as functional magnetic resonance imaging (fMRI) and electroencephalography (EEG), provides a direct and unbiased measure of brain activity during the observation of marketing stimuli (Pozharliev et al., 2017). These techniques are highly efficacious tools for investigating brain activity in neuromarketing, allowing researchers to analyse both the anatomical and functional aspects of the nervous system (Halsharif et al., 2020a; Heinonen, 2018; Jesus et al., 2022). In particular, MEG has gained interest in neurorehabilitation training due to its high temporal resolution (Pascarella & Pitolli, 2018; Zurawicki, 2010). Studies have employed MEG to quantify cortical activation in response to visual and audiovisual stimuli, thereby elucidating consumer behaviour and decision-making processes (Matsuzaki et al., 2022; Takada et al., 2018).

Transcranial magnetic stimulation. The technique is non-invasive and utilises magnetic fields to stimulate electrical currents in specific regions of the brain (Alvino et al., 2020; Cherubino et al., 2019; Halsharif et al., 2020a). TMS represents a powerful tool for investigating and manipulating brain functions, as it is capable of modulating neuronal activity by

applying rapidly changing magnetic fields through a coil placed on the scalp (Li et al., 2017; Romero et al., 2019). Furthermore, TMS is a valuable tool in the field of neuromarketing, as it enables researchers to examine the causal relationships between specific brain regions and consumer behaviour (Riddle et al., 2020). Its adaptability stems from its capacity to transiently alter neuronal excitability, rendering it an optimal tool for probing cognitive processes, emotional responses, and decision-making mechanisms (Opitz et al., 2018; Seo et al., 2016). Additionally, TMS has been employed as a therapeutic modality for a range of neurological and psychiatric conditions, underscoring its multifaceted role in neuroscience and its potential to elucidate the neural substrates of consumer preferences and decision-making in the context of marketing stimuli (Sebastian, 2014; Vassiliadis et al., 2018).

Steady-state topography. It is a non-invasive neuroimaging technique that analyses the electrical responses to repetitive visual or auditory stimuli in order to measure brain activity (Halsharif et al., 2020a; Silberstein et al., 1990). SST furnishes immediate insight into neural oscillations and functional connectivity in response to stimuli through the utilisation of high-density electroencephalography (EEG) recordings (Vialatte et al., 2010). This method offers an excellent temporal resolution, accurately capturing dynamic changes in brain activity (Ahmed et al., 2023b; Alvino et al., 2020). Furthermore, SST enables researchers to examine the cognitive processes and attentional mechanisms that are triggered by marketing stimuli (Bercea, 2012). Its adaptability derives from its capacity to examine how the brain responds to particular visual or auditory stimuli over time, thereby offering insights into the temporal dynamics of cognitive engagement and emotional processing (Cherubino et al., 2019). Furthermore, SST is notable for its utility in studying consumer responses and decision-making, thereby contributing to a more comprehensive understanding of the neural underpinnings of reactions to marketing content (Gray et al., 2003).

3. Methods

The study employed the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) protocol to identify pertinent scholarly literature on the subject of neuromarketing, utilising a bibliometric analysis approach. The study examined a number of key factors, including the leading countries, academic institutions, journals, authors, most highly cited papers and occurrences of specific keywords, in order to assess the progress of scholarly publications.

This study uses the Scopus database to analyse articles and review articles in July 2023, following the guidelines (Abuhassna et al., 2022; Abuhassna et al., 2023; Ahmed & Salmi, 2024; Halsharif et al., 2020b). Visualisation maps were created using VOSviewer and R Studio software, facilitating bibliometric research in fields such as neuromarketing (Ali et al., 2021a; 2021b). These tools have been used in previous studies to understand the development of neuroimaging tools. The study focused on articles and reviews using neuroimaging tools (e.g., fMRI, PET, fNIRS, EEG, MEG, SST and TMS) in marketing studies, with an emphasis on English-language articles published between 2007 and July 2023. The aim was to investigate global academic trends in the use of neuroimaging tools in marketing research through a systematic selection process.

This study provides an analysis of neuromarketing trends, thereby filling gaps in the existing literature. The analysis is guided by four research questions, which focus on key areas of interest and contribute to the advancement of neuromarketing knowledge.
1) What is the yearly dynamics in scientific publications in the field?
2) What are the most contributing a) countries; b) academic institutions; c) journals; and d) authors?
3) What are the most prominent keywords in the articles chosen?
4) What are the most frequently cited articles in the field?

In order to facilitate comprehension of the methods and instruments employed in this investigation, a more comprehensive outline is presented in Figure 2.

4. Results

4.1. Overview of Scientific Production

The study analyses 104 papers published between 2007 and 2023, with a particular focus on keywords, authorship patterns, and the growth of publications. The study reveals a high level of collaboration among authors, with a low number of single-authored documents and an average of 4.14 co-authors per document (see Figure 3).

The analysis of keywords, including "keywords plus" and author-assigned keywords, reveals a rich and nuanced vocabulary in neuroimaging in marketing research. This vocabulary reflects the multidimensional nature of the subject and indicates the presence of prevalent themes.

The study demonstrates a notable surge in the number of publications on neuromarketing, with over 50% published between 2020 and 2023 (see Figure 4). This suggests a dynamic landscape shaped by technological developments and the increasing acknowledgement of the value of neuroscientific methodologies in consumer behaviour research.
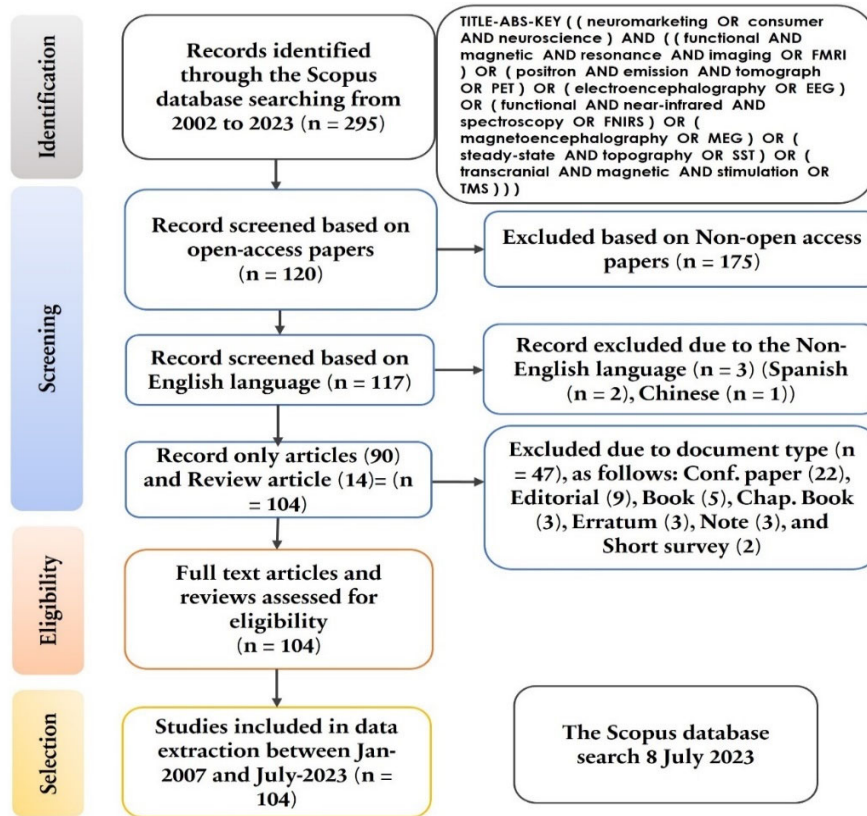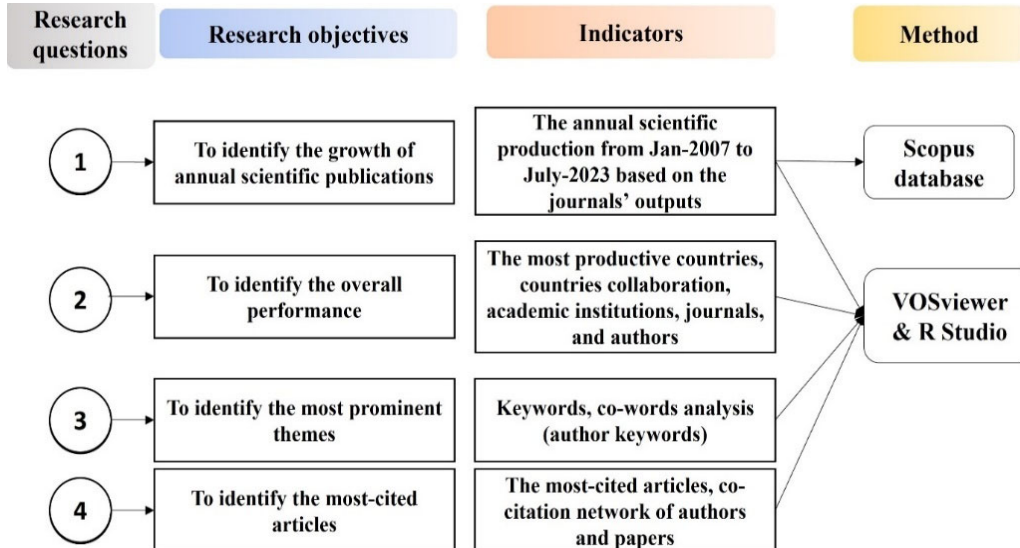
Figure 1. PRISMA process for extracting documents

Figure 2. The analytical structure of this study

4.2. Bibliometric Analysis

4.2.1. Outstanding Countries and Institutions

The analysis presented in this study provides a comprehensive examination of the global distribution of research productivity in a specific field, which is likely to be related to academic papers. The countries are classified into two groups according to their respective levels of productivity, with each group demonstrating a unique contribution to the corpus of literature (Table 1).

The initial category encompasses five countries – the United States, China, Germany, Italy, and Spain – that are distinguished by elevated productivity, with each nation producing a minimum of ten papers. This indicates that these nations are making a significant and concentrated contribution to the

Description	Results
MAIN INFORMATION ABOUT DATA	
Timespan	2007:2023
Sources (Journals, Books, etc)	56
Documents	104
Annual Growth Rate %	13.88
Document Average Age	3.85
Average citations per doc	18.23
References	7288
DOCUMENT CONTENTS	
Keywords Plus (ID)	599
Author's Keywords (DE)	353
AUTHORS	
Authors	372
Authors of single-authored docs	4
AUTHORS COLLABORATION	
Single-authored docs	4
Co-Authors per Doc	4.14
International co-authorships %	29.81
DOCUMENT TYPES	
article	90
review	14

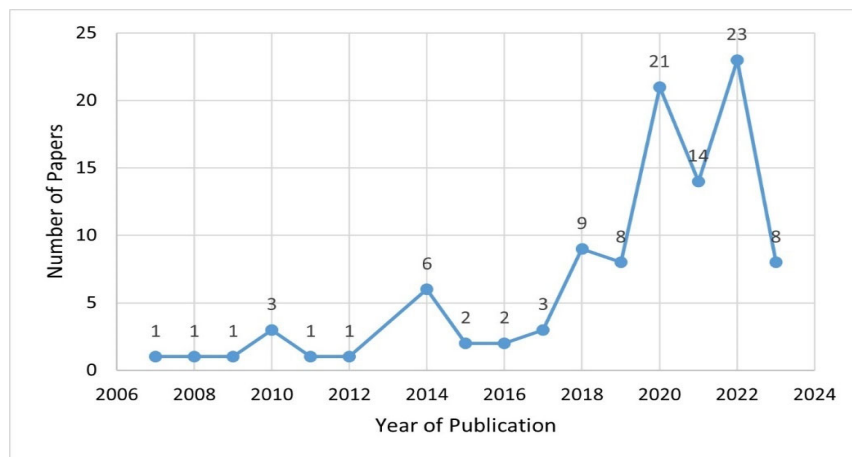**Figure 3. Main information about selected articles for this study**

Figure 4. The annual publications between 2007 and 2023

scholarly discourse. The United States is the most prolific country, with a total of nineteen articles and review papers, which contribute significantly to the field's overall output. The preponderance of these countries is further evidenced by the fact that they collectively account for over 50% of the total papers published since 2007, thereby underscoring their central role in shaping the research landscape in this domain.

A detailed examination of specific institutions within these highly productive countries provides a more nuanced understanding of the phenomenon under study. The California Institute of Technology, an American institution, has emerged as a leading academic entity, contributing two papers with the highest citation count (250). This exemplifies the influential role of select institutions in driving the impact of research. Conversely, while Italy has

produced twelve papers, its most prominent academic institution, the Università Cattolica del Sacro Cuore, has contributed five papers. This indicates variations in research focus and collaboration patterns within highly productive countries.

The second category comprises six countries – Australia, Denmark, the Netherlands, the United Kingdom, Austria and Malaysia – which are distinguished by a moderate level of productivity, with each country publishing between five and ten papers. Although less prolific than the preceding category, these countries nevertheless make a notable contribution to the field, offering diversity and breadth to the global research landscape.

The specific mention of notable academic institutions within these countries, such as Swinburne University of Technology in Australia and Universiti Teknologi Malaysia in Malaysia, provides insights into the localisation of centres of excellence and their impact on the overall research output. The study draws attention to the number of papers published and underscores the pivotal role of particular institutions in shaping scholarly discourse.

Table 2 serves to illustrate the considerable importance of international collaboration in the development of neuroimaging tools for use in the fields of neuromarketing and marketing research. The multiple country publications (MCP) rate is employed for the purpose of evaluating the extent of collaboration, with a rate of 50% or above indicative of a robust level of collaboration. Germany, Denmark, the United Kingdom, and Austria are identified as countries that are actively engaged in international collaboration. The data-driven approach offers comprehensive data on the rates of single country publications (SCP) for each country, with nine out of ten countries exceeding 50% of the ratio. Figure 5 provides a visual representation of both multi-country and single-country publications, offering a concise overview of global collaboration trends. This finding has the potential to facilitate a more comprehensive advancement of knowledge in the field of neuroimaging applications in marketing.

Table 1
Outstanding countries with a minimum of six articles

Country	TPs	TCs	Productive institution	TPs	TCs
USA	19	777	California Institute of Technology	2	250
China	12	37	Zhejiang University	3	7
Germany	12	328	Heinrich-Heine-Universität Düsseldorf	4	138
Italy	12	267	Università Cattolica del Sacro Cuore	5	27
Spain	10	70	Universidad de Granada	3	14
Australia	9	237	Swinburne University of Technology	4	147
Denmark	7	189	Aarhus Universitet	3	41
the Netherlands	7	124	Universiteit Twente	3	43
UK	7	115	Imperial College London	2	11
Austria	6	214	University of Newcastle, Australia	3	56
Malaysia	6	96	Universiti Teknologi Malaysia	2	27

Note: by the end of July 2023; TPs – total publication; TCs – total citations

Table 2
The ratio of MCP and SCP of production countries

№	Country	Articles	Freq	SCP	SCP Ratio	MCP	MCP Ratio
1	Italy	10	0.096	6	0.6	4	0.4
2	China	9	0.087	7	0.778	2	0.222
3	Spain	9	0.087	8	0.889	1	0.111
4	USA	9	0.087	8	0.889	1	0.111
5	Australia	8	0.077	5	0.625	3	0.375
6	Germany	8	0.077	4	0.5	4	0.5
7	Denmark	6	0.058	3	0.5	3	0.5
8	the Netherlands	5	0.048	3	0.6	2	0.4
9	UK	4	0.038	2	0.5	2	0.5
10	Austria	3	0.029	1	0.333	2	0.667

Note: MCP – Multiple countries publication; SCP – Single country publication; Freq – Frequencies
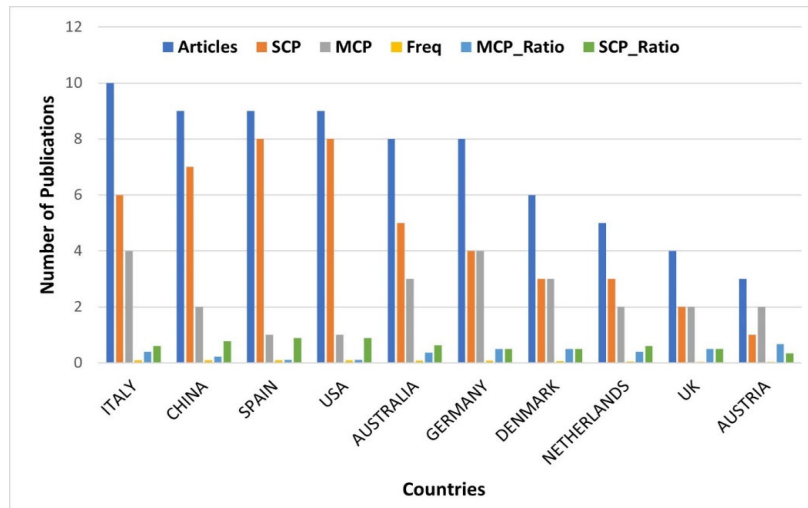
Figure 5. Diagram of the ratio of MCP and SCP of production countries

4.2.2. Productive Journals

Table 3 provides a list of the most significant academic journals that have made a notable contribution to the field of neuromarketing research, employing a range of neuroimaging tools. Frontiers in Human Neuroscience is the most highly regarded publication in this field, with eleven papers and a citation count of 172. The paper "Near-infrared spectroscopy (NIRS) as a new tool for neuroeconomic research" is the second most cited paper with 68 citations. Frontiers in Neuroscience and Frontiers in Psychology are notable journals, with Frontiers in Neuroscience publishing 180 citations. The most highly cited paper in this journal is entitled "Frontal Brain Asymmetry and Willingness to Pay". The remaining journals have made comparatively few contributions to the field of neuromarketing research, with each publishing fewer than five papers. However, the Journal of Economic Psychology stands out for its impact, with two noteworthy papers and the third most cited paper, "Celebrities and shoes on the female brain: The neural correlates of product evaluation in the context of fame".

4.2.3. Productive Authors

This section examines in detail prolific authors in neuromarketing research, specifically using neuroimaging tools. Table 4 shows that ten authors meeting the criterion of at least three publications were identified from five countries and six academic institutions, providing a nuanced understanding of global expertise in the field.

Italian institutions, in particular the Università Cattolica del Sacro Cuore and BrainSigns SRL, dominate the authorship, suggesting Italy's considerable influence in neuromarketing research using neuroimaging tools. The presence of authors from Australia, Spain, the Netherlands and Germany contributes to a diverse and collaborative international landscape.

Balconi, M., affiliated to the Università Cattolica del Sacro Cuore, is the most prolific author with five publications, underlining a significant scientific contribution. Kenning, P., affiliated to the Heinrich-Heine-Universität Düsseldorf, has the highest number of citations, indicating considerable impact and recognition within the academic community. The variation in citation counts between prolific authors emphasises the multifaceted nature of impact, which encompasses both the quantity and influence of publications.

A comparison of the number of publications and citations in the different countries reveals different contributions. Italian authors lead in the number of publications, indicating Italy's prominent role in shaping the volume of neuromarketing research. Conversely, Australian authors lead in the number of citations, indicating the increased attention and influence of their work within the academic community.

The mention of Casado-Aranda, L.A., from Spain, with three publications and a comparatively lower citation count, contributes to a holistic understanding of global research output in neuromarketing. This inclusion recognises the different levels of impact across countries and highlights the specific research landscape in Spain.

4.2.4. Keywords

The analysis aims to provide insights into the strength of associations between paired keywords, providing a quantitative metric for understanding the content and thematic trends within the field of neuromarketing (Ahmed et al., 2023a; Ahmed et al., 2022a; Alsharif et al., 2021d; Halsharif & Pilelienė, 2023; Pilelienė et al., 2024). Keywords are essential in bibliometric analysis as they serve as a quantitative measure, indicating the strength of associations between paired keywords. A higher frequency of

Table 3

Ten of the most prominent journals in the field of neuroimaging and neuromarketing

Source/Journal	TPs	TCs	Title of the most cited paper	TS
Frontiers in Human Neuroscience	11	172	"Near-infrared spectroscopy (NIRS) as a new tool for neuroeconomic research"	68
Frontiers in Neuroscience	10	180	"Frontal Brain Asymmetry and Willingness to Pay"	71
Frontiers in Psychology	10	51	"Revealing Unconscious Consumer Reactions to Advertisements That Include Visual Metaphors. A Neurophysiological Experiment"	19
Brain Sciences	5	1	"ADV at the Time of COVID-19 Brain Effect between Emotional Engagement and Purchase Intention"	1
Scientific Reports	4	70	"Modelling Peri-Perceptual Brain Processes in a Deep Learning Spiking Neural Network Architecture"	31
Cogent Psychology	3	64	"Established liked versus disliked brands: Brain activity, implicit associations and explicit responses"	40
European Journal of Marketing	3	42	"Trust me if you can – neurophysiological insights on the influence of consumer impulsiveness on trustworthiness evaluations in online settings"	36
Behavioral Sciences	2	25	"Consumer Neuroscience and Digital/Social Media Health/Social Cause Advertisement Effectiveness"	25
IEEE Access	2	13	"Electroencephalogram-Based Preference Prediction Using Deep Transfer Learning"	11
Journal of Economic Psychology	2	58	"Celebrities and shoes on the female brain: The neural correlates of product evaluation in the context of fame"	57

Note: by the end of July 2023; TPs – total publications; TCs – total citations; TS – times cited

Table 4

Top ten most productive authors

Author	TPs	TCs	Affiliation	Country
Balconi, M.	5	27	Università Cattolica del Sacro Cuore	Italy
Ciorciari, J.	4	147	Swinburne University of Technology	Australia
Gountas, J.	4	147	Swinburne University of Technology	Australia
Kenning, P.	4	251	Heinrich-Heine-Universität Düsseldorf	Germany
Angioletti, L.	3	22	Università Cattolica del Sacro Cuore	Italy
Babiloni, F.	3	154	BrainSigns SRL	Italy
Cherubino, P.	3	154	BrainSigns SRL	Italy
Casado-Aranda, L.A.	3	14	Universidad a Distancia de Madrid	Spain
Harris, J.M.	3	123	Swinburne University of Technology	Australia
Krampe, C.	3	34	Wageningen University & Research	the Netherlands

Note: by the end of July 2023

occurrence suggests a stronger link between keywords, allowing researchers to gain a comprehensive understanding of the content of an article. The strength of the link between keywords reflects their prevalence in the documents, and the total number of links represents the total occurrence of keywords in the article.

The study employs the RStudio software for a comprehensive analysis of co-occurring author keywords. By focusing on 100 keywords within the documents, the resulting dataset is sufficiently robust for analysis. This methodology is particularly valuable for elucidating key findings about the content of the article and evaluating thematic trends specific to neuromarketing.

The paragraph states that the results of the analysis are presented visually in Figure 6. The use of visual representation through figures can facilitate the interpretation of complex data. In this instance, Figure 6 provides a graphical illustration of the co-occurrence patterns among the selected keywords, offering a clear and accessible means of understanding the relationships and themes within the domain of neuromarketing.

Table 5 is a valuable resource that encapsulates key terms, their occurrences, and their total link strength (TLS) values. It provides quantitative insights into the prominence of specific keywords. The term "eeg/electroencephalography" emerges as the most frequently used keyword, appearing 46 times and having a substantial total link strength of 125. This suggests a notable focus on electroencephalography within the dataset, indicating its prominence in studies pertaining to neuromarketing and

Figure 6. Map of authors' keywords (100 words)

consumer neuroscience. The next most frequently occurring terms are "consumer neuroscience" and "neuromarketing," with 42 and 36 occurrences, respectively, and TLS values of 109 and 103, respectively. These terms serve to illustrate the central focus on the broader domains of consumer neuroscience and neuromarketing in the analysed literature.

The paper then proceeds to discuss tools that are widely used in neuromarketing and consumer neuroscience, including EEG, fMRI, ET, fNIRS, ERPs and GSR. These tools are used to study various aspects of consumer behaviour, such as decision-making, emotions, attention, emotional arousal, emotional valence, attitudes and other factors related to responses to marketing stimuli.

The specific keywords related to consumer behaviour are highlighted, with "consumer behaviour" appearing nine times and contributing to a TLS of 28. "Decision-making" appears seven times, accumulating a TLS of 20, indicating a significant focus on understanding decision-making processes. The term "emotion" appears four times with a TLS of 17, emphasising the role of emotions in consumer responses. Similarly, "attitudes" appears three times, contributing to a TLS of 12.

The paper also touches on the keywords "arousal" and "attention", each with three occurrences and TLS values of 10 and 8 respectively. These terms indicate the attention given to the study of arousal and attention in the context of consumer neuroscience. "Emotional valence" is mentioned twice, with a TLS of 6, indicating a lesser but still notable emphasis on understanding the emotional valence of consumer responses.

Finally, the keywords "advertising" and "brands" are discussed, with "advertising" appearing six times and having a TLS of 21, while "brands" is mentioned twice and has a TLS of 6. These terms suggest a considerable interest in exploring consumer responses to advertising and brand-related stimuli.

Table 5

Top twenty authors' keywords
with two occurrences at least

#	Keyword	Occurrences	TLS
1	EEG/ Electroencephalography	46	125
2	Consumer neuroscience	42	109
3	Neuromarketing	36	103
4	fMRI/ Functional magnetic resonance imaging	15	28
5	Consumer behaviour	9	28
6	Neuroscience	8	25
7	fNIRS	7	22
8	Eye tracking	7	18
9	Decision-making	7	20
10	Neuroeconomics	6	23
11	Advertising	6	21
12	ERP/ERPs	5	16
13	Emotion	4	17
14	Marketing	4	13
15	Attitudes	3	12
16	Arousal	3	10
17	GSR	2	11
18	Attention	2	8
19	Brands	2	8
20	Emotional valence	2	6

Note: TLS – total-link-strength

4.2.5. Citations

Citation analysis is an essential tool for researchers and practitioners in fields such as neuromarketing and consumer neuroscience, providing insight into the most influential papers. The focus here is on 104 publications that use various neuroimaging tools to study consumer behaviour. The inclusion criterion of at least 50 total citations in Table 6 helps to identify articles with significant impact.

Four papers stand out with more than 100 citations in total. "The Neural Mechanisms Underlying the

Influence of Pavlovian Cues on Human Decision Making" by Bray et al. (2008) is the most cited with 136 citations. "Defining Neuromarketing: Practices and Professional Challenges" by Fisher et al. (2010) follows with 125 citations. "On the Foundations of NeuroIS: Reflections on the Gmunden Retreat 2009" by Riedl et al. (2010) and "Hypothetical and Real Choice Differentially Activate Common Valuation Areas" by Kang et al. (2011) have 120 and 114 citations respectively.

The remaining papers in Table 6 have fewer than 100 citations, the lowest being "From 'Where' to 'What': Distributed Representations of Brand Associations in the Human Brain" by Chen et al. (2015) with 50 citations. This information is valuable for researchers and practitioners looking for key contributions in the field.

The discussion extends to the papers with the most citations per year. "Fontal Brain Asymmetry and Willingness to Pay" ranks second in total citations, but has the second highest citations per year (11.83). In contrast, "Consumer neuroscience for marketing researchers", ranked fifth in total citations, has the highest number of citations per year (15.17). These findings provide additional insights into the continuing impact and relevance of specific papers in the field over time.

4.2.6. Bibliographic Coupling (Authors)

The paragraph describes a study that employed the VOSviewer tool to assess the strength of the correlation between two authors by utilising bibliographic coupling. Bibliographic coupling is a technique that examines the similarity between authors based on their shared references. The results of the analysis are presented in Table 7, where link strengths represent the degree of correlation, and a higher number of links indicates a stronger connection between the references of the two authors.

The most significant correlation identified in the study was between the works of Ciorciari J., and Gountas J., with a notable 457 interconnections. This finding suggests the existence of a substantial and interconnected body of literature associated with these two authors, indicating a strong thematic similarity or evidence of collaborative work.

Table 6
The most cited materials (at least 50 citations)

Reference	Title of paper	Journal	TCs	Cs per year
Bray et al. (2008)	"The Neural Mechanisms Underlying the Influence of Pavlovian Cues on Human Decision Making"	"The Journal of Neuroscience"	136	8.50
Fisher et al. (2010)	"Defining neuromarketing: Practices and professional challenges"	"Harvard Review of Psychiatry"	125	8.93
Riedl et al. (2010)	"On the Foundations of NeuroIS: Reflections on the Gmunden Retreat 2009"	"Communications of the Association for Information Systems"	120	8.57
Kang et al. (2011)	"Hypothetical and Real Choice Differentially Activate Common Valuation Areas"	"Journal of Neuroscience"	114	8.77
Harris et al. (2018)	"Consumer neuroscience for marketing researchers"	"Journal of Consumer Behaviour"	91	15.17
Vecchiato et al. (2014)	"Neurophysiological Tools to Investigate Consumer's Gender Differences during the Observation of TV Commercials"	"Computational and Mathematical Methods in Medicine"	90	9.00
Ramsoy et al. (2018)	"Fontal Brain Asymmetry and Willingness to Pay"	"Frontiers in Neuroscience"	71	11.83
Kopton & Kenning (2014)	"Near-infrared spectroscopy (NIRS) as a new tool for neuroeconomic research"	"Frontiers in Human Neuroscience"	68	6.80
Stallen et al. (2010)	"Celebrities and shoes on the female brain: The neural correlates of product evaluation in the context of fame"	"Journal of Economic Psychology"	57	4.07
Cartocci et al. (2017)	"Electroencephalographic, Heart Rate, and Galvanic Skin Response Assessment for an Advertising Perception Study: Application to Antismoking Public Service Announcements"	"Journal of Visualized Experiments"	53	7.57
Stopczynski et al. (2014)	"Smartphones as pocketable labs: Visions for mobile brain imaging and neurofeedback"	"International Journal of Psychophysiology"	53	5.30
Chen et al. (2015)	"From 'Where' to 'What': Distributed Representations of Brand Associations in the Human Brain"	"Journal of Marketing Research"	50	5.56

Note: by the end of July 2023.

The second-highest correlation was identified between Gountas J., and Harris J.M., with a total of 389 links. This also indicates a significant degree of correlation in the references associated with these authors.

The third strongest correlation was identified between Kenning and Riedl, with a total of 348 links. This indicates a notable degree of interconnectivity between the references of these two authors, although slightly lower than the top two pairs.

In contrast, the connections between Riedl and Stahlhut are relatively limited, with only three links. This suggests a weak correlation between the references associated with these two authors. The low number of links indicates that there is a paucity of thematic or collaborative connections between the works of Riedl and Stahlhut in the analysed literature.

This analysis provides insights into the strength of connections between different pairs of authors, providing a quantitative measure of their collaborative or thematic association based on shared references. The results can be valuable for understanding the scholarly landscape, identifying potential research collaborations, and assessing the influence of particular authors within a given field.

5. Discussion

Compared to others, NM tools have emerged as valuable tools for researchers and practitioners to delve deeper into consumer behaviour (e.g., emotions, attention, preferences) towards stimuli such as advertising and brands (Ahmed et al., 2021; Guo et al., 2018; Halsharif et al., 2021a; Reimann et al., 2012; Venkatraman et al., 2015). These techniques have been used extensively in marketing research to determine effective communication channels such as television, radio, Facebook, Twitter and others for successful advertising (Fugate, 2007) and to uncover implicit gestures. The use of fMRI, PET, fNIRS, EEG, MEG, SST and TMS has several advantages in different research contexts. These neuroimaging tools are critical in advancing the understanding of

brain function, emotional and cognitive processes in relation to advertising and brands (Ahmed et al., 2023b).

Using the PRISMA framework, the study analysed 90 articles and 14 reviews on neuromarketing using various neuroimaging tools. The analysis revealed that the United States was the most prolific country in neuromarketing, with 19 influential documents and 777 citations. China, Germany and Italy also demonstrated their intellectual prowess with 12 seminal papers each. Notable institutions such as Università Cattolica del Sacro Cuore, Heinrich-Heine-Universität Düsseldorf and Swinburne University of Technology showed their brilliance. Prestigious journals such as Frontiers in Human Neuroscience and the most cited Frontiers in Neuroscience played a key role in shaping the scientific landscape. Balconi, M. led with five publications and 27 citations, while Ciorciari, J., Gountas, J. and Kenning followed closely with four publications and 147, 147 and 251 citations respectively. Babiloni, F. and Cherubino, P. made significant contributions with two publications each and secured the second highest number of citations with 154. The most cited neuromarketing paper was "The Neural Mechanisms Underlying the Influence of Pavlovian Cues on Human Decision Making" with 136 citations. The study identified strong links between Ciorciari, J. and Gountas, J. and Gountas, J. and Harris, J.M., while the weakest link was observed between Trettel, A. and Ykhlef, M. The study also highlighted the prominence of terms such as "EEG/electroencephalography", "consumer neuroscience" and "neuromarketing" with 46, 42 and 36 occurrences respectively, providing key insights into prevalent themes in the literature.

Overall, the research findings highlighted the relatively limited contribution of emerging economies to the field of neuromarketing. In light of this finding, the paper encourages scientists and researchers to actively participate in marketing research. It highlights the importance of non-invasive neuroimaging tools such as fMRI, PET, fNIRS, EEG, MEG, SST and TMS as powerful allies that provide deep insights

Table 7

The top authors pair with minimum documents (2) and citations of authors (62)

#	Item 1	Item 2	Links between items 1, 2
1	Ciorciari, J.	Gountas, J.	457
2	Gountas, J.	Harris, J.M.	389
3	Kenning, P.	Riedl, R.	348
4	Babiloni, F.	Cherubino, P.	242
5	Cherubino, P.	Maglione, A.G.	166
6	Ramsoy, T.Z.	Stahlhurt, C.	104
7	Maglione, A.G.	Trettel, A.	72
8	Harris, J.M.	Kenning, P.	40
9	Smidts, A.	Stahlhurt, C.	6
10	Riedl, R.	Stahlhurt, C.	3

into consumer behaviour and responses to advertising stimuli. The current study, guided by the prestigious PRISMA framework, embarked on an exciting quest and unearthed a treasure trove of fifty-one articles and seven reviews from the Scopus database.

6. Conclusion and Implications

General conclusion. The paper outlines the types of tools commonly employed in this field, such as fMRI, PET, fNIRS, EEG, MEG, SST, and TMS, and highlights their reliability in capturing and analysing emotional and cognitive responses to marketing stimuli. It emphasises the significance of these tools in revealing the connections between customers and their everyday context, shedding light on underlying emotional states, whether positive or negative.

Furthermore, the paper recognises the constraints within the industrial sector, observing that despite developments in neuromarketing instruments, their utilisation remains somewhat constrained. The paper makes a case for further research to investigate the potential benefits and drawbacks of neuroimaging tools in marketing research. This encompasses an understanding of how these tools can be effectively integrated with traditional methods to gain a deeper insight into consumer decision-making processes. Moreover, the paper proposes that further research should investigate the implications of neuroimaging tools for marketing strategies, including the potential for improving product design and advertising effectiveness.

The importance of non-brain tools in capturing and recording emotional responses is emphasised, indicating a recognition that a holistic approach using multiple methodologies is necessary for a thorough investigation. The paper encourages marketers and researchers to conduct comprehensive research to gain valuable insights into the effectiveness of marketing stimuli and their impact on consumers' emotions.

The study sees the use of neuroimaging tools in marketing research as an interesting and promising avenue for future research. It is hoped that the availability of training courses for marketers and practitioners to acquire the necessary skills and knowledge will increase. This, in turn, should lead to improved marketing strategies, increased effectiveness of advertising campaigns and a reduction in wasted marketing and advertising budgets.

This paper proposes the integration of neuromarketing tools with traditional marketing research methods, with the objective of enhancing the understanding of consumer behaviour and facilitating evidence-based marketing decision-making. The integration of these approaches is presented as a means of leveraging their respective strengths, thereby providing a more comprehensive and nuanced understanding of the complex factors influencing consumer responses.

Theoretical implications. The study significantly advances the theoretical foundations of neuromarketing by systematically examining 90 articles and 14 reviews using a range of neuroimaging tools. This comprehensive analysis contributes to the understanding of consumer behaviour in response to advertising stimuli and refines and extends the theoretical framework within neuromarketing. The identification of global academic trends and influential contributors provides valuable insights into cross-cultural influences on consumer behaviour. In addition, the study highlights emerging trends and potential research gaps, guiding future studies to fill current gaps and build on foundational work. The diverse methodologies uncovered in the literature provide a rich theoretical landscape for neuromarketing researchers.

Managerial implications. The study is of practical significance in strategic decision-making for marketing practitioners and decision-makers. Insights into the most influential neuroimaging tools, key contributors, and impactful journals provide managers with the tools to enhance advertising strategies and consumer engagement. Identifying influential collaborators and institutions offers strategic guidance for forming partnerships and fostering innovation. Furthermore, the study provides managers with benchmarks for performance evaluation in neuromarketing research, thus aiding in the selection of reliable partners and the informed adoption of neuroscientific approaches. In conclusion, the findings provide a link between theoretical developments and practical applications, influencing the strategic landscape of neuromarketing.

7. Limitations and Future Directions

Limitations. While this study offers valuable insights, it is important to acknowledge the limitations that warrant further consideration. Firstly, the use of the Scopus database may introduce a publication bias, as studies not included in this database may be overlooked. This limitation may impact the comprehensiveness of the analysis, potentially overlooking significant contributions to neuromarketing research. Furthermore, the temporal scope of the study, which encompasses articles and review articles up to July 2023, may impede its capacity to capture the latest advancements in a rapidly evolving field, potentially limiting the current applicability of its findings. The focus on English-language publications may introduce a language bias, thereby excluding valuable insights from non-English literature and potentially skewing the global representation of neuromarketing research.

Future directions. It is anticipated that the field of neuromarketing research will make significant advancements in the near future. Further studies could investigate the integration of multimodal neuroimaging techniques, including the combination of fMRI, EEG, and other modalities, with the objective of obtaining a more comprehensive understanding of consumer responses. Longitudinal studies may facilitate an understanding of the evolution of consumer behaviour over time, thereby offering insights into the dynamics of engagement. Moreover, encouraging cross-cultural research and interdisciplinary collaboration between neuroscientists, marketers, and psychologists can enhance the field's applicability and contribute to the development of more culturally sensitive and effective marketing strategies. It is imperative that ethical considerations are addressed and that methodological standardisation is promoted in order to ensure the credibility and reliability of neuromarketing insights in an evolving marketing landscape. It can be used cloud computing and internet of things (IoT) in the future in studying customer responses (Wang, 2021; Wang & Zhang, 2021).

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