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Review

Neuroimaging Techniques in Advertising Research: Main Applications, Development, and Brain Regions and Processes

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Abstract: Despite the advancement in neuroimaging tools, studies about using neuroimaging tools to study the impact of advertising on brain regions and processes are scant and remain unclear in academic literature. In this article, we have followed a literature review methodology and a bibliometric analysis to select empirical and review papers that employed neuroimaging tools in advertising campaigns and to understand the global research trends in the neuromarketing domain. We extracted and analyzed sixty-three articles from the Web of Science database to answer our study questions. We found four common neuroimaging techniques employed in advertising research. We also found that the orbitofrontal cortex (OFC), the ventromedial prefrontal cortex, and the dorsolateral prefrontal cortex play a vital role in decision-making processes. The OFC is linked to positive valence, and the lateral OFC and left dorsal anterior insula related in negative valence. In addition, the thalamus and primary visual area associated with the bottom-up attention system, whereas the top-down attention system connected to the dorsolateral prefrontal cortex, parietal cortex, and primary visual areas. For memory, the hippocampus is responsible for generating and processing memories. We hope that this study provides valuable insights about the main brain regions and processes of interest for advertising.

Keywords: bibliometric analysis; neuromarketing; brain processes; advertising research; neuroimaging tools; WoS database

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1. Introduction

Concepts, techniques, and methods have remained unchanged for a long period in marketing research. For example, marketing and advertising research relied on pen and paper for collecting data [1,2]. However, changing market structures (e.g., offline to online and globalization) demand new methods and techniques that are able to adapt to hyper-competitive marketing. Thus, academia and industrial environments have investigated how marketing research can benefit from integrating these techniques and methods to develop advertising campaigns [3]. In 2002, a novel approach emerged and the term "neuromarketing" was coined for the first time by Smidts [4] when he defined it as the application of neuroscience technology in marketing research. However, the Bright House company spread the neuromarketing concept widely by creating the functional magnetic resonance imaging (fMRI) department for marketing purposes [5,6]. Neuromarketing is a hybrid field that involves three main fields of neuroscience, psychology, and marketing [7].

Although the term "neuromarketing" appeared in 2002, some companies (e.g., Pepsi company) were already used neuroimaging techniques such as electroencephalography (EEG) before that, in order to solve marketing issues [8–11]. Neuroscientific research has revealed that the unconscious is very clearly taking over the consumerism and decision-making processes and thus, organizations and companies have been orienting their efforts toward the unconscious mind of the consumer, so neuromarketing studies are largely important for corporations [12].

Therefore, neuroscientific research has been expanded to study, describe, and explain the neural correlates of consumer behavior (e.g., decision-making), cognitive processes (e.g., memory, attention), and emotional processes (e.g., emotion) in advertising by using neuromarketing techniques [11,13,14]. Neuromarketing techniques have been divided into three clusters, as follows: (a) neuroimaging techniques such as functional magnetic resonance imaging (fMRI), positron emission tomography (PET), functional near-infrared spectroscopy (fNIRS), electroencephalography (EEG), magnetoencephalography (MEG), steady skin topography (SST), and single photon emission tomography (SPET); (b) physiological techniques such as, electrocardiogram (ECG), eye-tracking (ET), facial expression recognition, and galvanic skin response (GSR); and (c) behavioral measurements such as self-report, questionnaires, and observations [13]. Physiological techniques enable to measure the physiological functions (e.g., respiration rate, heart-rate, pupil dilation, fixation, eye movements, blood pressure, facial muscle movement, and perspiration) when consumers are exposed to advertisements [15]. Neuroimaging techniques enable to measure the cognitive and emotional processes toward advertisements [11,16,17]. Behavioral measurements reveal information about consumer behavior, impressions, and concerns. Self-report is one of the most widely used methods of collecting data about consumer states (e.g., attitudes, feelings, and beliefs) [13]. However, how the main neuroimaging techniques are employed in advertising campaigns is still unclear in academic literature. In addition, there is a lack of studies of the vital role of cognitive and emotional processes in advertising. Hence, this study presents the current scope, the most neuroimaging techniques applied in advertising campaigns. Due to the complex nature in this domain, we carried out a review of the literature to address the following research questions:

- **RQ1:** What is the most cited journal in the neuromarketing field?
- **RQ2:** What are the most employed neuroimaging tools in advertising research?
- **RQ3:** What are the brain processes and regions of interest for advertising research?

The rest of the paper is organized as follows. In Section 2, we explain the data collection and methodologies that were employed in this study, including a bibliometrics analysis. Section 3 presents the bibliometric analysis, the most common neuroimaging techniques applied in advertising, and the main brain regions and processes of interest for advertising. Section 4 presents the discussion and conclusion of our work.

2. Materials and Methods

To answer the three research questions, this study is divided into two folds. First, we have used a bibliometric analysis to know the global trends in the neuromarketing topic based on the outputs of publications such as the number of publications, citations, the productivity of each country and academic institution, and assessing the advancement in the scientific domain [18]. Second, we have followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework of Moher et al. [19] to select empirical and review papers that employed neuroimaging tools in advertising research, to fill the gap, and to understand the global research trends in a neuromarketing field and the neural correlates of emotional and cognitive processes in advertising. The research is characterized by extracting documents from the Web of Science (WoS) database relevant to our study. However, we also followed instructions recommended by Block and Fisch [20] to present an impactful bibliometric analysis and evaluate the structure of a specific research field that characterizes the most productive journals, authors, countries, institutions, and the most citations, with a brief description of each part. This process

would help us to understand the development of the neuromarketing domain and the field of advertising studies by identifying and analyzing the general and particular domain. Relevant documents were extracted from the WoS by using the following query applied to the title, abstract, and keywords: ("neuromarketing" OR "consumer neuroscience").

The overall number of publications was 570 documents from 2004 to 2020. A total of 63 articles were selected. As shown in Figure 1, we followed PRISMA framework, which includes four stages: (i) identification as recording identified through database searching, (ii) screening the record publications, (iii) eligibility means assessment the eligible publications for this review, and (iv) selecting and including studies, as follows:

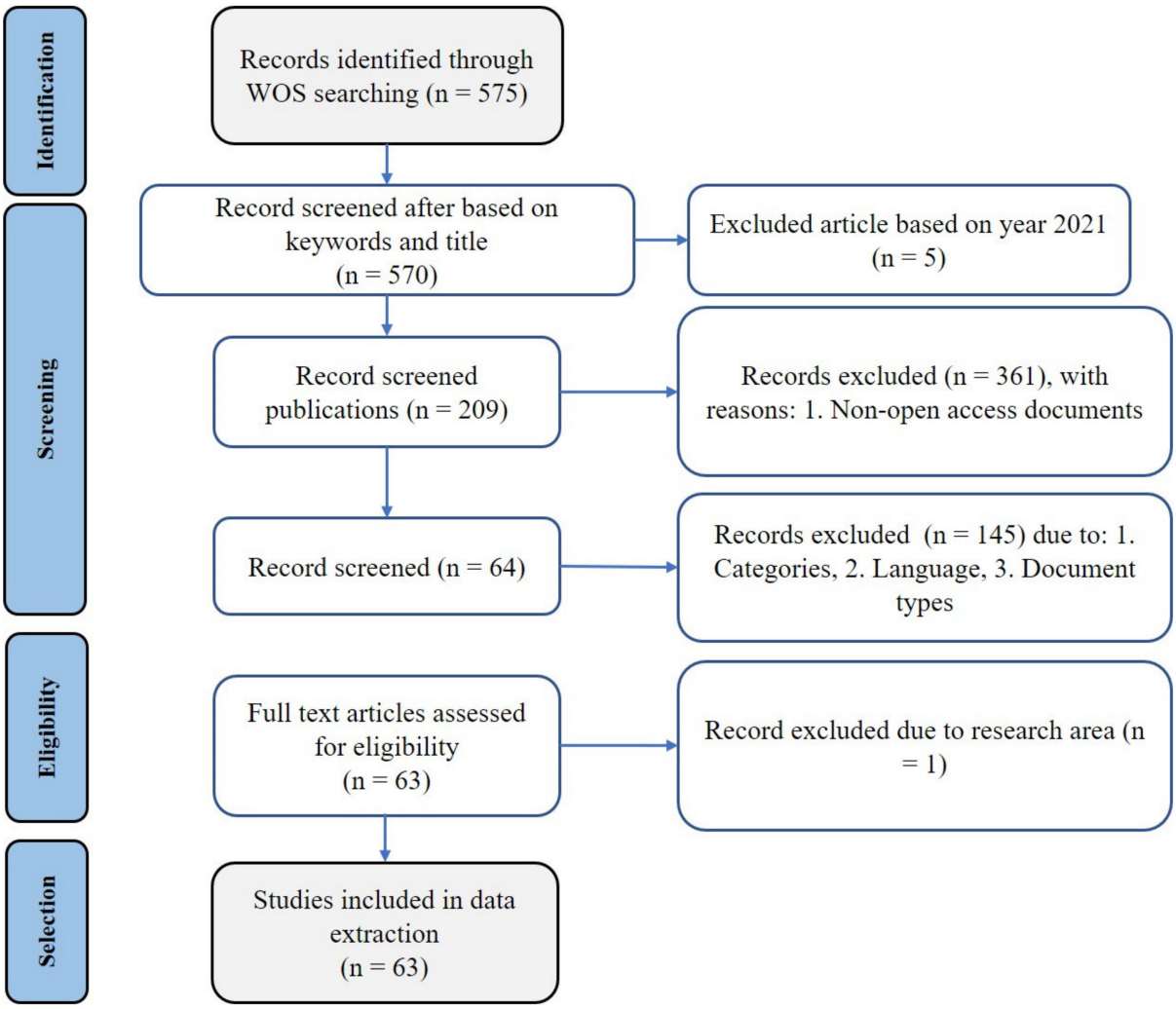

Figure 1. PRISMA flow chart. Source: own illustration.

- Articles and reviews published from 2004 to 2020 were included.
- We excluded any documents published in non-English languages.
- We excluded any irrelevant publications (e.g., book chapters, conferences, and so forth).

We selected studies that applied neuroimaging techniques in advertising campaigns, the scope of applying these techniques in advertising, as well as the neural correlates of cognitive (e.g., attention and memory) and emotional processes (e.g., emotion) in advertising. By reviewing the selected publications for this study, we will improve our insights to accomplish the objective of this review study.

3. Results

3.1. Bibliometrics Analysis

3.1.1. Leading Countries and Academic Institutions

Table 1 shows that the USA, Italy, UK, Germany, and China were the key players in the advancement of neuromarketing studies, which published approximately more than 50% of the global documents. Nevertheless, the USA led the top productive countries with 16 papers, which were published in several journals, and the University of California System was published in three papers. The second most productive country in the neuromarketing topic is Italy with nine papers. The third, fourth, and fifth productive countries in the list are UK, Germany, and China, with seven papers for each country. Although China is located in the fifth position in the most productive country, its academic institution Ningbo University has published the largest number of documents, with four papers among other academic institutions. The sixth country on the list is the Netherlands with four papers. Finally, Malaysia, Lithuania, Denmark, and Brazil published the same amount of publications, with three papers for each country.

Table 1. The 10 top prolific academic institutions and countries in the neuromarketing topic. Use the following URL to open the map of productive institutions in VOSviewer: https://bit.ly/3usc68y (accessed on 1 March 2021).

Country	TP	% of Selected Publications	The Most Prolific Institution	TPI
USA	16	35.6%	University of California System	3
Italy	9	20.0%	Sapienza University Rome	3
UK	7	15.6%	Aston University	2
Germany	7	15.6%	Heinrich Heine University Dusseldorf	3
China	7	15.6%	Ningbo University	4
Netherland	4	8.9%	Erasmus University Rotterdam	2
Malaysia	3	6.7%	Monash University Sunway	2
Lithuania	3	6.7%	Vytautas Magnus University	3
Denmark	3	6.7%	Copenhagen Business School	2
Brazil	3	6.7%	Universidade De Sao Paulo Univ Sao Paulo	1

Note: TP; total publications. TPI; total publications by institution.

3.1.2. Leading Authors

We found the top ten prolific authors in publishing about the neuromarketing area belong to seven countries/territories as tabulated in Table 2. These authors published a total of 25 papers, which indicates a high collaboration among them. Additionally, the most productive author is Ma, Qingguo from China, with a total of four papers, 11 citations by the end of 2020, and two h-index. Next is Lee, Nick from the UK, who published three papers in neuromarketing with 35 citations and three h-index, which is considered the highest h-index in the list. Meanwhile, Berns, Gregory s. from the USA published two papers with two h-index, and has the highest number of the citations with 462 by the end of 2020. Gier, Nadine Ruth from Germany published two papers and four citations. Finally, the author from Malaysia, named Goto, Nobuhiko, published two articles, 15 citations by the end of 2020, and one h-index.

Table 2. The 10 top productive authors in neuromarketing research. Use the following URL to open the map of productive authors in VOSviewer: http://bit.ly/3uvMHuI (accessed on 1 March 2021).

Author's Name	TP	TC 2004–2020	Cit. 2021	H-Index	Affiliation	Country
Ma, Qingguo	4	11	1	2	Zhejiang University of Technology	China
Lee, Nick	3	35	1	3	Aston University	UK
Grigaliunaite, Viktorija	3	7	0	2	Vytautas Magnus University	Lithuania
Pileliene, Lina	3	7	0	2	Vytautas Magnus University	Lithuania
Berns, Gregory S.	2	462	5	2	Emory University	USA
Babiloni, Fabio	2	80	0	2	Sapienza University Rome	Italy
Brandes, Leif	2	29	1	2	University of Warwick	UK
Chamberlain, Laura	2	29	1	2	University of Warwick	UK
Gier, Nadine Ruth	2	4	0	1	Heinrich Heine University Dusseldorf	Germany
Goto, Nobuhiko	2	15	1	1	Monash University	Malaysia

Note: TP; total publications. TC; total citations. Cit; citation.

3.1.3. Leading Journals

The findings indicate that the Frontier in Neuroscience journal is the most productive journal with 12 documents, as tabulated in Table 3, followed by Frontiers in Human Neuroscience, which published five documents. The 3rd productive journal is Neuropsychological Trends which has published three documents. Biological Psychology, Cognitive Neurodynamics, Computational Intelligence and Neuroscience, European Journal of Marketing, and Scientific Annals of Economics and Business have published the same number of documents, two for each journal.

Table 3. The most productive journals in neuromarketing research (minimum publication two documents). Use the following URL to open the map of productive journals in VOSviewer: http://bit.ly/3pEvjQE (accessed on 1 March 2021).

Source/Journal	TP	TC 2004–2020	H-Index
Frontiers in Neuroscience	12	87	5
Frontiers in Human Neuroscience	5	13	3
Neuropsychological Trends	3	3	1
Biological Psychology	2	15	1
Cognitive Neurodynamics	2	39	2
Computational Intelligence and Neuroscience	2	60	2
European Journal of Marketing	2	31	2
Scientific Annals of Economics and Business	2	7	2

3.1.4. Keywords Analysis

The keywords co-occurrence has a significant quantitative (numerical) technique in bibliometrics [21] to investigate scientific constructs according to the assumption because keywords provide a coherent explanation to the articles' content [22], wherein the connection between two keywords is expressed by a numerical value, which indicates a link strength between these two keywords; a higher numerical value means a stronger link (link strength) [23]. The link strength between two keywords represents the number appearances of both these keywords in the same article. The total number of links indicates the aggregate number of appearance together in the same paper. In VOSviewer, we set one as the minimum occurrences of a keyword, which means keywords will appear on the bibliometric map at least one time between these two keywords that occur together in the same paper. In this study, a keywords co-occurrence analysis has been conducted, which involved 420 keywords from 63 articles in 41 journals with one source as a minimum number of documents. Additionally, the synonymic keywords have been analyzed

before inserting the data into VOSviewer. For example, "neuromarketing", and "consumer neuroscience".

Comerio and Strozzi [22] proposed that the keywords co-occurrence analysis is significant to provide general claims about the content of articles. Scholars usually use keywords co-occurrence analysis as an effective method to address the trends of research on a particular subject by exploring existing academic articles [18], including the neuromarketing field [24]. By following Khudzari et al. [18], We carry out keywords co-occurrence analysis to assess the hot themes in neuromarketing. The result of the keywords co-occurrence map (Figure 2) shows that the neuromarketing research is mainly concentrated on decision-making (13 occurrences, 165 link strength), which means that decision-making appeared thirteen times and the link strength for these aggregate appearance is 165 links with neuromarketing topic; as we aforementioned, the higher the number value, the stronger the link. This indicates that most of the research on neuromarketing focused on examining the association between consumer behavior and marketing practices. One possible interpretation of that is the mismatching between the conscious world, which drives marketing practices (i.e., advertising), and the unconscious world, which drives decision-making processes in the human brain [25].

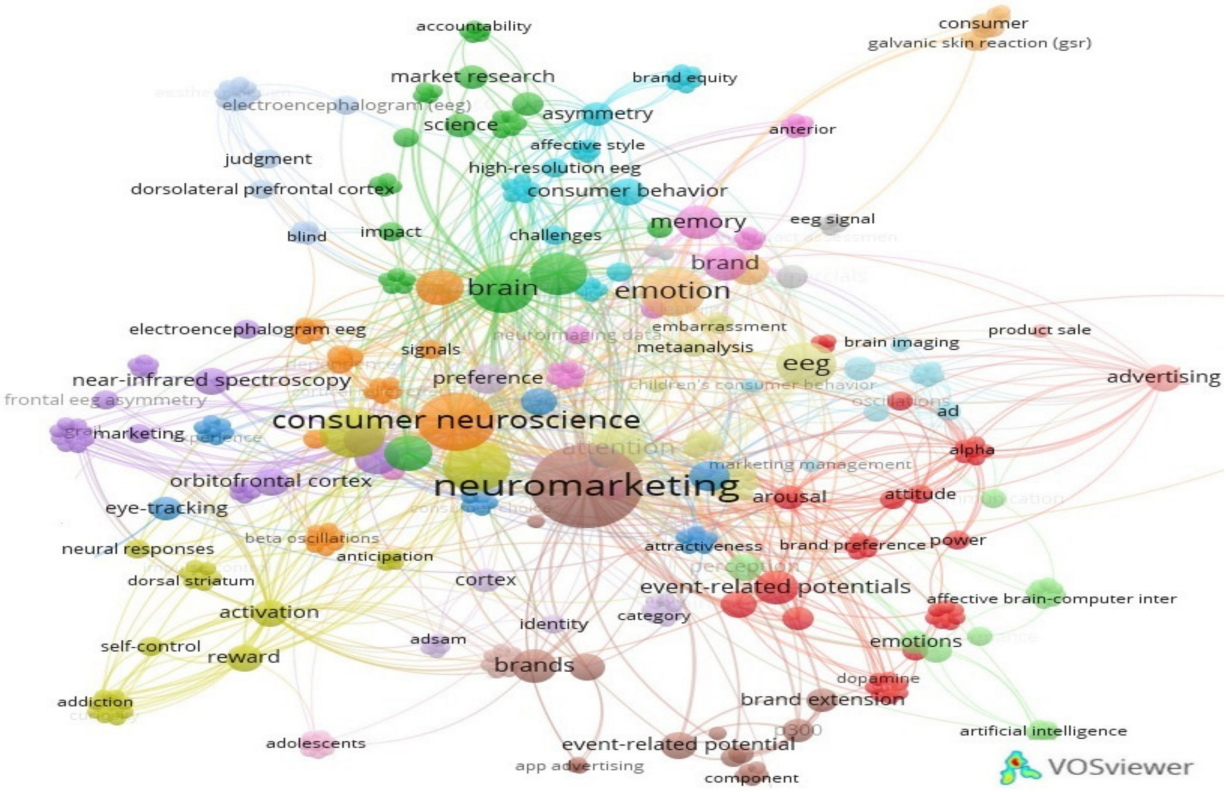

Figure 2. The bibliometric map of all keywords co-occurrence. Use the following URL to open this map in VOSviewer: http://bit.ly/3qDdmmQ (accessed on 1 March 2021).

Additionally, it was expected to have a strong connection with other consumer behavior aspects such as "emotion", which is the second most examined theme(13 occurrences, 159 link strength), followed by "attention" (10 occurrences, 141 link strength). Furthermore, the fMRI was observed to be a tool highly associated with neuromarketing research (14 occurrences, 268 link strength), followed by "EEG" (11 occurrences, 132 link strength), then "ERP" (6 occurrences, 91 link strength). Table 4 presents a summary of the most frequent keywords, wherein the highest keyword occurrence is neuromarketing.

Table 4. Top keywords by the frequency of their occurrence.

Keyword	Occurrences/Frequency	Total Link Strength
Neuromarketing	38	409
Consumer neuroscience	18	243
fMRI	14	268
Decision-making	13	165
Emotion	13	159
Attention	10	141
Brain	12	139
EEG	11	132
Neuroscience	10	112
ERP	6	91
Neuroeconomics	6	79

3.1.5. Citations Trend

To answer the RQ1, we identify the most common articles in the neuromarketing subject by using citation analysis. Citation analysis indicates the number of citations by other documents to a specific document in order to determine the impact and popularity of the academic article [26]. We analyzed the citation of 63 articles. The findings showed that the most cited journal among neuromarketing journals is Nature Review Neuroscience with approximately 347 citations. In addition, the result shows that the most citation articles that were cited more than 100 times were published by Nature Review Neuroscience and Elsevier, as tabulated in Table 5. Ariely and Berns [27] published the most cited articles, with 347 citations, while the least cited document in the list was published in 2013 by Kong et al. [28], with 24 citations.

Table 5. The ten top articles on WOS ordered by citation score among selected publications.

Authors/Year	Title	Journal	TC 2020
Ariely and Berns [27]	Science and society neuromarketing: The hope and hype of neuroimaging in business	Nature Reviews Neuroscience	347
Berns and Moore [29]	A neural predictor of cultural popularity	Journal of Consumer Psychology	120
Vecchiato et al. [30]	On the use of EEG or meg brain imaging tools in neuromarketing research	Computational Intelligence and Neuroscience	56
Bruce et al. [31]	Branding and a child's brain: An fMRI study of neural responses to logos	Social Cognitive and Affective Neuroscience	41
Schneider and Woolgar [32]	Technologies of ironic revelation: enacting consumers in neuromarkets	Consumption Markets & Culture	32
Lin et al. [33]	Fusion of electroencephalographic dynamics and musical contents for estimating emotional responses in music listening	Frontiers in Neuroscience	32
Morris et al. [34]	Mapping a Multidimensional Emotion in Response to Television Commercials	Human Brain Mapping	27
Chen et al. [35]	From "Where" to "What": Distributed Representations of Brand Associations in the Human Brain	Journal of Marketing Research	26
Treleaven-Hassard et al. [36]	Using the P3a to gauge automatic attention to interactive television advertising	Journal of Economic Psychology	25
Kong et al. [28]	Electronic evaluation for video commercials by impression index	Cognitive Neurodynamics	24

Co-Citations Analysis

Co-citation also helps to identify the thematic gaps and structure of literature in a specific topic through co-citation analysis [20]. Additionally, it helps scholars to identify the topic area and the content of that topic through assessing the most frequently cited references together. Similarity in theory, method, and subject can be indicators of the

appearance of two publications more than once in the reference list. Therefore, we have used the VOSviewer software to measure the correlation between a couple of references by using the link strength between them, wherein the number of the total refers to the link strength between these references [37]. Table 6 shows the numbers of link strength between the couple of authors, wherein higher numbers means higher correlations between them. We found that 21 pairs of articles co-cited with each other at least ten times. Additionally, we also found that the number of link strength between Lee et al. [38] and Lee et al. [39] is 34 links, as the strongest co-citation correlation between a couple of authors. The link strength between Lee et al. [39] and Ramsøy et al. [40] was the second strongest co-citation between a couple of authors, with 13 links, followed by Ariely and Berns [27] and Berns and Moore [29]. These findings confirm our discussion in the body of literature in neuromarketing, wherein neuromarketing concentrates on the consumer's behaviors, benefits of neuromarketing in advertising research, and the neural correlates in the brain toward advertisements.

Table 6. The ten top document pairs with more than 3 link strength.

Title	Author 1	Author 2	Link Strength between Authors 1,2
This is your brain on neuromarketing: reflections on a decade of research	Lee et al. [38]	Lee et al. [39]	34
Welcome to the jungle! The neuromarketing literature through the eyes of a newcomer	Lee et al. [39]	Ramsøy et al. [40]	13
Neuromarketing: the hope and hype of neuroimaging in business	Ariely and Berns [27]	Berns and Moore [29]	13
From "Where" to "What": Distributed Representations of Brand Associations in the Human Brain	Chen et al. [35]	Hsu and Yoon [41]	13
Trust me if you can–neurophysiological insights on the influence of consumer impulsiveness on trustworthiness evaluations in online settings	Hubert et al. [42]	Lee et al. [39]	7
Electronic evaluation for video commercials by impression index	Kong et al. [28]	Vecchiato et al. [30]	6
Neural signals of selective attention are modulated by subjective preferences and buying decisions in a virtual shopping task	Goto et al. [43]	Lee et al. [39]	5
A neural predictor of cultural popularity	Berns and Moore [29]	Chen et al. [35]	5
The neuroscience of consumer choice	Hsu and Yoon [41]	Ramsøy et al. [40]	5
Ethical responsibility of neuromarketing companies in harnessing the market research–A global exploratory approach	Pop et al. [44]	Schneider and Woolgar [32]	5
Branding and a child's brain: an fMRI study of neural responses to logos	Bruce et al. [31]	Chen et al. [35]	4
Social Consumer Neuroscience: Neurophysiological Measures of Advertising Effectiveness in a Social Context	Pozharliev et al. [45]	Wei et al. [46]	3

Co-Citation Network and Data Clustering

VOSviewer software has been used for analysis of the co-citation network that helps scholars to address the intellectual development in a specific area. It has identified some clusters to carry out the content analysis; thereby studying, exploring, and understanding the structure and nature of neuromarketing tools in the advertising field. We found

49 articles that co-cited at least one time with another. Among these articles, we noticed that at least ten times of co-citation have occurred just in 21 articles. We followed the instructions recommended by Baker et al. [47]; Ali et al. [48]; Alsharif et al. [24] to visualize the co-citation network map of the top ten articles by using VOSviewer software. Similarly, we used the weighted citation count that is provided by VOSviewer software to get the high-quality articles in each cluster.

As shown in Figure 3, the analysis results of the relevant documents illustrated three clusters with a high correlation between them. Among these three clusters, the green one is the largest cluster, which is dominated by Ariely and Berns [27] with 605 total citations, followed by the red one, which is led by Vecchiato et al. [30] with almost 198 total citations. Finally, the blue group is led by Schneider and Woolgar [32] with approximately 107 total citations. For the green group, the citations number of Ariely and Berns [27], Berns and Moore [29], Bruce et al. [31], Chen et al. [35], Treleaven-Hassard et al. [36], Hsu and Yoon [41], Santos et al. [49], and Hubert et al. [42] are 347, 120, 41, 26, 25, 16, 16, and 14, respectively. For the red group, the citations of Vecchiato et al. [30], Lin et al. [33], Morris et al. [34], Kong et al. [28], Goto et al. [43], Chew et al. [50], and Pozharliev et al. [45] are 56, 32, 27, 24, 16, 16, and 15, respectively. For the blue group, the citations of Schneider and Woolgar [32], Pop et al. [44], Ramsoy et al. [40], Lee et al. [39], and Lee et al. [38] are 32, 23, 22, 19, and 11, consecutively. Although these clusters/groups address various aspects of neuromarketing, they are highly interconnected and complementary.

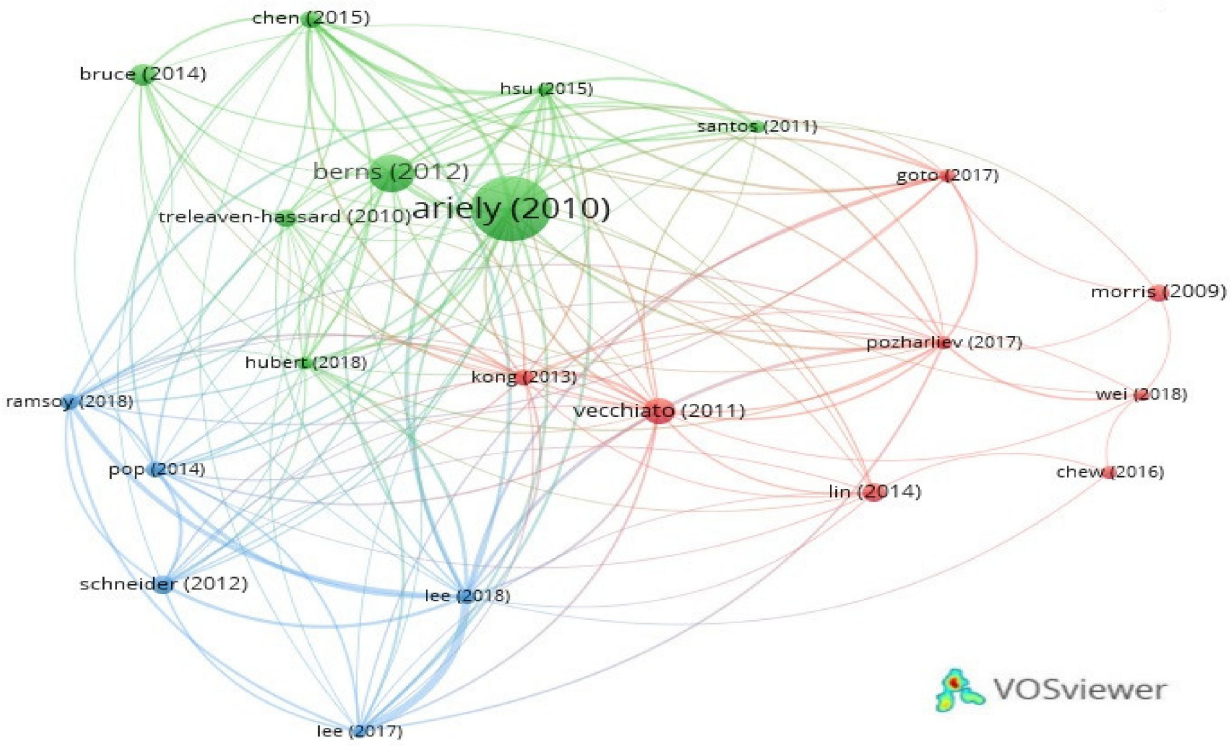

Figure 3. Map of documents citations 21 articles (minimum of 10 citations). Use the following URL to open this map in VOSviewer URL: http://bit.ly/3aByx3o (accessed on 1 March 2021).

3.2. An Overview of Neuroimaging Tools Used in Advertising Research

Advertising is the branch that most benefits from neuromarketing tools. Neuromarketing tools (e.g., psychological and neuroimaging tools) have been used to know the influence of advertising on the neural mechanisms of consumers and decision-making [51–53]. For example, these tools enable to identify neural correlates of emotional and cognitive processes in advertising, to identify the negative or the positive elements in advertising that cause aversion or approach behavior, to determine visual and sound features, to select

the suitable media for advertising [54], to obtain unspoken new information [24], and thereby creating more effective commercial advertisings [55], social initiative ads [56], and antismoking campaigns [57,58]. These tools record and measure the emotional and cognitive processes toward advertising and the effect of stimuli to be implemented at the purchase point to promote sales [59].

Advances in non-invasive neuroimaging tools in the last decade facilitated to record consumers' neuro-signals with wearable, portable, reliable, and comfortable tools. That has grabbed immense attention from both academia and industrial field, and collaboration between marketers, neuroscientists, and psychologists in order to better understand what drives consumer behavior and neural processing of advertising in the human brain [60]. For example, it has divided neuroimaging tools that provide evidence on neural correlates of advertising and consumers' behavior into two categories, as follows: (1) recording electrical activity signals such as electroencephalography (EEG) and magnetoencephalography (MEG), and (2) recording metabolic activity signals such as functional magnetic resonance imaging (fMRI) and functional near-infrared spectroscopy (fNIRS) [13,61–65].

By neuroimaging tools, it has become possible to record and analyze the neural signals activity in the brain; thereby, these tools have become significant for early evaluation of marketing practices such as advertising [66,67]. The neuroimaging tools such as fMRI, fNIRS, EEG, and MEG are common used in advertising research, and undoubtedly, each tool has pros and cons (e.g., cost, analysis data time, sample size, and spatial and temporal accuracy) [14].

3.2.1. Functional Magnetic Resonance Imaging

FMRI is also a non-invasive tool that used huge magnetics to detect the metabolic changes in the brain by recording the level of oxygen in the blood vessels, wherein the active regions in the brain produce stronger signals than inactive regions [68,69]. Additionally, it has excellent spatial accuracy (estimated 1–10 mm^3 in deep structure of the brain) and acceptable temporal resolution (estimated 1–3 s) [70]. Alongside that, it uses 3D technology to record and analyze the brain's signals and display them on the monitor [35], which is helping the researchers and scientists to measure brains' reaction, such as emotional and cognitive processes, toward advertising [60,71–76], wherein fMRI is used to know the influence of advertising on buying decisions [76,77]. Articles have been analyzed one-by-one, and the authors found that the fMRI tool was used in ten articles (approximately 17% of total articles).

3.2.2. Electroencephalography and Magnetoencephalography

EEG is used the first time to measure consumers' response toward television advertisements in the early of 1970s [11]. EEG is a non-invasive tool using electrodes on the scalp to record the frequency of the active neurons in the brain directly [78]. Additionally, EEG can record the activation regions in the brain in milliseconds due to the high temporal resolution, but on the opposite, has a poor spatial resolution that enables to record the cortical brain activity (approximately 1 cm3 brain structure) [70,74,79–81]. According to literature, EEG has five frequency bands such as delta (0–4 Hz), theta (4–7 Hz), alpha (8–15 Hz), beta (16–31 Hz), and gamma (larger than 32 Hz) [46]. EEG is not as expensive and noisy as the fMRI technique, but is limited to recording the cortical activity of the brain; thereby, it is not a good technique for recording the regions underneath the cortical [68]. EEG is used to measure the cognitive processes (e.g., attention, memory) and emotional valence [67,82–84]. MEG is similar to EEG, but MEG uses a magnetic field to measure the activity regions in the brain, and it has a greater spatial resolution than EEG and high temporal resolution [79]. Both of them are somewhat limited to record the cortical activity of the brain; thereby, they are not good technologies for recording the regions underneath the cortical [68]. We analyzed articles one-by-one, and the authors found that the EEG tool has been used in fifteen articles (almost 24% of total articles), which is deemed as the most

used tool in advertising research within a neuromarketing context, and the MEG tool was employed twice in two articles (approximately 4% of total articles).

3.2.3. Functional Near-Infrared Spectroscopy

fNIRS is analogous to fMRI, is a non-invasive tool that is used to record modifications in hemoglobin flow (e.g., oxyhemoglobin and deoxyhemoglobin) during brain activity and establish a map of the blood oxygenation in the local brain area [85], wherein the active regions in the brain required more oxyhemoglobin [86]. However, fNIRS has poor spatial resolution that is limited to recording the cortical regions and cannot be employed to measure the deeper structures of the brain, and the temporal resolution is relatively acceptable (estimated in few seconds) [12]. However, there are several advantages of the fNIRS tool such as being portable, inexpensive, and not noisy. Each tool used in neuromarketing research has pros and cons, making them more or less suitable for various research circumstances. Based on the results, it has been found that the fNIRS was used in two articles (approximately 4% of total articles) due to it being a new tool.

These tools depend on temporal and spatial accuracy in recording the activity regions to answer questions related to the marketing issues [87]. Although, all these tools have been applied in advertising campaigns to evaluate the neural correlates of constructs such as emotion, memory, and attention [88] to evaluate the neural processing in advertising [89]. Table 7 illustrated the main neuroimaging tools that have applied in advertising campaigns, advantages and disadvantages, measure brain activity (e.g., cognitive and emotional processes), and when they are used.

The answer of the RQ2, we have analyzed the selected articles one-by-one, and it was found that the EEG tool has been used in fifteen articles (almost 24% of total articles), which is deemed as the most used tool in advertising research within a neuromarketing context, followed by the fMRI tool, which was used in ten articles (approximately 17% of total articles), then the MEG tool was employed twice in two articles (approximately 4% of total articles). Finally, although the fNIRS is not so expensive a tool compared to others and considered as a new neuroimaging tool, therefore, it was used in two articles (approximately 4% of total articles). Therefore, the EEG tool is considered as the most neuroimaging tool that used in advertising research.

Table 7. Application of neuroimaging techniques in advertising campaigns.

Tool	Brain Activity (Cognitive and Emotional Processes)	When Is It Used?	Advantages	Disadvantages	Cost
fMRI	Memory, sensory perception, emotional valence (e.g., positive or negative), emotional arousal (e.g., high or low), attention, reward, engagement.	Testing advertisements, brand, packaging design, prices, reposition a brand, sensory celebrity endorsement, online experience, product quality, promotion, product characteristics, predicting consumer's choices and identify their needs.	High spatial accuracy (estimated by 1–10 mm^3 of deep structures), reliable and valid for measuring cognitive processes (e.g., attention, emotion, and memory), localizing neural processing during consumer choices and consumption experience, ability to detect changes in chemical composition or changes in the flow fluids in the brain.	Low temporal accuracy (estimated by 1–10 s), expensive, non-scalable, inconvenient, the complexity in data analysis, and ethical barriers as an invasion of privacy, need wide rooms.	High
EEG	Emotions (e.g., valence and arousal), attention, memory, cognition and recognition, engagement or boredom, excitement, and mental workload.	Testing advertisements, logo, developing advertisements, in-store environment, app and social media, website design and usability, movie trailers, packaging design, pricing, sensory studies, prints and images design, and identifying the key moments of an advertisements or video.	High temporal accuracy (estimated by milliseconds), relatively inexpensive, non-invasive tool, data analysis straightforward, valid for measuring cognitive information processing, statistical software packages available, allows comparisons between left and right hemispheres.	Low spatial accuracy (almost 1 cm^3), non-scalable, results can be influenced by artifacts and experimental settings, difficult to retrieve the exact location for each recorded signal, it is not possible to record the emotional arousal.	Moderate- High
MEG	Attention, memory, perception.	Testing advertisements, brand, new product, packaging design, sensory studies, and identify needs.	Good temporal accuracy, non-invasive, able to detect changes in chemical components.	Low spatial accuracy, expensive, and ethical barriers, need for a room with low temperatures.	High
FNIRS	Attention, emotion (e.g., valence and arousal), sensory perception.	Testing advertisements, brand, prices, product (e.g., quality, characteristics, and experience).	Low sensitivity to motion artifacts, portable, low cost, use in real-world situations, comfortable.	Low spatial accuracy and temporal accuracy.	Moderate

Source: [12,60].

3.3. Main Brain Processes and Regions of Interest for Advertising

Every year, millions and maybe billions of US dollars are spent on advertising campaigns to reach a large number of target audiences and maintain the consumers' purchase processes. Selecting media channels should be compatible with the purpose of advertising, features of product and target market characteristics. Thus, every day consumers are exposed to hundreds of ads by media such as TV, radio, and so forth [90]. Kotler and Keller [91] defined advertising as a paid communication to inform or persuade target audiences about a certain organization, product, brand, service, or even idea. Globally, when the coronavirus put a halt on many industries, the spending on advertising worldwide has been increasing steadily. It is expected to go back on a steady growth track starting in 2021, and exceed 630 billion US dollars in 2024, wherein TV advertising spending in 2019 amounted to more than 176 billion U.S. dollars. Although it is expected to decrease to nearly 158 billion dollars by 2022, it will remain the largest spending sector among media sectors [92].

In today's hyper-competitive environment, advertising has become more complicated and challenging, therefore, marketing research should adapt to this new situation to achieve advertising excellence [12]. At the end of the 20th century, businesses began employing concepts and neuroscience tools such as the fMRI to study the consumer behavior (e.g., decision-making) toward marketing stimuli. The findings showed that the majority of mental processing occurs unconsciously or subconsciously, which highly contributes to decision-making [93]. The majority of studies examine the impact of advertising on attention, emotions, memory, and making decisions processes. For instance, neuromarketing studies focus on how consumers evaluate, process, and experience advertisements [36,94,95]. Hence, neuroimaging tools has been introduced to explore, understand, analyze, and explain the consumer behavior (e.g., decision-making), emotional processes (e.g., emotions and feelings), and cognitive processes (e.g., attention and memory) toward advertising campaigns [94–99].

Indeed, advertising is the branch that most benefits from neuromarketing [100] because neuromarketing is capable to record and measure the impact of advertising on the neural mechanisms of consumers and decision-making in the human brain [53,101]. Thus, neuromarketing has improved our understanding of cognitive, neuronal, and emotional processes in the brain related to advertising campaigns [59]. Advertising illustrated a rising interest in measuring cognitive and emotional processes. Figure 4 illustrated the proposed framework of brain processes and regions of interest for advertising.

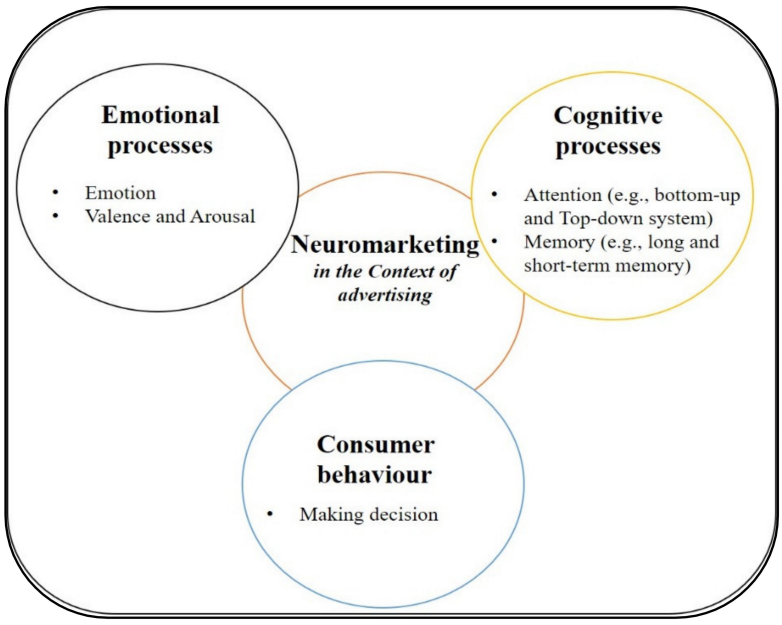

Figure 4. The proposed framework of main brain processes of interest for advertising. Source: own illustration.

3.3.1. Decision-Making Processes

For decades, marketing research oriented all efforts to understand how the consumer decision-making and the mechanisms of making decisions. Therefore, many models and theories aimed to understanding the decision-making process through qualitative or quantitative research methods [11]. The market research has been focused on qualitative methods because researchers believe maybe these methods can help to reveal consumers' decision-making process [55]. According to [102], the consumers do not fully realize what led them in taking a particular decision, and it has been discovered that the making decision process is more complicated than we had realized. This led us to infer that the decision-making process is not only relying on rational factors, but also unconscious processes such emotion, attention, and memory [103]. Therefore, there are essential factors that are playing a vital role in decision-making processes such as emotions, attention, and memory. That is the reason for orienting towards consumer neuroscience studies [104,105].

To answer the second part of the RQ3, it has been found that several areas of the PFC are the most important regions in the consumer brain when we talk about decision-making processes, wherein the regions behind the frontal praise, the premotor cortex and the motor cortex, translate the decisions into concrete actions [106]. For example, some studies showed that the orbitofrontal cortex (OFC) and the ventromedial prefrontal cortex (vmPFC) are engaged in making decisions through the perceived value of ads or products, processing different choices [107,108]. The dorsolateral prefrontal cortex (dlPFC) plays a vital role in decision-making processes; in terms its responsibility for cognitive control over emotions [109]. In addition, the ventrolateral prefrontal cortex (vlPFC) plays a vital role in motivating social norm compliance by display expose to threats from others [110]. Therefore, these regions in the brain can provide valuable insights about decision-making processes and consumer choices.

3.3.2. Emotional Processes

At the beginning of the 21st century, the role of emotions increasingly grabbed attention from both academia and industrial environments because emotions drive consumer choices [111]. Emotion is one of the aspects that most gets the attention of many researchers. Indeed, emotions are accompanied by involuntary somatic reactions such as facial expressions (e.g., smiling and frowning) and physiological reactions (e.g., sweating), which are caused by changes in the autonomic nervous system (ANS) [112]. The role of emotions in decision-making has been further explained through neurological and cognitive frameworks such as the somatic marker theory [113]. The majority of researchers agreed on two dimensions of measuring emotion: (a) valence, and (b) arousal [53]. Valence refers to either positive emotions (e.g., pleasure) or negative emotions (e.g., displeasure) that are produced by a stimulus or the situation that elicits individuals [114–116], while arousal refers to the intensity of emotional responses, which are commonly used to classify the different forms of emotional affect either high arousal (e.g., surprised) or low arousal (e.g., calmness) (Figure 5) [114,117,118]. It may be high when the stimulus produces a high activation in the participation (e.g., surprised) or maybe low when produces low activation (e.g., calmness). Several models have affirmed on both valence and arousal as two dimensions of emotion [119–121]. With these two dimensions, valence measures from positive to negative while emotional arousal measures from high to low [117,121,122]. In the same context, it is too difficult to separate between them because stimuli used to induce emotional valence, as well as to determine a change in emotional arousal [123]. Therefore, it is not only important to examine the role of positive and negative stimuli in attention and the associated processes, but also to dissociate between different levels of arousal within the emotional categories, which can be achieved [124].

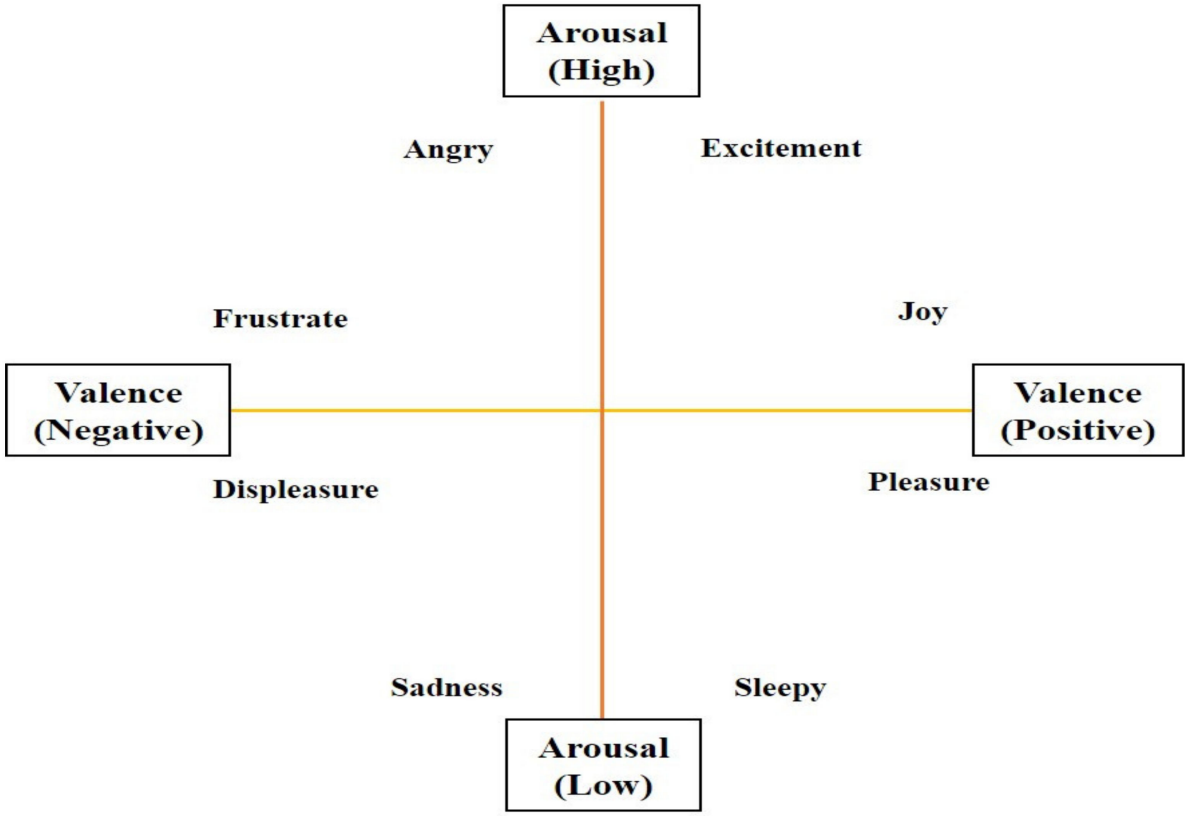

Figure 5. Valence and arousal model of emotions [118].

Contemporarily, researchers attempted to investigate brain activity signals correlated with an increase of emotional processes during the interaction with marketing stimuli such as advertisements [88,125]. To answer the second part of the RQ3, the literature findings showed that the frontal cortex (FC) and prefrontal cortex (PFC) regions play a central role in generation of emotions [126,127]. The left PFC is linked with approach behavior, while the right PFC connected with withdrawal/avoidance behavior [128]. Additionally, the amygdala is correlated with regulation of emotional responses, which involves the emotion processing toward marketing stimuli such as ads [110]. For example, fMRI studies showed that the positive valence (pleasure) related to a stronger activity in the orbitofrontal cortex (OFC), while negative valence (displeasure) associated with a stronger activity in the lateral OFC and left dorsal anterior insula [129]. O'Doherty et al. [130] found that a negative valence is connected to a stronger activity in the lateral OFC. Morris et al. [34] carried out the experiment to record the neural reactions of the three keys of emotion (e.g., arousal, dominance, and pleasure) toward TV ads by using fMRI tool. They found that the arousing and pleasant advertising are connected to the frontal and temporal brain regions. Similarly, the fMRI has been used by Chen and Morris [73] to record emotional responses toward TV ads. The findings revealed that the arousal and pleasure play a vital role in emotions toward advertisements, which led to decision-making.

3.3.3. Cognitive Processes

Attention and emotion are highly connected to each other [131,132]. The PFC also plays a vital role in attention, which is linked with the neurons of processing visual stimuli in the occipital lobe (primary visual cortex) in the brain [133]. Consumers receive approximately 11 million bits of information every second through their senses (e.g., vision, olfactory, and so forth), but the ability of consumers to process information has been estimated at 50 bits [134]. That leads us to attention and how consumers perceive and process information, and thus select information that gets prioritized over other available

information [122]. According to Meneguzzo et al. [135], perception of unconsciously perceived stimuli has activated the anterior cingulate cortex (ACC) and insula cortex in order to shape the basis of conscious perception. According to the literature, there are two types of attention system: (a) bottom-up (saliency filters), and (b) top-down system [13,136]. Furthermore, the anterior cingulate cortex is playing a vital role in a dynamic relationship between top-down modulation and bottom-up primary sensory [135,137]. For example, Smith and Gevins [138] found that occipital lobe (OL) is connected to attention processes to TV ads. A recent fMRI study found that the compatibility between advertising and gender voice (male, female) induce endogenous attention regions [139].

- Bottom-up system (visual saliency/involuntary control); this system is driven by automatic neural processes toward the external world. In other words, in this system, the process begins from the external stimuli (e.g., color, contrast, brightness, etc.) that automatically grab consumers' attention, therefore, the signal comes from external stimuli to the eyes to the thalamus regions and then to the primary visual region in the occipital lobe (OL), as depicted in Figure 6 [13,136,140–142].

Figure 6. The model of bottom-up attention system. **Source:** own illustration.

- Top-down system (goal-driven attention/voluntary control); this system is oriented by consumers toward goals and relies on internal and external states, goals, and expectation (goal-driven attention). In this system, the dlPFC and parietal cortex are engaging and modulating the activation of the primary visual cortex in the occipital lobe, as shown in Figure 7 [13,136,140–142]. In other words, this is where you need to focus your mental energy, need to think hard about what you want to look at. Therefore, the signal begins from the internal world of the consumer.

Figure 7. The model of top-down attention system. Source: own illustration.

Memory studies provide valuable insights into the neural correlates of advertising in the brain. Memory is the most complicated variable among others, and marketers and advertisers are highly interested in encoding and retrieving memories besides long-term memory (LTM) and short-term memory (STM) processes [132,140]. To answer the second part of the RQ3, it has been noticed that the hippocampus (HC) plays a major role in generating memories and processing of memory. Additionally, the amygdala (AMY) is located next to and closely related to the HC, which is a significant modulator of the memory system [143]. Therefore, emotions also play a vital role in memory processes, which help us to store and remember memories [132,144]. Rossiter et al. [145] conducted the first study to measure visual memory encoding toward TV ads by using EEG. They found that the left-brain hemisphere is responsible for transferring the information from short-to-long term memory. Fallani et al. [146], Astolfi et al. [147] used EEG to assess the brain regions triggered by successful memory-encoding of TV ads. The findings showed more activity in the cortical area irrespective the frequency of the EEG. The EEG investigations

into the effect of message advertising on the recognition memory. The results showed activity in the gamma band, which directly effects memory, and also the significance of the EEG tool in study the advertising message processing [148]. Previous fMRI study found that greater activity in the amygdala and fronto-temporal are linked with memory ads (memorable and unmemorable) [149,150].

3.4. Ethics

Actually, the significant concern for the term "Neuromarketing" has only quickly increased throughout the last decade, which led to discussing series of ethical issues not only in society, but also in scientific committees, media, and press [151]. For example, when the publicity and media have reported about the potential dangers of NM regarding finding a "buy button" in the individuals' mind by advertisers and marketers [152], to analyze their private thoughts and emotions to impact on their purchasing decisions, besides manipulation of the consumers' minds [153]. NM is used to create better products or ads to entice consumers, but not manipulate the consumers' minds [152]. For example, companies can know their consumers' preferences and behaviors by NM and, thus, can provide more beneficial and profitable services and products. According to Ariely and Berns [27], NM's application by companies concentrating on profit rather than consumers' wellbeing through harmful ads for products (e.g., tobacco, alcohol ..., etc.). This may be true to some extent, and the reason to indicate NM for violating ethical boundaries and breaking the consumers' trust.

In addition, many scientists and researchers have pointed out that NM might threaten individuals' privacy if this technology can deal with consumer behavior effectively and accurately [154]. However, others have argued that these worries are probably premature because state-of-the-art imaging technology does not allow for precise predictions of consumers' decisions [155]. Thus, NM danger concerns have led several governments (e.g., France) to take some concrete procedures against rogue use of NM tools [156]. Therefore, the ethical issues are considered the most sensitive factors that should be considered when neuro-scientists, neuro-marketers, and companies conduct their academic and commercial NM research [51]. Thus, companies have to abide by rules and ethics issues [157]. Plus, companies should abide by the laws and the government's declarations regarding consumers, children, and patients [151]. For instance, any studies related to human research should follow the government's laws, and it must conduct a rigorous investigation after any human researches by government and company ethics committees [158].

From an academic perspective, according to Plassmann et al. [159], there are three major challenges, as follows: Firstly, consumer neuroscience research often faces the criticisms that they provide correlational evidence, but not causal evidence; thereby, they provide valuable information about understanding the consumers' brain, not consumers' behavior. Accordingly, marketing researchers are encouraged to see neuromarketing as an additional tool to improve/develop behavioral measures and interpretation. Secondly, because of the small sample size, the experiments of neuroscience lack generalizability and reliability of the findings; for example, if we look at publications in prestigious journals (e.g., Journal of Cognitive Neuroscience and Journal of Marketing Research), the sample size of experiments is almost 20–30 volunteers in each circumstance, to present converging evidence toward the specific case. The last challenge is interpreting findings; it is assumed that the brain region is united based on the previous study. In other words, it has been noticed that when a certain cognitive process happens, a particular region in the brain is active, but there might be another cognitive process that is not examined directly, but is associated with that cognitive process (i.e., a reverse inference) [11].

In this regard, firstly, companies and organization have to focus on the orientation of the NM toward the right way by increasing the wellbeing of society and produce profitable products to satisfy the actual consumers' needs and desires; meanwhile, it should not fall into promoting harmful products such as, but not limited to, tobacco, which the press and media can exploit to fuel speculations and trigger aggressive attacks on NM.

Secondly, companies and organizations should not look at these arbitrary assumptions and continue to strive for success and stay productive. Eventually, it is hoped that all companies follow the government rules and instructions to secure the consumers' safety and privacy foremost.

4. Discussion

In recent years, the majority of research focused on studying the neural correlates of consumer behavior (i.e., decision-making), emotional and cognitive processes that have applied in advertising campaigns to explain the conscious and unconscious processes that occur in the human brain and pinpoint the active regions of these processes in the mind. We have followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework based on Moher et al. [19] to select relevant documents for this review study as the neuroimaging techniques applied in advertising. The findings suggest that the number of papers has been rapidly growing since 2004. Interestingly, approximately 50% of the total publications were contributed by the USA, Italy, England, Germany, and China, while other remained studies were placed in several continents such as Europe, Latin America, Asia, African regions, and Australia (e.g., see Table 1). Although the USA is the most productive country with 16 papers, China was the most productive country in terms of the number of publications per author, for example, Ma, Qingguo, with four papers. However, the most productive journal is Frontiers in Neuroscience, with 12 documents and 87 total citations. Therefore, we encourage scholars and researchers to further inspect the neuromarketing subject and its techniques from emerging countries.

In the last decade, neuroimaging techniques have developed, and therefore, grabbed attention of both academics and industries. The authors adopted the bibliometrics analysis because it would help to answer the RQ1. The findings showed that the most cited journal among neuromarketing journals is Nature Review Neuroscience with approximately 347 citations. It is significant to provide a clear overview of preferred and popular neuroimaging techniques employed in advertising studies. We found a wide set of techniques used in advertising research, but at the same time, we observed that there are some common neuroimaging techniques among researchers. Thus, we found four common neuroimaging techniques that were preferred and used in advertising research such as fMRI, EEG, MEG, and FNIRS [13,160,161]. The comprehensive review of selected articles in order to answer the RQ2, it was found that the EEG is the technique employed most in advertising research to record/measure the consumer behavior (i.e., decision-making), cognitive (i.e., attention and memory) and emotional (i.e., emotion) processes compared to fMRI due to less cost and high temporal resolution [1,6,60]. Whereas the EEG was used in fifteen articles, which account for approximately 24% of total articles, the fMRI has been used in ten articles, which account for almost 17% of selected articles, while the MEG and fNIRS were employed in two articles, with approximately 4% of total articles for each technique.

In addition, papers emphasized the advantages of the fMRI in recording the distal brain structures compared with other techniques in responsible regions on decision-making processes [14,162,163]. The choice of appropriate technique by researchers or marketers is dependent on research questions and marketing purposes. No less important and linked to RQ3, in this review, it has been found that the advertising research is interested to measure the consumer behavior (i.e., decision-making), cognitive (e.g., attention and memory) and emotional [164] processes. Additionally, the findings showed that the PFC, located in the frontal lobe (FL), is the most significant region when it comes to decision-making processes. For example, the OFC, the vmPFC [108], and the dlPFC play a central role in decision-making processes [109]. In addition, we found the left PFC and right PFC linked to approach and avoidance behavior, respectively. While the OFC engaged in positive valence (pleasure), lateral OFC and left dorsal anterior insula were associated with negative valence of emotion (displeasure) [129]. Finally, the FL and temporal lobe (TL) are engaged to dimensions of emotion (valence and arousal) [34]. For attention, we found thalamus and primary visual regions in the OL engaged in bottom-up attention system as well as dlPFC, parietal

cortex, and primary visual regions engaged in top-down attention system [13,136,140,141]. The hippocampus was linked with generating and processing memories, and the amygdala related to the modulator of the memory system [143]. In addition, it has found that the activation of the right hemisphere is associated with subliminal stimulation, while the left hemisphere is related to supraliminal stimulation, which led us to infer that the right hemisphere is related to emotional processing and left hemisphere associated with higher level emotional processing [135,165].

5. Conclusions

Implication of the research findings for theory and practice: Theoretically, the current findings can be divided into three folds, as follows: Firstly, neuroimaging techniques such as fMRI, EEG, MEG, and fNIRS in assessing the neural correlate of decision-making, cognitive, and emotional processes can be beneficial in marketing research (e.g., advertising, branding). Secondly, it will help the marketers and scholar to identify the positive and negative elements in advertisements before putting it in the real-world, thereby, enhance the strengths and address the weakness, which lead to more effective advertising campaigns. Third, the majority of the studies focused on detecting the neural correlates of emotional and cognitive processes in the brain toward advertising (e.g., message effectiveness), thereby, the ability of these processes to predict consumer behavior after advertising campaigns. In addition, there are some studies focused on gender voice and political messages in advertising campaigns. Therefore, these three folds together can explain the neural correlates of cognitive and emotional processes of interest for advertising. An application of this research may offer measurable explanations of how advertising works in consumers' mind, therefore creating the irresistible advertising campaigns.

Limitations and Future research: Although we tried to minimize the shortcomings in methodology, this study comes with a limitation that offers opportunities for future research. We focus on the publications that were published in the English language and overlooked the non-English language publications, therefore our study is not completely bias-free. For future trends, we suggest that scholars should investigate the impact of neuromarketing research on moral and ethical issues alongside the contributions of neuromarketing research in other disciplines such as economics and crisis management. It is significant for scholars to employ and design an experiment well to get high accuracy results.

General Conclusion: For decades, marketers and advertisers tried to understand what is in the consumer brain and how they make decisions. Neuroscientific research has shown that the majority of mental processing occurs unconsciously or subconsciously, which highly contribute to decision making. In today's hyper-competitive environment, advertising has become more complicated and challenging, so marketing research should adapt to this new situation to achieve advertising excellence. Hence, neuromarketing has been introduced to explore, understand, analyze, and explain the consumer behavior (e.g., decision-making), emotional processes (e.g., emotions and feelings), and cognitive processes (e.g., attention and memory) toward advertising campaigns. Most studies in advertising demonstrate the vital role of the cognitive and emotional processes in decision-making, wherein the PFC and FL are the most important regions when it comes to making decisions.

The findings suggested that neuroimaging techniques are highly important to measure and record decision-making, cognitive, and emotional processes in the consumer mind toward advertisements. For example, fMRI and EEG are deemed as the most preferred techniques that are used in advertising research. We believe that our study provides a comprehensive overview of the current and the main common neuroimaging techniques that are applied in advertising research, as well as the main brain processes and regions of interest for advertising campaigns. We hope that this study will help scholars and practitioners to identify the appropriate technique for their experiments to increase their accuracy and reliability results.

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