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MODERN NEUROIMAGING METHODS IN CONTEMPORARY NEUROECONOMICS AND NEUROMANAGEMENT

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A b s t r a c t

In the modern world, an interdisciplinary approach is required to study the psychological and economic underpinnings of market phenomena as well as the behaviors and attitudes of market actors. Neuroscience plays an increasingly important role in the identification of brain correlates of decision-making processes in research and business. The aim of this study was to present modern neuroimaging methods that are most widely used in economic sciences and management, and to determine their theoretical and practical relevance. The study provides a theoretical background for empirical research that can be conducted independently. Research into consumer behavior should involve an interdisciplinary approach, therefore selected literature on neuroeconomics and neuromarketing was reviewed. The role of neuroimaging was synthetically described, the results of selected research studies were presented, and the implications of functional magnetic resonance imaging (fMRI) and electroencephalography (EEG) for neurofinance, neuromarketing, and neuromanagement were analyzed.

The purpose of the literature review was to emphasize the growing significance of a holistic approach to consumer research and to discuss the applicability of fMRI and EEG in economic research. In business, both neuroimaging methods can be applied to optimize products and services to ensure that they meet customer needs and preferences. Neuroimaging techniques have many advantages, but attention should also be paid to ethical considerations in research and commercialization of research results.

NOWOCZESNE METODY NEUROOBRAZOWANIA WE WSPÓŁCZESNEJ NEUROEKONOMII I NEUROZARZĄDZANIU

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Abstrakt

Współczesne realia społeczno-gospodarcze implikują interdyscyplinarne podejście badawcze do psychologiczno-ekonomicznych uwarunkowań zjawisk i zachowań podmiotów rynkowych. Coraz większą rolę w identyfikacji mózgowych korelatów procesów decyzyjnych na gruncie naukowym i biznesowym odgrywa neuronauka. Celem artykułu jest przedstawienie nowoczesnych metod neuroobrazowania stosowanych najczęściej na gruncie ekonomii i zarządzania, a także określenie ich użyteczności w aspekcie poznawczym i aplikacyjnym. Artykuł ma charakter teoretycznych rozważań i stanowi tło teoretyczne do przeprowadzenia własnych badań empirycznych. Mając na uwadze konieczność interdyscyplinarnego podejścia do badania zachowań konsumenckich, dokonano przeglądu wybranej literatury przedmiotu z zakresu neuroekonomii i neurozarządzania. Syntetycznie scharakteryzowano istotę neuroobrazowania, przedstawiono wybrane wyniki badań, a także możliwość wykorzystania metody funkcjonalnego rezonansu magnetycznego (fMRI) i elektroencefalografii (EEG) w obszarze neurofinansów, neuromarketingu i neurozarządzania.

Badania literaturowe służyły podkreśleniu rosnącej roli holistycznego podejścia badawczego do analizy konsumenta oraz ukazaniu przydatności metody fMRI i EEG na gruncie badań ekonomicznych. Praktycznym aspektem wykorzystania metody fMRI i EEG w sferze biznesowej jest możliwość optymalnego dostosowania oferty produktowo-usługowej do potrzeb i preferencji konsumentów. Pomimo wielu zalet neuroobrazowania, należałoby jednak zwrócić większą uwagę na kwestie etyczne prowadzonych badań i komercyjnego wykorzystania wyników badań.

Introduction

Contemporary neuroscience is an interdisciplinary field of study which focuses on the biological underpinnings of human behavior in the context of neural networks and the central nervous systems. Neuroscience combines knowledge from various fields of science, including medicine, biology, biophysics, biochemistry, psychology, and information technology (Squire *et al.*, 2013, p. 3-15). The complex reality of the modern world and the close links between economic, social, and technological phenomena require a holistic approach to research on human behavior. Research into adaptive mechanisms, social functioning, and resource-limited decision-making is conducted in social and economic sciences. Due to the rapid development of the global market, new approaches are needed study the forces of supply and demand, consumer preferences, and products. Innovative approaches are required in both business and science.

Neuroeconomics is a relatively new and dynamically developing branch of economics that combines methods and theories from economics, psychology, and neurophysiology. Neuroeconomic research focuses on decision-making under risk and uncertainty, delayed reinforcement, ethics in economic decision-making, and the economic decisions made by individuals (consumers) and groups (consumer groups, societies) (Kenning & Linzmajer, 2011, p. 111; Noga, 2017, p. 102). The main aim of neuroeconomic research is to propose a unified scientific theory to explain the behavior of market actors (Camerer, 2006, p. 416-419). In turn, the purpose of neuromarketing studies is to evaluate the practical relevance of neuroscience research for business and management (Stach & Popek, 2013, p. 49). This interdisciplinary field of study combines multiple academic disciplines, including management, psychology, philosophy, and neurobiology, to identify the neural mechanisms that underly management decisions and promote the development of management competences (Wollenweber, 2016; 2021). Neuroimaging studies provide information about teamwork mechanisms that can be used by managers to improve productivity, offer effective solutions to problems, prevent conflict, develop and harness the potential of human resources, and build a goal-oriented culture in an organization.

This article is a theoretical discussion on the applicability of modern neuroimaging methods for neuroeconomics and neuromanagement. The aim of the study was to describe the specificity of fMRI and EEG as the two most popular neuroimaging methods in economics and management, and to determine their theoretical and practical relevance. The following research questions were formulated: 1) Which modern brain imaging (neuroimaging) methods are applied in neuromarketing?, and 2) What are the practical implications of neuroimaging methods for economics and management? A literature review was conducted with the use of Google Scholar (http://scholar.google.com/) and ResearchGate (https://www.researchgate.net/) web search engines based on the following keywords: neuromarketing literature review, EEG, and fMRI. Databases were selected based on the list proposed by A. Booth *et al.* (2016, p. 113) and the arguments made by E. Orduna-Malea *et al.* (2017).

Neuroeconomics and neuromarketing are multidisciplinary fields that seek to explain the affective, cognitive, behavioral, and social components of economic decision-making based on neural activity in the human brain. Interdisciplinary research teams composed of economists, managers, and psychologists observe human behavior and build models to explain consumer decisions, whereas neurobiologists apply the appropriate research tools to explain biological mechanisms underpinning economic decision-making (Glimcher & Rustichini, 2004, p. 447-452). Non-invasive imaging methods, mainly fMRI and EEG, are used in neuroeconomics and neuromanagement to analyze brain activity during decision-making under controlled conditions (Glimcher *et al.*, 2009). Increasingly sophisticated and innovative methods for analyzing the bioelectrical activity of the brain are being developed, and the results have both theoretical and practical

implications for economics and management research, which suggests that fMRI and EEG can significantly expand our knowledge about consumer behavior and contribute to the development of neuroeconomics and neuromanagement.

Literature Review

In recent years, neuroimaging methods have been increasingly used in economics and marketing research. The literature reviews and bibliometric analyses conducted by P. Duque-Hurtado *et al.* (2020); N. Nilashi *et al.* (2020); R. Sharma and A. Sinha (2020); F.S. Rawnaque *et al.* (2020); L. Robaina--Calderín and J.D. Martín-Santana (2021); A.H. Alsharif *et al.* (2021); A. Byrne *et al.* (2022); T. Asunakutl and T. Aydoğan (2022); A.H. Alsharif *et al.* (2023); G.V. Jayavardhan and N. Rajan (2023); G. Srivastava and S. Bag (2023); P. Tirandazi *et al.* (2023), revealed that numerous imaging methods and tools are being applied in research. According to A.H. Alsharif *et al.* (2021), the largest number of neuromarketing research papers have been published in the USA, Spain, Italy, the United Kingdom, and Germany, which suggests that these countries are the key contributors to neuroimaging research (Alsharif *et al.*, 2021, p. 6). A steady increase was also observed in the number of research articles relating to neuromarketing research, which can be generally divided into two groups: theoretical studies and experimental studies (Duque-Hurtado *et al.*, 2020, p. 530). In recent years, most scientists have focused on the strengths and weaknesses of neuromarketing research (Cherubino *et al.*, 2019; Songsamoe *et al.*, 2019), consumer involvement (Lim *et al.*, 2021), and behavioral control (Lim & Weissmann, 2023). A.H. Alsharif *et al.* (2021) reviewed 106 articles and found that brain activity was monitored with both electrical and metabolic methods such as electroencephalography (EEG) functional magnetic resonance imaging (fMRI), and functional near-infrared spectroscopy (fNIRS), whereas physiological activity was controlled during positron emission tomography (PET), galvanic skin response (GSR), and electrocardiogram (ECG) tests (Alsharif *et al.*, 2023, p. 6).

Most consumer behaviors and purchasing decisions are unconscious or subconscious processes that take place in deep brain structures, which is why neural correlates of brain processes play a very important role in marketing and management research. According to W.M. Lim (2018), EEG and fMRI are the most popular neuroimaging methods in marketing research, followed by ECG, ET, GSR, and EMG. A recent review revealed that EEG was the most widely used neuroimaging method in the marketing mix (in 37 (35%) of the reviewed articles), followed by fMIR (in 25 (24%) of the reviewed articles) (Alsharif *et al.*, 2023, p. 7, 8). According to M. Nilashi *et al.* (2020), a combination of three neurophysiological imaging techniques, i.e. EEG, MEG and fMRI, is increasing

applied in marketing research. The cited authors found that neuroimaging methods are most widely used in business (23.39%), psychology (14%), and neurological sciences (11%) (Nilashi *et al.*, 2020, p. 25, 28).

The neuromarketing approach focuses on biological and neurophysiological process that affect consumer decision-making. R. Sharma and A. Sinha (2020, p. 14668, 14669) identified the existing research gaps where neuromarketing methods could be applied to analyze decision-making and consumer behavior, including in the field of cognitive psychology, psychological factors, and external and internal reflexes in social and biological categories of variables. Research has demonstrated that neuromarketing methods and neuroinformation systems can be applied to identify consumer emotions during decision-making and build effective marketing strategies (Rajab & Sharma, 2017). The emotions that accompany consumer choices and preferences are difficult to capture in traditional questionnaire surveys. The main purpose of neuroimaging is to expand our understanding of the neural correlates of emotions, attention, perception, memory, and decision-making (Alvino, 2019). Electroencephalography, fMRI, and fNIR provide accurate and reliable measurements of neural responses to specific marketing stimuli (Turel & Bechara, 2021). Therefore, neuroimaging methods can fill in research gaps relating to the affective, cognitive, and behavioral aspects of consumer decision-making.

Neuroimaging Methods in Neuroeconomics and Neuromanagement

In knowledge-based economies characterized by rapid technological change, sophisticated research methods are increasingly used to analyze market phenomena and consumer behavior, and to determine the influence of various types of information (stimuli) on consumer decision-making. In this context, neuroeconomics research focuses on changes in brain activity elicited by decision-making and external stimuli.

Innovative magnetic resonance imaging (MRI) techniques are used in modern neuroimaging to obtain information about brain morphology and activity during decision-making (Modo & Bulte, 2011). The most advanced MRI methods include magnetic resonance spectroscopy (MRS) which visualizes cerebral energy metabolism (Zhu & Barker, 2011, p. 203-226), and functional MRI (fMRI) which measures changes in brain activity (Huettel *et al.*, 2013). Diffusion-weighted imaging (DWI) is also a popular technique that generates specific brain maps (Thijs *et al.*, 2001, p. 1205-1211), including economic maps of the brain. Diffusion Tensor Imaging (DTI) analyzes diffusion anisotropy in the central nervous system and provides quantitative information about nervous tissue in the brain (Basser

et al., 2000, p. 625-632). Functional near-infrared spectroscopy is also applied in research (Vecchiato & Babiloni, 2011; Cakir *et al.*, 2018; Krampe *et al.*, 2018).

Other neuroimaging methods in neuroeconomics and neuromanagement research include positron emission tomography (PET) (Isabella *et al.*, 2015; Ramsoy, 2015), magnetoencephalography (MEG) (Ramsoy, 2015), electroencephalography (EEG) (Skriabin *et al.*, 2021), event-related potentials (ERP), and intracellular and extracellular action potentials of a single neuron (Nilashi *et al.*, 2020, p. 24; Jayavardhan & Rajan, 2023, p. 141-143). Responses to specific stimuli can be also evaluated based on the results of blood, urine, and cerebrospinal fluid tests, and responses to intravenously administered drugs. Four types of methods are most frequently used in neuromarketing research: neuroimaging (direct measurement of brain activity), biometric techniques (measurement of brain activity elicited by new, significant, or motivating stimuli; heart rate and respiratory rate measurements; analysis of posture and facial expression), oculography (measurements of eye movement), and psychometric methods (measurement of response times which reflect hidden and unconscious associations and attitudes).

Functional MRI is a non-invasive assessment of brain activity, and it has the greatest theoretical and practical significance in economic research (Alvino *et al.*, 2020). Functional MRI combines conventional MRI with measurements of blood flow in the brain (Parizel *et al.*, 2011), and it detects hemodynamic changes in capillaries. Local blood flow is strongly correlated with the activity of central nervous system tissue (Boz *et al.*, 2017). Brain activity is monitored based on changes in oxygenated and deoxygenated hemoglobin observed in the magnetic field. Active brain regions (regions that are activated during consumer decision- -making) require more oxygen and accumulate more oxygenated hemoglobin. Brain activity is measured based on changes in the strength of the MRI signal from active and less active regions of the brain (Ogawa *et al.*, 1990). Blood-oxygen- -level-dependent (BOLD-contrast) imaging is an fMRI method that monitors brain activity based on changes in blood oxygenation. Decision-making processes are evaluated and economic and non-economic determinants of consumer decisions are identified by measuring the rate and volume of blood flow in the brain and the resulting activation of nervous tissue.

Electroencephalography is also a useful neuroimaging technique in economic research. This non-invasive diagnostic method is applied to measure the bioelectrical activity of the brain and the action potential of the central nervous system (Cherubino *et al.*, 2019). During an EEG exam, electrodes are placed on the scalp and voltage fluctuations between electrodes are measured (Rawnaque *et al.*, 2020). The signal is amplified, and an electrogram of the spontaneous electrical activity of the brain during decision-making is recorded (Byrne *et al.*, 2022, p. 2). The results are interpreted based on the frequency and amplitude of brain waves. H. Berger was the first scientist to measure human brainwaves (1929). The main types of brain waves are alpha waves (8-12 Hz; 30-100 mcV/m),

beta waves (12-30 Hz; >30 mcV/m), gamma waves (25-100 Hz), theta waves (3,5-8 Hz), and delta waves (1-3 Hz). Each frequency band corresponds to different mental states. A knowledge of brain waves is needed to assess consumers' and decision-makers' responses and perceptions of various stimuli (Aditya & Sarno, 2018; Rawnaque *et al.*, 2020, p. 15).

In an era of rapid technological and social change, the decisions made by consumers and producers constitute an important topic of research and drive business strategies, which spurs the search for innovative, accurate and reliable research methods. The syncretism of economics and medicine is thus unavoidable.

Theoretical and Practical Relevance of Neuroimaging

Decision-making scenarios and marketing stimuli can significantly affect the human physiology, influence the decision-making process, determine purchasing decisions, or elicit specific behaviors in a team. Neuroimaging techniques that measure the signals generated by tissues and organs, and the generated images of tissue and organ structure are valuable tools in research on consumer behavior (Hamzehei *et al.*, 2011, p. 139-148). Bodily responses to specific economic and marketing stimuli provide a wide range of valuable information. An interdisciplinary approach to analyses of the decision-making process and the attitudes and behavior of market actors increases the explanatory power of economic and management sciences (Polowczyk, 2010, p. 497). Neuroeconomics research explores the neuromicroeconomic aspects of market behavior in individuals, as well as the neuromacroeconomic aspects of market behavior in groups (Noga, 2017, p. 106). Research on human functioning and decision-making is conducted in a strictly economic context, as well as in the general social context (Karim *et al.*, 2019). According to C.F. Camerer and G. Loewenstein (2004), economic models represent a simplified reality based on strictly rational principles, and they will be replaced by behavioral models over time. D. Kahneman and V. Smith received the Nobel Prize in economics for their pioneering research in behavioral economics and decision-making, which will pave the way to the broad implementation of this interdisciplinary approach. In studies examining consumer behavior, the information acquired with the use of medical diagnostic tools will provide answers only about biological responses to marketing stimuli (Kenning & Linzmajer, 2011, p. 111). The extent to which these findings can be applied in business practice is strictly determined by the researchers' ability to interpret diagnostic results in the economic and marketing context (Ariely & Berns, 2010, p. 131).

The results obtained with the use of neuroimaging tools, in particular fMRI and EEG, have broad practical relevance for neurofinance, neuromarketing, and neuromanagement.

The aim of neurofinance research is to identify the key determinants of investment decisions and to explore the biological mechanisms underpinning investor behavior (Glimcher & Rustichini, 2004, p. 447-452). Utility is a central concept in financial research. C. Frydman *et al.* (2021) tested the utility of investor behavior by measuring brain activity with the use of fMRI. This pioneering study demonstrated that neuroeconomics offers valuable tools for testing mathematical and economic models. Neuroimaging assessments provide strong evidence for the realization utility theory. The cited study confirmed that neural activity in the ventromedial prefrontal cortex (vmPFC), an area in the brain that is critical for reward and value-based decision-making, was positively correlated with profit or loss in a financial transaction. Profit realization increased the activation of the ventral striatum (vSt) which is implicated in reward processing, whereas loss realization decreased vSt activity. An fMRI examination revealed that subjects with a strong vmPFC signal were more likely to realize capital gains, whereas a significant correlation was not observed between VmPFC activation and loss realization. Neuroimaging revealed the presence of a positive correlation between vSt activity and profit realization (Frydman *et al.*, 2012). The results of fMRI assessments confirmed that investors derive utility from realizing gains in market transactions.

Functional MRI was also used to map reward and punishment processing in the human brain and its impact on investment decision-making (Yarkoni *et al.*, 2011, p. 665-670). The cited study confirmed the dual-system hypothesis and the functional lateralization of responses to gain and risk (areas activated in the left hemisphere: SN/VTA, vmPFC, ventral striatum; areas activated in the right hemisphere: dorsal striatum, anterior insula, dmPFC/ACC, amygdala). The activity of the right hemisphere increased in response to a capital gain, whereas the activity of the left hemisphere increased in response to loss. In turn, cash payments activated the prefrontal cortex which is a part of the brain's reward system (Rorden *et al.*, 2007, p. 1081-1088). These observations imply that the brain perceives money as a valuable object or a source of pleasure which activates older receptors in the reinforcement system (Smith, 2013). The motives and mechanisms underlying investment decisions were also investigated in neurofinance research. Functional MRI assessments revealed that the anterior insula was responsible for risk aversion. In turn, risky investment decisions led to the activation of the nucleus accumbens which processes and reinforces reward stimuli (Maciejasz--Świątkiewicz & Musiał, 2014).

The applicability of neuroimaging was also tested in neurobanking to determine the motives and strategies of individuals and institutions in the banking and finance sector, to identify factors that influence decision-making in the banking sector, and to classify the gains and risks associated with banking and financial transactions (Flejterski, 2008, p. 532).

Neuroimaging tools are increasingly used in neuromanagement research which integrates knowledge from applied psychology, behavioral economics,

and neurophysiology. Neuroscience research focuses on team management, business strategies, sales, and communications (Dai, 2019; Karim *et al.*, 2019; Titov & Pluzhnik, 2020; Wollenweber, 2021; Asunakutlu & Aydoğan, 2022). Neuromanagement studies test image and authority building techniques in organizations, personal development and employee support models, and methods for managing human resources, projects, change, conflict, and negotiations. Neuromanagement consists of several subdisciplines that are based on the behavioral approach, including neuromarketing, neuroleadership, and neuropsychology in management. According to research, employee recognition, professional development opportunities, and a friendly workplace environment are the key motivational factors that boost productivity (Spitzer, 2012, p. 137). Neuroleadership combines the results of neuroscience research with business practice, mainly in the context of leadership, change management, consulting, and coaching. W. Dai (2019) defined neuromanagement as a neural mechanism of multimodal interactions. S. Titov and E. Pluzhnik (2020) observed that in an era of rapid scientific progress and the emergence of neurosciences, management had to be redefined, and its key variables had to be analyzed from a different perspective. An interdisciplinary concept was needed to explain decision-making processes, leadership practices, change management, innovation, creativity, productivity, employee engagement, and emotions. T. Asunakutlu and T. Aydoğan (2022, p. 428-444) described the practical implications of neuromanagement in a biometric analysis of neuroscience research in management and organization.

In neuromarketing, fMRI and EEG are not only useful tools for theoretical research, but they are also increasingly applied for commercial purposes. The results of neuroimaging assessments are used to develop pricing strategies and plan marketing campaigns. In neuromarketing, medical diagnostic tools and the knowledge of human behavior are applied to optimize marketing messages. In turn, neurobranding is an innovative approach to developing strategies and marketing techniques based on neuroimaging data with the aim of assessing consumer responses and identifying marketing stimuli that trigger the desired responses. The applicability of EEG in marketing has been recognized by numerous researchers, including G. Vecchiato *et al.* (2009, p. 57-60; 2010, p. 165-179; 2011); T. Nyoni and W.G. Bonga (2017, p. 30-38); A. Byrne *et al.* (2022); J. Siddique *et al.* (2022). The potential of EEG in marketing research was also discussed by H. Mruk and M. Sznajder (2008); G. Zaltman (2008); M. Lindstrom (2009); L. Zurawicki (2010); R. Ohme *et al.* (2011), A.K. Pradeep (2011). The applicability of EEG in neuromarketing was examined by G. Vecchiato *et al.* (2010, p. 165-179) who monitored changes in the brain activity of subjects watching commercial, political, and public service announcements on television. Television commercials that were remembered and regarded as pleasant increased the heart rate and brain activity, mainly in the theta band in the left hemisphere. Changes in brain activity were monitored with the use of EEG which proved to be a highly accurate tool for determining which parts

of an advertisement elicited emotional reactions and which triggered cognitive processing. The study demonstrated that the engagement of orbitofrontal circuits varied over time in subjects watching standard commercial spots and emotional spots (non-profit companies) (Babiloni *et al.*, 2006, p. 3676-3679). High-resolution EEG was also used to monitor brain activity in subjects watching a documentary interrupted by commercials and to compare cortical areas that were engaged by the commercial and the documentary. A review of the literature and business practices indicates that EEG is a useful tool in neuromarketing research because it identifies the connections between brain hemispheres and determines the bioelectrical activity of the brain in response to various triggers. Alpha activity registered in the left hemisphere (frontal lobe) is indicative of positive emotions, friendly responses, and subjective preferences, but alpha activity in the right frontal lobe is associated with the opposite emotions. These emotions exert a significant influence on purchasing decisions.

Montague *et al.* (2004) recreated the Pepsi Challenge campaign with the use of fMRI to examine subjective consumer preferences for Coca-Cola and Pepsi. Functional MRI is a useful tool for analyzing the involvement of different brain regions in subjective value coding and individual preferences that influence perceptions of value and decision-making (Clithero & Smith, 2009, p. 11).

According to T. Nyoni and W.G. Bonga (2017, p. 30-38), the results of neuromanagement and neuromarketing studies enable businesses to optimize product branding before launch, monitor consumer responses, increase brand recognition, boost advertising effectiveness, increase revenues through market segmentation, increase customer satisfaction and loyalty, implement optimal marketing strategies to achieve business goals and maximize profits, and create a friendly organizational culture that promotes management. However, despite the benefits of neuroimaging, the ethical aspects of neuromarketing research and the use of neuroimaging data for commercial purposes stir controversy.

Similarly to other neuroimaging methods, EEG and fMRI have considerable diagnostic value, but they are not free of drawbacks such as artifacts that can affect the quality of the obtained images. Three types of artifacts originating from different sources can be identified in EEG examinations. The first type of artifacts are external artefacts that arise outside of the patient's body, including electrode signals, disruptions during signal reinforcement, conversion of analog signals to digital signals, and other equipment-related artifacts. Artifacts belonging to the second type are generated across the boundary of the internal and external environment, and they are associated with changes in electrode impedance, high frequency oscillations, electrode displacement, cerebral blood flow, respiration, ballistocardiography artifacts, bioelectrical skin reactivity, and the reference electrode. The third type of artifacts are caused by internal (physiological) processes that accompany the natural bioelectrical activity of the body, including artifacts associated with muscle activity, eye movement, blinking, and tongue movement.

The quality of measuring equipment and the MRI scanner plays an important role in neuroimaging. The most accurate results are generated by scanners with high spatial, contrast, and temporal resolution. Temporal resolution of several milliseconds is required to monitor changes in brain activity associated with the processing of visual and acoustic stimuli in television commercials. Despite its advantages, MRI is relatively the most expensive neuroimaging technique due to the high cost of MRI scanners and other monitoring devices. Brain scanning, data collection, and image analysis are also time-consuming processes, and MRI scanners have to be operated by highly qualified medical personnel. As a result, neuroimaging studies involving MRI are difficult to conduct on a large scale. The use of fMRI for research purposes requires considerable funding, and such studies are performed only in highly specialized, interdisciplinary research centers.

In conclusion, neuroimaging techniques such as fMRI and EEG can fill in the knowledge gap in conventional psychological and behavioral research. Neuromarketing studies often combine fMRI and EEG to generate accurate and reliable results. According to neuroscience research, the following brain regions play a key role in thought and decision-making processes: ventral striatum (reward), nucleus accumbens (pleasure), orbitofrontal cortex (reward-based decision-making), medial prefrontal cortex (positive emotions and bond strengthening), prefrontal cortex (self-regulation), and the insula (risk processing). Neuroimaging provides reliable data for empirical research and promotes the development of realistic economic models.

Discussion

The present study accentuates the need for an interdisciplinary approach in modern economic research that fuses insights from medical diagnostic methods. The applicability of EEG and fMRI in economic and management research was described. However, the study has certain limitations because it merely outlines the discussed problems. Systematic reviews of neuromarketing studies are available in the recent literature (2023-2020). The present study lays the groundwork for a systematic review of studies in the field of neuromanagement, which can be followed by empirical research involving EEG and fMRI (the authors are medical professionals who are qualified to provide diagnostic imaging, electrodiagnostic, and radiation therapy services). The existing research focuses mainly on commercial marketing, and in the future, the applicability of EEG and fMRI should be also examined in the context of social marketing. Social marketing is a process of planning, implementing, and controlling programs to influence behavior and resolve social problems. Such studies would have important theoretical and practical implications. Individual and social attitudes towards

consumption are evolving in an era of rapid socioeconomic change. The COVID-19 pandemic has led to changes in individual and social values, and it can be hypothesized that psychological factors will play an increasingly important role in consumer behavior, and that personality traits largely determine consumer support for cause-related marketing, ethical marketing, and green marketing.

Objective neuroimaging methods, including EEG and fMRI, contribute to cognitive realism and enable researchers to accurately describe and predict market phenomena and purchasing decisions. On hypercompetitive markets, modern neuroimaging techniques can increase the effectiveness of business and marketing strategies, improve customers' perceptions of promotional and advertising activities, enhance the attractiveness of products and services, improve brand image, and optimize product prices. The wide range of diagnostic methods for monitoring brain activity and the advancements in neuroradiology clearly indicate that MRI and EEG will play an increasingly important role in research (Siwek, 2015, p. 17-20). The rapid development of artificial intelligence and biometric solutions will also contribute to the popularity of neuroimaging techniques in both research and business.

Despite the above, rigorous standards should be introduced to ensure that the use of modern neuroimaging methods in research does not violate ethical principles. Moral issues and ethical guidelines should be observed in both neuroscience research and commercial applications that rely on neuroimaging tools. A review of the literature indicates that most experimental studies highlight the advantages of neuroimaging, but disregard the ethical and axiological aspects of the applied research methods. Therefore, potential ethical risks associated with neuroimaging should be analyzed because the commercialization of neuroimaging data and information about consumer behavior can violate individual rights. A code of ethics for neuromarketing research was proposed by E.R. Murphy *et al.* (2008). Neuroethics is thus a critical consideration in contemporary neuroscience and consumer neuroscience. Neuroeconomics and neuromanagement are interdisciplinary fields with considerable research and development potential. However, in an era of dynamic scientific progress, the ethical boundaries of neuroimaging should be clearly defined, and the axiological foundations of contemporary neuromarketing and neuromanagement should be described.

Conclusions

Brain activity determines the ways in which information is received, processed, stored, and memorized. Research studies analyzing the structure, physiology, properties, and functions of the human brain and its regions contribute valuable information about biological mechanisms underpinning decision-making

and economic choices. The current study relies on the assumption that the empirical research in neuroscience can promote the development of economics and management as scientifically rigorous fields. The syncretism of medicine (neurology and radiotherapy), psychology (cognitive-behavioral), and economics (experimental and behavioral) implies that neuroimaging will have a growing number of theoretical and practical implications. Neuroimaging will also contribute to the implementation of optimal, practical and innovative solutions in business practice. A better understanding of affective and cognitive processes in the human brain plays a special role in research on individual and group decision-making and consumer behavior.

Neuroimaging is particularly useful for developing economic maps of the brain which present the activity of various brain regions in economic decision-making. Dynamic social and technological processes in the market environment increasingly often catalyze changes in business strategies. Innovative and objective research methods play a significant role in research on affective, cognitive, and behavioral attitudes of market actors, which also promotes the evolution of research methodologies.

Neuroimaging tools are objective because fMRI and EEG register direct responses of the central nervous systems that cannot be controlled or manipulated by the tested subject, which has significant theoretical and practical implications. Functional MRI and EEG scans can be used to model economic and managerial decision-making. Economics, management, psychology, and neuroscience search for the mechanisms underlying human behavior and the determinants of the decision-making process. Neuroimaging tools provide accurate information about neural and bioelectrical activity and support brain mapping. A robust knowledge of the determinants of economic and managerial decision-making contributes to the development of behavioral theories, and it enables scientists to predict future events. Neuroimaging can be used to validate the existing consumer behavior theories. In the future, neuroimaging could also be implemented in social marketing.

In conclusion, modern neuroeconomics and neuromanagement supported by advanced brain imaging tools set the theoretical framework for research into the potential of the human brain and the rationality of purchasing decisions. At present, neuroimaging is used mainly in the fields of neurofinance, neurobanking, neuromarketing, neuroleadership, and neuromanagement. Neuroimaging results contribute to the implementation of innovative solutions in business practice.

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