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Usage of Neuroscience Tools in the Decision-Making Process: Current State of the Art

Uso de ferramentas da neurociência no processo de tomada de decisão: Estado atual da arte

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Resumo

Esta Revisão Sistemática da Literatura (RSL) visa identificar a literatura existente sobre o uso de ferramentas de neurociência em estudos de tomada de decisão. Uma RSL foi conduzida de acordo com diretrizes estabelecidas e com ferramentas específicas para apoiar o processo. A revisão resultou na seleção de 10 estudos primários dentre os 2.250 iniciais. Apesar de destacar os benefícios das ferramentas de neurociência, sua integração na tomada de decisão permanece limitada à análise de padrões de comportamento em estágios específicos do processo decisório. Os autores fornecem um guia de pesquisa com questões em aberto para o avanço deste campo. Este trabalho mapeia o panorama tecnológico, identifica os estágios aplicáveis e elucida os benefícios das ferramentas de neurociência na tomada de decisão, oferecendo insights valiosos sobre seu uso e suas vantagens.

Palavras-chave: revisão sistemática da literatura, ferramentas neurocientífica, processo de decisão

Abstract

This Systematic Literature Review (SLR) aims to identify existing literature on the use of neuroscience tools in decision-making studies. An SLR was conducted using established guidelines and specific tools to support the process. The review resulted in 10 primary studies selected from 2,250 initial ones. Despite highlighting the benefits of neuroscience tools, their integration into decision-making remains limited to analyzing behavior patterns at specific stages of decision-making. The authors provide a research guide with open-ended questions to advance this field. This work maps the technological landscape, identifies applicable stages, and elucidates the benefits of neuroscience tools in decision-making, offering valuable insights into their use and advantages.

Keywords: *systematic literature review, neuroscientific tool, decision process*

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Introduction

Efficient decision-making within dynamic and intricate environments remains a perpetual challenge for today's leaders and managers Belton & Stewart, 2002; Vincke, 1992). This challenge is compounded by the need to evaluate multifaceted factors and navigate thorough uncertainties, often involving collaboration among multiple stakeholders (Bender & Leodir Lobler, 2023). In this context, the application of systematic decision-making processes becomes indispensable, providing decision-makers with invaluable support in formulating effective solutions that align with their objectives and preferences.

However, the pursuit of optimal decision-making outcomes is not devoid of hurdles (Pinochet et al., 2018). While traditional methods offer frameworks for analysis, they may fall short of capturing the intricacies of the decision-making process, as they are susceptible to heuristic biases and subjective influences (Silva, 2021). Herein lies the promise of incorporating neuroscientific technologies, offering more profound insights into decision-making, free from cognitive biases and manipulative tendencies (Issac & Issac, 2019).

Recent advancements underscore the transformative potential of neuroscience tools in decision-making contexts, with the burgeoning accessibility of biometric sensors broadening their applications (Duarte et al., 2021). Techniques such as eye-tracking, electroencephalogram (EEG), electrocardiogram (ECG), functional magnetic resonance imaging (fMRI), skin conductance response (SCR) have not only permeated organizational studies, elucidating aspects of leadership dynamics and consumer behavior (Parra Vargas et al., 2023; Gerpott et al., 2018; Berčík et al., 2024), but have also found utility in diverse domains including financial analysis, visualization methodologies, marketing research (Astor et al., 2013; Roselli et al., 2018, 2019; Yazid et al., 2020).

Despite the burgeoning interest, the integration of neuroscience in decision-making processes remains relatively nascent, leaving pertinent questions unanswered (Massaro, 2017; Issac & Issac, 2020). Hence, this paper embarks on a Systematic Literature Review (SLR) to synthesize existing knowledge, drawing insights from nine meticulously selected primary studies. The review aims to delineate the application of neuroscience tools in decision-making research, shedding light on their roles, benefits, and potential implications. By delineating the technological landscape, identifying stages of applicability, and elucidating reported benefits, this work aims to provide a comprehensive understanding of the nexus between neuroscientific technologies and decision-making processes.

The structure of this paper unfolds as follows: Section 2 provides an overview of key decision-making concepts; Section 3 presents related works; Section 4 outlines the research methodology, including the results of the SLR and discussions based on extracted data; Section 5 examines potential threats to the validity of this study and proposes mitigation strategies; Section 6 summarizes existing research gaps in a specific area and offers a research roadmap for guiding future research endeavors, and, finally, the conclusions are presented in Section 7 (EN: RAD adopts the editorial standard of not numbering sections).

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Background

Decision problems arise when there are multiple alternatives to choose from, each associated with various, often conflicting objectives (Vincke, 1992; Belton & Stewart, 2002). Furthermore, involvement of multiple decision makers increases complexity, as solutions must accommodate varying preference structures (Bender & Leodir Lobler, 2023).

To minimize the inherent uncertainty in such scenarios, a methodological approach is essential. The decision problem is systematically formulated to determine the optimal configuration among the available alternatives, especially in multi-objective decision scenarios (Tronco et al., 2019). In this context, Herbert Simon's model, later expanded by George Huber, divides the decision-making process into five phases: intelligence, design, choice, review, and implementation.

In the Intelligence phase, information is gathered about the problem to ensure the identification of decision problems. Data from various sources related to the problem's cause and scope are collected and processed to gain a proactive perspective by anticipating problems. Efficient analysis in this stage is crucial for ensuring that the problem is correctly defined and modeled.

In the Design phase, decision alternatives, their viability, implications, and accessibility are generated. This phase also considers the decision method and interactions with the decision maker to understand their preference structure. In the Choice phase, alternatives are compared to select the best one or propose improvements, depending on the problem's nature. The Review phase occurs before implementation for correcting errors and deviations. Finally, the decision is implemented.

Nevertheless, the decision-making process is far from straightforward, primarily due to the complexity of the variables involved. Simon (1971) notes that this complexity is compounded by people's limited capacity to consider various consequences of their decisions. Despite transparent processes and decision-maker confidence in the outcomes, cognitive factors can influence them, leading to deviations from full rationality.

From these initial studies by Simon, research in managerial and organizational cognition advanced, leading to a series of contributions investigating cognitive systems and architectures that support organizational life (Massaro, 2017). Along with these advances, neuroscience tools have become an invaluable aid in decision-making processes. The scientific examination of psychological and physiological responses gained significance in the 1990s as data collection tools became more accessible (Casado-Aranda & Sanchez-Fernandez, 2022). The integration of neuroscience into the decision-making process offers a more profound understanding free from heuristic biases and manipulation by decision-makers (Sinha et al., 2021), thereby complementing traditional decision-making methods.

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Related Works

We identified other systematic reviews that examined topics related to our study. For instance, Alsharif et al. (2024) focused on empirical studies that utilized neurophysiological and physiological tools to investigate consumer behavior and advertising within neuromarketing. Their objective was to synthesize research on how emotional responses, motivational attitudes, attention processes, perceptions, rewards, and memory influenced consumers' decisions.

Casado-Aranda and Sanchez-Fernandez (2022) discussed advances in neurophysiological techniques in marketing and consumer decision-making. They highlighted research questions for marketing scholars interested in decision-making approaches, products, pricing, communication, and retail scenarios. Their study aimed to provide insights into the primary biomarkers and neuroscience tools used to understand customers, neurophysiological techniques that complement or replace traditional marketing methods, and the ethical implications of these tools.

Radtke Caneppele et al. (2022) conducted a bibliometric comparison study to examine how neuroscientific tools are used and discussed in ongoing research on strategy in organizations. In this study, the authors considered the potential of neuroscientific tools for the mind-brain relationship, but suggested that, given criticisms and challenges, they should be used as support, in addition to other traditional research techniques, to assess constructs and mechanisms related to strategic decisions and choices in organizations.

Sanchez-Fernandez et al. (2021) employed a bibliometric approach to track the evolution of advertising research using neuroscience tools. They analyzed trends in advertising studies using neuroimaging and psychophysiological methods to uncover the brain mechanisms underlying consumer decision-making. This work provided a research agenda for advertising scholars and communication professionals interested in consumer neuroscience.

Cinel et al. (2019) offered an overview of neuroscience technologies, with a particular focus on human cognitive enhancement and projections for future developments in this field. They noted that no single neuroscience technology is ideal for entirely influencing or observing brain activity, as each has unique trade-offs in spatial and temporal resolution, portability, and more.

Harris et al. (2018) conducted a review of studies investigating the potential use of neuroscience tools to analyze public health marketing campaigns and social causes. The study aimed to understand successful public health campaigns that increased public awareness while incurring lower costs than unsuccessful ones.

Another related empirical review by Solnais et al. (2013) sought to define the boundaries and scope of consumer neuroscience, drawing on existing findings from neuroimaging techniques, specifically fMRI, EEG, and MEG. The study revealed that none of the 34 selected studies combined various neuroimaging techniques, despite recommendations in the literature.

In contrast to the aforementioned studies, this SLR investigates aspects of the decision-making process at the stage level using neuroscience tools. It focuses on

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decision structuring and analyzes how these technologies are integrated throughout the problem-solving process. Furthermore, it highlights the contributions of these technologies to decision-making. The primary aim is to contribute to both the literature and practice by providing insights into the use of neuroscience tools to address decision-making challenges and identifying research opportunities within the decision-making process.

Research Method

SLRs are a method for making sense of large amounts of information and mapping areas of uncertainty, identifying where little or no relevant research has been conducted, and where further studies are needed (Petticrew & Roberts, 2006). In this sense, Petticrew and Roberts (2006) state that an SLR is a type of research focused on well-defined questions that identify, select, evaluate, and synthesize the relevant available evidence, thereby contributing to answering questions about what works and what does not.

For planning the SLR, the process structure defined by Duarte et al. (2021) was adopted. This structure, using process models, illustrates the sequence of activities to be performed at the stages of an SLR. The subsections that follow present the SLR developed, discussing its details as needed.

Planning

In the SLR planning stage, the research protocol was defined, including the research questions (RQs), research strings, and the digital libraries used as research sources. Defining this protocol is essential when conducting a secondary study, such as an SLR (Brereton et al., 2007).

Subsequently, inclusion and exclusion criteria, the data extraction strategy, and criteria for evaluating the quality of the studies were defined. Finally, protocol analysis and feedback were performed to validate and suggest improvements. These activities are presented in the following sections.

Formulation of the Search String

The research questions were formulated to determine the focus and scope of the search. For this purpose, the PICOC structure (Population, Intervention, Comparison, Outcome, and Context) (Petticrew & Roberts, 2006) was considered, which helps researchers determine what is essential for the ongoing investigation, facilitating the definition of research questions guiding the extraction phase of the process (Souza et al., 2019). The PICOC analysis is presented below:

(1) Population: studies that utilize neuroscience technologies to understand decision-making processes.

(2) Intervention: the use of neuroscience technologies to analyze aspects related to decision-making processes.

(3) Comparison: not applicable, as no comparison between selected studies was performed.

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(4) Outcome: relate points of interest for the use of neuroscience technologies in decision problems, such as the types of technologies used, the decision stages covered in the studies, and the publication details.

(5) Context: works that highlight the use of neuroscience technologies to analyze decision-making processes.

From the understanding of the PICOC, the main research question (RQ) and the secondary ones (SRQ) were defined as follows:

RQ. How is neuroscience technology being utilized to understand aspects related to stages of decision-making processes?

SRQ1. What technologies were adopted in the selected studies?

SRQ2. At what stage of the decision-making process, structuring is being employed?

SRQ3. What contributions were reported regarding the use of technology in the decision-making process?

Definition of Search Strings

The definition of strings involves identifying keywords derived from PICOC, including their synonyms, spelling variations, acronyms, and correlates (Galvão & Ricarte, 2019). Identifying a suitable search string for each review is an iterative activity and requires experience and knowledge of the research area (Kitchenhand & Brereton, 2013; Fabbri et al., 2013).

These terms were connected by logical operators, generating Boolean expressions that were used in automated searches of digital libraries. Thus, the search strings were constructed using the logical connective "AND" to join the main terms and "OR" to combine synonyms. It is important to note that the defined terms must adequately represent the intended objectives of the work. Therefore, it is relevant to conduct validation and adaptation tests on the strings beforehand (Duarte et al., 2021). Thus, the search string is as follows:

("biosensor" OR "biometric sensor" OR "neurophysiological tool" OR "neurophysiological technology" OR "neuroscience tool" OR "neuroscience technology" OR "neurophysiological data")

AND

("decision making" OR "decision-making" OR "decision process" OR "decision making process" OR "decision-making process")

Selection of Research Sources

Six digital libraries were selected to execute the search strings: ACM Digital Library, Scopus, Web of Science, IEEE Xplore, ScienceDirect (Elsevier), and SpringerLink. The selection of these libraries is justified by their coverage of key publication forums on this theme, with no restrictions on publication date or content type during the process.

However, due to the large number of studies available in the Springer Link library, only studies in the disciplines of Business and Administration and Computer Science and Engineering were included, as they are directly related to the objective of this research. Additionally, Google Scholar1 was used to search for additional information about each selected study, including the number of citations.

Definition of Inclusion and Exclusion Criteria

The definition of inclusion (I) and exclusion (E) criteria helps researchers in selecting relevant studies for analysis and data extraction (Souza et al., 2019). Table I presents the inclusion and exclusion criteria defined in the study.

Table 1

Inclusion and exclusion criteria

CRITERIA	DESCRIPTION
I1	Peer-reviewed primary studies from journals, conferences, and workshops that address the use of neurophysiological technologies in understanding decision-making.
I2	Relevant studies cited by the authors of the articles identified during the exploratory study.
E1	Studies not available for download in the original databases and whose authors did not respond to our requests.
E2	Studies with only the abstract available; extended abstracts or short articles (less than six pages).
E3	Studies with the identical content or duplicate studies.
E4	Studies that did not address the research question (RQ and SRQ1-3).
E5	Studies not written in English.
E6	Studies that did not meet the predefined quality criteria.

Source(s): Table by authors.

Definition of Quality Assessment

There is consensus that the quality of selected primary studies is critical for obtaining reliable results in empirical studies; however, there is no consensus on what constitutes a high-quality study (Kitchenham, 2007; Souza et al., 2019; Duarte et al., 2021). Thus, four quality assessment criteria (QA1-QA4) were defined to be applied in exclusion criteria E6.

The QA1 criterion is divided into four general (G) and four specific (S) criteria, as shown in Table II, with scores ranging from 0 to 1 based on the alignment of the selected studies with the research objective. Therefore, a weighted average was calculated to obtain the score for QA1. Studies with scores greater than three were considered to have QA1 = 'high', studies with scores between 1.5 and 3 were considered to have QA1 = 'medium', and studies with scores lower than 1.5 were considered to have QA1 = 'low'. Equation 1 describes the formula used.

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Table 2

Quality assessment checklist for QA1

General Items (G) 25%	Specific items (S) 75%
G1. Is there an explicit definition of the problem and the motivation for the study? (1.0) There is an explicit description of the problem and the motivation. (0.5) There is a general description of the problem and/or the motivation. (0.0) There is no description of the problem or motivation.	S1. Is there an explicit description of the results of the experiment using the neuroscience tool(s) in the study? (1.0) The results of the experiment are properly related to the use of the tools. (0.5) Only some evidence of the results is related to the use of the tools. (0.0) There is no relation of the results with the use of the tools.
G2. Is there a methodological description of the study? (1.0) There is a detailed description of the method used. (0.5) There is only a simplified description of the method used. (0.0) There is no description of the method used.	S2. Is there an explicit description of how the neuroscience tool(s) were used in the decision-making process? (1.0) There is a description of how the tools were used in the study. (0.5) There is only superficial information describing how the tools were used. (0.0) There are no definitions on how the tools were used.
G3. Insights (and/or lessons learned) are presented for further studies: (1.0) There is an explicit presentation of insights (and/or lessons learned). (0.5) There is a general presentation of some insights (and/or lessons learned). (0.0) There is no description of insights (and/or lessons learned) in the study.	S3. Is there an explicit description of the study's decision-making problem(s)? (1.0) There is an explicit description of the problem(s) in the study. (0.5) There is only superficial information about the problem(s) in the study. (0.0) There are no definitions about the problem(s) in the study.
G4. There is a presentation about the limits that the study encountered and overcame: (1.0) There is an explicit description of the limits found in the study. (0.5) There is only a superficial description of some limits encountered. (0.0) There is no description of the limits found during the study.	S4. Is there a statistically significant number of participants with different profiles in the experiment? (1.0) There is a significant number with different profiles, being ≤ 30 for all profiles. (0.5) There is a significant number, >30, for just one profile. (0.0) There is not a significant number of participants.

Source(s): Table by authors.

Equation 1

$$QualityScore = \left[\frac{\sum_{G=1}^{4} QA1}{4} + \left(\frac{\sum_{S=1}^{4} QA1}{4} x3 \right) \right]$$

The second quality criterion (QA2) evaluated the papers based on the publication's forums. For this assessment, CORE-ERA2 and SJR3 were used to determine rankings for conferences and journals, respectively. Studies published in congresses rated as "A" or journals categorized in quadrants "Q1" or "Q2" were classified as QA2=′high′. Papers published in congresses rated as "B" or journals in

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quadrants "Q3" or "Q4" were classified as QA2='medium'. Studies published in forums rated as "C" or "not classified", were classified as QA2='low'.

The third quality criterion (QA3) assesses quality based on the number of citations. For this analysis, the number of Google Scholar citations was used as a parameter. Studies with more than five citations were classified as QA3='high', studies with up to five citations were classified as QA3='medium', and studies without citations were classified as QA3='low'.

The fourth criterion (QA4) relaxes the QA3 criterion, evaluating studies published in the last five years. Thus, studies with at least one citation published after 2018 were classified as QA4 = 'high', and studies without any citation published after 2018 were classified as QA4 = 'medium'. To avoid exclusion based on the quality evaluation criterion E6, a study should achieve QA1 $\geq$ 1.5 and either QA2 and QA3 or QA2 and QA4, equal to 'medium' or 'high'.

Protocol Analysis and Feedback

External reviewers evaluated the protocol. The purpose of this step was to review and validate the SLR protocol. Thus, the protocol was reviewed by two specialists in Evidence-Based Software Engineering, to whom the objective of the study, the process followed, and the results were presented. Following the presentations, discussions ensued, and comments were collected from the evaluators.

A pilot test was conducted to identify any potential problems in the application of the protocol. After the first test, suggested adjustments were made, and a new test was performed. No protocol problems were identified during the second test run.

Conduction

In the SLR conduction stage, researchers search the strings in each of the search sources defined in the protocol. In this study, 2,250 primary studies were collected. These studies were imported into the StArt tool (Hernandes et al., 2012), and the titles and abstracts were read, applying the inclusion and exclusion criteria E1–E5. This initial process yielded 94 relevant studies. Then, the complete reading of the relevant studies was carried out, applying the exclusion criterion E6. At this stage, 84 papers were rejected for not meeting the quality assessment criterion E6, with 61 papers rejected for not meeting the QA2–QA4 quality criteria and 23 for not meeting the QA1 quality criterion, reducing the number of studies to 10 for final analysis. Figure I summarizes this process.

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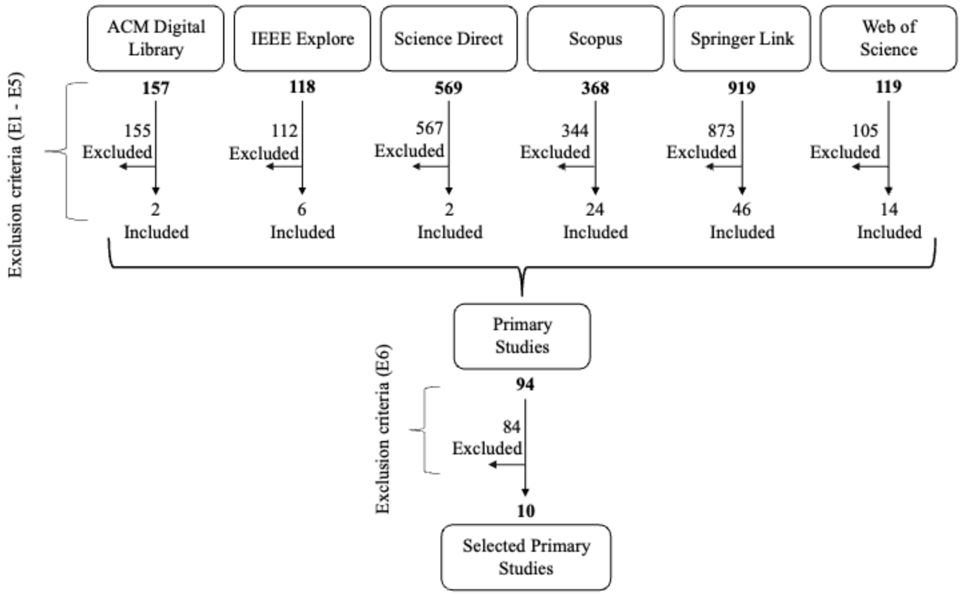
Figure 1

Overview of the selection of primary studies



Source: the authors

Results

This section presents a summary of the demographic data from the primary studies, followed by a discussion of the results with respect to the four research questions defined in Section Formulation of the Search String.

Demographic Data

This section describes important information such as where, when, and by whom the selected papers published. Table III shows the selected primary studies along with their respective citation numbers, totaling 301. The most cited paper was authored by Astor et al. (2013), cited in 138 papers. In this study, the authors conducted two laboratory experiments integrating the physiological data of financial decision-makers with information technology artifacts. The objective was to design and implement a NeuroIS tool (Neuro-Information-Systems) that uses neurophysiological tools to enhance decision-makers' emotional awareness in financial decision-making contexts, thereby improving their skills in effective emotional regulation and enabling a balance between emotions and decision-making actions.

The second-most-cited article was by Roselli et al. (2019), with 53 citations. In this study, the authors used neuroscience to investigate how decision-makers evaluate graphical representations in the multicriteria decision-making method. They experimented using eye-tracking to enhance the FITradeoff decision support system (Flexible and Interactive Tradeoff) within the context of Multi-Attribute Value Theory (MAVT), providing analysts with insights into using graphic artifacts to visualize consequences in multicriteria decision-making.

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The third-most-cited study was authored by Roselli et al. (2018), with 29 citations. In this study, the authors employed neuroscience tools to analyze the inconsistencies and behavioral patterns of decision-makers in multicriteria decision-making processes using the Tradeoff Elicitation Procedure (Keeney & Raifa, 1976) in trade contexts. They used eye-tracking technology and EEG to evaluate business decisions, including supplier, equipment, product, and maintenance policy selection; investment decisions; and portfolio composition.

It is noteworthy to highlight the relevance of the author de Almeida in the field, who contributed to five out of the nine selected papers, accumulating a total of 130 citations. Similarly, author Roselli has four of the nine publications, totaling 118 citations. Equally important are the contributions of authors Frej, da Silva, and Costa, each with two publications, totaling 83, 33, and 33 citations, respectively.

Table 3

Overview of selected primary studies

Title	Author	Citations	Technologies applied	Decision-making process phases investigated
Ratings or Sales? The Neural and Psychological Processes of Online Experience Product Purchase: Evidence from a Sample of Chinese University Students	Chen *et al.* (2022)	1	EEG	Choice
A new approach for product evaluation based on integration of EEG and eye-tracking	Zhu *et al* . (2022)	6	EEG and eye tracking	Choice
Exploring cognitive aspects of FITradeoff method using neuroscience tools	Da Silva *et al.* (2022)	12	EEG and eye tracking	Design
Seeing it is like touching it: Unraveling the effective product presentations on online apparel purchase decisions and brain activity (An fMRI Study)	Jai *et al* . (2021)	24	fMRI	Choice
Decision-Making Analysis using Arduino-Based Electroencephalography (EEG): An Exploratory Study for Marketing Strategy	Yazid *et al.* (2020)	2	EEG	Choice
Analysis of graphical visualizations for multi-criteria decision making in FITradeoff method using a decision neuroscience experiment	Roselli and Almeida (2020)	15	EEG and eye tracking	Design
Neuroscience experiment applied to investigate decision-maker behavior in the tradeoff elicitation procedure	Roselli *et al.* (2020)	21	EEG and eye tracking	Review
Decision neuroscience for improving data visualization of decision support in the FITradeoff method	Roselli *et al.* (2019)	53	eye tracking	Design
Neuroscience Experiment for Graphical Visualization in the FITradeoff Decision Support System	Roselli *et al.* (2018)	29	eye tracking	Design
Integrando Biossinais em Sistemas de Informação: Uma Ferramenta NeuroIS para Melhorar a Regulação Emocional	Astor *et al.* (2013)	138	ECG	Choice

Source: the authors

In Table 3, eight of the ten selected papers were published in journals, while the remaining two were published in conference proceedings. Of the eight papers published in journals, two appeared in the Annals of Operations Research. Furthermore, it is noteworthy to underscore the topic′s significance in current research, as nine of the ten selected studies are recent and have garnered substantial citations.

Context

This section discusses the results of selected primary studies in relation to the four research questions defined in section 4.1.1. The main research question (RQ) aims to understand how neuroscience technology is used to investigate aspects of decision-making processes.

In this context, Chen et al. (2022) used neuroscience tools to explore consumer buying behavior and the underlying processes influenced by online extrinsic cues – attributes indirectly related to the product. The study evaluated consumer purchase decisions considering two extrinsic cues: sales volume and ratings from other consumers on online experience products.

Zhu et al. (2022) integrated neuroscientific tools to infer customers' preferences regarding product design aspects and visual attractiveness. Jai et al. (2021) evaluated how the brain makes purchasing decisions when encountering different types of visual presentation strategies. Neuroscientific technology aims to identify the involvement of various neural circuits in purchase decision-making regarding different types of visual sensory information.

Similarly, Yazid et al. (2020) conducted a study to assess factors affecting visual stimuli during the decision-making process. Astor et al. (2013) developed a NeuroIS tool, based on serious games, to incorporate physiological electrocardiogram data into financial decision-making. The tool aimed to enhance decision-makers' performance by increasing awareness of their emotional state through biofeedback, thereby reducing impulsive decisions driven by high arousal levels.

Da Silva et al. (2022). Roselli and Almeida (2020) and Roselli et al. (2019; 2018) investigated decision-makers′ behavior patterns during the FITradeoff preference elicitation process, employing eye-tracking and electroencephalogram tools. Da Silva et al. (2022) analyzed cognitive aspects during the elicitation process, examining the impact of different criteria on decision maker performance. Roselli and Almeida (2020) studied decision-makers' behavior patterns when viewing bar graphs and tables during the preference elicitation process. Roselli et al. (2018) explored the potential of using graphical visualization in the FITradeoff Decision Support System (DSS), while Roselli et al. (2019) assessed how participants handle decision problems presented only with graphical information. Roselli et al. (2020b), on the other hand, utilized the Tradeoff model as a multicriteria model Elicitation Procedure (Keeney & Raifa, 1976), analyzing behavioral patterns and inconsistencies generated by this approach. All studies in this category were conducted with engineering students who had prior knowledge of the adopted multicriteria methods.

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The subsequent research question (SRQ1) addresses the technologies adopted in the selected studies. Table III presents the authors and the technologies used in their respective studies. It is worth noting that, among the various neuroscientific technologies available, nine out of the ten selected studies utilized EEG and/or eye-tracking.

Regarding the second research question (SRQ2), the studies were categorized into five phases, following the model developed by Herbert Simon and expanded by George Huber: intelligence, design, choice, review, and implementation. However, the selected studies covered only the phases of design, choice, and review, as shown in Table III. Thus, there is a lack of research in the intelligence and implementation phases.

In the design phase, da Silva et al. (2022) utilized these tools to monitor the evolution of attention and effort levels during the ordering of the scale constants, exploration of consequence space, and the elicitation process. The studies by Roselli et al. (2018; 2019) analyzed decision-makers' behavior patterns when using various types of graphic visualization during the preference elicitation process. Similarly, Roselli and Almeida (2020) conducted experiments to investigate human behavior using bar graphs and tables, aiming to identify distortions generated during the modeling process of the FITradeoff decision method.

During the selection phase, Chen et al. (2022) compared online purchase decisions for experience items (products whose attributes can only be evaluated in person and after purchase) with research items (products whose attributes can be objectively evaluated even before purchase). Zhu et al. (2022) integrated EEG and eye-tracking to predict raters' preferences in real time and provide multifaceted supporting information for product designers. Jay et al. (2021) studied brain activation during online purchasing decisions under various visual presentation strategies using fMRI. Yazid et al. (2020) examined consumers' reactions to purchase decisions resulting from video advertising using EEG. Astor et al. (2013) used ECG to identify how emotional state influences decisions, altering subjects' perceptions and reactions to certain situations. In the review phase, Roselli et al. (2020b) used neuroscientific technologies to investigate inconsistencies during the decision-review stage in mathematically robust decision-making methods such as the Tradeoff Elicitation Procedure.

The third question (SRQ3) addresses the contributions reported regarding the use of technology in structuring the decision-making process. The selected studies demonstrate positive results regarding the contributions neuroscientific tools can make to structuring decision-making processes.

For instance, following the categorization of decision-making process stages, da Silva et al. (2022) highlighted that as the drawing stages progress, the pupil size increases, indicating greater cognitive effort. The authors concluded that decision makers should receive greater support during the elicitation of their preferences, which could come from a decision analyst, actors involved in the decision-making process, or Decision Support Systems (DSS).

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Similarly, Roselli et al. (2018; 2019) found that the use of tables yielded more consistent responses than other visual aids in preference elicitation processes. The authors attribute this higher consistency rate of tables to the likely inclusion of additional information alongside graphical data.

In Roselli and Almeida (2020), the authors compared decision problems' design steps by analyzing (1) equal weights and different weights and (2) bar graphs and tables. Results from the first comparison suggested that visualizations with equal weights yielded higher success rates in decision-making. Regarding the second comparison, bar graphs and tables with equal weights showed similar hit rates. However, for bar graphs and tables with different weights, the results indicated that tables outperformed bar graphs in four out of the five comparisons conducted in the experiment.

In the choice phase, Chen et al. (2022) examined experience products and found results that contrasted with previous studies on research products. Previous studies suggested that the interaction between product reviews and sales volume was additive. However, in the authors′ study, neuroscientific tools enabled them to verify that in experienced products, evaluations have a greater influence on purchase intention. At the same time, the effect of sales volume is attenuated. The authors also emphasize that marketing professionals must consider the contextual factors of the products offered online to define efficient promotional strategies.

Zhu et al. (2022) reported that product evaluation results obtained when people are experiencing products are considered more impartial and reliable than reported materials. They argue that the use of these measures is advantageous to avoid bias and subjectivity in the process. The authors also point out that the fusion of several neuroscientific modalities enables greater benefits by compensating for the limitations of each technology.

In Jai et al. (2021), the authors highlighted that neuroimaging tools enable high accuracy in predicting purchase decisions, with rotation videos the most successful category compared to static photos and zoom. Yazid et al. (2020) demonstrated, through an experiment, statistically significant brainwave activity during the observation of an advertising video. As a contribution to neuroscientific technologies, the authors reported a reduction in the time required to assess customer reactions and improved data accuracy, helping analysts and organizations create more effective content aligned with customer requirements.

Finally, Astor et al. (2013) revealed the potential of NeuroIS tools based on biofeedback integrated into information technology artifacts. These tools provide users with direct feedback on their emotional state, improving their skills for effective emotional regulation in financial decision making.

In the review phase, Roselli et al. (2020) conclude the decision-making phases and state that neuroscience tools can enrich research by capturing variables related to unconscious processes, which can be obtained continuously in real time. By analyzing inconsistencies in the Tradeoff decision model Elicitation Procedure, the authors found that greater cognitive effort was required when decision-makers needed to explore the space of consequences more, indicating low engagement and motivation.

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Validity Threats and Their Mitigation

The subjectivity in an SLR poses a potential threat to its validity, particularly during the planning and execution stages. To mitigate this risk, the SLR was analyzed by reviewers who evaluated adherence to the protocol outlined in section 4. A validation session involved two software engineering specialists, as described in section 4.1.6. Their feedback proved invaluable in enhancing the quality of the SLR.

Another concern is the quality of the selected papers for analysis and data extraction, given the lack of consensus on the ideal approach to this task (Duarte et al., 2021). To address this issue and introduce more objectivity, we employed the QualityScore approach, assigning scores to each paper based on predefined quality criteria. Additionally, we opted for papers with peer-review status only and utilized quality assessment criteria grounded in bibliometric impact information.

Moreover, data collection poses a challenge to comprehensive validation. As digital libraries continually index new papers, search results vary with each query. Hence, we executed the search string and stored the retrieved studies in the StArt tool for subsequent analysis and data extraction.

Research Roadmap

The analysis of the studies selected in this SLR identifies potential issues for future exploration. Thus, this section presents some of the open questions, which were not found in the primary studies, suggesting new insights and additional studies for future research, in particular, those described below:

(1) Studies that integrate different neurophysiological and psychophysiological tools from those used in the studies highlighted here, incorporating different data obtained directly from the brain and from the relationships between psychic and physiological phenomena. For example, the skin conductance response (SCR) technology, which measures the activity of sweat glands in the hands, indicates greater emotional stimulus when the hands are perspiring, or magnetoencephalography (MEG), which analyzes the magnetic fields generated by neuronal electromagnetic activity. In addition, other parameters can be investigated, such as arterial pressure and the relationship between heart rate and blood pressure, including pulse transition time as a way to assess changes in the emotional and attentional state of decision-makers.

(2) Studies that use neuroscientific technologies to analyze the effectiveness of the elicitation process of the decision maker, in relation to consistency with their stated preferences. The idea is to understand how the human brain processes information and how the amount of mental load affects task performance, to improve decision-maker performance. Thus, it is valid to define a guide to good practices that highlights factors that can overload mental resources and/or strategies to improve performance in decision-making activities, thereby enhancing the decision-maker's experience and increasing the effectiveness of their decisions.

(3) Studies that use neuroscientific technology to analyze the decision-making process in all its stages. The proposal is to understand the decision-making process in

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its entirety, given that the studies presented here analyze only the phases separately. This would allow a broader understanding of the decision maker's rationality, from the problem's understanding phase to the implementation of the resulting choices. In this issue, it is still possible to direct studies to compare the decision-making phases with the problem-solving phases, thereby verifying the decision-maker's consistency levels using neuroscientific technologies.

(4) Research that develops and supports understanding of neurophysiological patterns in group decision-making. Considering that the selected papers provided only individual-level decisions, the idea is to understand the individual perspectives, emotions, engagement, and/or motivation of decision makers in group decision models. Technologies such as EEG and fMRI, for example, enable mapping of group members' brain activity while they are engaged in decision discussions. This can reveal brain activity patterns associated with specific states, such as attention, emotion, or reward responses. This information can help to identify when group members are engaged, bored, or emotionally influenced during the decision-making process.

(5) Studies that explain how the nature of the decision problem impacts the efficiency of the decision maker during the preference elicitation process. The proposal here is to use neuroscientific tools to assess whether decision makers maintain satisfactory performance during the elicitation process (in terms of time response, number of alternatives, nature of the criteria, and degree of the decision maker's knowledge of the problem). This question invites further studies that define elicitation structures that explore the visual aspects during this project phase.

(6) Research focused on the intelligence stage of the decision-making process. In this sense, the proposal would be to analyze neurophysiological patterns in the phase of collecting information about the problem. That is, the tools would evaluate decision makers' behavior when they verify the existence of the problem, providing feedback on their levels of attention and motivation during the definition of its scope. This research is relevant because the intelligence stage may influence subsequent stages of the decision-making process.

Conclusions

The systematization of the literature conducted in this study aimed to provide a comprehensive view of how neuroscientific tools are being used to understand aspects of decision-making. The aim was to gather empirical evidence that would enhance understanding of the subject, including the technologies adopted, the stages of the decision-making process in which these technologies were employed, and the reported contributions of these technologies to the decision-making process. Therefore, the detailed description of the methodology employed in this SLR is highly beneficial, as it enables and encourages replication.

From the array of studies using neuroscientific technologies, evidence indicates that, while these technologies offer significant contributions, their use remains limited to analyzing decision-makers' behavior patterns at specific stages of decision-making. It was also observed that there is a strong tendency to utilize eye-

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tracking and EEG technologies, with a concentration of studies in the design and choice stages of the decision-making process.

Furthermore, the results reveal that studies in this field are predominantly recent, mostly dating from the last five years, indicating significant potential for further development. Finally, the findings facilitate understanding of the contributions that neuroscientific tools can make in structuring decision processes, including the comprehension of decision-makers' behavior patterns and the support of decision analysts.

Based on this understanding, the authors proposed a research framework with open-ended questions to facilitate the development and improvement of studies in the field of decision-making. It is expected that researchers in the field can capitalize on these opportunities to address some of the highlighted theoretical gaps.

Grades

1. https://scholar.google.com
2. http://portal.core.edu.au/conf-ranks/
3. https://www.scimagojr.com/journalrank.php

Declarations

Conflict of interest All the authors declare that there is no conflict of interest.

Ethical Approval This article does not contain any studies with human participants or animals performed by any of the authors.

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