# BIBLIOMETRIC ANALYSIS AND REVIEW OF NEUROSCIENCE OF FINANCIAL DECISION-MAKING: A NEUROFINANCE PERSPECTIVE

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## ABSTRACT

*Integrating concepts from economics, psychology, and neurology in financial decision-making is a relatively new field known as Neurofinance. The aims of the study are to identify the principal topics within neurofinance research, highlight areas requiring further investigation, and assess the contributions of neuroscience to understanding financial decision-making. Additionally, the study examines the influence of individual differences, cognitive biases, and emotions on investment behavior. Employing the PRIMA model and bibliometric analysis, 63 publications from the Scopus database published between 2004 and 2023 were analyzed. These publications involved 149 authors from 22 countries. Although the field is still in its early stages, the findings indicate growing interest in applying neuroscience to financial decision-making. The review identifies four primary research areas: investor psychology, behavioral finance, neurofinance, and the mental health of stock market traders. The results suggest that further research is necessary, particularly to develop strategies for establishing a more robust theoretical foundation.*

**Keywords**: Bibliometric Analysis, Behavioural Finance, Neurofinance, Neuroscience, Psychology In Finance.

## INTRODUCTION

The traditional economic and finance theories are based on the assumption that humans act as rational agents. Traditional theories emerged to develop a set of principles that underlie financial decision-making (Plous, 1993). The utility model expected return values and portfolio diversification, but required assistance in explaining how individual investors make decisions in a real business environment (Markowitz, 1952). In the real market, investors often violate the Markowitz theory (Markowitz, 1952), for example, by exhibiting irrational behaviors and failing to diversify their portfolios to mitigate risk. Instead, they are happier with specific categories of assets and are not always risk-averse (Lizarazo, 2013). Hence, rational agents, as explained in traditional finance theories, systematically deviate from the optimum portfolio, and the theories of behavioural economics and behavioural finance seek to explain such violations. The most renowned concepts of heuristics and biases, as well as the prospect theory of decision-making under risk (Tversky & Kahneman, 1973), are considered the foundations of behavioral finance studies. However, while behavioural finance theories explain how investors act and interact with the financial environment, they cannot describe why and how investors exhibit such behaviour. A Renowned Study (Tseng, 2006) did not find behavioural theories comprehensive. Further exploration of the human brain and the application of neuroscience experiments in financial decision-making (Tseng, 2006; Lo & Repin,



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2002; Barberis & Xiong, 2012; Frydman et al., 2014; Hassan et al., 2013) has demonstrated its utility in providing a more comprehensive understanding of investors' behavior. This leads to the foundation for applying neuroscience experiments in decision-making by studying the root cause behind human decision-making behaviours. Researchers (Miendlarzewska et al., 2019) have defined a relatively new field, neurofinance, as a combination of neuroscience and finance, which involves studying human brain activities while processing and evaluating financial information. Furthermore, individual differences, including gender, genetics, neuroanatomy, personality, emotions, psychological biases, and stress, influence financial decision-making (Miendlarzewska et al., 2019). Also, in a laboratory environment, Researchers (Bussoli et al., 2022; Ceravolo et al., 2019; Burke et al., 2010) investigating the impact of disclosure documents and mutual fund product attributes on financial decision-making revealed that a product's perceived value decreased with its risk and reward profile (RRP). When red (or blue) is used on the RRP scale and the historical performance graph in the documentation, people tend to think the product is less (or more) desirable than it would be if it were all black and white. Lastly, as determined by eye tracking, a longer visual processing time correlates with a more favorable opinion of one's appearance. Neurofinance studies (da Rocha Lima Filho & Rocha, 2017) emphasize the importance for financial industry supervisors and regulators to investigate how various product features and disclosure documents impact consumers' ability to make informed financial decisions. Researchers (Ceravolo et al., 2019) discovered that how financial information is presented affects how investors process and view it. Researching the brain's role in investor behaviour is essential when examining financial product documentation. Regulators and management should use neuroscientific methods to study investor reactions to financial disclosure materials.

Theories of neuroscience divide the human brain mainly into three major parts: (a) the forebrain, (b) the mid-brain, and (c) the hind-brain. The forebrain, also known as the cerebrum, is the brain's most significant part, consisting of two components: (a) the cortex and (b) the limbic. Studies (Peterson, 2007a, 2007b) describe the cortex as having two parts: the neocortex and the prefrontal cortex. Higher brain functions, such as thought and action, are located in the prefrontal cortex, often referred to as the brain's rational center. The other part of the cortex is the limbic system, which is responsible for storing memories and processing emotions, and is often referred to as the emotional brain. Apart from decisions, neuroscience explains that when decision-making occurs in investors' brains, the expected reward estimations are crucial and attract attention. Some researchers (Levy & Glimcher, 2012; Sugrue et al., 2005) have discussed how optimum decision-making primarily depends on the value computations of a 'common neural currency' that allows reward values to be compared across different rewards on a single scale.

Dishonesty is progressively rising across social domains, backed by behavioural and neurological data (Garrett et al., 2016). According to the study, the frequency of self-serving dishonesty grows with time. Dishonest behavior and amygdala signal reduction are associated with neuronal adaptability, as revealed by functional MRI. Significantly, the degree of decreased amygdala sensitivity in current judgments indicates the escalation of dishonesty that would occur later.

## Problem Statement

This research reviews the various spheres that encompass knowledge in neurobiology and its application to financial decision-making. It is through such a review that the exact area in which further research is required can be found. Although it is evident that stock investors sometimes behave irrationally, the motives behind this irrational behavior are not well understood. Decision-makers and stakeholders can be further assisted in creating a better trading environment by gaining a



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deeper understanding of the brain's responses during trading. The study primarily aims to investigate the impact of neuroscience on financial decision-making and the well-being of stock investors.

This research also reviews studies on how the brain affects investor behavior. The first section describes the literature search process, sorting, and analysis. Subsequent sections provide an overview of traditional finance and how neuroscience explains investor behavior. The discussion then examines the brain functions active in financial decision-making and why neuroscience experiments are relevant to finance. This article is organized as follows: the second section discusses the background and definition of neurofinance; the third section compares neurofinance to traditional finance. Subsequent sections then explore the new research and practical applications of neurofinance. The final section provides a discussion, recommendations, and ideas for future research. The purpose of this study is to present a clear overview of the current state of research in neurofinance and answer the following research questions:

RQ1: What are the study trends in using neuroscience in financial decision-making about publication year, sample country, journal of publishing, authors, publications, and journals that have contributed?

RQ2: What does the content analysis reveal about the knowledge delivered by the past research studies in neurofinance?

RQ3: What is the intellectual and conceptual structure of neuroscience in financial decision-making?

The findings of this study contribute to both theory and practice by providing a comprehensive overview of the emerging field of neurofinance. Bibliometric analysis results provide academics with an overview of the scope and depth of prior research on the application of neuroscience to financial decision-making. The content analysis, in conceptual and thematic structures, identifies research themes for future exploration. For instance, bibliometric research may provide a sound quantitative basis for meta-analyses that advance the field; see Danvila-del-Valle et al. (2019). In addition, these findings help practitioners understand neurofinance applications in financial decisions that exist today, identify gaps in research, and provide insight into the neural processes underlying financial decisions Figure 1.



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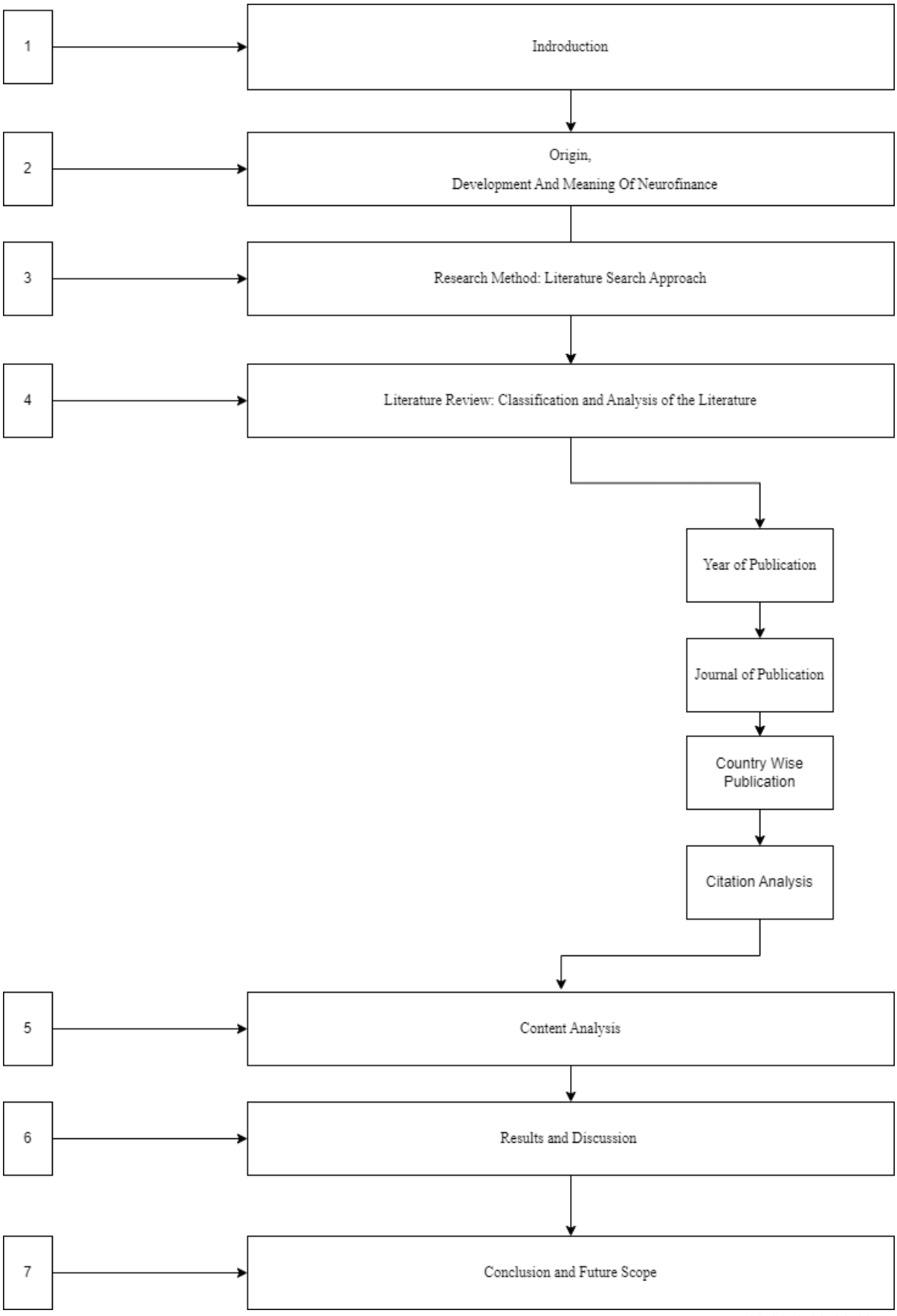




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**FIGURE 1**
**FLOW DIAGRAM (COMPILED BY THE AUTHORS), A GRAPHIC REPRESENTATION OF HOW THE PAPER WAS DIVIDED INTO PARTS**

## Origin, Development, And Meaning of Neurofinance

The Financial theories are designed to explain, describe, and predict the behavior of financial markets. According to Shiller (1981), the neoclassical efficient market hypothesis is primarily theoretical and of little practical use. Yaari (1987) presented the dual theory of choice under risk as a more practical version of expected utility theory that better describes how people make choices. In the market, informed traders are considered rational, while uninformed or noise traders are thought to make inadequate decisions, to be emotionally responsive to news, and to misunderstand simple financial concepts. Informed traders rarely commit cognitive errors, whereas noise traders do, according to Shefrin and Statman (1994).

The well-known traditional financial theory, the efficient market hypothesis (EMH), posits that no individual or group can consistently outperform the market (Fama, 1998). However, many economic situations, such as economic bubbles and subprime crises, are difficult to explain using the standard EMH. Many other primary questions remain, with significant evidence available primarily in real-time. The suffering of the stock market due to money illusion, which the EMH does not address, is a real-time decision-making situation for individuals that requires explanation, and the EMH model often fails (Cohen et al., 2005). Behavioral finance is a branch of behavioral economics that has evolved with new insights and better explanations of investors' behavioral aspects. Behavioral finance describes how investors deviate from the underlying assumptions of rational decision-making, and the authors explain the systematic biases in decision-making (Tversky & Kahneman, 1973; Simon, 1956). Tversky & Kahneman (1973) conducted a series of behavioral experiments to quantify deviations in choice using risk prospects as a variable and found that the behavioral theory is more prominent. Subsequently, prospect theory emerged to address variations in the maximization of expected utility (Madan et al., 2017; Wu et al., 2012), in which investors are risk-averse to gains and risk-seeking to losses. The study by Barberis & Xiong (2012) described a model to define investors' utility, which they directly derive from the realization of gains or losses; they referred to this realization as utility. Further, the study by Barberis & Xiong (2012) suggested using neural data to estimate investors' realization utility. The evolution of neurofinance is a combination of neuroscience and finance that seeks to understand how the human brain processes financial information when financial decisions are made, and what happens before, during, and after. Neuroscientific studies enable economists to comprehend the biological primary drivers of human decision-making, whereas neuro-finance experiments employ neuroscientific tools to discover the drivers and moderators of choice behavior. Biofeedback, blood volume pulse, heart rate, electromyographical signals, breathing, and body temperature change are examples of neurofinance experimental apparatus. Recent advances in technology have enabled the use of tools such as fMRI and PET scans to measure brain activity while people make decisions. These scans track blood flow in the brain and show activity, but they do not capture rapid changes very well. In contrast, EEG and MEG can record brain activity with much higher time accuracy. Using these neuroscience tools, researchers in neurofinance can study how people take financial risks, form expectations, make valuations, respond to information, and are influenced by factors like competition and group behavior (Peterson, 2014).

## Research Method: Literature Search Approach

This study examines the intersection between neuroscience and finance, employing systematic review and bibliometric methods. Systematic literature reviews minimize bias in the selection of material and, hence, are considered a scientific gold standard. Bibliometric analysis utilizes statistical



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methods to assess publications and monitor the impact of researchers and journals over time. Each author independently reviewed the selected studies, and only those that were agreed upon were included for further analysis. Bibliometric data can help us understand connections between publications. Systematic literature reviews are valued because they are comprehensive and allow the answering of specific questions about the state of a field (Paul et al., 2021; Snyder, 2019; Kraus et al., 2020).

This review analyzed academic publications applying neuroscientific ideas to financial decision-making. Data were analyzed both bibliometrically and through a systematic review, following the PRISMA recommendations. The analyses were supported with tools like Vosviewer and Biblioshny. Keywords were chosen based on previous research and run through Scopus on October 12, 2023, without filtering for publication year. The first relevant publication was in 2004; therefore, the time span analyzed spans from 2004 to 2023 in finance, economics, and related fields. Scopus was selected because it has broader coverage compared with the Web of Science, according to recent comparisons. Generally, it was observed that sources indexed by Scopus largely overlapped those indexed by Web of Science, with Scopus indexing more unique sources than Web of Science could index. However, this is considered a limitation for this study that may be improved upon in the future. Bibliometric analysis is a scientific technique that has gained popularity as a multidisciplinary tool for comprehending the temporal development of a study subject, identifying its boundaries, establishing key figures, and discovering new avenues of research. It facilitates scholars in objectively mapping the intellectual framework within a field. It is a cross-disciplinary method that enables mapping directions and topics covered in the growth of a subject area. In conducting our bibliometric analysis, this study will utilize network, co-occurrence, and bibliographic coupling analysis. Similar studies have been conducted, such as the one by Costa et al. (2019), which utilized network, co-occurrence, and bibliographic coupling to analyze data from behavioral economics and behavioral finance research, identifying gaps and opportunities.

This paper began with a database search, during which 289 papers were identified as related to our keywords. In order to narrow the search, we used the following key terms: "neuroscience and finance," "psychology and the stock market," "neurologic mechanism and market bubbles or crashes," "neurofinance and investment," "neuroscience and asset valuations or asset price," "investor behaviour and brain," or "neuroscience and the stock market." The authors have included only those articles that contained any of the search keywords in the title, abstract, and keywords of the article. The study only limited the search to articles in economics, econometrics, finance, business, management, accounting, and social sciences. A comprehensive selection method is employed to select the papers to be analyzed in this study. To find a research article, the eligibility criterion was applied to finalize the analysis papers: the Method, Objective, Findings, Exclusion of Literature Reviews, Bibliometric Analysis, and central theme should all relate to neurofinance. A literature review and bibliometric analysis were also excluded, allowing for a focused examination of the scholarly impacts of the selected publications. Five papers out of the total number were written in languages other than English and were thus excluded. Thus, 284 papers were left for full-text analysis, out of which 221 did not fulfill the eligibility criteria and were thus eliminated. Ultimately, 63 relevant journals were identified for analysis in this study. The selected 63 publications provide a wide range of neuroscientific research on financial decision-making. These also discuss how neurological mechanisms can explain market dynamics and how investor behavior can be studied using neuroscience. The compilation of research provides a comprehensive understanding of the complex relationship between neuroscience and finance. The flow chart for the article review using the PRISMA paradigm is depicted in Figure 2.



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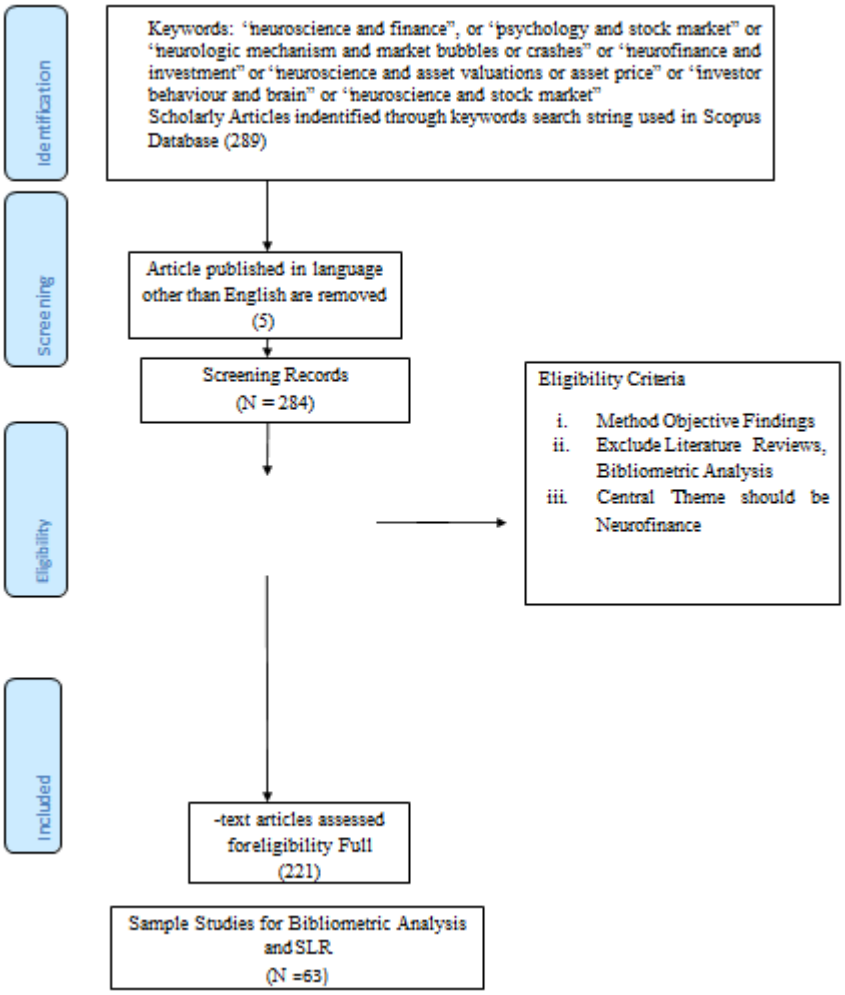


**FIGURE 2**
**PRISMA FRAMEWORK DEPICTING THE STUDY SELECTION PROCESS**

**Source-** Author's unpublished data Oct' 2023

## LITERATURE REVIEW: CLASSIFICATION AND ANALYSIS OF THE LITERATURE

### Year of Publication

Figure 3 displays the publications distributed between 2004 and 2023. The trend of the articles over time is fascinating. The number of articles increased significantly after 2012. Upon further investigation, it was found that the average number of studies published per year is approximately four. The United States alone published 16 articles during the year of analysis. The increase in publications indicates a recent development in people's general understanding of the impact of mental states or neural processes on financial decision-making. Human brains have primitive components developed for natural environments, which can lead to poor financial decision-making in modern scenarios (Miendlarzewska et al., 2019).

Cohen et al. (2005) argue that cognitive systems are adapted to natural settings, which may



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contribute to persistent challenges in managing financial problems. This perspective underscores a misalignment between human cognition and the requirements of contemporary economic environments, revealing frequent failures in decision-making under financial stress. Consequently, there is a growing demand for comprehensive analysis in this area. Furthermore, the proliferation of digital platforms and databases has significantly increased the volume of research material available. Neuroscience and related disciplines have experienced rapid growth due to recent technological advancements.

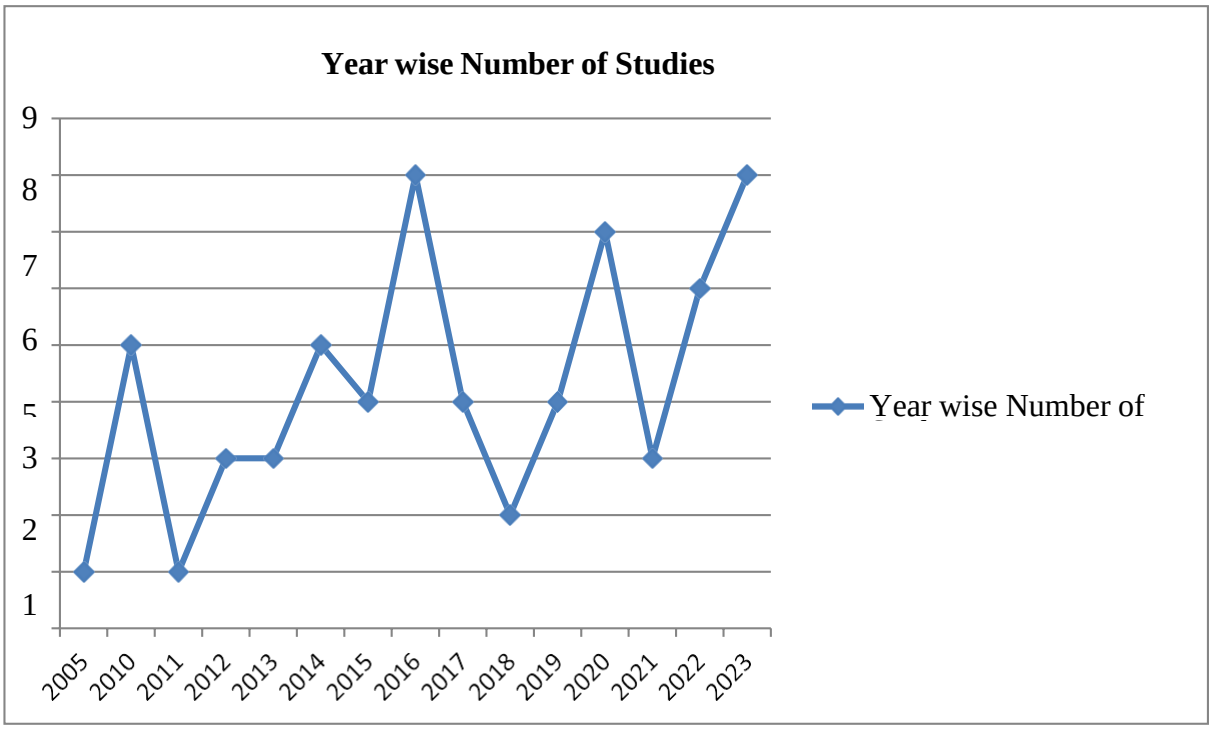


**FIGURE 3**
**YEAR-WISE CLASSIFICATION OF STUDIES ON NEUROSCIENCE FOR FINANCIAL DECISION-MAKING (PRIMARY SOURCE)**

## Country-wise Classification

Figure 4 illustrates the bifurcation of articles based on the country where the authors collected the data or chose the geographic domain for their studies. the visualization shows that developed countries, such as the usa and the uk, have been the primary locations for most studies. on the other hand, developing countries have been targeted less, resulting in fewer studies. the primary reason for this anomalous distribution of study is that, in developed countries, since the 1990s (known in the united states as the decade of the brain), interest in and pursuit of knowledge in this field have only seemed to grow (dekker et al., 2012).

Figure 5 depicts the division of papers based on the country where the authors collected the data or selected the geographic domain for the study. According to the visualization, developed countries such as the United States and China have been the principal locations for most studies. Developing countries, on the other hand, have received less attention, resulting in fewer studies. The primary reason for such an atypical distribution of research is that in developed countries, interest in and pursuit of knowledge in this field has only increased during the 1990s (dubbed the "Decade of the Brain" in the United States) (Dekker et al., 2012). According to PubMed, in the mid-1960s, an average of 3,000 papers containing the word "brain" were published annually (Markram, 2013; Fan & Markram, 2019). Most neurofinance



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studies in developing nations, such as India, focus on this area of research. In terms of research, the possible factor is more generalized. The industrialized world has significantly more resources and a better understanding of the long-term impacts of thorough research in this field. Developing or low-income countries need more research funding and other pressing challenges to address, rather than comprehending the long-term benefits of research. This results in a surplus of fruitful research in industrialized countries and a scarcity in their equivalent countries.

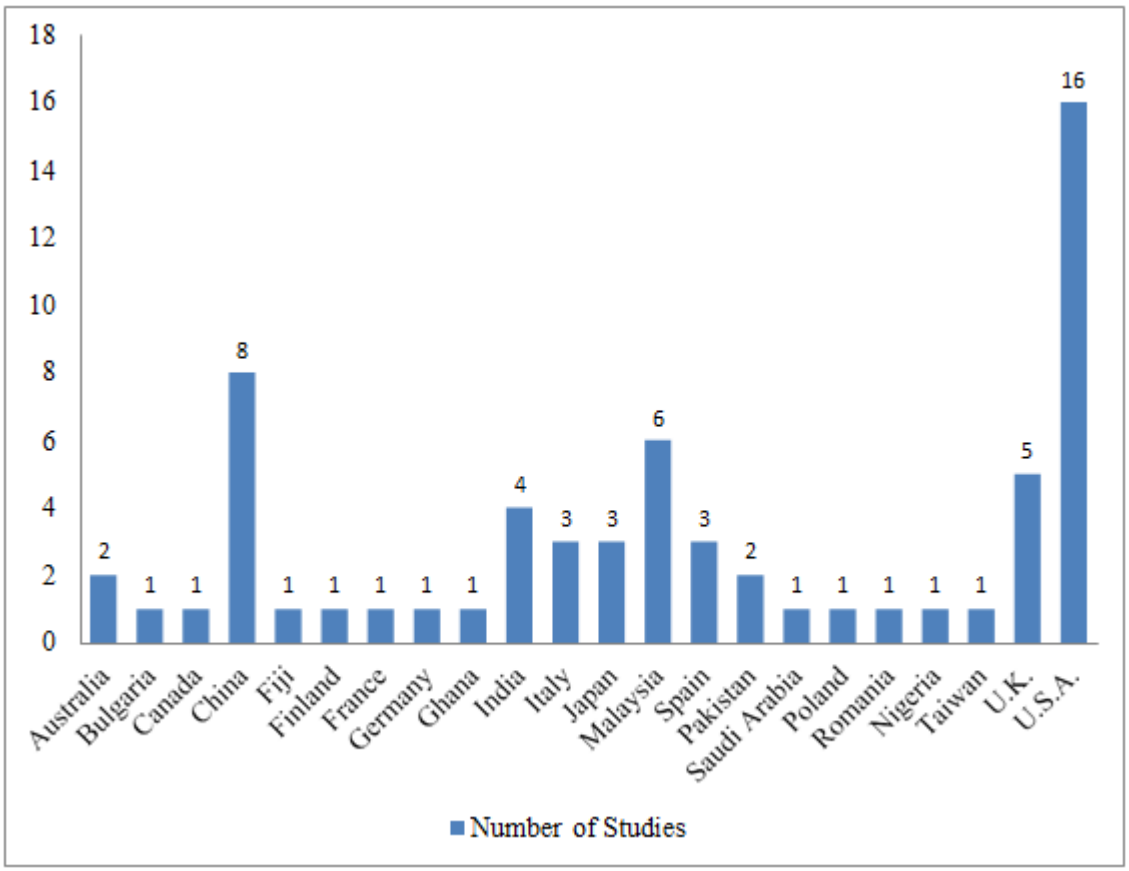


**FIGURE 4**
**COUNTRY-WISE BIBLIOMETRIC COUPLING**



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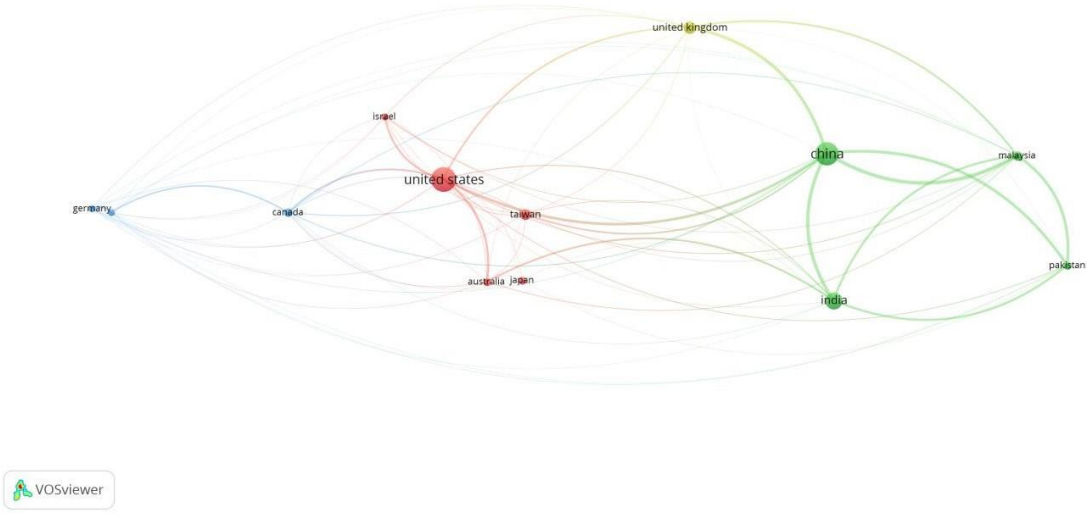


**FIGURE 5**
**COUNTRY-WISE BIBLIOMETRIC COUPLING (PRIMARY SOURCE)**

## Journal of Publication

This review analysed 63 research papers from 61 journals on a specific subject. Each journal contributed an average of one paper, while three published two publications each. The Journal of Behavioural Finance, Frontiers in Neuroscience, Frontiers in Human Neuroscience, Psychological Reports, Nature Neuroscience, and Addictive Behaviours are noteworthy journals that disseminate research at the intersection of neuroscience and decision-making. These publications stand out for their dedication to expanding our understanding of the intersection of neuroscience and decision sciences, highlighting the growing importance of this multidisciplinary field of study. Nature Neuroscience, with an impact factor of 25 and a Decision Support System grade of 7.5, exemplifies the recognition that leading journals accord to research in this field. Figure 5 provides an overview of the data collected. The distribution can be understood succinctly in light of the confluence of decision-making and neuroscience in the sampled publications. With several publications in significant journals and endorsements from prestigious platforms such as Nature Neuroscience, this research topic is gaining recognition and importance in neuroscience and decision sciences. Figure 6 illustrates the critical journals on "Neuroscience in finance" and the number of articles published in each of these publications.



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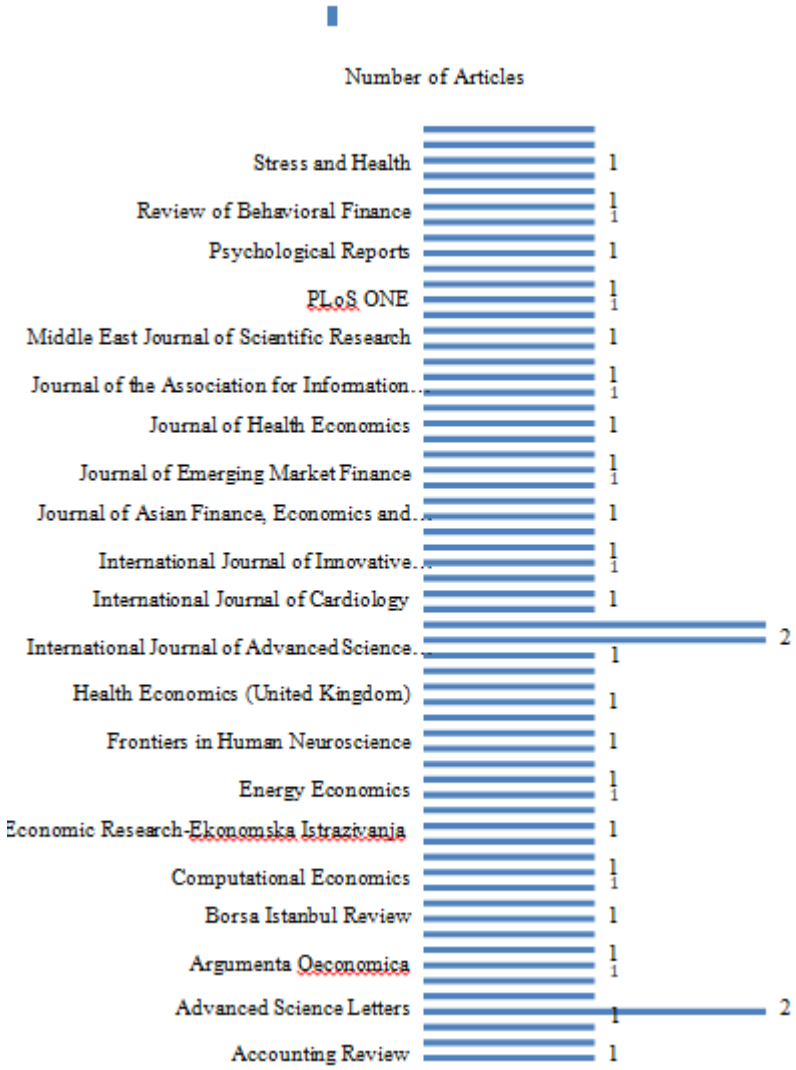


**FIGURE 6**
**PUBLICATION JOURNALS DISTRIBUTE ARTICLES**

## Citation Analysis

A collection of the most frequently cited writers, papers, and other references in the field of financial decision-making neuroscience is provided in Table 1. The quantity of citations indicates the extent to which a source has influenced the development of a particular academic topic. A highly regarded source has significantly impacted the field's development. According to their significance and applicability, authors of studies must choose which publications to mention (Donthu et al., 2022; Arora & Chakraborty, 2021). However, as citation counts can be distorted by the age or experience of a source, various indices, such as the h-index, g-index, and m-index, are employed to measure the impact of a source.

The word "index," first used by a researcher (Hirsch, 2005), describes the total number of articles (h) in a journal that have received at least h citations from other authors. Additional significant indicators are the index and the g-index (Alonso et al., 2010; Egghe, 2006). The calculations of the m-index are done by the formula h/n, where n is the number of years since the first publication of a journal,



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and h is the author's or journal's h-index. The word "g-index," which a researcher (Egghe, 2006) first used in 2006, describes the maximum number when articles are ranked decreasingly in terms of citations, such that the top g-index articles are cited at least two times.

**Table 1**
**MOST CITED SOURCES**

| Element | h_index | g_index | m_index | TC | NP |
|---|---|---|---|---|---|
| Advanced science letters | 2 | 2 | 0.286 | 10 | 2 |
| International journal of bank marketing | 2 | 2 | 0.4 | 20 | 2 |
| Accounting review | 1 | 1 | 0.143 | 41 | 1 |
| Acta oeconomica | 1 | 1 | 0.125 | 2 | 1 |
| Addictive behaviours | 1 | 1 | 0.2 | 40 | 1 |
| Applied economics | 1 | 1 | 0.5 | 1 | 1 |
| Asian academy of management journal of accounting and finance | 1 | 1 | 0.125 | 8 | 1 |
| Australian journal of management | 1 | 1 | 0.091 | 26 | 1 |
| Borsa istanbul review | 1 | 1 | 1 | 2 | 1 |
| Brain research bulletin | 1 | 1 | 0.053 | 41 | 1 |
| Computational economics | 1 | 1 | 0.125 | 2 | 1 |
| Consumption markets and culture | 1 | 1 | 0.077 | 12 | 1 |
| Decision support systems | 1 | 1 | 0.083 | 4 | 1 |
| Economic research-ekonomska istrazivanja | 1 | 1 | 0.125 | 5 | 1 |
| Economics | 1 | 1 | 0.111 | 7 | 1 |
| Economics bulletin | 1 | 1 | 0.1 | 3 | 1 |
| Energy economics | 1 | 1 | 1 | 3 | 1 |
| Euromed journal of business | 1 | 1 | 0.25 | 5 | 1 |
| Frontiers in computational neuroscience | 1 | 1 | 0.1 | 1 | 1 |
| Frontiers in human neuroscience | 1 | 1 | 0.071 | 41 | 1 |
| Frontiers in neuroscience | 1 | 1 | 0.083 | 38 | 1 |
| Frontiers in psychology | 1 | 1 | 0.333 | 55 | 1 |
| Ifac-papers online | 1 | 1 | 0.2 | 2 | 1 |
| International conference on management science and engineering - annualconference proceedings | 1 | 1 | 0.1 | 4 | 1 |
| International journal of advanced science and technology | 1 | 1 | 0.25 | 1 | 2 |
| International journal of business innovation and research | 1 | 1 | 0.071 | 15 | 1 |
| International journal of cardiology | 1 | 1 | 0.125 | 5 | 1 |
| International journal of economics and management | 1 | 1 | 0.5 | 1 | 1 |
| International journal of environmental research and public health | 1 | 1 | 0.25 | 17 | 1 |
| International journal of innovative computing and applications | 1 | 1 | 0.125 | 1 | 1 |
| International journal of social economics | 1 | 1 | 0.1 | 5 | 1 |
| Journal of business venturing | 1 | 1 | 0.25 | 53 | 1 |
| Journal of experimental psychology: animal behavior processes | 1 | 1 | 0.071 | 57 | 1 |
| Journal of financial regulation | 1 | 1 | 0.5 | 1 | 1 |
| Journal of health economics | 1 | 1 | 0.091 | 151 | 1 |
| Journal of machine learning research | 1 | 1 | 0.111 | 37 | 1 |
| Journal of systems science and complexity | 1 | 1 | 0.111 | 3 | 1 |



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| | | | | | |
|---|---|---|---|---|---|
| Journal of the association for information science and technology | 1 | 1 | 0.2 | 21 | 1 |
| Middle east journal of scientific research | 1 | 1 | 0.091 | 5 | 1 |
| Nature neuroscience | 1 | 1 | 0.125 | 93 | 1 |
| Personality and individual differences | 1 | 1 | 0.071 | 247 | 1 |
| Plos one | 1 | 1 | 0.1 | 24 | 1 |
| Procedia computer science | 1 | 1 | 0.25 | 7 | 1 |
| Progress in neuro-psychopharmacology and biological psychiatry | 1 | 1 | 0.083 | 48 | 1 |
| Psychological reports | 1 | 1 | 0.071 | 2 | 1 |
| Public health | 1 | 1 | 0.5 | 12 | 1 |
| Qualitative research in financial markets | 1 | 1 | 0.333 | 7 | 1 |
| Social network analysis and mining | 1 | 1 | 1 | 2 | 1 |
| Social neuroscience | 1 | 1 | 0.111 | 53 | 1 |
| Stress and health | 1 | 1 | 0.125 | 4 | 1 |

The researchers evaluated several articles on the application of neuroscience in financial decision-making in this study. Using Google Scholar, they found citations and chose the most relevant and noteworthy works. Among the 63 papers studied, 51 had obtained citations from other sources, showing that their work was valued and reputable by other researchers. A notable observation was made regarding 13 newly published publications that have yet to garner citations. As such, most of these papers lack citations, which may raise questions about their reputation and relevance in current scholarship. The citation patterns, showing that most articles gain attention while some await more significant recognition or involvement, replicate the discrepancy in the reception of the research.


**FIGURE 7**
**CO-CITATION NETWORKS OF DOCUMENTS**

This study utilized co-citation analysis (Figure 7) to identify the underlying principles of neurofinance. Co-citation analysis measures the frequency with which two publications are cited in a third article (Aria & Cuccurullo, 2017; Zupic & Čater, 2015). The third document generates an active relationship by citing the first two documents (Backhaus et al., 2011; Culnan et al., 1990). Co-citation analysis is based on writers citing other works due to the similarity, relevance, and relatedness of the field (Donthu et al., 2022). The most frequently cited paper is "The Investor Psychology and Stock Market Behavior during the Initial Era of COVID-19: A Study of China, Japan, and the United States" by researchers (Naseem et al., 2021), published in the journal Frontier in Psychology—Table 2 lists other significant research that has contributed to our understanding of the neurology of financial decision-making.



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**Table 2**
**MOST CITED REFERENCES AMONG THE EXAMINED 289 DOCUMENTS**

| S.N. | Document | citations | Total link strength |
|---|---|---|---|
| 1 | De & Thaler (1985) | 3191 | 0 |
| 2 | Daniel et al., 1998 | 2545 | 13 |
| 3 | Christelis et al., 2010 | 401 | 1 |
| 4 | Cao & Wei (2005) | 270 | 8 |
| 5 | Ritter (2003) | 255 | 5 |
| 6 | Alter & Penheimer (2006) | 231 | 1 |
| 7 | Mcinerney et al., 2013 | 151 | 1 |
| 8 | Levy & Yagil (2011) | 127 | 8 |
| 9 | Dzielinski (2012) | 123 | 0 |
| 10 | Ren et al., 2019 | 102 | 3 |

Table 3 highlights the ten most influential authors in the field based on the results. The selection was made based on the authors' h-index, which was 2 for all authors, and the g-index, which was 2 or 3 for all authors. Additionally, the analysis focused on the ratio of the h-index to the number of years of publication. The first author, Ahmad Z, was found to have an influential score of 0.2 with a g-index of 0.4, a score also achieved by authors such as Ceravolo MG, Farina V, Fattabene I, Leonelli L, and Raggetti G. These scores indicate the influence these authors have on the research field. The m-index ranged from 0.2 to 0.4, indicating potential for research collaborations among all authors.

**Table 3**
**INFLUENTIAL AUTHORS**

| S.N. | Element | H_index | G_index | M_index | TC | NP | PY_start |
|---|---|---|---|---|---|---|---|
| **1** | AHMAD Z | 2 | 2 | 0.2 | 13 | 2 | 2014 |
| **2** | CERAVOLO MG | 2 | 3 | 0.4 | 39 | 3 | 2019 |
| | | | | | 399321 | | |
| **3** | FARINA V | 2 | 2 | 0.4 | 20 | 2 | 2019 |
| **4** | FATTOBENE L | 2 | 3 | 0.4 | 21 | 3 | 2019 |
| **5** | LEONELLI L | 2 | 2 | 0.4 | 20 | 2 | 2019 |
| **6** | MANGEE N | 2 | 2 | 0.2 | 10 | 2 | 2014 |
| **7** | OTHMAN M | 2 | 2 | 0.286 | 10 | 2 | 2017 |
| **8** | RAGGETTI G | 2 | 3 | 0.4 | 21 | 3 | 2019 |
| **9** | RAZI NIM | 2 | 2 | 0.286 | 10 | 2 | 2017 |
| **10** | YAACOB H | 2 | 2 | 0.286 | 10 | 2 | 2017 |

## Content Analysis

## Conceptual Structure

Conceptual structure facilitates the understanding of the relationship between concepts and words in documents. Co-word networks are networks of words that frequently co-occur. Deconstructing a conceptual structure involves two steps: first, identifying the critical study field themes and subfields, and then, using a bi-dimensional matrix to map these themes and subfields. The subjects of "Neuroscience of Financial Decision Making" emerged and developed, and as a result of discussions, debates, and partnerships among researchers, the agenda was determined, and articles were published. During this time, the theme of "Neurofinance," which was one of the pillars supporting the growth of



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the Neuroscience of Financial Decision-Making field before its emergence (Razi et al., 2017), evolved into a motor theme (Miendlarzewska et al., 2019; Frydman et al., 2015; Li et al., 2019). "Neurofinance" is a component of the "Computational Neuroscience and Financial Decision Making" theme (Table 4).

**Table 4**
**IMPORTANT RESEARCH FRONTS IN 5 CLUSTERS ON TWO DIMENSIONS OF CENTRALITY AND DENSITY**

| Cluster | Research Front | Hot Topics | Authors |
|---|---|---|---|
| 1 | Computational Neuroscience and Financial Decision-Making | Computational neuroscience is a field of study that aims to understand the brain's workings. It has been widely used to identify interesting trends in investment choices. While sentiment analysis has been used in neurofinance research to quantify emotions and biosignal analysis | Ceravolo et al., 2019; Razi et al., 2017; Sano, 2022; Mateu et al., 2018; Peterson, 2005; Chen et al., 2016; Royit et al., 2023 |
| 2 | Neurofinance and Stock Information | The brain activity of investors revealed a strong link between news reports and the corresponding market sentiment. Findings indicate that news significantly impacts market volatility, and a sense of humour among investors is closely related to the news received. | da & Rocha, 2017; Frydman et al., 2015; Hirsto, 2011; Yamaji et al., 2016; Mussel et al., 2015; Chi & Shanthikumar, 2017 |
| 3 | Investors Mental Healthand Stock Market | They contend that shifts in financial wealth can affect health outcomes, with psychological impact resulting fromanguish. | Benrouba & Boudour, 2022; French, 2023; Kroth et al., 2010; Benrouba & Boudour, 2023; Mills & Nower, 2019 |
| 4 | Cognitive Biases and Irrational Behaviour | Addressing stock market anomalies requires understanding investor conductand cognitive biases as manifestations ofirrational behaviour. | Ritter, 2003; Ren et al., 2018; Mills & Nower, 2019; Antony, 2020 |
| 5 | Stock Prediction andInvestor Psychology | Illuminates the relationship between investor mood, psychology, and stock trends, advancing discussion on market oddities. | Li et al., 2019; Yao & Luo, 2009; Qadan & Aharon, 2019; Mishra & Smyth, 2010 |

## Theoretical contributions

Researchers have explored how neuroscience theories apply to financial decision-making by creating different theoretical frameworks. Realization Utility Theory looks at how stock investors assess and value their actual results. The Self-Serving Dishonesty Theory explains the psychological factors underlying dishonest actions driven by self-interest in investment choices. Behavioural finance theory furthers the discussion by explaining how human psychology and behaviour influence financial decisions and market outcomes. Some academics link neuroscience with economics to extend the research of neurofinance and neuroeconomics, aiming to understand the brain mechanisms that underlie financial behavior and decision-making. The significance of emotions in economic theory has been highlighted by numerous scholars. Their research demonstrates the central role of affective states in shaping economic decisions by systematically documenting how variations in emotional states influence risk preferences, investment behavior, and market dynamics. These methodological approaches offer novel insights and valuable findings that enhance understanding of individual behavior in economic settings.



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## Thematic Structure

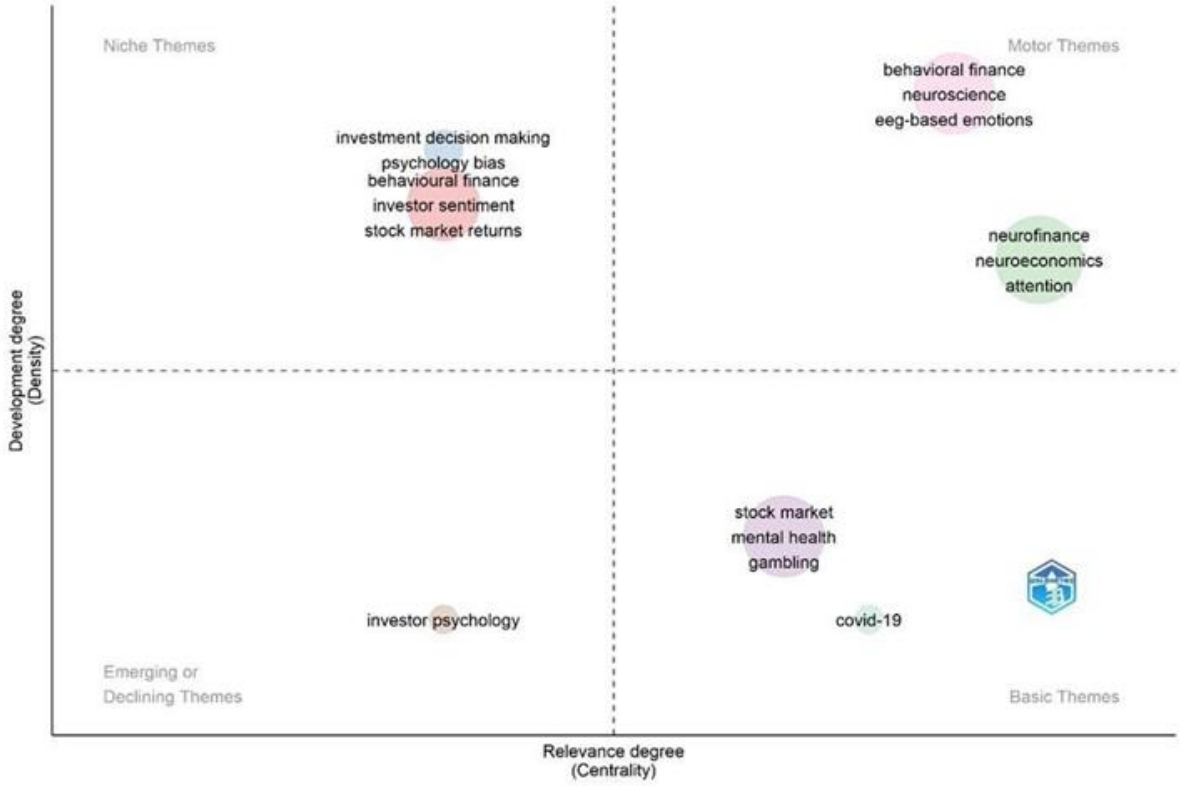


**FIGURE 8**
**COMPOSITE THEMATIC MAP OF THE NEUROFINANCE**

Based on centrality and density (Figure 8), the algorithm divides the themes into four groups: 1) motor themes, which are significant and well-developed concepts for organizing a study field; 2) Niche themes, particular and ancillary topics, and transversal themes to the research area. 3) Emerging or decreasing themes: low-density and centrality topics to the research field; 4) Basic themes, fundamental, universal (Hirsch, 2005; Samal & Mohapatra, 2020; Cobo et al., 2015). The study created a thematic map using the term plus and established three constraints to preserve information richness without compromising map readability. The algorithm generated seven distinct clusters on the thematic map. The studies were then retrieved and analyzed based on these thematic axes and relevant keywords.

### Motor themes

The motor themes are located in the top right quadrant. The algorithm created two motor theme clusters. The main themes driving the cluster are neuroeconomics, neurofinance, and behavioural finance. Three additional cluster-driving themes included behavioural finance, emotion-based EEG, and neuroscience in finance. The motor topics are finance and neurology. As we have already seen when discussing the authors' network of collaborators, research on the neurology of financial decision-making has been conducted (Frydman et al., 2015; Li et al., 2019). Computational neuroscience is also a field that studies the functioning of the human brain. In recent years, it has been increasingly used to identify interesting patterns in investment decisions. This research pioneers biosignals, specifically EEG-based emotion recognition, in neurofinance, a field that has traditionally measured emotions using sentiment analysis. Behavioural finance recognizes the impact of emotional and cognitive errors on investment



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performance. Therefore, taking preventive steps to protect investors' funds is necessary, as highlighted by researchers (Razi et al., 2017).

## Niche Themes

The top left quadrant of this field identifies niche areas in finance, such as stock market return, investor sentiment, behavioral finance, and investment decision. This quadrant is unique because it addresses how neuro issues impact financial decisions. Researchers also emphasize the need to understand how the brain's workings interact with financial decisions. Society is dynamic, and its component parts interact in complex ways: depending on the definition that is used, there can be either risk or uncertainty; measurable risk is cause for optimism, but immeasurable uncertainty results in anxiety and decision making (Sano, 2022; Mateu et al., 2018; Almansour et al., 2023). Measurable financial credit represents trust, and trust is the mortar that supports the risk-sharing that is part of life; however, increasing levels of credit tend to destroy trust. When a credit bubble bursts, trust is destroyed, leading to an economic decline that cements relations in a system and prohibits action: this lack of trust destroys the very foundation of social systems- health, economic, and collective rationality-by promoting unorganized complexity, which limits the creation of value and makes the potential for random events higher (Aria et al., 2020). The analysis of the data was conducted using SEM-PLS, and the results indicate that representational biases and availability have a positive impact on investment decisions (Cobo et al., 2015). It is surprising to note that there is no evidence of the moderating impact of locus of control. Pakistani investors tend to prefer information that is readily available and often accept information from friends and relatives without verification. The non-personality-specificity of heuristic biases in investment decision-making, or the heterogeneity of cultural sample attributes, can make locus-of-control moderation insignificant. It is in the top-left quadrant where researchers become engaged with the richer dimensions of neurofinance. By engaging with topics, they demonstrate that they are concerned with understanding the specifics of how the brain influences financial decisions. This area is becoming a niche research hub, demonstrating how neuroscience and finance are converging to present new opportunities.

## Emerging or Declining Themes

The bottom-left quadrant describes neurofinance themes that are either emerging or declining. This reflects the rapid growth in the field since 2018. Current research increasingly explores the application of neuroscience to finance. Two key themes have emerged: investor psychology and decision-making. Interdisciplinary questions have also begun to emerge, mainly regarding how neurobiology influences investor decisions. This quadrant depicts the different emerging concepts and research questions that enhance neurofinance. There is a growing focus on the relationship between the brain and financial decision-making. Decision-making and investor psychology are two core themes that dominate, underscoring the need for further research on these topics. Financial markets reflect the cumulative thinking and feelings of people (Janecka, 2014). Such a belief indicates that individual and/or group cognition can create cycles in the marketplace. However, the emotions that drive price fluctuations, including optimism, pessimism, fear, and hope, are not well understood (Naseem et al., 2021; Mengov et al., 2019).

The collective behavior of financial markets is a product of the combined intellectual and emotional undertakings of several individuals (Janecka, 2014). Researchers (Royit et al., 2023; Janecka, 2014; DifHövel & Gehrke, 2022) suggested that the mechanism of price fluctuations, a product of market mood and emotions of optimism, fear, hope, and pessimism, is not well comprehended. They found that biases were substantial in favour of growth stocks in the nation's equity market. At the same time, investors are more confident in growth stocks than in value stocks despite the market



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fundamentals. Investor Psychology in the Stock Market: Empirical Research on the Impact of Overconfidence on Business Valuation & Portfolio Selection also finds that investors accord substantial consideration to the events and fundamentals of performance (Akinde et al., 2018; Aljifri, 2023). Additionally, researchers Bouteska & Regaieg (2020) studied investor psychology and found that the Moon phase has a significant impact on investors' psychology and stock trade performance. Researchers (Naseem et al., 2021; Mengov et al., 2019; Albada & Nizar, 2022; Tuyon et al., 2016) discussed the significant impact of the sudden rise and rapid transmission of COVID-19 on investors' psychology, influencing their ability to make optimal decisions.

## Basic themes

The foundation of the field lies in the lower right quadrant, which encompasses broad, interdisciplinary challenges such as the stock market, mental health, and the use of gambling robots. Neurofinance, an emerging discipline that integrates neurology and finance, remains in its early stages of development. This quadrant provides an overview of the fundamental concepts of neurofinance, illustrating the relationship between finance and neurology. The investigation of how neural processes influence financial decision-making employs diverse disciplines and methodologies, as evidenced by research on the stock market, mental health, and gambling robots. These topics advance the field and highlight the dynamic nature of neurofinance. Research indicates that strategic gamblers are more likely to experience severe gambling problems, while non-strategic gamblers tend to be older, female, and divorced. Nevertheless, both groups, compared to individuals without gambling problems, exhibit difficulties with self-control and cognitive flexibility. These findings suggest that, despite differences in age or background, compulsive gamblers share traits such as impulsivity and rigidity. Real-time online stock and cryptocurrency trading introduces further concerns, as noted by Oksanen and colleagues. Additional studies have identified a correlation between stock market fluctuations and mental health, with declines in the market associated with increased cases of neurotic disorders, particularly among older adults. Furthermore, analyzing emotions expressed in social media posts may offer valuable insights for mental health monitoring.

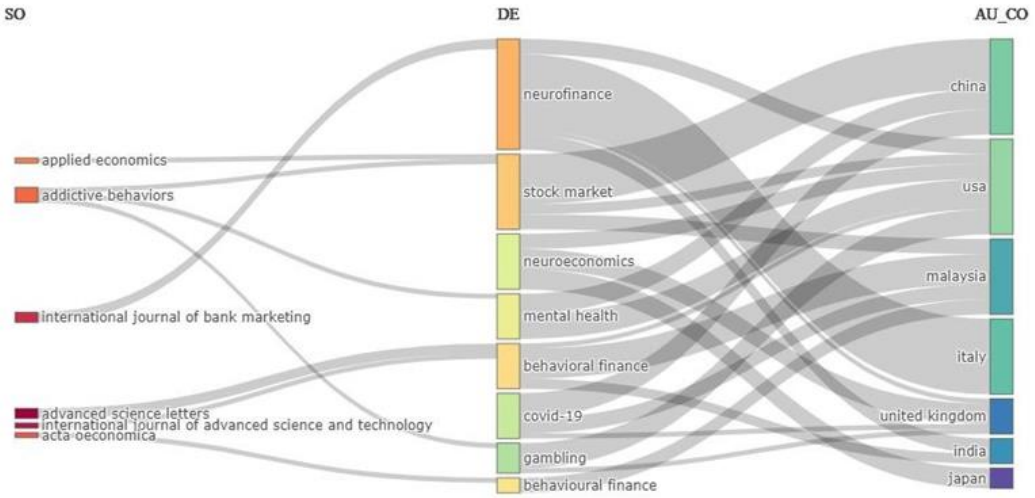


**FIGURE 9**
**ALLUVIAL GRAPH SHOWING THEMATIC EVOLUTION**



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The concepts of neurofinance, investment decision-making, and behavioural finance have collectively advanced the application of neuroscience in financial decision-making, as illustrated by the alluvial graph (Figure 9). This area has gained increasing prominence within neurofinance across various countries and sources, and it remains a central theme providing the theoretical foundation for research in the field. Figure 9 indicates that Italy has the highest number of neurofinance publications, while India has the fewest. In the United States, a limited number of authors contribute to neurofinance, whereas most studies published in China address the stock market and mental health. Major neuroeconomic articles are distributed relatively evenly among countries such as the United States, the United Kingdom, and Japan. This review identifies key authors, influential papers, and leading journals, offering insights into the development of neurofinance. A comprehensive analysis uncovers the field's complexity by examining its conceptual and intellectual structure. Thematic maps provide visual representations of the evolving core concepts in neurofinance. Furthermore, an examination of the most frequently cited articles highlights significant contributions that have shaped the scientific discourse. This investigation enhances understanding of the evolution of neurofinance and the prominent figures guiding its trajectory. By emphasising notable academic achievements, this study advances knowledge in neurofinance and offers essential guidance for scholars seeking to integrate neuroscience and finance.

## CONCLUSION

Neuroscience should play a more active role in financial decision-making studies. For example, analyzing EEG signals or brain activity may help explain how investors make choices and what they might be thinking. Therefore, other methods might include machine learning or data analysis that would allow the extraction of information on the brain's contribution to making these decisions. It would be useful to track eye movements, heart rate, and other physical indicators that reveal how decisions to invest are made. Surveys and interviews, conducted in conjunction with these, might compare how different individuals or groups make financial decisions. Although there is still room for improvement, this review combined bibliometric analysis with a systematic review using the PRISMA statement, which was useful in selecting articles and helped maintain the quality of the selection. The research findings are of relevance to neurofinance scholars, as this review highlights key resources, top-cited articles, and leading authors, which may guide new scholars in this field or those interested in understanding how the brain influences financial choices. It has also provided a clear overview of the main ideas and the structure of neurofinance, which can be useful to others in the same field. The paper has identified areas that are important, specialized, or new for further study. Generally, it provides a broad overview of the current status of neurofinance and some new directions the field is taking.

### Theoretical Implication

This study draws five theoretical conclusions based on the results to inform future research on the application of neuroscience in financial decision-making. Firstly, our findings offer insight into the current limits and scope of neurofinance research. Consequently, this may help scholars focus on previously unexplored and innovative problems and encourage a broader application of brain research in financial decision-making. Secondly, it may be beneficial for researchers to identify prominent scholars and organizations as potential partners and mentors to further research in this field. Third, the results of the co-citation and dynamic co-citation analyses, based on the content analysis of theme clusters, provide scholars with essential details about renowned and significant publications that may be considered cornerstones of this field of study. This information will be helpful to future scholars. The concerns identified through network, citation, and co-citation studies can be the subject of further in-depth investigation thanks to these papers. Fourth, we can suggest important future study directions that



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researchers may pursue based on the content analysis of the identified topic clusters. Lastly, this study may also support methodological breakthroughs in future studies by conducting research based on neural data application in financial decision-making via mathematical modeling and empirical investigations.

## Practical Implications

Researchers in the sector who wish to contribute to the existing body of knowledge may find the study's conclusions helpful. Based on the findings, this paper suggests four practical implications for managers and financial management policymakers to help facilitate the adoption and deployment of neuroscience applications in financial decision-making. First, the study suggests that professionals, such as managers, monitor investors' brain activity while making financial decisions. They can utilize our research to gain a deeper understanding of the diverse range of financial decision-making domains and the significance of neurofinance. Second, these practitioners may utilize the findings of esteemed studies—identified through network analyses—to discuss the trade-offs and design decisions that could potentially address the primary obstacles to applying neuroscience to financial decision-making, as previously mentioned in the literature. Third, the results suggest that the research on brain science that influences financial decision-making needs to be effectively examined. Finally, industry-based practitioners could find it helpful to use bibliometrics to draw boundaries between individual research areas of interest regarding a more sophisticated application of neuroscience in various financial managerial domains, including financial asset management, capital markets, and the stock market.

## Limitations and Future Scope for Research

These limitations, therefore, provide a potential avenue for future research. Using only one database, Scopus, limited the sectoral coverage of publications. Future bibliometric analysis, however, can enhance this coverage by incorporating other databases, such as PsycINFO, IEEE, or Web of Science. We also did not consider literature published in trade publications, books, conference proceedings, or sources other than academic journals. Future research might expand its scope by incorporating these sources, thereby deriving a more comprehensive perspective on the application of neuroscience in financial decision-making. We also excluded research on the legal industry in this study; however, it could be useful to draw valuable insights for future investigations. Finally, while our analysis gives an overview of an entire field, future studies could delve deeper with more detailed analyses, such as systematic reviews or meta-analyses. Despite these limitations, this study certainly provides valuable insights that will guide scholars, practitioners, and policymakers in neurofinance. Scholars can take these limitations into consideration while planning future research agendas. In fact, practitioners and policymakers navigating the complex world of financial decision-making will find an understanding of the neuroscientific foundational origins enlightening, as derived from this study, for the creation of regulatory frameworks, risk management procedures, and investment strategies. Our analysis also identifies areas where further research is needed, thereby creating a platform for future studies in neurofinance.

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