Decoding Financial Decisions: The Power of EEG in Neurofinance Research (A Review)

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Abstract

With the application of robust neuroscientific tools in mapping financial decisions, research in Neurofinance has gained increased recognition in recent years. Among all the available neuroimaging tools, EEG has provided considerable evidence that overcomes the drawback associated with traditional self-reported measures. Moreover, despite a rise in EEG-based research, studies in the present academic literature are scattered and confusing. The purpose of the present systematic literature review was to consolidate the existing body of knowledge and to make it simpler for other researchers to locate pertinent studies. After a thorough analysis of the literature over 12 years; two key themes have been identified- risky decision-making and portfolio strategies. Additionally, it has been found that the majority of studies were conducted in a lab setting with simulated market conditions. Finally, we also presented prospects for the suitability of EEG in different aspects of financial decisions for the immediate identification of errors.

Keywords: Neurofinance; EEG; Risky decision; Investment; Portfolio.

Introduction:

To err is human. Whereas over 30 years, Traditional finance theories (Stephen, 2005) are applied with the prime assumption that human beings are rational agents (Eugene, 1970, 1995; Markowitz, 1952; Miller & Modigliani 1961); making decisions in a rational manner. These traditional theories are normative and clearly explain what should be the best course of action in a particular situation with the given constraints. Despite a long history of the rationality-based theories, these theories are failed to explain the reason behind the market anomalies (Chang et. al 2008; Siegel & Thaler, 1997; Thaler, 1992;).

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Market anomalies are the projection of individual investors behavior at the aggregate level; availability of funds, cognition level of the decision-makers, time duration under which decision need to be finalized, expected outcome, risk involved and social influence are some of the factors that deviate the decision-making from the concept of rationality (Dimson, 1988). Therefore, to explain the heterogeneity in financial decisions and provide to reasons behind market irregularities a new discipline emerged in the name of Behavioral finance.

Researchers in the field of Behavioral finance believes that financial decision-makers are not fully rational as they have limited availability of time, efforts and information with them (Becker, 1962; Kahneman & Tversky 1979; Rabin, 1998; Thaler 1990); also termed as bounded rationality (Simon, 1990). With the assumption of bounded rationality Behavioralist have done some remarkable work in the form of disposition effect and prospect theory (Kahneman & Tversky 1979; Shefrin & Statman, 1985). Later on, a large number of behavioral errors were also examined with respect to financial decisions (Jain & Gupta, 2020; Massa & Simonov, 2005; Zahera & Bansal, 2018); described as behavioral biases (Pompian, 2012). Despite these contributions the integrity of the behavioral finance is also challenged on the ground that it is providing only *ex post* explanation of a puzzled phenomenon (Ritter, 2003). Therefore, recently a new discipline has emerged as "Neurofinance" where researchers have started incorporating insights from the neuroscience to provide *ex ante* predictions of the financial decisions (Quednow, 2022; Wu & Knutson 2012).

Neurofinance works on the mapping of neural correlates which are generated by the different parts of the brain. The neural correlates of individuals are recorded and analyzed before, during and after a particular decisional task. Nowadays a number of brain mapping techniques such as fMRI (Functional Magnetic Resonance Imaging), MRI (Magnetic Resonance Imaging), Eye Tracking, MEG (Magnetoencephalography), EEG (Electroencephalogram) etc. are used to map and analyze the financial decisions (Srivastava et. al, 2020). Among all the available neuroimaging techniques EEG has high temporal resolution, which ensures accuracy in mapping the specific brain region that is involved in the decision-making. In addition to high temporal resolution, low cost involved in setting up EEG studies makes it more appropriate technique for the experimental studies in the field of financial decision-making (Kraemer et. al, 2020). Hence, the present study is focused on the identification of various brain regions involved at the time of financial decisions and to thoroughly understand the

applicability of EEG in the decision processes and the behavioral aspects of financial decision-making.

Material and Methods:

Search Strategy

Scopus and WOS databases were systematically searched for the published articles. The primary search terms were as follows: (EEG OR electroencephalogram) AND (Financial OR investment) AND (decision*). This search yielded 113 articles. Primary screening was conducted by two researchers, with title and abstract of all the resulted articles. All the articles in which the abstract specifically mentioned the application of EEG in financial decisions were fully reviewed.

Selection Criteria

Researchers included only studies that explicitly mentioned research design and applied EEG in decisions of saving, investment, household finance, tax and gambling. No sample and age restriction were applied. Studies published in language other than English and review papers were excluded from the present study. Following this predefined inclusion and exclusion criteria, a total number of 16 studies were included in the study. As depicted in Figure 1, researchers have followed PRISMA framework for reporting the systematic selection of the studies.

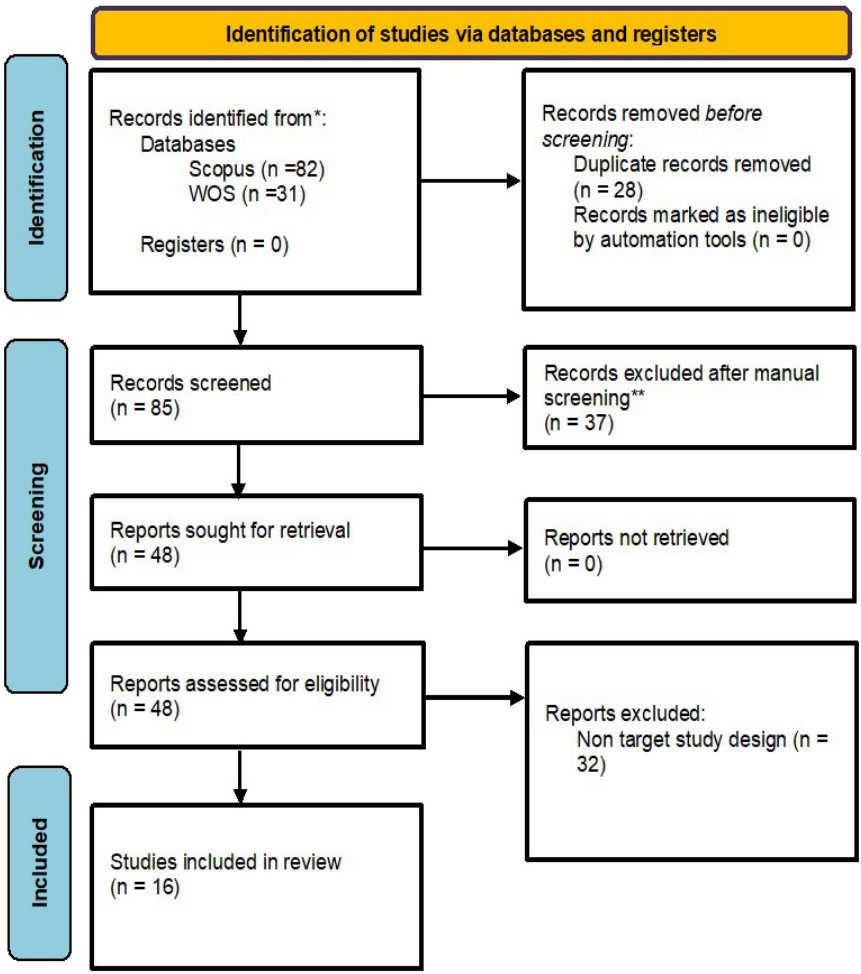

Figure 1. **PRISMA Flow chart**

Data extraction and Analysis:

Following a comprehensive review of relevant studies, data extraction was conducted, encompassing author(s), year of publication, sample size, number of EEG electrodes utilized, and key findings of the selected research papers. This methodical approach ensured a thorough examination of existing research, facilitating a robust analysis of the collected data.

Results

All the study characteristics are summarized in Table 1. These 16 studies included a total Number of 398 participants comprising of 388 healthy adults and 10 patients diagnosed as Attention Deficit Hyperactivity Disorder (ADHD); a neurological disorder that is associated with three major behavioral patterns- 1. Inattention, 2. Hyperactivity and 3. Impulsivity (National Institute of Mental Health, 2024). Individuals with ADHD, face a number of challenges that ranges from simple day to day decision making to more complex decision making such as financial Planning and Investment. Furthermore, Simulated Stock Market and Gambling Task were widely used research design among the reviewed studies. The remaining studies used a diverse range of experimental designs including, Sequential- Decision Task, Balloon Analogue Risk Task (BART), Social Dilemma Task and Tax Decision Task. Under these experimental studies, participants were asked to take a number of decisions on the basis of some predetermined stimulus. Later on, their decision outcomes were analyzed and correlated with the activation of different brain parts.

Table 1. Characteristics of 16 reviewed studies.

Author & Year	No. of Participants	EEG Electrodes	Study Design	Findings
Gehring & Willoughby, 2002	12	42	Gambling Task	Medial frontal contributes to the speedy decision-making of higher-level cognitions.
Mintai et al., 2011	19	30	Gambling Task	Activation of the cortical area and central arousal in potential gain and loss respectively.
Sands & Sands. 2012	*NA*	64	Real Life Experience	Positive emotion can be evaluated with the activation of the left frontal brain.

Rocha, 2013	*NA*	*NA*	Simulated Stock Market	Market humor as a measure of Global Systematic Risk.
Vieito et al., 2015	40	20	Simulated Stock Market	Financial market participants follow either rule-based or instance-based strategy.
Mussel et al., 2015	20	31	BART	Diminished FRM (feedback-related negativity) in people high on greed.
Rocha et al., 2015	40	20	Simulated Stock Market	Different neural patterns for buying, selling, and holding stock decisions in the brain of males and females.
Abouzari et al., 2016	20	128	Gambling Task	ADHD nongamblers and ADHD gamblers generate different electrical signals in the Fronto-Cortical brain.
Pedroni et al., 2017	39	58	Sequential Decision Task	EEG microstates mediate the influence of prior decision outcome.
Wang, 2018	16	NA	Empirical	Individual likes and dislikes influences group decisions.
Yang et al., 2018	20	64	experimental software	Organization and sequence of the information impact individual emotions.

Balconi et al., 2019	35	16	Tax experimental task	Decision in social condition has exhibited increased theta activity in the frontal cortices.
Mussel & Hewig, 2019	59	NA	Social-Dilemma Task	Individuals high in greed lacks in behavior adjustment.
ang et al., 2019	25	64	Crowd Funding Project Task	Social information affects crowdfunding as herd behavior in the financial market.
Toma & Miyakoshi, 2021	28	14	Simulated Stock Market	Increased delta waves in the lateral frontal brain before the formation of the bubble.
Toma, 2023	25	14	Asset Bubble Market	EEG provided 80% accuracy in predicting and classifying decision-makers on the basis of overconfidence and trading performance.

Word Cloud

Figure 2. Demonstrates the word cloud consisting of 100 frequently occurring keywords in the selected publications. The word cloud is constructed using NVivo software with full text analysis of 16 research papers. Furthermore, the word EEG and electroencephalogram were used as stop word to identify the major themes where EEG has been applied.

Figure **2. Word cloud**

In word cloud (Figure 2) of the selected research papers the majorly occurring keywords include market, value, financial decision and stock price. Therefore, word cloud also confirmed that EEG is applied in the finance decisions that directly relates to the market in respect of investment, value, price etc.

Application of EEG in stock market:

Risk Tolerance and Preference

Financial decisions have varied probability of the inherent risk with them. The same level of risk may be perceived differently by different individuals, which is often difficult to measure. The review has provided evidence that the brain area involved in the risky-decision can be mapped with EEG instrument in a simulated stock market or gambling task (Gehring & Willoughby, 2002; Mintai et al., 2011; Rocha, 2013; Vieito et al. 2015). These decision-making tasks are designed to reflect proxy decision for the actual risky choices. EEG data has reported that Medial-Frontal cortex of the brain, which is responsible for the higher cognitive decision-making generates high negative event related brain potential when the outcome is loss (Gehring & Willoughby, 2002). Furthermore, it has been found that the presence of greed in the financial market leads to increase in the risk-taking capacity of the individuals that eventually results into stock market bubble (Mussel et al., 2015). In another study conducted by Rocha (2013),

depicted that Global Systematic Risk can be predicted through neuroeconomic models to evaluate individual risk, as a key factor of market humor. Therefore, incorporating neuroscience in the risky decisions is useful for the early identification of financial market collapse.

Disparity in Investor's Wealth:

Individual's financial strategies are shaped by their acquired financial knowledge and experience. This knowledge and experience influence their cognitive processes, enabling them to recognize and respond to real-world financial uncertainties in a manner consistent with their learned strategies. The initial experience of the investors in the financial market decides their further strategies in the market and portfolio construction (Mussel et al., 2015; Rocha, 2013). Therefore, investors who initially dealt in bear market creates different neural patterns from those who started in the bull market. Moreover, in financial market gender is also an important factor that results into difference in the decision-making process. Recently, researchers have provided evidence that stock market can be divided into male brain and female brain; females exhibit different neural correlates then males, particularly in the decisions of Buy, Hold and Sell decisions for their stocks in the portfolio (Abouzari et al., 2016).

Discussion:

Financial decisions are one of the important aspects of human decisions; A variety of decisions with certain or uncertain outcome comes under the scope of finance. Although studies included in the present SLR are heterogeneous, but remarkably exhibited the application and suitability of non-invasive EEG technology in finance research to provide scientific clues of human brain. Medial Frontal and lateral frontal are the most explored brain regions in risky choices. For instance, male and female follow different neuronal patterns to arrive on the same decisions. With the help of these decisional biomarkers separate learning strategies could be formulated. Therefore, different brain might have different circuits for learning from the past negative outcome. Regardless of the extraordinary findings, high cost and complex data of EEG recordings cannot be overlooked for the limited literature on this methodology.

Conclusion:

While EEG technology has a long history, it is not adopted as mainstream tools in finance. Moreover, finance researchers are combing tools of psy-

chology and neuroscience to capture the reasons of unexplained heterogeneity in the decisions. This study systematically identified the demographic distribution and application of EEG for mapping neural correlates of financial decision-making. Moreover, it may be beneficial to explore application of EEG in identifying behavioral biases in financial decision. However, Data recording and analyzing of EEG does not always feasible to conduct, to gain the benefits of high temporal information. Several challenges need to be overcome in terms of cost and complexity involved in EEG studies. Therefore, future work is necessary to create appropriate experimental environment for EEG technology exhibiting more real-life decision-making processes.

Overall, this study highlighted that brain mapping through EEG can be used for detailed analysis of risky choices, portfolio strategies and reward processing. In the field of neurofinance EEG research has an exciting future, particularly in providing neuronal markers of decision.

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