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Bibliometric Analysis of EEG Studies in Sports

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Abstract
This study aims to analyze 566 studies published between 1998 and 2023 on sports and electroencephalography (EEG) from a bibliometric perspective. EEG, a non-invasive tool for assessing cognitive and psychomotor performance in sports, has seen growing applications as technological and methodological advances continue to enhance its utility in sports research. These applications demonstrate EEG's potential to optimize athletes' training, evaluate performance, and deepen expertise and understanding. The research employed document analysis to examine the data, with studies on sports and EEG in the Web of Science (WoS) database serving as the primary data source. Data analysis was conducted using the VOSviewer software. The findings indicate that research in this area began in 1998, with the majority of studies to date being conducted in the United States. Additional findings are discussed comprehensively in the results section. The insights derived from this analysis contribute to understanding the progression of the field, identifying its strengths and weaknesses, and highlighting researchers' areas of focus.

Keywords: EEG, Sports, Bibliometric Analysis, Neuroimaging.

Introduction

Electroencephalography (EEG) is a noninvasive tool used in various fields such as neuroscience, psychology, and medicine, providing valuable information about brain function and functions such as cognitive function, brain development, emotional recognition, and brain connectivity (Kober et al.,2020; Hasan&Tatum,2021)

The first human EEG was recorded by German psychiatrist Hans Berger in 1929, marking a significant advancement in neuroscience. The technique has evolved into, a critical tool for understanding brain dynamics and diagnosing conditions such as epilepsy, sleep disorders, and brain injuries (Tseng et al.,2024).

In recent years, the exploration of sports performance through electroencephalography (EEG) has gained traction, deepening the understanding of neurocognitive and motor processes critical for athletic success. EEG, a non-invasive technique, enables real-time monitoring of brain oscillations linked to motor control, sensory processing, and cognitive efficiency, providing insight into how elite athletes achieve optimal performance. For instance, EEG neurofeedback has been shown to improve psychomotor efficiency by modulating neural activity in specific brain regions, with studies noting that increased sensorimotor rhythm (SMR) power often correlates with enhanced coordination, balance, and reaction time—key skills in sports (Cheng et al.,2024)

Moreover, the focus has expanded to include the identification of EEG biomarkers that may predict performance outcomes. Recent systematic reviews emphasize the value of EEG neurofeedback training (NFT) in strengthening athletes' cognitive control and resilience under pressure, potentially reducing mental fatigue and optimizing in-game decision-making (Onagawa et al., 2023). Research has also highlighted that EEG biomarker applications are still developing, with ongoing challenges such as movement artifacts during dynamic sports activity and a need for standardization in data interpretation to increase reliability and practical utility (Mikicin et al.,2018; Hatfield et al.,2020; Jeunet et al.,2020)

As EEG methodologies advance, their application in sports training programs promises to enhance both individualized training and evidence-based protocols, helping athletes achieve greater neural efficiency and peak performance states through targeted brain training.

Through a systematic review of empirical studies, this research aims to contribute valuable knowledge to the growing field of sports neuroscience.

Material and Method

In this research, the document analysis technique, one of the data collection methods, was used. For this analysis, all eight indexes of the Web of Science Core Collection (WoSCC) were used as electronic databases.

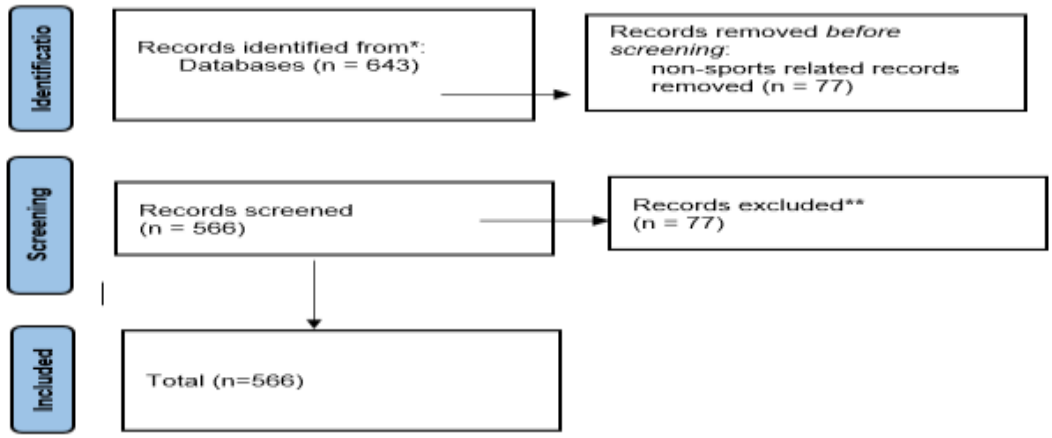
In the first stage, keywords were determined and studies related to sports and EEG were searched in the Web of Science database with the keywords "Sport and EEG". As a result of this scanning, a data set consisting of 566 publications was reached. To analyze the data set received in the second stage, the VOSviewer program was used, which allows the creation of collaborative networks of countries and authors publishing in the field of sports and EEG, due to the advantages of bibliometric analysis in creating visual graphs and processing big data. VOSviewer is a program used for bibliometric analysis to identify the most cited authors, organizations, countries, and keywords based on citation networks (Yu & Yu,2023).

Bibliometric analysis refers to the use of statistical and mathematical methods to quantitatively analyze the literature in a particular field (Hussain & Ahmad, 2023). It

contributes to identifying the main areas of science, mapping trends, and providing an overview of academic research in these specific areas. One of the advantages of bibliometric analysis is that it detects the tendencies of researchers on the subject. Additionally, the use of bibliometric analysis tools such as the Science Mapping Analysis Software Tool SciMAT and VOSviewer has allowed researchers to visualize and analyze the structure and trends of international sports research (Soós & Kiss, 2020).

Flow Diagram in Data Analysis

Designed with Preferred Reporting Items for Research, Systematic Reviews and Meta-Analyses (PRISMA).



Findings

Country	Citation	Record
1. USA	2799	145
2. GERMANY	1283	92
3. ITALY	1138	49
4. ENGLAND	1108	37
5. CANADA	802	48
6. CHINA	639	75
7. AUSTRALIA	508	28
8. TAIWAN	423	41
9. SWITZERLAND	288	11
10. SPAIN	284	24
11. BELGIUM	244	4
12. SCOTLAND	243	5
13. NETHERLANDS	235	12
14. JAPAN	229	19
15. FRANCE	209	16
16. BRAZIL	173	9
17. WALES	155	8
18. POLAND	152	21
19. LUXEMBOURG	106	10
20. SOUTH KOREA	103	5
21.SWEDEN	125	6
22.AUSTRIA	120	14
23. NEW ZEALAND	88	5
24. QATAR	88	2
25. TURKIYE	73	12

Table 1. Publication and citation distribution by country

When we look at the Publication and Citation Distribution by Countries table, the USA ranks first with 2799 citations, as in the density map. In second place is Germany (1283 citations), and in third place is Italy (1138). Turkıye (73 citations) ranks 25th in the list of 63 countries found to have sports and EEG-related studies in the WoS database.

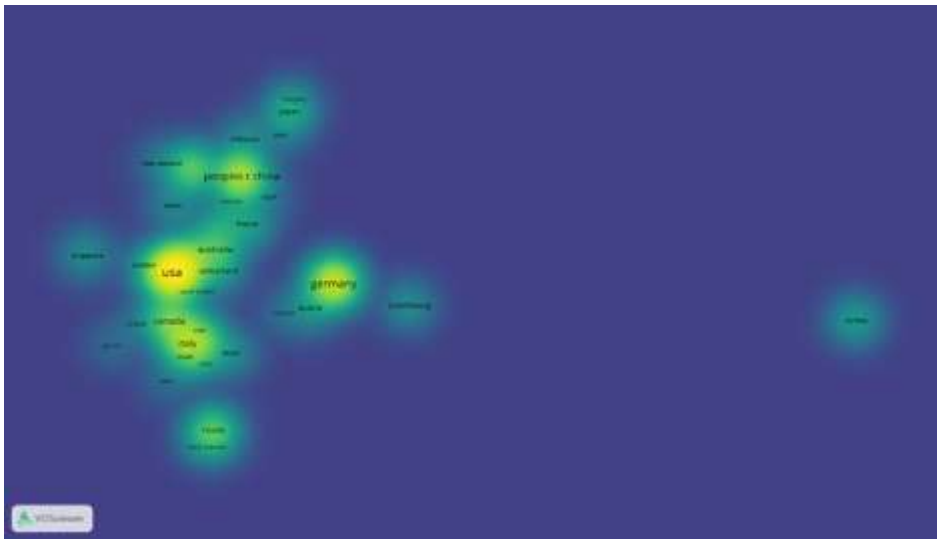


Figure 1. Density chart by countries

When you look at Figure 1, you can see the density chart of countries on sports and EEG publications taken from the WoS database. There are a total of 63 countries that have studies

on this subject. The points in the chart where the yellow color is dominant represent the countries where the most work is done. The USA and Germany are the most notable countries in this field.

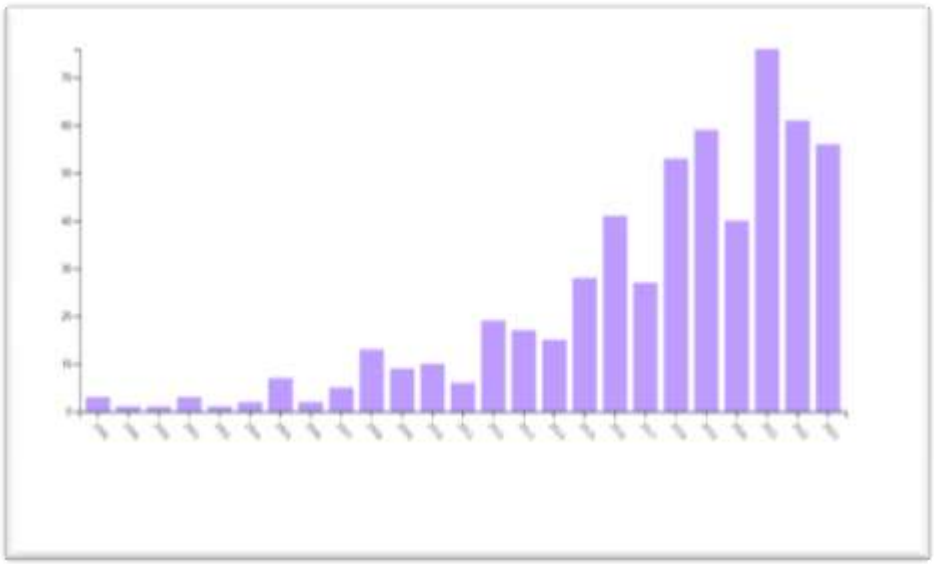


Figure 2. Publication and citation distribution by years

When the publication and citation distribution graph of studies on sports and EEG is examined by years, it is seen that there was an increase in 2018-2019 and the most intense study period on the subject occurred in 2021 (76 publications). Considering that the current analysis was conducted in December 2023, it is thought that interest in the subject will gain momentum in 2024, similar to the last 3 years.

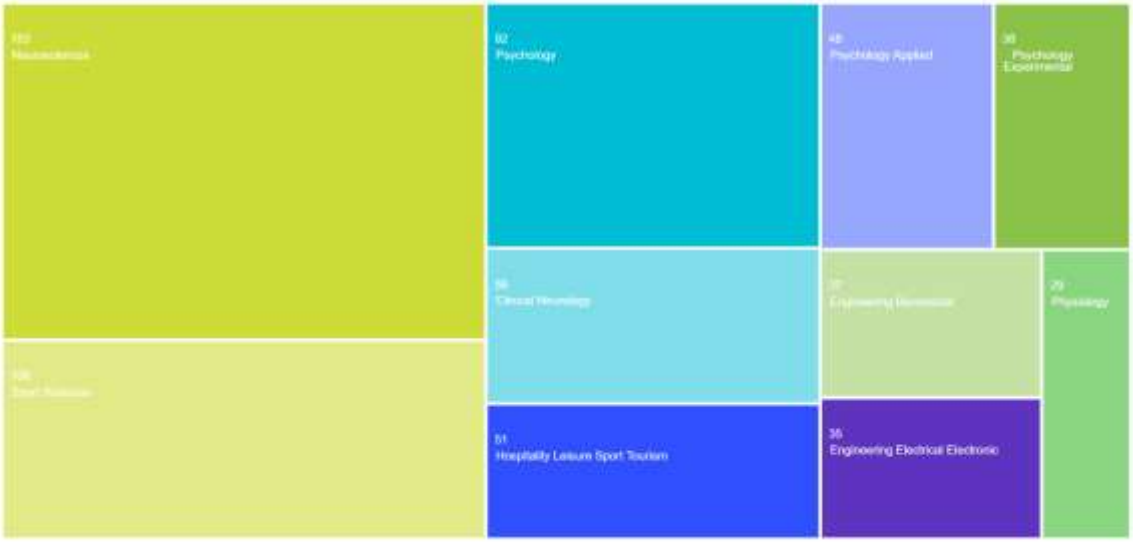


Figure 3. Distribution map according to research areas

A TreeChart chart can be seen according to the distribution map according to research areas, sports topics and EEG-related studies. “Neuroscience” ranks first with 183 studies. Then, "sports sciences" with 108 publications, "psychology" with 92 publications, "clinical neurology" with 58 publications and "accommodation entertainment sports tourism" with 51 publications were in the top five.

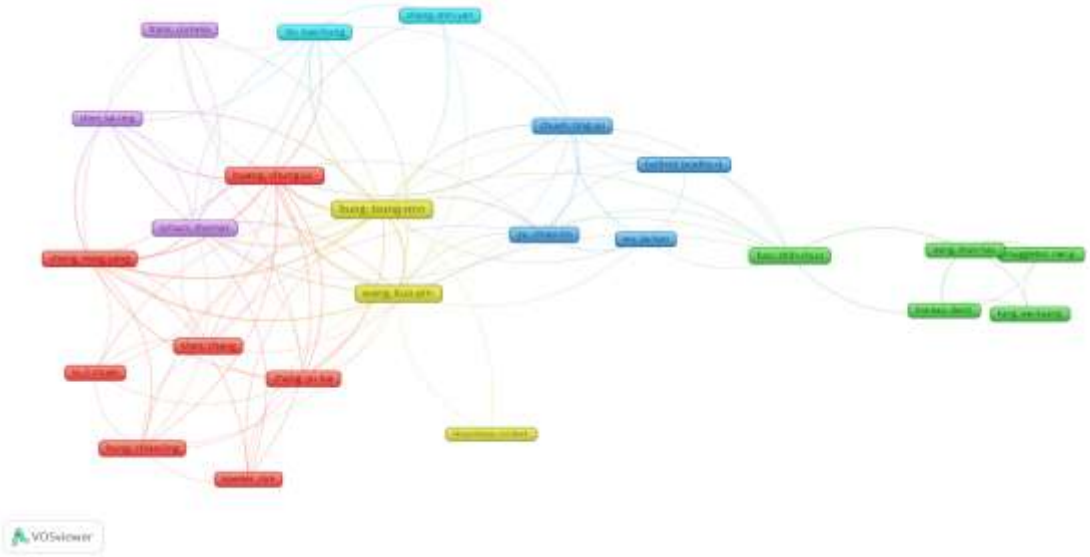


Figure 4. Network map of co-author distribution by years

In Figure 4, the co-author distribution map obtained for studies on sports and EEG consists of 24 nodes, 6 clusters, and 101 connections. While 2221 authors have done work related to the subject, the author who has done the most work is "Hung-tsung-min" and the 7 authors whose works have been cited the most are "Del Percio, Claudio, Babiloni, Eusebi-Fabrizio, Marzano-Nicola" (It was determined that 8 publications had 553 citations each).

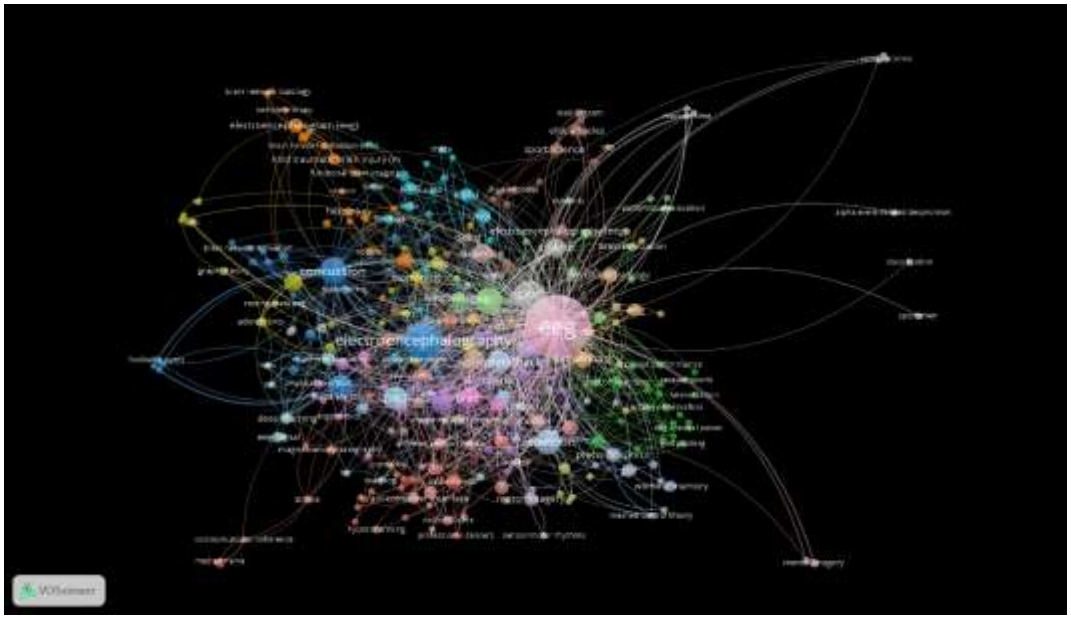


Figure 5. Network map of keywords

Figure 5 shows the network map containing 1570 different keywords examining sports and EEG-related studies. It was determined that the 3 most used keywords were "EEG, Electroencephalography and sports". Subsequently, 'collision, attention, and brain' are the most used keywords. The network map of the keywords in Figure 5 was obtained by studies using at least 2 keywords. According to this; 296 items, 21 clusters, and 1498 links were found.

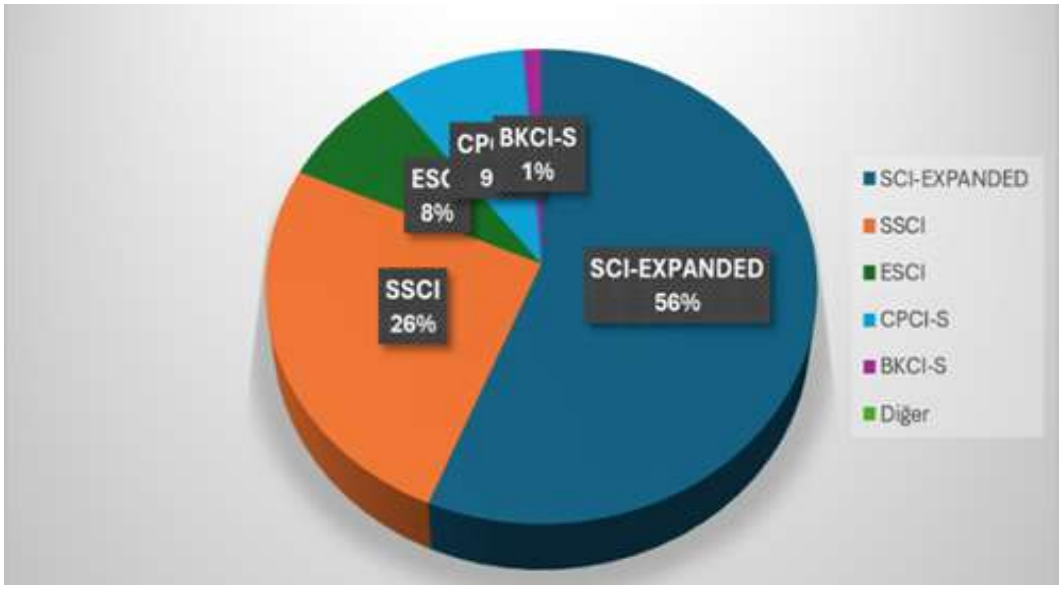


Figure 6. Distribution by indexes

Figure 6 shows the journals where studies on sports and EEG are published. It is seen that the first 5 rows are SCI-EXPANDED (385), SSCI (175), CPCI-S (63), ESCI (55), BKCI-S (8) publications. Others include CPCI-SSH, BKCI-SSH, and A&HCI publications.

Major platforms that disseminate research on the relationship between EEG and sports performance include "Human Brain Mapping," "Neuroscience & Biobehavioral Reviews," "Applied Psychophysiology and Biofeedback," "Frontiers in Human Neuroscience," "Scandinavian Journal of Medicine and Science in Sports," "Frontiers in Psychology," "Cognitive Neurodynamics," "Research Quarterly for Exercise and Sport," "European Journal of Sport Science," "Journal of Sport and Exercise Psychology," "BMC Neuroscience," "Scientific Reports," "Frontiers in Sports and Active Living," "Developmental Neuropsychology," "Stadium - Hungarian Journal of Sport Sciences," and "Biomedical Human Kinetics."

Figüre 7. Document type chart

According to the document-type chart of sports and EEG-themed studies, it was determined that 435 of the findings were articles, 59 were proceeding papers, 44 were review, 26 were meeting abstract and 9 were book chapters (others).

Discussion and Conclusion

The widespread use of EEG today can be attributed to its noninvasive nature, versatility, and applications in various fields. Electroencephalography (EEG) is becoming increasingly common in clinical practice due to its relatively low cost, ease of setup, noninvasiveness, and good temporal resolution (Dora & Holcman, 2021). EEG applications in sports sciences have provided new insights into the nature and development of athlete performance. This effort has been aided by recent advances in EEG data acquisition, including improvements in hardware portability and comfort, as well as reduced preparation times (Park et al., 2015).

The analysis of publications and citations related to sports and EEG from the WoS database reveals notable trends and patterns in research output. The USA leads with the highest number of citations, followed by Germany and Italy, while Turkey ranks 25th in citation frequency among the 63 countries contributing to this field. The density map further underscores the dominance of the USA and Germany in sports and EEG research, with these nations leading in both publication output and citation counts.

The data also indicate a significant increase in the volume of publications starting in 2018, with the peak occurring in 2021, suggesting a growing interest in the intersection of neuroscience and sports. This trend is expected to continue in 2024, reflecting ongoing advancements in EEG technology and its applications in sports performance.

Regarding research areas, neuroscience stands out as the dominant field, with significant contributions from sports sciences, psychology, and clinical neurology. These interdisciplinary connections highlight the diverse applications of EEG in understanding cognitive and motor processes in sports. Moreover, the collaborative nature of this research is illustrated by the co-author network, with prominent researchers such as Hung-Tsung Min and Del Percio et al. making substantial contributions to the field.

The use of EEG in sports is also evident in the proliferation of key terms like "collision," "attention," and "brain," which frequently appear in the studies. These keywords suggest a focused interest in cognitive processes and their relation to athletic performance. Additionally, major scientific journals, particularly those within the SCI-EXPANDED and SSCI databases, play a crucial role in disseminating research on EEG and sports, reflecting the growing recognition of this interdisciplinary field.

The 16 most popular journals publishing studies using EEG in the field of sports were reached. It was determined that the journal that published the most studies among these journals was "Frontiers in Psychology". Among these journals, it was determined that the journal that published the most studies was "Frontiers in Psychology". These journals published many studies such as psychomotor performance, cognition, neurofeedback, and athletic performance. They have been primary platforms for disseminating research on the relationship between EEG and sports performance, covering a variety of topics.The extensive publication of studies in these journals underscores the increasing relevance and importance of EEG in understanding the cognitive and psychophysiological aspects of sports performance.

Finally, the document type distribution reveals that the majority of studies are articles, with a smaller number of proceedings papers, reviews, and book chapters. This indicates that primary research articles remain the core method for exploring the relationship between EEG and sports. As the field continues to evolve, it is clear that EEG will play an increasingly important role in enhancing athletic performance and advancing sports science.

Thanks to the bibliometric analysis, the analysis of publications on the subject and the resulting keywords can provide insight into the potential future directions of the research. Using frequently occurring trends and keywords, information can be gathered to understand the evolving nature of their field, identify gaps in the existing literature, and design studies to address these gaps. It is suggested that studies can be carried out in many fields and contents by using the Web of Science database together with different databases such as Scopus and Proquest.

In the literature, studies have been identified on various topics related to EEG and sports performance. These include areas such as neurofeedback in sport psychology (Cheng et al.,2024; behavioral performance (Fang et al.,2022), motor control (Parr et al.,2023), performance level (Tharawadeepimuk& Wongsawat, 2021), emotional processing (Lee et al.,2020), mental skills (Corrado et al.,2024).

Future research should focus on improving these methodologies and exploring their long-term effects on performance, as well as working in multidisciplinary fields, to ensure that EEG remains a reliable tool in sports science.

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