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Bibliometric Analysis of EEG and Eye Tracking Techniques in Executive Function Research

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Abstract

This study examines the relationship between vocabulary testing app usage frequency and motivation enhancement among adult EFL learners, with a focus on the moderating role of primal motivation (conceptualized as fundamental learning drives distinct from initial engagement factors). Analyzing data from 43 Chinese EFL learners, results revealed no direct correlation between usage frequency and motivation enhancement ($r = -0.069$, $p > 0.05$), challenging the assumption that increased app exposure inherently boosts motivation. However, primal motivation significantly moderated this relationship ($p = 0.002$), suggesting that learners with strong fundamental drives sustain engagement regardless of usage patterns. Additionally, English proficiency positively correlated with app usage ($r = 0.366$, $p = 0.016$), indicating advanced learners may utilize apps more strategically. The findings offer critical implications for theory and practice. Theoretically, they extend motivation frameworks to digital contexts by introducing primal motivation as a key sustainer of engagement, bridging gaps in MALL literature. Practically, they highlight the need for: (1) app developers to move beyond MCQ-dominated designs toward hybrid formats that stimulate deeper cognitive engagement; (2) educators to assess and nurture primal motivation (e.g., through goal-setting interventions) before app implementation; and (3) institutions to integrate apps as supplementary tools, particularly for proficient learners. This study calls for a paradigm shift in MALL design—from frequency-focused metrics to motivation-sustaining ecosystems—to optimize long-term language learning outcomes.

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Introduction

Executive function (EF) is a multifaceted construct that encompasses a variety of cognitive processes essential for goal-directed behavior, self-regulation, and adaptive functioning in daily life. In the context of neuroscience and neuropsychology, executive function is often associated with the activity of the prefrontal cortex and its connections with various brain regions, which together form the executive control network. This network is critical for high-level cognitive processes such as working memory, inhibitory control, cognitive flexibility, planning, and problem solving (Baggetta & Alexander, 2016; Shen et al., 2019; Diamond, 2013; Kolb & Neuwirth, 2020).

The conceptualization of executive function has evolved significantly over the years. Traditionally, executive functions were viewed as a single entity, but contemporary research suggests a more diverse understanding that separates “cool” and “hot” executive functions. “Cold” executive functions are primarily cognitive and involve processes such as working memory and attentional control, while ‘hot’ executive functions are more emotionally charged and relate to self-regulation in social contexts (Baggetta & Alexander, 2016; Siregar, 2018). This distinction is important as it highlights the different demands placed on executive functions in different situations, especially in educational and developmental settings (Blair, 2016).

Executive function (EF) studies have traditionally divided executive function into two main domains: cold EF and hot EF (Zelazo & Carlson, 2012). Cold EF includes purely cognitive processes, such as attention control, planning, and working memory, which usually do not involve emotions (Dixon, 2015). In contrast, hot EF relates to emotional or social situations, such as decision-making involving risk or emotion regulation (Martin & Delgado, 2011). EEG and ET technologies enable in-depth exploration of these two domains. EEG provides insight into brain activity patterns associated with cognitive control in cold EF and neural responses to emotional situations in hot EF (Guo et al., 2017).

ET, on the other hand, tracks visual patterns reflecting attentional priority in cold EF tasks and behavioral responses to emotional stimuli in hot EF (Both et al., 2011; Poyato & Vázquez, 2021). The integration of EEG and ET provides a holistic approach to uncover the relationship between neural and behavioral processes, which contributes to a better understanding of the complex mechanisms behind EF in various contexts. In real-life situations, 'cold' EF and 'hot' EF often work synergistically. For example, decision-making in situations involving risk or emotional distress requires a combination of cognitive control from 'cold' EF and emotion regulation from 'hot' EF (Roiser & Sahakian, 2013). Research suggests that this interaction is important in the context of education, mental health, and social skill development (Ono et al., 2011). The interaction between 'cold' EF and 'hot' EF not only influences individual decisions but can also shape group dynamics in complex social situations (Corr, 2013).

Neuroscientific studies have identified specific brain regions that contribute to executive function, particularly within the frontal lobes. The dorsolateral prefrontal cortex (DLPFC) is often involved in tasks that require cognitive control and decision-making, while the anterior cingulate cortex (ACC) plays a role in error detection and emotion regulation (Diamond, 2013; Kolb & Neuwirth, 2020). Moreover, the integration of information across different brain regions is essential for the effective functioning of executive processes, which suggests that executive functions are not only localized but also distributed across a network of interconnected areas (Kolb & Neuwirth, 2020; Alvarez & Emory, 2006).

Research has shown that executive functions are critical for academic success and social competence, especially in early childhood. The development of these functions is rapid during the preschool years and is influenced by both genetic and environmental factors, including parenting practices and educational interventions (Blair, 2016; Bernier et al., 2010). For example, children who exhibit strong executive function skills tend to perform better in math and literacy, suggesting that these cognitive abilities serve as foundational skills for learning (Clark et al., 2010; Rose et al., 2012). Moreover, the malleability of executive function implies that targeted interventions can improve these skills, leading to better outcomes across multiple domains (Blair, 2016).

In clinical settings, deficits in executive function are often observed in individuals with neurodevelopmental disorders, such as dyslexia and ADHD, as well as psychiatric conditions such as schizophrenia (Reiter et al., 2004; Sabhesan & Parthasarathy, 2005). These deficits can manifest as difficulties in planning, regulating and regulating emotions, which can significantly impact on daily functioning and quality of life. Therefore, neuropsychological assessments that evaluate executive function are essential for diagnosing and developing treatment plans for these individuals (Banich, 2009). The interaction between executive function and emotional processes is another important area of research. High levels of stress can impair executive function, highlighting the importance of emotional regulation in maintaining cognitive control (Blair, 2016; Finkenzeller, 2023).

This relationship underscores the need for a holistic approach in educational and therapeutic contexts, where cognitive and emotional skills are developed simultaneously to foster resilience and adaptability in children and adults (Fatwikiningsih, 2016; Warmansyah, 2023). In summary, executive function represents a complex interplay of cognitive processes that are critical for effective self-regulation and goal-directed behavior. Its development is influenced by a variety of factors, including brain structure, environmental context and emotion regulation. Understanding the nuances of executive function through the lens of neuroscience and neuropsychology not only enhances our understanding of human cognition, but also informs practical applications in education, clinical practice and beyond.

Research on executive function (EF) is crucial in understanding human cognitive function as EF serves as a key regulator in various complex cognitive processes. EF includes abilities such as working memory, self-control, and cognitive flexibility, all of which are necessary for decision-making and adaptive behavior in everyday situations (Tsai et al., 2021; Logue & Gould, 2014). Research shows that EF is not only related to academic performance, but also to mental health and social skills (Yeh et al., 2016; Qi, 2023). In addition, studies on EFs provide insights into how impairments in these functions can affect individuals' quality of life, especially in more vulnerable populations such as the elderly and children with developmental disabilities (Corbo & Casagrande, 2021; Corbo & Casagrande, 2022). For example, research shows that educational interventions designed to improve EF can have a positive impact on children's cognitive development, indicating the potential to improve educational outcomes (Bermúdez-Rivera et al., 2022; Gentile et al., 2020). Furthermore, an understanding of EF also helps in the development of rehabilitation strategies for individuals with neurological disorders, such as dementia and bipolar disorder, where EF is often affected (Paunescu & Miclutia, 2015; Funahashi & Andreau, 2013). Thus, research on EF not only enriches our knowledge of cognitive mechanisms but also has significant practical implications in education and mental health.

The role of modern technology in measuring executive function (EF) is increasingly important, particularly through the use of techniques such as electroencephalography (EEG) and eye trackers (ET). EEG allows researchers to monitor the brain's electrical activity in real-time, providing insight into the cognitive processes underlying executive function, such as attention control and decision-making (Diamond, 2013; Friedman & Miyake, 2017). Using EEG, researchers can identify brainwave patterns associated with different aspects of EF, including inhibition and working memory, which are crucial in understanding how individuals function in everyday situations (Diamond, 2013; Friedman & Miyake, 2017).

Meanwhile, eye tracker technology provides valuable data on attention and visual information processing, which are key components in executive function. By tracking eye movements, researchers can evaluate how individuals prioritize information and make decisions, as well as identify difficulties in impulse control and attention (Willoughby et al., 2011; Zartman et al., 2013). The combination of these two technologies not only improves our understanding of EF but also enables the development of more effective interventions to improve cognitive abilities, especially in at-risk populations, such as children and individuals with neuropsychological disorders (García et al., 2021). Thus, modern technologies such as EEG and eye trackers contribute significantly to the measurement and understanding of executive function, paving the way for more in-depth research and better clinical applications.

Executive function (EF) has significant relevance in various fields, including education, psychology, and neuroscience. In the context of education, EF plays an important role in facilitating learning and the development of academic skills. Research shows that good EF abilities, such as working memory and self-control, are positively associated with students' academic performance Ramírez-Luzuriaga et al., 2021; Diamond & Ling, 2016). For example, interventions designed to improve EF in children can improve educational outcomes and prepare them for greater academic challenges (Diamond & Ling, 2016). In the field of psychology, EF is closely related to mental health and psychological well-being. Deficits in EF have been associated with various psychological disorders, including depression and anxiety, suggesting that the ability to regulate emotions and behaviors is essential for good mental health (Farruggia et al., 2020; Rock et al., 2013).

Research has also shown that individuals with better EF abilities tend to have a higher quality of life and better adaptability to stress (Díaz-Morales & Escribano, 2014). From a neuroscience perspective, EF is considered an important indicator of higher cognitive function and is related to activity in the prefrontal cortex area. Neuroimaging research has shown that disruptions in brain networks that support EF can contribute to a variety of neurological and psychological disorders (Farruggia et al., 2020; Larsen et al., 2015). As such, a better understanding of EF may aid in the development of more effective intervention strategies to improve cognitive function and mental health (Kruger, 2011).

Electroencephalography (EEG) is a technique used to record the brain's electrical activity through electrodes placed on the scalp. The working principle of EEG is based on the detection of electrical signals generated by neurons as they communicate with each other. When neurons are activated, they produce changes in electrical charge that can be measured and recorded as brain waves Rini (2015). EEG provides information on a variety of mental states, including attention, emotions, and level of consciousness, with very high temporal resolution, enabling real-time detection of brain activity (Sahroni et al., 2020). The ability of EEG to detect brain activity in real-time makes it an invaluable tool in a variety of applications, including cognitive research, clinical diagnosis, and Brain Computer Interface (BCI) development (Nasution, 2023). For example, EEG can be used to monitor the brain's response to certain stimuli, such as in studies on the effects of stress or emotions, as well as to identify brainwave patterns associated with neurological conditions such as epilepsy (Sahroni et al., 2020). Thus, EEG serves not only as a diagnostic tool, but also as a means to understand more about human cognitive function and behavior.

Eye trackers are technologies used to record and analyze eye movements, which provide insights into visual attention and decision-making. The working principle of eye trackers involves using cameras and sensors to detect eye position and movement, including saccades (rapid movements between focal points) and fixations (periods where the eyes remain on one point) (Ayiei, 2020; Katz et al., 2018). Data obtained from eye trackers can be used to determine areas of interest (AOI) and analyze how individuals focus their attention on specific visual stimuli (Maruta et al., 2012).

The main function of eye trackers in monitoring visual attention is their ability to provide accurate data on where and for how long a person looks at certain objects or information. This is extremely useful in a variety of applications, including psychology research, marketing, and user interface design (Vervoort et al., 2013; Mera & Stumpf, 2014). For example, in the context of marketing, eye trackers can be used to understand how consumers pay attention to advertisements and products, as well as to identify the elements that attract their attention the most (Yu & Smith, 2016). Moreover, in the context of decision-making, eye trackers can help uncover the cognitive processes underlying individual choices, providing insights into how visual attention influences decisions (Shiro et al., 2021; Damji et al., 2018).

EEG and Eye Tracker technologies present distinct and unparalleled advantages when juxtaposed with conventional methodologies, which include but are not limited to interviews or self-report-based assessments that rely heavily on individuals' subjective accounts (Cantoni & Porta, 2014; Cott & Brenner, 1998). EEG, or electroencephalography, is able to capture and record the brain's intricate neural responses in real-time, providing direct insights into cognitive processes (Mustafa & Magnor, 2014; Millett et al., 2015), while ET, or eye tracking, closely monitors and analyzes visual patterns to elucidate the attentional priorities that individuals exhibit (Melman & Eden, 2016; Navalpakkam & Churchill, 2014). The remarkable synergy and integration of these dual advanced technologies facilitates comprehensive and multidimensional analyses that transcend the limitations and shortcomings of traditional methods, making it extremely difficult, if not impossible, to achieve the same level of understanding and insight through alternative approaches.

Previous studies on the integration of EEG and eye trackers in the measurement of executive functions have shown several limitations. One of the main challenges is that eye movements can often cause artifacts that interfere with the quality of EEG data, thus complicating accurate analysis Wenzel et al. (2016; Plöchl et al., 2012). Although there have been advances in eye tracker technology that allow recording of eye movements without interfering with EEG recordings, there is still a need for further research that combines these two methods effectively (Dimigen et al., 2011; Nikolaev et al., 2016). Existing research tends to focus on one method alone, thus overlooking the synergistic potential of combining both techniques to gain a more comprehensive understanding of the cognitive processes underlying executive function (Scharinger et al., 2015; Luan & Lv, 2023).

In addition, the lack of bibliometric studies that map research trends and patterns in this area is also an obstacle. While some studies have used bibliometric approaches to evaluate trends in eye tracker research in general (Atabay & Güzeller, 2021; Yang & Wang, 2015), no analysis has specifically highlighted the integration of EEG and eye trackers in the context of executive function. This suggests an opportunity to conduct a more in-depth analysis of research developments in this area, as well as to identify areas that require further attention (Huang et al., 2020). As such, further research integrating these two techniques and a comprehensive bibliometric analysis may provide better insights into the dynamics and progress in executive function studies.

The integration of Electroencephalography (EEG) and Eye-Tracking (ET) technologies offers unique advantages in the study of executive function (EF) that other methods lack. EEG allows direct observation of brain electrical activity with high temporal resolution, providing real-time data on neural responses to cognitive tasks (Gevins et al., 1995). Meanwhile, ET complements the analysis by monitoring visual and attentional patterns, directly reflecting decision-making processes and attentional control (Eimer, 2015; Enstrom & Rouse, 1977). The combination of these two technologies provides a multidimensional approach that integrates brain and behavioral data, allowing for more in-depth analysis than traditional methods such as cognitive tests or self-report-based interviews. Moreover, the integration of EEG and ET is able to reveal the dynamic relationship between brain activity and visual behavior simultaneously, providing a more holistic insight into EF mechanisms, which was previously difficult to achieve with a single tool.

Bibliometric analysis is an important approach in academic research that aims to map research trends, identify collaboration patterns, and evaluate the contributions of institutions, countries, and authors in a particular field (Salinas-Ríos & García López, 2022; Dulla et al., 2021). In the context of executive function (EF) research, bibliometric analysis provides deep insights into the distribution of literature, emerging topics, and interrelationships between studies from various disciplines (Shekarro et al., 2021; Lyer & Srinivasan, 2020). Bibliometric analysis not only helps understand the dynamics of research development, but also plays a strategic role in fostering innovation, cross-national collaboration, and integration of interdisciplinary approaches (Sillet, 2013; Salinas-Ríos & García López, 2022). By utilizing bibliometric analysis, researchers can identify gaps in the literature and accelerate the development of new methods relevant for EF studies, especially with the integration of EEG and ET technologies. The use of this method also allows researchers to formulate more precise and relevant research questions, which can lead to findings that have a significant impact in the field of cognitive neuroscience.

Research in the field of executive function (EF) shows an increasingly broad pattern of collaboration, involving various institutions, countries and disciplines (Burgess, 1997; Ardila, 2019). Bibliometric analysis reveals close links between researchers from different regions, creating a global academic network that drives the development of EEG and ET technologies (Stefanidis et al., 2018). In addition, emerging research topics include the utilization of EEG to understand brain mechanisms in decision-making and attention, as well as the use of ET to explore visual patterns in educational and marketing contexts (Vecchiato et al., 2011; Tekin et al., 2017). Another trend involves the integration of advanced technologies, such as machine learning, to analyze complex EEG and Eye tracker data, further expanding the scope of applications in various fields (Jamal et al., 2023). This research highlights the importance of cross-institutional collaboration in driving technological innovation and deeper interdisciplinary development.

Results derived from comprehensive research on executive function, commonly referred to as Executive Function, have a wide range of practical applications that can be used in a variety of fields and contexts (Nemeth & Chustz, 2020; Pineda, 2000). For example, interventions based on EEG, which stands for electroencephalography, and ET, which signifies eye tracking, have been effectively used to determine and identify specific cognitive weaknesses or deficits present in children diagnosed with Attention Deficit Hyperactivity Disorder, or ADHD, and these identified weaknesses then lay the foundation for the development and design of specialized training programs that focus primarily on improving attention-related skills (Heywood & Beale, 2003; Kirk et al., 2017; Bikic et al., 2015). In the field of education, data collected regarding executive function is used strategically to formulate and create curricula designed to simultaneously foster the development of cognitive abilities and emotional skills ensuring a holistic approach to student learning and growth. (Romero López et al., 2017).

The purpose of this article is to conduct a bibliographic analysis related to electroencephalography (EEG) and eye tracking techniques in executive function research. The main focus of this analysis was to identify the most influential authors, map the most productive collaborations between researchers, institutions, and countries, and explore trends, developments, key contributions, and key concepts in the field. This review provides a comprehensive overview of the evolution of the literature in the field of executive function through a bibliographic approach, specifically through EEG and ET approaches. The contributions of this article provide significant academic implications in the field of neuropsychology, particularly in the use of EEG and ET to understand executive function performance. More than simply mapping research trends and patterns, this article identifies key factors that influence the relevance and acceptance of research in an academic context. By highlighting the importance of the literature as a foundation for the development of innovative ideas, both in theoretical frameworks and practical applications, this article reinforces the role of EEG and ET as important tools in exploring cognitive mechanisms.

It is hoped that the results of this study also emphasize how academic productivity can be enhanced through effective management of collaborative environments, creating synergies across disciplines to produce more valuable research. As such, this article opens up opportunities for broader academic collaboration, supports the integration of concepts from different disciplines, and provides a strategic foothold for more purposeful research in the future. This approach not only contributes to theory development in neuropsychology, but also to practical applications that can improve understanding and interventions related to executive function.

Method

Using bibliometric analysis serves as an important tool for understanding research trends, impact, and collaborations in various fields. These analyses quantitatively assess scientific output, enabling the identification of influential publications and emerging areas of research. For example, studies have shown that bibliometric methods can effectively track the progress and orientation of research in specific domains, such as fitness and music therapy applications, highlighting the importance of these analyses in guiding future investigations (Liu & Avello, 2021; Li et al., 2021). Moreover, bibliometric practices are increasingly being integrated into academic libraries, thus enhancing their ability to support researchers by providing insights into publication patterns and citation metrics (Gumpenberger et al., 2012). In addition, bibliometric studies have been instrumental in evaluating the impact of certain research initiatives, such as the NIH Clinical and Translational Science Awards, by demonstrating the value of interdisciplinary collaboration and resource allocation (Llewellyn et al., 2019). The application of bibliometric techniques not only helps in understanding the historical development of a research field, but also assists in forecasting future trends, thus making it an essential component in contemporary academic research (Hakimova et al., 2020; Liu, 2023).

This article was prepared by conducting a structured and systematic literature search, and it follows an existing protocol to obtain accurate and relevant results. The protocol contains more specific keyword definitions, time series filtering, and classification by grouping documents that are relevant to the general research topic. This approach aims to help access a variety of useful information including the nationality of the author, the field of research, the type of publication used, keywords and subject names related to the main theme. There is a procedure to be followed for the collection of data and information relevant to this issue.

Each step in the steps of the literature search was undertaken with care and attention to try to cover a wider range of data. In this article, as far as possible to support functional arguments, deep logical reasoning, and a balanced perspective. Data collection was conducted with a literature search on November 3, 2024 using the Scopus database from Scimago Research Group, Web of Science (WOS) from Clarivate Analytics and PubMed from the National Library of Medicine. This process, using search criteria, keywords such as electroencephalography or eeg, eye tracker or or eye tracking and executive function or cognitive performance, time period (1992-2024), as well as document type (research article, conference paper, conference review, proceedings paper, review and early access).

Based on the overall search results in the data base, it produces 309 documents, including 178 documents from Scopus, 96 documents from WOS and 35 documents from PubMed. Furthermore, the results of the three databases were filtered, where 97 documents were identified as duplicates and 212 documents remained. The total remaining documents consisted of 157 articles, 11 conference papers, 6 conference reviews, 14 proceedings papers and 23 reviews and 1 early access review). This research adopted the bibliometric analysis method following two main stages as outlined by Županič & Čater (2014): first, study design and document collection; second, data analysis, visualization and interpretation. The analysis process was conducted using R Studio software version 2023.09.0, utilizing the Bibliometrics package and Biblioshiny package to support comprehensive data processing and presentation.

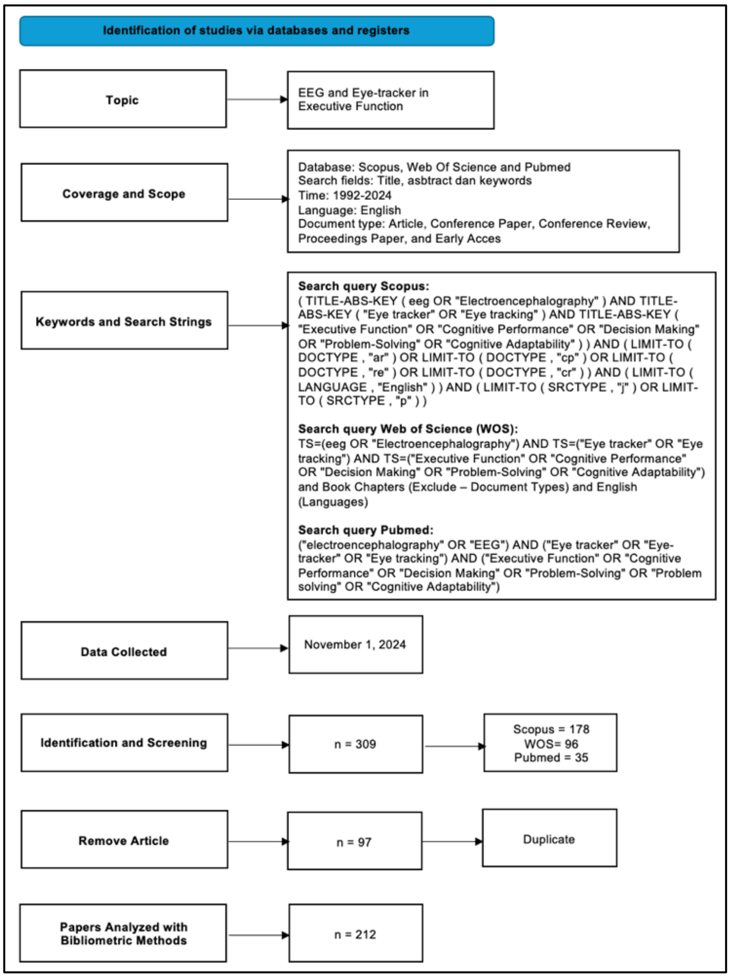

Figure 1. Preparing EEG and Eye-tracker Research Article

Results

Most Influential Author in the Field of Research on the Use of EEG and ET on Executive Function

Based on the bibliometric analysis of publications and citation counts in Table 1, authors who have made significant contributions to EEG and Eye-tracker research on executive function were found. Authors such as Anja, A., Davis, F., and Dimoka, A., are listed as the authors with the highest citations, reaching 235 citations despite having only one publication each. This confirms that the quality of their research is highly influential in expanding the literature in this field. Their research shows a high level of impact despite their lower quantity productivity.

Table 1. Authors with top Publications and citations

Rank	Productive Author	TP	TC	h	g	m	Most Cited Authors	TC	TP	h	g	m
1	Baglio, F	4	16	2	4	0.400	Anja, A	235	1	1	1	0.077
2	Borgnis, F	4	16	2	4	0.400	Banker, R	235	1	1	1	0.077
3	Cipresso, P	4	16	2	4	0.400	Benbasat, I	235	1	1	1	0.077
4	Riva, G	4	16	2	4	0.400	Davis, D	235	1	1	1	0.077
5	Cabral, S C A	3	28	3	3	0.600	Davis, F	235	1	1	1	0.077
6	Da Silva, A	3	28	3	3	0.600	Dennis, A	235	1	1	1	0.077
7	Fabrikant, S	3	19	3	3	0.273	Dimoka, A	235	1	1	1	0.077
8	Rossetto, F	3	16	2	3	0.500	Gefen, D	235	1	1	1	0.077
9	Chen, X	3	6	1	2	0.200	Gupta, A	235	1	1	1	0.077
10	Liu, Z	3	42	1	3	0.200	Kenning, P	235	1	1	1	0.077

Notes. TP = Total Publications; TC = Total Citations; h = h-index; g = g-index; m = m-index.

In contrast, authors such as Baglio, F., Borgnis, F., Cipresso, P., and Riva, G., who have four publications each, show higher productivity. However, their total citations (16 citations) are in the moderate category when compared to the contributions of the highest-cited authors. Other authors such as Cabral, S. C. A. and Da Silva, A., who have three publications each, register a higher total of citations (28 citations), showing productivity consistent with a greater level of impact than their peers who have the same number of publications.

This analysis highlights the importance of considering not only the number of publications, but also their quality and impact on the development of EEG and Eye-tracker research. For example, Anja, A., and his colleagues made a major contribution through a single highly cited work, while Baglio, F., and his group showed broader productivity but with lower citation impact. In this context, the study suggests combining high productivity with in-depth research quality to enhance the EEG and Eye-tracker literature on executive functions. Thus, future understanding and applications of these technologies are expected to develop further through a balanced combination of productivity and quality in ongoing research.

Author Collaboration Network in the Field of Research on the Use of EEG and ET in Executive Function

Several major collaboration clusters contribute to the development of research in this area, as shown by the visualization of the collaboration map in EEG and eye-tracker research related to executive functions. Baglio, F. and Rossetto, F. belong to the most common collaboration cluster, which shows their interconnectedness and their emphasis on important elements in neurocognitive research. Both in terms of productivity and relevance of their research, this group is a prominent center of collaboration. In contrast, Cabral, S. C. A. and Carneiro, D. demonstrate efforts to develop innovative empirical approaches. The aim of their collaboration is to develop techniques and methodologies that support the investigation of the relationship between visual cognition and executive function. It appears that other groups, such as Chen, C. and Liu, Y., are helping to expand insights into the validity of measurement tools and the applicability of technology in evaluating executive function.

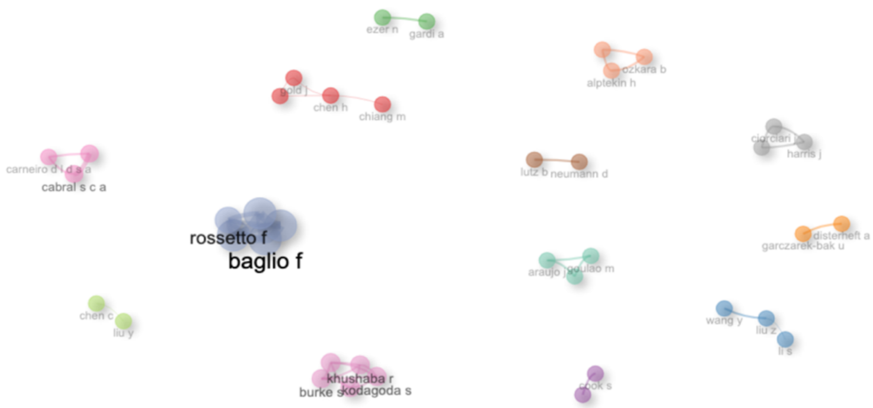

Figure 2. Collaboration Map in EEG and Eye-tracker Research

Alptekin, H., and Ozkara, B.'s group, along with a couple of collaborators such as Lutz, B., and Neumann, D., make more specialized contributions to the application of EEG and eye surveillance in various fields. They seem to concentrate on the applicative approach, especially in looking at how different variables affect the outcome of the study. In addition, pairs such as Wang, Y. and Liu, Z. are involved in international collaborations, which shows the importance of a multidisciplinary perspective in this research. In their method, the understanding of executive function is based on socio-economic and cultural aspects. The Khushaba, R. cluster, with Burke, and Skodagoda, S., contributed greatly to research centered on the development of EEG technology. Their focus on the combination of theory and application helps strengthen the foundation of neurocognitive research in this area. Overall, this collaboration map shows that cross-disciplinary synergies and contributions from different clusters resulted in EEG and eye-tracker research on executive function. This research strengthens the theoretical basis and opens up new opportunities for technological applications that support cognitive development and executive function.

Most Productive Institution in Research in the Field of EEG and ET Use of Executive Function Research

Zhejiang University ranked first with a total of 8 articles based on institutional productivity data. This shows that the university is the most productive in EEG and eye surveillance research related to executive function. The university greatly contributes to the development of cross-disciplinary research focused on the application of neurocognitive technologies. The University of Pennsylvania produced seven articles in second place. The institution is renowned as one of the leading research centers supporting the development of theories and applications of executive function, particularly through EEG and eye-tracker technologies. Research conducted there often has a major impact on the academic literature.

Table 2. Most Productive Institutions.

Rank	Institutions	Total Article
1	Zhejiang Univ	8
2	University Of Pennsylvania	7
3	Poznan Univ Econ and Business	6
4	Univ Liverpool	6
5	Mcgill University	5
6	Univ Cattolica Sacro Cuore	5
7	Virginia Commonwealth Univ	5
8	Boston Univ	4
9	Indian Inst Technol Madras	4
10	King's College London	4

The University of Liverpool and Poznan University of Economics and Business came in third, with 6 articles each. Both institutions show that applying a multidisciplinary approach is key. The University of Liverpool addresses neurocognitive aspects and their applications in various fields, while the University of Poznan focuses on the relationship between cognition and economics. The three universities McGill, Università Cattolica del Sacro Cuore, and Virginia Commonwealth University have five articles in the next ranking. These three institutions consistently contribute to the development of research. The focus of this research ranges from theoretical studies to effective applications of EEG technology and eye surveillance.

The list is completed with four articles from King's College London, Boston University, and the Indian Institute of Technology Madras. These institutions have made significant contributions, especially in adding technical and global perspectives to executive function research. However, their productivity is lower than the institutions at the top of the rankings. Overall, these data show that institutions around the world are focusing on EEG and eye-tracker research on executive function. The geographical spread of research in this area is shown by the dominance of institutions in North America, Europe, and Asia. This shows the importance of interdisciplinary and cross-regional cooperation in the development of these neurocognitive studies.

Most Productive Countries in Research in the Field of EEG and ET Use of Executive Function Research

Table 3 and figure 3 data show that the USA is the most productive as well as the most impactful country in research related to eye monitoring and EEG on executive function. The USA ranked first in both categories with 102 publications and 463 citations. The citation per publication (S/P) ratio of 13.20 indicates the high quality of the research and the great contribution of the USA to enrich the literature in this field. China's research production took second place with 56 publications, but its level of influence was slightly lower, ranking 7th with 158 citations and an S/P ratio of 7.20. This suggests that, despite its high productivity, China's research may have received less widespread academic attention compared to other countries.In contrast, Germany had 23 publications (ranking 6th in productivity) and had great influence with 314 citations (ranking 2nd) and an S/P ratio of 26.20. The high citation ratio indicates that German research is often an important reference in the relevant literature. With 42 publications and 276 citations, the United Kingdom (UK) is ranked third in productivity.

Research from the United Kingdom shows a balance of quantity and quality with an S/P ratio of 19.70, making it one of the main contributors to the development of the sector. In terms of productivity, Italy and Australia rank next, with 35 publications and 29 publications respectively. Australia is ranked 4th with 240 citations and an S/P ratio of 21.80, while Italy is ranked 5th with 211 citations and an S/P ratio of 19.20. This data shows that, although their productivity is slightly lower compared to the United States and the United Kingdom, these two countries still have a globally recognized research reputation. Countries such as Switzerland, Korea and the Netherlands show significant influence despite having only a few publications. For example, Switzerland has an S/P ratio of 29.70, which is the highest on this list, indicating outstanding research quality; Korea also excels with an S/P ratio of 47.70, showing that despite only a few publications research from Korea is highly influential. In contrast, some countries such as Spain, Poland, and Brazil have moderate levels of productivity but lower influence, with S/P ratios of 7.20-18.10.

Table 3. Countries with Most Citations and Publications

Number	Productive Country	TP	Influential Countries	TC	C/P
1	USA	102	USA	463	13.20
2	China	56	Germany	314	26.20
3	UK	42	United Kingdom	276	19.70
4	Italy	35	Australia	240	21.80
5	Australia	29	Italy	211	19.20
6	Germany	23	Switzerland	178	29.70
7	Spain	19	China	158	7.20
8	Chile	18	Korea	143	47.70
9	Poland	15	Canada	127	18.10
10	Brazil	14	Netherlands	85	17.00

Notes. TP = Total Publications; TC = Total Citations; S/P = Citattions/Publication

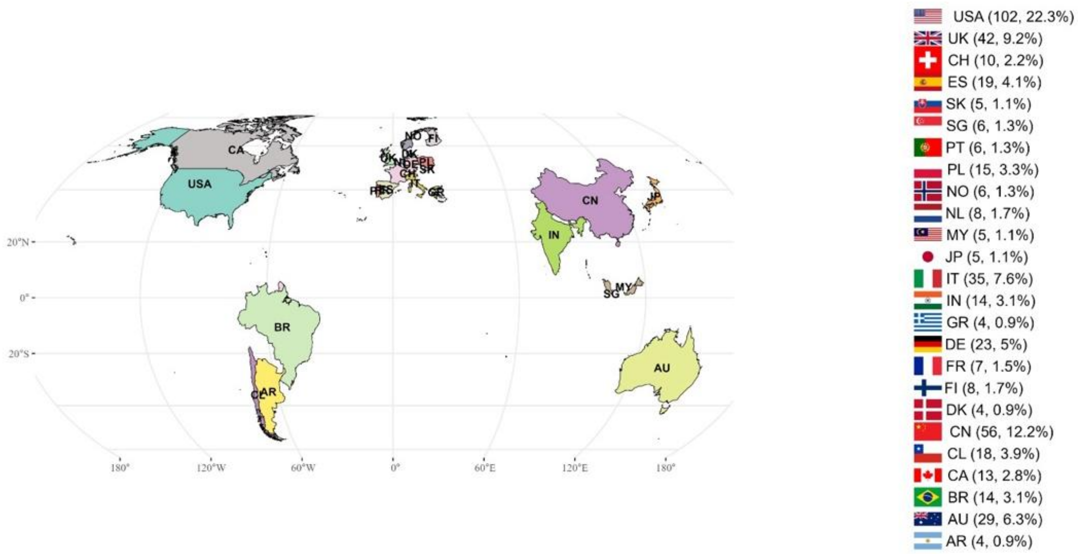

Figure 3. Regional Map of Productive EEG Research Countries

Trends in Research Topics in the Field of Research on the Use of EEG and ET on Executive Function

Studies on the use of EEG and eye-trackers in executive function have undergone significant development with a focus on relevant keywords and research trends over time. The technologies "electroencephalography" and "eye tracking" were highlighted for their frequent appearances, with the highest number of occurrences being 81 and 63, respectively. This suggests that these two technologies are the main tools used to explore executive function. In addition, specialized topics such as "neuromarketing" (18) and "event-related potentials" (11) show more specialized applications. Examples of "neuromarketing" involve the use of "electroencephalography" and "eye-trackers" to understand consumer behavior, while ERPs examine the brain's response to cognitive stimuli. Additionally, research attention on "cognition" (9) and "executive function" (7) indicates a focus on cognitive processes and executive function as key areas. The use of the term "machine learning" (8) indicates the trend of incorporating advanced technologies in the analysis of EEG and eye-tracker data, which increases the breadth and effectiveness of research. On the other hand, although rarely discussed, "brain-computer interface" shows potential for future development even though it is not a major focus at present.

Table 4. Relevant Keywords for EEG and Eye-tracker Research

Keywords	**Frequency**
electroencephalography	81
eye tracking	63
neuromarketing	18
event-related potentials	11
cognition	9
eye movements	9
machine learning	8
executive function	7
consumer behavior	7
brain computer interface	6

According to the times, the analysis of research trends shows an ever-changing development. To illustrate, "electroencephalography" started to attract attention from 2018 and continued to grow until 2022, confirming its role as a key technology in executive function research. A similar increase in popularity of "eye tracking" occurred on the same trend from 2020, peaking in 2023, indicating a growing interest in this technology. Topics such as "neuromarketing" and "executive function" received notable attention in 2023, indicating applications that increasingly focus on cognitive and behavioral aspects of humans. However, there is a significant increase in the trend of topics such as "machine learning" and "cognition" through 2024, showing how advanced technologies play a role in supporting more complex data analysis. However, some keywords such as "brain-computer interface" only appear relevant in 2014 without significant progress, indicating that research on this topic is more limited compared to other fields.

Overall, these research trends reflect an increasingly multidisciplinary direction. EEG and ET technologies continue to take center stage for understanding executive function, both in terms of theory and applications in various contexts. Recent trends show the integration of advanced technologies such as machine learning to support more complex and efficient analyses, while specific applications such as "neuromarketing" and "consumer behavior" expand the scope of research beyond the traditional domain of executive function. Thus, in the future, it is expected that research in this field will continue to evolve with more holistic and innovative approaches, expanding our understanding of cognitive dynamics and human behavior as well as its practical applications.

Table 5. Trends in EEG and Eye-tracker Research Topics

Keywords	Frequency	Year (Q1)	Mid Year (Q2)	Year (Q3)
electroencephalography	81	2018	2021	2022
eye tracking	63	2020	2021	2023
neuromarketing	18	2020	2022	2023
event-related potentials	11	2017	2019	2020
cognition	9	2019	2021	2024
eye movements	9	2013	2019	2020
machine learning	8	2021	2022	2024
executive functions	7	2020	2021	2023
consumer behavior	7	2019	2021	2022
brain computer interface	6	2014	2014	2014

Journal that Produces Research in the Field of Research on the Use of EEG and ET on Executive Function

Figure 4 shows the significant growth in publications of EEG and Eye-tracker research on executive function, with the dominance of five major journals: Neuropsychologia, Frontiers in Neuroscience, Sensors, PLoS One, and IEEE Access. Since 2015, Neuropsychologia has been an important platform focusing on the integration of EEG and Eye-tracker technologies in understanding executive function, making it a journal that made early and significant contributions in this field. Frontiers in Neuroscience is rapidly growing as one of the leading journals, presenting a wide range of neuroscience-based research relevant to this topic. In the 2018-2020 period, Sensors began to make major contributions, bringing a multidisciplinary approach with a focus on innovative technologies to enhance behavioral and cognitive studies. These publications show increased attention to the role of technology in understanding executive function.

Meanwhile, PLoS One and IEEE Access reinforce the trend with consistent contributions to technology-based research and innovative methods. PLoS One focuses on exploratory multidisciplinary studies, while IEEE Access pays particular attention to technological applications and innovative approaches relevant to executive function research. Both journals support the development of practical applications in neuropsychology, education, and cognitive behavioral studies. The dominance of these five journals reflects the significant growth trend in EEG and Eye-tracker research, which not only improves research methodologies but also broadens insights into executive function. Their role demonstrates the increasingly complex and multidisciplinary dynamics of scientific development, in which technology plays a key role. Taken together, these five journals not only support the rich and focused literature on executive function research but also point to the future direction of the field. This trend confirms that the integration of technology with multidisciplinary approaches will continue to drive significant advances, opening up new research opportunities in a variety of related fields.

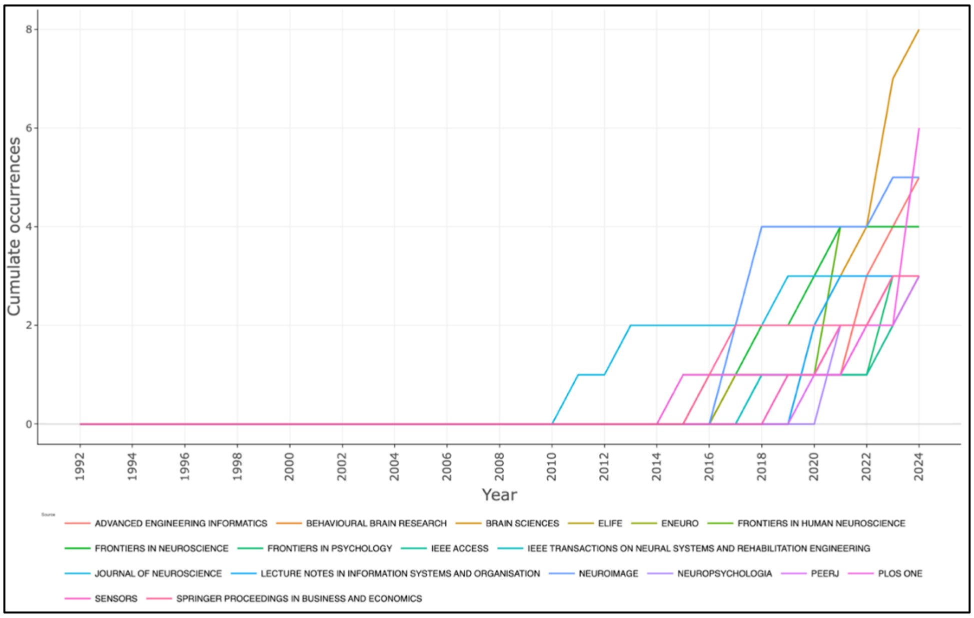

Figure 4. Sources of EEG and Eye-tracker Articles Over Time

Research Developments in the Field of Research on the Use of EEG and ET on Executive Function

Figure 5 displays the growth in the number of research publications on the use of EEG and eye-trackers in relation to executive function between 1992 and 2021. In the early phase, from 1992 to 2000, the graph shows a very minimal publication rate, with almost no research activity recorded. This suggests that at that time, the use of EEG and eye-trackers in executive function research was not yet a major focus. Perhaps, the supporting technology was still limited or the high cost of research was a major deterrent. From 2001 to 2010, a slight increase in the number of publications began to appear, although the growth was still slow. Research in this field began to grow gradually, as technological advances made EEG and eye-trackers more accessible. By the end of this period, around 2010, the graph shows signs of a more consistent increase, although the number of publications is still relatively small compared to the following period.

The period from 2011 to 2015 shows a more pronounced increase. At this stage, the number of publications began to increase more rapidly, with the first peak recorded in 2014. This suggests that interest in this area of research is growing, perhaps due to the increasing recognition of the role of EEG and eye-trackers in understanding executive function. In addition, advances in methodology and the use of these tools in cognitive contexts have greatly contributed to the increased interest in research. The greatest increase occurred between 2016 and 2021, where the graph shows a significant spike, especially starting in 2018. This increase may be triggered by rapid technological advancements, the adoption of EEG and eye-trackers as standard tools in neuroscience research, as well as a higher awareness of the importance of executive functions in various aspects of life. In 2021, the number of publications reached its highest point, reflecting the peak of interest and research contributions on this topic. Overall, this graph shows how EEG and eye-tracker research in executive function has evolved from an under-the-radar topic to one of the fastest growing fields in the last decade.

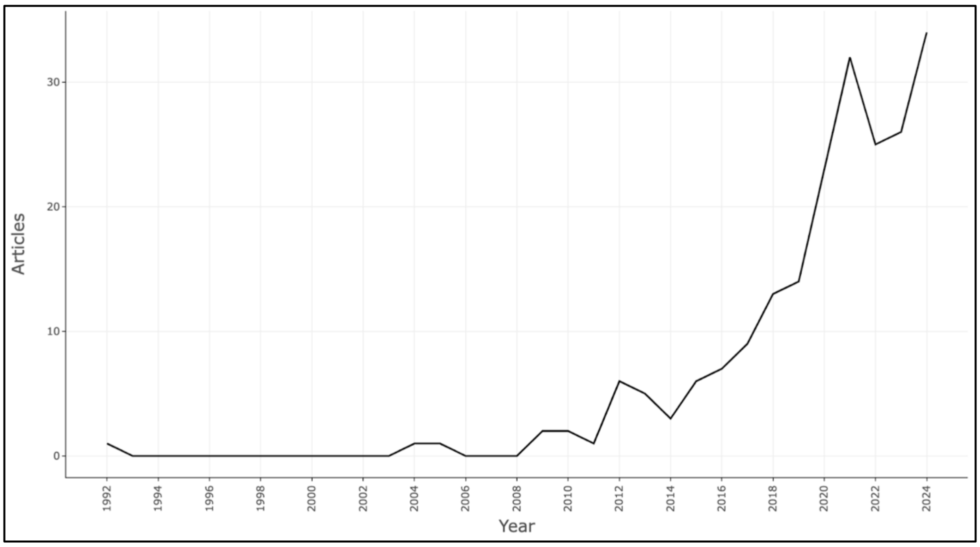

Figure 5. Development of EEG and Eye-tracker Research Over Time

Papers that support the concept of Research on the Use of EEG and ET on Executive Function

Table 6 lists the articles with the most citations that support research on the use of EEG and Eye-tracker on executive function, with the main indicators being total citations (TC) and normalized citations (N/TC). The highest-cited article is by Dimoka et al. (2012), which discusses product uncertainty in online marketplaces, with 235 citations and 18.08 total citations per year. This article shows high relevance in linking cognitive aspects with EEG-based approaches. Polanía et al. (2014) and Lee et al. (2018) came in second and third place, with 150 and 139 citations, respectively. Polanía et al. highlighted the role of neural oscillations in perception- and value-based decision-making, whereas Lee et al. introduced an EEG-EOG-based spelling system with visual feedback. This work is highlighted for its innovative approach in incorporating EEG technology to support practical applications.

Table 6. Most Cited Articles

First Author	Article Title	TC	TC/Year	N/TC
Dimoka, A	Dimoka, A., Hong, Y., & Pavlou, P. A. (2012). On product uncertainty in online markets: Theory and evidence. *MIS quarterly*, 395-426. https://doi.org/10.2307/41703461	235	18.08	3.81
Polanía, R	Polanía, R., Krajbich, I., Grueschow, M., & Ruff, C. C. (2014). Neural oscillations and synchronization differentially support evidence accumulation in perceptual and value-based decision making. Neuron, 82(3), 709–720. https://doi.org/10.1016/j.neuron.2014.03.014	150	13.64	2.80
Lee M	Lee, M., Williamson, J., Won, D., Fazli, S., & Lee, S. (2018). A High Performance Spelling System based on EEG-EOG Signals With Visual Feedback. *IEEE Transactions on Neural Systems and Rehabilitation Engineering, 26*, 1443-1459. DOI:10.1109/TNSRE.2018.2839116	139	19.86	3.75
Harris, J	Harris, J. M., Ciorciari, J., & Gountas, J. (2018). Consumer neuroscience for marketing researchers. *Journal of consumer behaviour*, *17*(3), 239-252. https://doi.org/10.1002/cb.1710	106	15.14	2.86
Schneider, C	Schneider, C., Fulda, S., & Schulz, H. (2004). Daytime variation in performance and tiredness/sleepiness ratings in patients with insomnia, narcolepsy, sleep apnea and normal controls. *Journal of sleep research*, *13*(4), 373–383. https://doi.org/10.1111/j.1365-2869.2004.00427.x	95	4.52	1.00
Debie, E	Debie, E., Fernandez Rojas, R., Fidock, J., Barlow, M., Kasmarik, K., Anavatti, S., Garratt, M., & Abbass, H. A. (2021). Multimodal Fusion for Objective Assessment of Cognitive Workload: A Review. IEEE Transactions on Cybernetics, 51(3), 1542-1555. [8846583]. https://doi.org/10.1109/tcyb.2019.2939399	93	23.25	7.48
Wieber, F	Wieber, F., Thürmer, J. L., & Gollwitzer, P. M. (2015). Promoting the translation of intentions into action by implementation intentions: behavioral effects and physiological correlates. *Frontiers in human neuroscience*, *9*, 140516. 10.3389/fnhum.2015.00395	93	11.57	2.18
Stasi, A	Stasi, A., Songa, G., Mauri, M., Ciceri, A., Diotallevi, F., Nardone, G., & Russo, V. (2018). Neuromarketing empirical approaches and food choice: A systematic review. *Food research international*, *108*, 650-664. 10.1016/j.foodres.2017.11.049	81	11.57	2.18
Khushaba, R	Khushaba, R. N., Greenacre, L., Kodagoda, S., Louviere, J., Burke, S., & Dissanayake, G. (2012). Choice modeling and the brain: A study on the Electroencephalogram (EEG) of preferences. *Expert Systems with Applications*, *39*(16), 12378-12388. 10.1016/j.eswa.2012.04.084	79	6.08	1.28
Savage, S	Savage, S. W., Potter, D. D., & Tatler, B. W. (2013). Does preoccupation impair hazard perception? A simultaneous EEG and eye tracking study. *Transportation research part F: traffic psychology and behaviour*, *17*, 52-62. 10.1016/j.trf.2012.10.002	70	5.83	1.86

Keterangan. TC = total citation; TC/Year= total citation per year; N/TC = normalization of total citations

The article by Harris et al. (2018), which discusses consumer neuroscience, made a significant contribution with 106 citations and 15.14 total citations per year, highlighting the application of EEG in understanding consumer behavior. Meanwhile, the work of Schneider et al. (2004) presents a unique perspective on daily performance variations in the context of sleep disorders, albeit with a lower number of citations (95). The article by Debie et al. (2019) registered the highest total citation value per year (23.25) with a focus on assessing cognitive load through multimodal fusion, reflecting the strength of the multidisciplinary approach. Overall, these articles highlight strong trends in EEG and Eye-tracker research, reflecting significant influence in developing theoretical and practical insights into executive function. Their contributions not only broaden the scope of the literature, but also emphasize the importance of innovative technologies in supporting behavioral and cognitive research.

Key concepts of the field EEG and ET Usage Research on Executive Function

EEG and ET Usage Research on Executive Function was analyzed using thematic maps and factor analysis to uncover patterns and relationships in the literature. Thematic maps visualize interrelationships between topics and trends, while factor analysis explores hidden patterns between variables. By referring to Michel Callon's framework, which includes centrality, density, and rank centrality, this approach provides an overview of the research structure as well as identifying key themes for further development (Callon et al., 1983; Callon, 1986; Callon, Courtial, & Laville, 1991).

In this study, 6 clusters were identified (figure 6), each of which provides specific information. Cluster 1 connects eye tracking, EEG, and cognition, which is relevant to the research on the Use of EEG and ET on Executive Function. The combination of eye tracking and EEG enables in-depth analysis of cognitive processes in executive functions, such as attention and decision-making, by monitoring brain activity and eye movements simultaneously. Characterized by high density and high relevance, cluster 1 focuses on the research base of EEG and Eye-tracker in the context of cognition. Cluster 2 highlights Decision Neuroscience with keywords Eye and Neurophysiology, directly related to EEG and ET research on Executive Function. The use of EEG and eye tracking helps understand the neurophysiological processes underlying decision-making and executive function, by monitoring the interaction between the brain and eye movements. Cluster 2 characteristics have high depth (density) but lower relevance (centrality), describing more specific topics in research related to decision making and eye physiology.

Cluster 3 focuses on Assessment, with the keywords Working Memory and Executive Functions, which is highly relevant to EEG and ET research on Executive Function. The use of EEG and eye tracking in this research allows for a more in-depth assessment of working memory capacity and executive functions, as well as how these two aspects interrelate in the context of decision-making and information processing. The characteristics of this cluster focus on evaluation, working memory and executive function, with in-depth development but lower relevance. Cluster 4 focuses on Neuromarketing, with the keywords Consumer Neuroscience and Marketing, which is concerned with the use of EEG and ET in understanding executive function in consumer behavior. This research helps uncover the influence of attention and decision-making on consumer responses, as well as the cognitive processes behind purchase decisions. The characteristics of this cluster are high density and relevance, illustrating a theme that is already rapidly growing and widely applied in a marketing context.

Cluster 5 focuses on Decision Making and Pupil Dilation, which is related to the use of EEG and eye tracking to measure physiological responses during decision making. This research reveals how pupil changes and brain activity interact in support of executive functions such as information processing and decision making. The characteristics of this cluster are low density and low relevance, suggesting that this topic may be on the wane or developing less. Cluster 6 focuses on Eye Movements, Visual Search, and Attention, which relates to the use of EEG and eye tracking in executive function research. Together they help to understand how eye movements and attention relate to brain activity when performing tasks that involve visual information processing and decision-making. The characteristics of this cluster focus on visual processing and attention, with high density but lower relevance compared to other themes.

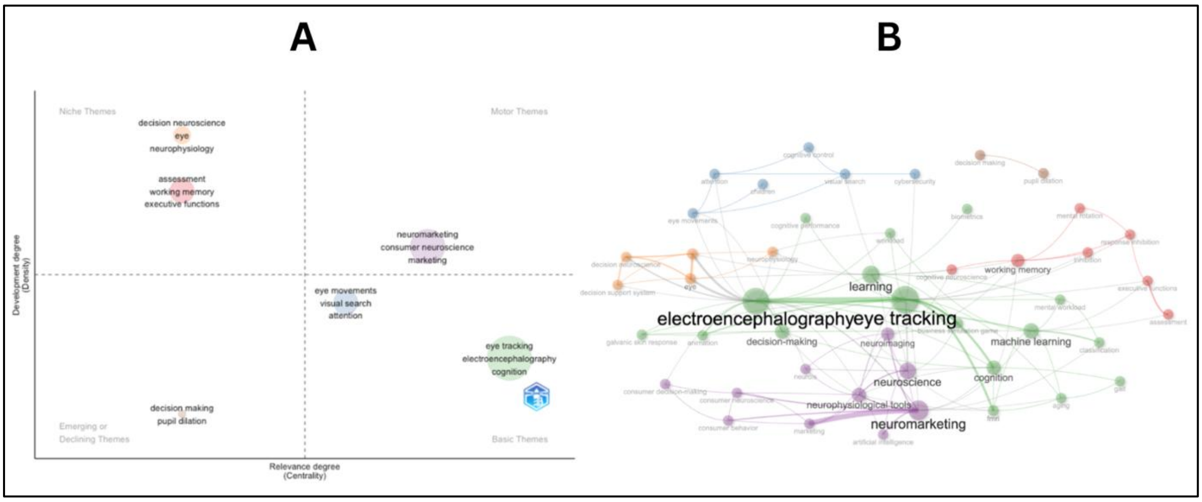

Figure 6. Cluster-Based Thematic Map in EEG and Eye-Tracking

Multiple Correspondence Analysis (MCA) complements factor analysis by visualizing relationships between categorical variables, such as keywords, thus facilitating the exploration of complex data. This technique is often used in bibliometric studies to analyze the co-occurrence of keywords, revealing the intellectual structure within the research domain (Chatzipetrou & Moschidis, 2016; Cankül & Keskin, 2022). Together with factor analysis, MCA provides a comprehensive framework for bibliometric analysis, which supports a deeper understanding of academic outcomes and research dynamics. The word maps generated from MCA analysis use color to depict clusters that reflect subfields or topics that often co-occur, providing insights into research focus and literature trends. This map helps researchers identify key concepts, significant trends, and areas that require further investigation in EEG and ET research on Executive Function. In addition to being an exploratory reference, the map also guides in formulating future research directions and enriches understanding of the complex interactions between concepts in the field.

The results of the MCA analysis (figure 7) in this study revealed six clusters. Cluster 1 represents a red display that highlights diverse aspects of research on the use of EEG and ET tools in the context of executive function. It includes keywords such as "eye.tracking," "electroencephalography," "cognition," "eye.movements," "machine.learning," "assessment," "decision.making," "fmri," "learning," "visual.search," "attention," "working.memory," "workload," "aging," "cognitive.control," "cognitive.workload," "consumer.behavior," "executive.functions," "gait," "galvanic.skin.response," "inhibition," "mental.rotation," "mental.workload," "neurophysiology," "pupil.dilation," "response.inhibition," "animation," "arousal," "business.simulation.game," "children," "classification," "cognitive.neuroscience," "cognitive.performance," "consumer.decision.making," "cybersecurity," "dyslexia," "epilepsy," "experiment," "eye.movement.related.potentials," "facereader," "facial.expression," "fnirs," "functional.networks," "higher.education," "human.factors," "infant," "information.overload," "lpp," "magnetic.resonance.imaging," "multimodal.data.fusion," "n1," "n170," "n2," "n400," "p3," "performance," "product.reviews," "purchase.intention," "saccades," "serious.game," "spatial," "speech," "theta.oscillations," "training," "traumatic.brain.injury," "valence," and "vision".

Cluster 2 represents a blue display, including keywords such as "neuromarketing," "consumer.neuroscience," "marketing," "neuroscience," "neurois," "artificial.intelligence," "marketing.research," "neuro.tourism," and "neuroscientific.tools." Cluster 3 represents a green display, encompassing keywords such as "neuroimaging," "neurophysiological.tools," "physiological.tools," and "tools." Cluster 4 represents a purple display, containing keywords like "biometrics," "gender," and "social.goal.models." Finally, Cluster 5 represents an orange display, featuring keywords such as "decision.neuroscience," "eye," "tracking," "decision.support.system," and "fitradeoff.method."

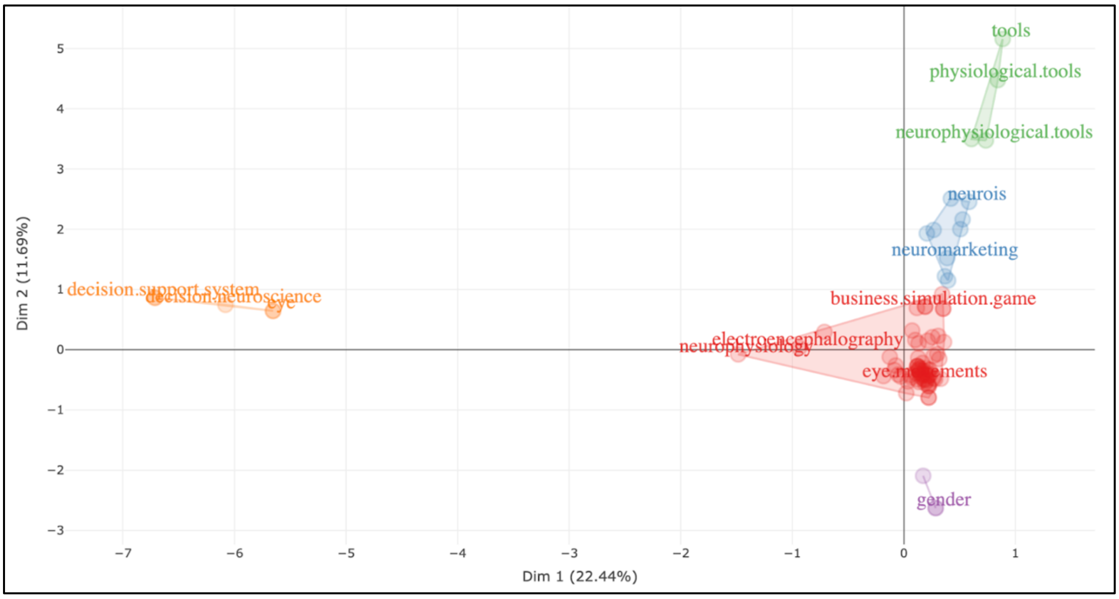

Figure 7. Keyword Map in EEG and Eye-Tracking Research

Discussion

of "electroencephalography (EEG) and eye tracker (ET)" with executive function in cognitive performance. The research identifies key authors, highlights leading universities and countries contributing to the field, explores trends in research topics related to "electroencephalography (EEG) and eye tracker (ET)" and executive function, tracks the development of research over time, and evaluates the types of publications that have been critical in supporting the concept of using "electroencephalography (EEG) and eye tracker (ET)" with executive function in cognitive performance, along with the main ideas in this research field.

This study aims to further investigate the outcomes related to the application of "electroencephalography (EEG) and eye tracker (ET)" in executive function and cognitive performance, as well as their significance and relevance to advancing research in this domain. As the scientific field exploring EEG and ET continues to grow, the focus on measuring executive function drives academic inquiries into related areas. Therefore, it is anticipated that through historical analysis and a research framework, the development of knowledge on the use of "electroencephalography (EEG) and eye tracker (ET)" in executive function within cognitive performance can be mapped.

The findings of this study reveal several aspects related to "electroencephalography (EEG) and eye tracker (ET)" in executive function. The first finding highlights the most influential authors in this research area and identifies the factors affecting the impact of publication size on the development of research ideas. This is evident from the top 10 authors ranked highest in studies related to "electroencephalography (EEG) and eye tracker (ET)" in executive function. Anja, A., Davis, F., and Dimoka, A., with 235 citations from a single publication, occupy the top position due to their work examining product uncertainty in online markets using EEG, which connects cognitive aspects to decision-making in uncertain environments. Their research is highly relevant and innovative in applying EEG technology to understand consumer behavior, making it a key reference in this field.

On the other hand, Baglio, F., Borgnis, F., Cipresso, P., and Riva, G., despite having four publications, have garnered only 16 citations. This indicates that although their productivity is high, their work is more specific and focused on narrower fields, such as sleep disorders and mental health, limiting its impact on the development of the "electroencephalography (EEG) and eye tracker (ET)" literature in the context of executive function. This finding highlights that in research on "electroencephalography (EEG) and eye tracker (ET)," the quality of relevant content, innovation in connecting technology with real-world issues, and the relevance of the topic play a more critical role in determining the impact of the research than merely the number of publications an author produces.

The next findings can be observed through the most productive institutions in "electroencephalography (EEG) and eye tracker (ET)" research on executive function, reflecting success in building multidisciplinary collaborations and global relevance. Zhejiang University emerges as the most productive institution with eight articles, focusing on neurocognitive applications, while the University of Pennsylvania, with seven articles, contributes significantly through the integration of EEG and ET theories and technologies with broad impact. The University of Liverpool and Poznan University of Economics and Business, each with six published articles, adopt multidisciplinary approaches, such as combining neurocognition with economics. The dominance of institutions in North America, Europe, and Asia underscores the importance of cross-regional collaboration in addressing global challenges. These results highlight that high productivity must be accompanied by relevant contributions to strengthen neurocognitive literature on a global scale.

The most productive countries and the geographical distribution of research on "electroencephalography (EEG) and eye tracker (ET)" in executive function are also key findings of this study. The analysis of national productivity in this field highlights the crucial role of the combination of quantity, quality, and research impact. The United States leads with 102 publications and 463 citations, reflecting the strength of its research infrastructure, substantial funding, and extensive cross-institutional collaboration networks, which produce influential literature that serves as a global reference. China, despite its high productivity with 56 publications, records only 158 citations, indicating that its research is more specific or less integrated into international academic networks. Conversely, Germany, with just 23 publications, achieves 314 citations, demonstrating a focus on high-quality and globally relevant research, making it a key reference in the field. These findings emphasize the importance of international collaboration strategies, the relevance of findings, and a focus on quality to lead EEG and ET literature.

Another finding of this study is the trend in research topics related to “electroencephalography (EEG) and eye tracker (ET)” in executive function. The analysis of research trends in the use of “electroencephalography (EEG) and eye tracker (ET)” for executive function reveals that these two technologies have become central to the field, with EEG appearing 81 times and eye tracking 63 times, underscoring their key roles in monitoring brain activity and visual behavior. These trends have grown since 2018 for EEG and 2020 for eye tracking, peaking in 2023, in line with the advancement of understanding human cognitive processes and behavior. Specific topics such as neuromarketing and ERP highlight the application of these technologies in understanding consumer behavior and brain responses to stimuli. The integration of machine learning, with eight mentions, is becoming increasingly popular for analyzing more complex “electroencephalography (EEG) and eye tracker (ET)” data. Meanwhile, research in cognition and executive function continues to emphasize decision-making processes. Overall, these trends reflect an increasingly multidisciplinary direction, integrating advanced technologies and expanding the applications of “electroencephalography (EEG) and eye tracker (ET)” from executive function to other fields such as neuromarketing and artificial intelligence development. This provides a foundation for more holistic and innovative research.

The next finding concerns the journals supporting the research concept of “electroencephalography (EEG) and eye tracker (ET)” in executive function. The dominance of five leading journals in this field reflects their significant role in supporting literature and advancing multidisciplinary technology. “Neuropsychologia”, as the primary platform since 2015, has become a key journal focusing on the early integration of EEG and ET in understanding executive function, making it an essential reference for researchers. “Frontiers in Neuroscience” has rapidly grown with a diverse range of neuroscience-based studies, strengthening its position as a leading journal. “Measurement Science and Technology”, a journal emphasizing advanced methodologies and measurement innovations, gained prominence between 2018 and 2020. It brings a multidisciplinary approach with a focus on technological advancements, contributing significantly to behavioral and cognitive studies. “PLoS One”, emphasizing exploratory multidisciplinary studies, and “IEEE Access”, highlighting technological applications and innovative methods, round out this trend with consistent contributions to the development of practical applications in neuropsychology and education. These five journals lead the field by facilitating the publication of research employing innovative approaches and advanced technologies. This dominance underscores that the integration of technology within a multidisciplinary approach is key to broadening insights into executive function and opening new avenues for future research.

The findings related to the development of research on "electroencephalography (EEG) and eye tracker (ET)" in executive function also reveal a significant transformation from a relatively underexplored field to one experiencing rapid growth. In the early stages, publications were minimal due to technological limitations and high costs. Gradual growth became evident as advancements in technology made EEG and ET more accessible and relevant for cognitive studies. A significant surge occurred in subsequent periods, driven by recognition of the potential of EEG and ET in understanding executive function and the integration of advanced technologies such as machine learning. The peak in publication growth reflects the maturation of technology and the increasing application of EEG and ET in education, healthcare, and decision-making. This trend underscores the critical role of EEG and ET as primary tools in multidisciplinary studies of executive function.

Another key finding is the papers supporting the research concept of "electroencephalography (EEG) and eye tracker (ET)" in executive function. The most-cited articles in this area demonstrate significant contributions to expanding the literature and establishing practical applications in the field. One such example is the work of Dimoka et al. (2012), which, with 235 citations, successfully linked EEG technology to understanding cognitive aspects in online market uncertainty, making it a primary reference in the literature. Additionally, the study by Polanía et al. (2014), with 150 citations, introduced an innovative approach through the analysis of neural oscillations for decision-making based on perception and value. These two articles exemplify how EEG- and ET-based research can have a substantial impact by integrating advanced technology into the study of behavior and executive function. This highlights the relevance of these technologies in paving the way for more multidisciplinary and application-oriented research directions.

The core research concept revolving around the utilization of advanced technologies, namely "electroencephalography (EEG) and eye tracker (ET)" in relation to executive function, as demonstrated by the comprehensive results obtained from a thorough analysis, strongly suggests the necessity of focusing on the synergistic integration of EEG and ET technologies to achieve a deeper understanding of complex cognitive processes. These processes encompass critical areas such as attention, decision-making, and working memory. This study strategically incorporates significant factors, including but not limited to density and centrality rankings, meticulously grounded in the framework proposed by Michel Callon, to rigorously evaluate the relevance, significance, and depth of various research themes within this domain. The extensive analysis conducted serves to illuminate and unravel the underlying structure of the intricate relationships among these themes, thereby emphasizing their essential and pivotal roles within the broader literature on executive function. The research identifies six major clusters that build upon these concepts: Eye-tracker, Decision Neuroscience, Assessment, Neuromarketing, Decision Making, and Eye Movements. The primary focus lies on the first cluster, which pertains to the foundational use of EEG and ET in deeply analyzing cognitive processes.

Cluster 1 illustrates the collaboration between "electroencephalography (EEG) and eye tracker (ET)" and cognition, particularly in relation to executive function. ET monitors patterns and directions of eye movements, indicating where visual attention is directed, while EEG records electrical brain activity to uncover the neural mechanisms associated with cognitive functions. The integration of these tools provides a comprehensive approach to investigating the relationship between attention, decision-making, and various aspects of executive function. This approach is crucial for studying executive functions, which encompass complex skills such as planning, attention management, and decision-making. Collecting data from both ET and EEG allows researchers to analyze how the brain interprets information in connection with visual attention, yielding vital insights into human responses in specific situations. The approach supports dual-dimensional analysis: physiologically through EEG, which reveals brain wave patterns related to attention, stress, and decision-making; and behaviorally through ET, which uncovers visual focus and explicit attention. As a result, distinct relationships between brain activity and visual attention can be identified during tasks requiring executive function. The characteristics of this cluster demonstrate a strong connection (close interplay between ET, EEG, and cognition) and significant relevance (critical applications for fundamental cognitive research). This highlights that the combination of ET and EEG not only offers technical insights but also serves as an effective method for exploring and understanding human cognitive processes.

Cluster 2 focuses on "decision neuroscience," exploring brain activity that influences decision-making. This cluster highlights the use of electroencephalography (EEG) and eye tracker (ET) to understand decision-making at the neurophysiological level. EEG records brain activity to reveal neural patterns associated with information processing, weighing options, and reacting to stimuli. Conversely, ET tracks eye movements as indicators of visual attention and information-search strategies during decision-making. The integration of these two methods offers a clear approach to illustrating the relationship between brain activity and visual behavior. This research primarily addresses specific aspects of executive function, particularly decision-making. Neurophysiology clarifies how the brain weighs choices, evaluates risks, and reacts to outcomes, while eye movement data provides direct evidence of how attention is directed. Consequently, this research enhances the understanding of key processes that influence human decision-making. The characteristics of this cluster indicate significant depth (density), reflecting a strong focus on the relationship between brain activity, eye movements, and decision-making, supported by a closely-knit research community. However, the importance or centrality of this cluster is reduced due to its limited scope, which constrains its influence on broader research in executive function or cognition. This positions the cluster as a specialized yet critical subfield within neuroscience research.

Cluster 3 highlights “assessment,” focusing on the evaluation of working memory and executive functions in information processing. This cluster centers on working memory and executive function, two critical cognitive elements essential for decision-making and information processing. Working memory enables the temporary storage and manipulation of information, while executive functions encompass skills such as attention, impulse control, and planning. Research in this cluster investigates how these two elements contribute to cognitive processes, utilizing EEG to track neural activity and eye tracking (ET) to observe patterns in visual attention. The application of EEG and ET facilitates a comprehensive assessment approach. EEG provides insights into brain activity related to working memory capacity and information processing during complex cognitive tasks, while ET reveals how visual attention is allocated and managed. This combination offers valuable understanding of the relationship between brain function and behavior concerning executive functions. The characteristics of this cluster emphasize assessment, focusing on the development of detailed tools and methods to measure working memory capacity and executive functions. These methods allow for thorough analysis, though their application to other studies may be limited due to their specialized focus. This positions the cluster as important for investigating specific subfields but with a smaller impact on the broader context of cognition.

Cluster 4 examines "neuromarketing" and its relationship with brain function in understanding how consumers behave and make choices in marketing. The emphasis is on neuromarketing, a technique that combines principles of consumer neuroscience with marketing to gain deeper insights into consumer actions. Using tools like EEG and eye tracking (ET), this research explores brain functions related to attention, decision-making, and consumer choices. EEG reveals how the brain responds to marketing cues, such as advertisements or products, by capturing emotional responses, focus, and cognitive evaluations. ET tracks where consumers direct their gaze, offering insights into how they navigate product pages or assess advertisement design elements. This integration enables direct examination of how brain activity correlates with consumer viewing behavior, providing valuable perspectives on decision-making processes in the context of marketing.

Executive functions such as managing attention and making decisions play a crucial role in influencing consumer behavior. EEG and ET provide extensive insights into how consumers process information, weigh options, and make purchasing decisions. Consequently, this research uncovers the cognitive mechanisms underlying preferences, engagement, and emotional responses to a product or service. The features of this cluster demonstrate high density, reflecting well-connected themes that bridge neuroscience, marketing, and executive functions. Additionally, its significant importance implies that neuromarketing has rapidly evolved and possesses wide-ranging practical applications in enhancing marketing strategies, including product development, advertisement creation, and improving consumer experiences. This cluster represents one of the fastest-growing areas at the intersection of cognitive science and practical applications.

Cluster 5 focuses on "decision making," particularly examining how individuals respond by emphasizing physical reactions during the decision-making process. This cluster highlights the relationship between decision-making and pupil dilation, a significant area of interest in cognitive research. Pupil dilation serves as a physiological indicator to evaluate reactions to cognitive challenges, attention, and emotions during decision-making. In this research, EEG is crucial for analyzing brain activity associated with information processing, while eye tracking (ET) monitors pupil changes to capture automatic responses. However, due to the method's narrow focus on a single aspect, its scope is more limited than studies that comprehensively address cognition or executive functions. Investigations in this cluster examine specific executive functions, such as how the brain evaluates information and makes decisions in particular situations. While providing useful insights, pupil dilation represents only a small fraction of the broader cognitive processes.

The application of these findings is restricted as they are not easily connected to broader domains, such as working memory, impulse control, or attention. The characteristics of this cluster demonstrate low density, with weaker connections between studies due to its limited and backward-focused scope. Research on pupil dilation typically appears as part of broader studies rather than as a prominent independent topic. Additionally, the low significance suggests that findings within this cluster have limited influence on other research in cognition or executive functions. Its relevance may also be diminished as this subject is currently less popular or advancing as rapidly as other areas in neuroscience or decision-making research.

Cluster 6 focuses on "eye movement" and its relationship with visual search, attention, and how visual information is processed during cognitive activities. This cluster centers on eye movements, visual search, and attention, aiming to understand how visual attention is directed and how critical details are selected during visual tasks. Research in this cluster employs eye tracking to analyze patterns of eye movements, such as saccades and fixations, elucidating methods of visual search and attention direction. Conversely, EEG is used to uncover neural activity related to visual information processing, attention, and decision-making.

The combination of these techniques enables a comprehensive examination of how visual actions relate to brain activity. Regarding executive function, the research emphasizes specific aspects such as visual processing and attention. However, it does not encompass broader aspects of executive function, such as working memory, impulse control, or planning. Consequently, the relevance of this cluster to broader themes in executive function is somewhat limited. The practical applications of these findings are primarily focused on visual contexts, including human-machine interfaces, education, or design. The characteristics of this cluster demonstrate high density, with strong interconnections among studies focusing on eye movements, attention, and visual search. Nevertheless, its importance is comparatively lower than other themes due to its focus on a specific subfield of executive function. Thus, while this cluster provides valuable insights into visual processing, its impact on the larger field of cognitive research is limited.

Conclusion

This study found that, as a result of increasingly advanced technologies and methodologies, the use of electroencephalography (EEG) and eye tracking (ET) has rapidly developed to study cognitive performance and executive functions. Using bibliometric analysis of 212 articles, the research identifies key contributions from the most productive authors, institutions, and countries in this field. It also explores emerging trends, such as the use of EEG and ET in neuromarketing, decision-making, and the evaluation of executive functions. The results indicate that international collaboration and the integration of advanced technologies, such as machine learning, are key factors driving progress in this industry. Identified research clusters, such as Eye-Tracker, Decision Neuroscience, and Neuromarketing, highlight the potential of EEG and ET to understand complex cognitive components like attention, decision-making, and visual information processing. Overall, the study affirms that a deeper understanding of cognitive processes is needed through multidisciplinary approaches and technological integration. It demonstrates that the use of EEG and ET is beneficial for developing applications in various fields, such as education, marketing, and neuropsychology. Future research is expected to expand the use of these technologies and significantly contribute to exploring more complex cognitive processes.

Limitations

The study presents several limitations that should be considered. One significant challenge lies in the integration of EEG and eye-tracking (ET) methods, as eye movements often cause artifacts that interfere with the quality of EEG data, complicating accurate analysis. Despite technological advancements, the seamless combination of these tools remains a hurdle, necessitating further research and development. Another limitation is the lack of comprehensive bibliometric studies that specifically map trends and research patterns in the integration of EEG and ET for studying executive functions. This gap indicates the need for a more robust strategic framework to guide future research.

Additionally, while EEG and ET technologies have advanced, they still face methodological constraints, such as limitations in EEG signal resolution and the precision of eye-tracking measurements. These constraints may affect the reliability and depth of findings. Geographical imbalance in research contributions is another concern, with the majority of influential studies originating from a few regions, particularly the USA, Europe, and Asia. This dominance may overlook valuable insights from underrepresented regions. Moreover, the research tends to focus narrowly on specific applications, such as neuromarketing and decision neuroscience, potentially leaving areas like rehabilitation and educational interventions underexplored.

The scope of research topics also reflects a concentration on certain keywords and trends, such as cognition and neuromarketing, which may not fully capture the multidisciplinary potential of EEG and ET. Furthermore, the analysis is limited to publications up to 2024, which might not encompass long-term developments in the integration of these technologies. Addressing these limitations will require a more inclusive, comprehensive, and forward-looking approach to advance research on the application of EEG and ET in understanding executive functions.

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