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SURVEY ARTICLE

Emerging Themes and Future Directions in Neurodesign and Human-Computer Interaction: A Systematic Review

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ABSTRACT
While considerable research has been conducted, the field of neurodesign and human-computer interaction (N-HCI) has yet to be methodically delineated in light of contemporary studies. In this context, this paper undertakes a systematic review with dual objectives: (a) to uncover emerging research themes within N-HCI, and (b) to provide future directions for research on N-HCI. Employing robust systematic review methodologies, this paper scrutinized 122 pertinent documents, revealing four principal emerging research themes and constructing a conceptual framework that synthesized key concepts in N-HCI. The results underscored the relative under-development in research that leverages neural evidence to enhance general human-computer interface design, and the notable absence of research at the intersections of the "user" and "environment" aspects of neurodesign with HCI. Accordingly, this paper identifies underdeveloped areas in existing research that require more depth and blank areas in the conceptual framework that call for exploration as future directions.

KEYWORDS
Emerging themes; future directions; neurodesign; human-computer interaction; systematic review

1. Introduction

The rise of neurodesign as a compelling multidisciplinary field is relatively recent, beginning with the fusion of neuroscience and design thinking around 2010. As a culmination of this pioneering cross-disciplinary approach, neurodesign emerged as a way to deepen our understanding of how the rules of brain activity in human experience guide the design. Neurodesign also has other variants such as "neuro-design" and "neuro design", reflecting stylistic and regional choices rather than differences in the field. For clarity, the form "neurodesign" will be used consistently in this paper, although the original spellings in cited works will be preserved to maintain accuracy.

With the expansion of neuroscience research globally, the concept of neurodesign has received considerable attention among scholars in various academic communities. Simultaneously, this growing interest has been supported and furthered through numerous institutions. For example, Southeast University in China refined the concept of neurodesign in 2014 by applying neuroimaging techniques to product and interface design. Southeast University also held China's first academic conference on neurodesign in 2019. Meanwhile, Stanford University in the United States launched the Neurodesign Research Initiative in 2018, focusing on design team collaboration and related thinking patterns. Additionally, related books have been intensively published. Weinschenk (2009) in *Neuro Web Design* applies insights from neuroscience, psychology, and the study of motivation and decision-making to website design. Bridger (2017) in *Neuro Design* explores the intersection of neuromarketing and design, offering insights from neuroaesthetics to enhance customer engagement and profitability. Similarly, Hofmann (2019) in *Neuro Design* bridges neuroscience and psychology with design and marketing, introducing fundamental neuro-design concepts and practical techniques. Neurodesign encompasses a wide range of fields including product, interface, team collaboration, website and marketing, aiming to optimize user engagement and satisfaction through neuroscience-based design solutions. It signifies a shift in academia and industry towards a more human-centered, science-driven approach to design.

The interest in neurodesign development has greatly increased over the last five years, with various fields committed to finding breakthroughs from it. Human-computer interaction (HCI) is one of these fields. The integration of neurodesign and HCI has given rise to a new field, termed Neurodesign and Human-Computer Interaction (N-HCI). This specific field is dedicated to applying the principles and techniques of neuroscience to design more efficient and more engaging HCI systems. The rapid emergence of N-HCI is mainly driven by three factors. First, there have been significant advancements in neuroimaging techniques, such as functional Magnetic Resonance Imaging (fMRI), Event-Related Potentials (ERP), and Electroencephalography (EEG), which have become more precise, easier to operate,

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and more widely applicable. Second, there has been a continuous increase in people's expectations of HCI experiences. This trend is particularly propelled by the rapid iteration of smart devices such as smartphones, tablets, robots, and ongoing advancements in artificial intelligence (AI) applications like voice recognition, image recognition, and sentiment analysis. These developments emphasize user-centered interaction experiences that involve the application of neural evidence. Third, the demand from people with disabilities for advanced interaction methods, such as brain-computer interface (BCI), necessitates neurodesign support for these types of HCI. This support ensures the systems are accessible, intuitive, and capable of facilitating seamless interaction without relying on traditional physical input methods.

In the field of N-HCI, well-known academic conferences have conducted a series of related seminars. Two noteworthy topics are "Neurotechnology in Human-Computer Interaction: Principles, Methods And Applications" at HCI International 2020 and "NeuroDesign in Human-Robot Interaction: The making of engaging HRI technology your brain can't resist" at IEEE SMC 2022. Similarly, among the main book publishers, two significant works include "Neurodesign: Applications of Neuroscience in Design and Human–System Interactions" by CRC Press and "NeuroDesign in Human-Robot Interaction" by Frontiers.

In addition to conferences and books, researchers have published a lot of papers in the field of N-HCI. Neuroimaging techniques reveal users' subconscious psychological states, enabling HCI researchers to better understand brain responses to interfaces and interactions, thereby improving HCI design. For example, a study by Liu et al. (2023) on ERP examination of cognitive and perceptual effects of icon design found that components such as P1, P2, and LPP can help in evaluating and refining the design of mobile application icons. Similarly, Shao and Xue (2021) utilized ERP to investigate the brain's inhibition effect on audio-visual semantic interference in Chinese interfaces, indicating that icon design must consider the semantic understanding of users. Li et al. (2023), Niu et al. (2023), and Bai et al. (2022) uniquely contribute to HCI design using EEG technology. Li et al. (2023) examine how EEG can assess users' preferences for robot voices, underscoring the significance of sound in human-robot interaction. In contrast, Niu et al. (2023) investigate the impact of visual shapes and numbers on the efficiency of Steady-State Visual-Evoked Potentials Brain-Computer Interface (SSVEP-BCI) through EEG, offering insights for enhancing visual BCI. Bai et al. (2022) explore how viewing angles and stimulus types can improve Motor Imagery Brain-Computer Interface (MI-BCI) performance through EEG, highlighting the importance of ergonomic and visual design in BCI usability. Together, these studies underscore the profound impact that integrating neurodesign with HCI can have, predicting that N-HCI will play a significant role in shaping the future of HCI design.

Although researchers have published a series of papers, most of these are article-type papers, with few being review-type papers. Some partially relevant review-type papers generally provide an overview from a broad perspective of neurodesign or HCI but lack a specific focus on N-HCI. Balters et al. (2023) introduce the emerging field of design neurocognition, applying brain imaging tools to understand cognitive processes in design. This review briefly mentions the design thinking process in HCI design. However, its focus is more on the broader design research rather than on detailed HCI research. This potentially limits its contribution to N-HCI. Yakubu Bala and Damla (2021) analyze the evolution of HCI in the context of modern technologies such as cloud computing and IoT. While their study insightfully analyzes the evolution of HCI design approaches, it focuses predominantly on broader aspects of HCI in the context of new technologies and user-experience design, leaving a gap in understanding how neurodesign principles could systematically enhance HCI, thereby providing limited contribution to the field of N-HCI.

In contrast, other review-type papers have focused on more narrow aspects of N-HCI, without providing an overall picture of the field. For instance, Vasiljevic and de Miranda (2020) explore the development, design, and evaluation of BCI-based games, highlighting their implications for HCI. However, their review narrowly focuses on BCI games within N-HCI, thus limiting its broader contribution to the field. Similarly, Yang et al. (2021) examine the advancements and clinical applications of BCI in stroke neurorehabilitation, specifically noting the improved outcomes when BCI is integrated with AI technologies. Yet, their scope is confined to rehabilitation applications, restricting their contribution to N-HCI. Likewise, Hussain et al. (2021) and Stroppa et al. (2023) concentrate on robotics within N-HCI. Hussain et al. (2021) discuss the intricacies of robotic designs and control strategies. Stroppa et al. (2023) investigate the use of evolutionary computation in exoskeleton design. These reviews are limited to specific applications within robotics, thereby offering limited insights into the broader N-HCI field.

Thus far, no studies have been found that accurately organize the key scientific contributions in N-HCI. For researchers embarking on preliminary research in this field, the relevant literature often appears fragmented and disorganized. These issues make it challenging to clearly identify the current research landscape of N-HCI. Although connecting the scientific research in N-HCI holds great potential, pinpointing key themes and development opportunities within the field remains a challenging endeavor. In light of this, this paper sets forth two primary study objectives: the first (referred to as SO1) is to ascertain the main content of research conducted so far, with a particular emphasis on the research themes within N-HCI; the second (referred to as SO2) is to delineate future directions for research on N-HCI. To accomplish these objectives, a systematic review was conducted. This review is the first of its kind in the field, not merely from a broader perspective of neurodesign or HCI, nor focusing on a narrower aspect such as BCI games, but rather comprehensively and accurately organizing the key scientific contributions in N-HCI, their themes, and future directions. More practically, this paper offers guidance for a more systematic approach to HCI from the neurodesign perspective, catering to the developmental needs of HCI.

2. Materials and methods

2.1. Search strategy and setting

This paper includes a thorough review of literature, utilizing the systematic review methodology proposed by Tranfield et al. (2003), which encompasses a structured review protocol, comprehensive literature search, selection of studies based on pre-set criteria, critical appraisal of each study's methodological quality, and synthesis and transparent reporting of the findings. Additionally, this review adheres to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines by Moher et al. (2009), a benchmark for enhancing transparency and completeness in systematic reviews and meta-analyses. PRISMA's 27-item checklist and four-phase flow diagram ensure comprehensive reporting. In alignment with PRISMA, this systematic review meticulously details the search strategy, selection criteria, data extraction, and analysis methods, risk of bias assessment in included studies, systematic presentation of results, and discussion of findings in relation to the study objectives.

The literature search was carried out in June 2023, initially using both the Scopus and Web of Science databases. Scopus was later selected for its wider range of relevant results, especially in the fields of neurodesign and HCI. This selection encompassed a substantial number of publications also found in alternative databases, facilitating the retrieval of metadata for the purposes of bibliometric and content-based evaluations. To ensure a thorough initial sample, the search terms were set as either "neurodesign" or combinations of "neur* AND design" and "*computer AND (interaction OR interface)". These terms were combined in four strategies to search article titles (TITLE) and keywords (KEY), as detailed in Table 1. Following the creation of the initial sample, repetitions were removed, and filters for document type and language (English) were implemented. The selection was narrowed to articles and reviews in journals from the Scopus database, given that their adherence to a strict peer-review process. This study did not impose any limitations concerning the publication period or the field of knowledge.

2.2. Final sample selection procedure

The initial search yielded 1483 documents. For refining this to the final sample, each document was carefully evaluated with the aim of including only those that are directly pertinent to the current study objectives. The criteria for inclusion mandated that a document must explicitly establish a connection between neurodesign and HCI, contributing to both fields. The criteria for exclusion encompassed:

- Documents not primarily focused on neurodesign and HCI.
- Documents that use neurodesign merely as a general context without contributing to this knowledge system.
- Documents that do not employ concepts, theories or methods related to HCI.

The final sample was selected according to the PRISMA Screening Procedure shown in Figure 1. First, two researchers independently screened all documents, primarily assessing the title, abstract, and keywords. Second, they compared their assessments of each document and resolved any disagreements by reaching a consensus iteratively. Third, if a consensus could not be reached by the two researchers, a third researcher made the decisive judgment. The final sample included 122 documents, all of which are listed in Appendix A for reference. These documents formed the foundation for the analysis.

2.3. Data analysis

Quantitative and qualitative methods were employed to investigate the implementation of neurodesign in HCI. The quantitative analysis involved the use of VOSviewer software, a free network analysis tool (Eck & Waltman, 2009). This software extracts and visually represents information from the analyzed literature, utilizing bibliometric data to visualize similarities and create maps. For the qualitative analysis, electronic datasheets were utilized for comprehensive analysis.

To achieve SO1, which is to pinpoint the emerging research themes within N-HCI, this study employed a three-stage methodology. The first stage involved executing a co-occurrence network analysis of authors' keywords using VOSviewer software, resulting in the identification of keyword groups. The second stage entailed a detailed thematic analysis of the papers within these groups, conducted by a team of four researchers, leading to the identification of specific themes of these groups. Finally, the third stage employed a thematic synthesis based on the conceptual linkage among these themes, categorizing themes with similar content. The final stage laid the foundation for this systematic review.

Table 1. Research strings utilized for constructing the document Pool.

Research Strings	Results
TITLE (neurodesign OR (neur* AND design)) AND TITLE (*computer AND (interaction OR interface))	28
TITLE (neurodesign OR (neur* AND design)) AND KEY (*computer AND (interaction OR interface))	231
KEY (neurodesign OR (neur* AND design)) AND TITLE (*computer AND (interaction OR interface))	175
KEY (neurodesign OR (neur* AND design)) AND KEY (*computer AND (interaction OR interface))	2398
Total	2832
Excluded duplicates	2491
(LIMIT-TO (DOCTYPE, "Article") OR LIMIT-TO (DOCTYPE, "Review")) AND (LIMIT-TO (LANGUAGE, "English"))	1483

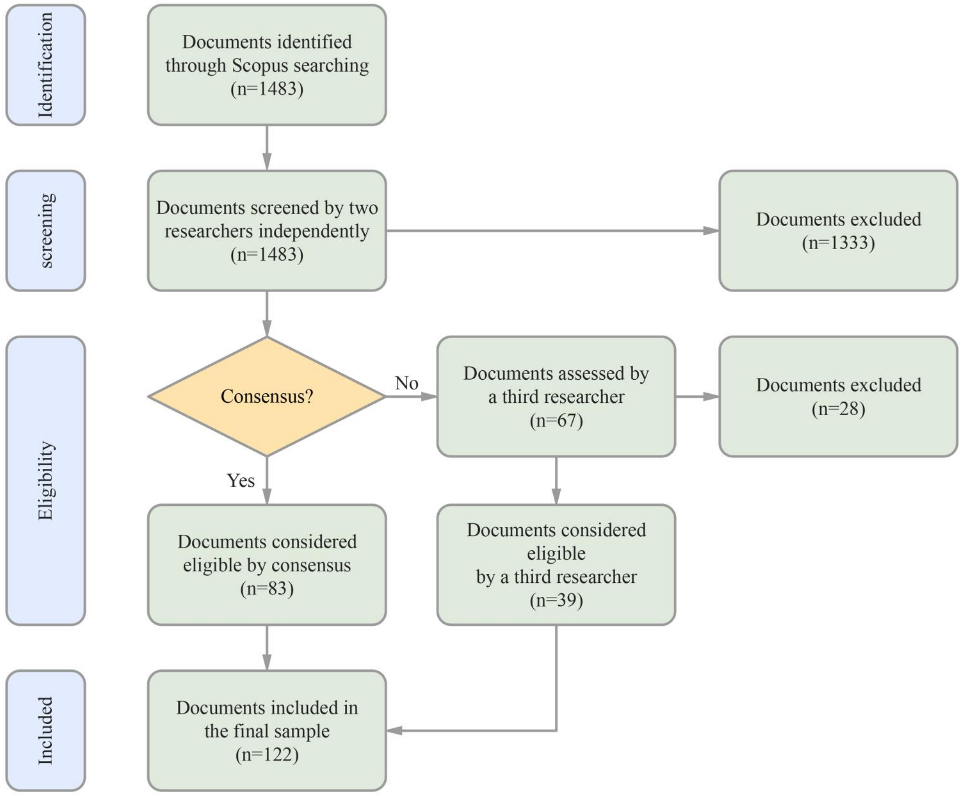

Figure 1. PRISMA screening procedure for final sample selection.

To achieve SO2, which is to delineate future directions for research on N-HCI, this study employed a two-pronged methodology. First, it identified opportunities in N-HCI research by pinpointing areas of underdevelopment in existing studies. Second, it explored additional opportunities by addressing unexplored areas within a conceptual framework, which demonstrated the intersections of various aspects of neurodesign and HCI.

3. Results

The co-occurrence network of authors' keywords generated by VOSviewer software is displayed in Figure 2. This visual representation includes only keywords appearing in at least two documents from the sample. To build the co-occurrence network, the keywords "design", "human-computer interaction", "HCI", "human-computer interface", "brain-computer interface" and "BCI" were excluded as they served as search terms for constructing the document pool. Keywords that had different spellings but identical meanings were consolidated to reduce redundancy. Ultimately, the VOSviewer software identified nine groups, each represented by a distinct color.

The colors, keywords, and frequencies of the keywords for the nine groups are listed in Table 2.

Two inherent biases may arise when relying solely on keyword groups to determine themes. First, if the choice of keywords is determined by the authors, the bias will be their personal experiences and views of the field. Second, if the choice of keywords is restricted by journals' mandatory list, the bias will be their aims and scopes. Therefore, this study conducted a detailed thematic analysis based on keyword groups. A team of four researchers carefully analyzed the documents in each group to identify specific themes. The themes of groups resulting from the detailed thematic analysis are shown in Table 3.

Thematic analysis identified 15 themes from nine groups. This study further conducted a thematic synthesis based on the conceptual linkage among these themes, categorizing themes with similar content and pinpointed four principal themes, as shown in Table 4.

4. Discussion

The subsequent sections are structured in alignment with the outlined study objectives. Section 4.1 addresses SO1, focusing on the main content of existing research, with an emphasis on the research themes within N-HCI. Section 4.2 addresses SO2, focusing on outlining the future directions for research on N-HCI.

4.1. Emerging themes in N-HCI

The results indicate that existing research primarily focuses on four principal themes. Each principal theme, encompassing several themes, is described in detail below.

4.1.1. Comprehensive overview of themes

A. The papers related to Principal Theme A indicate that the integration of HCI and neurodesign can effectively

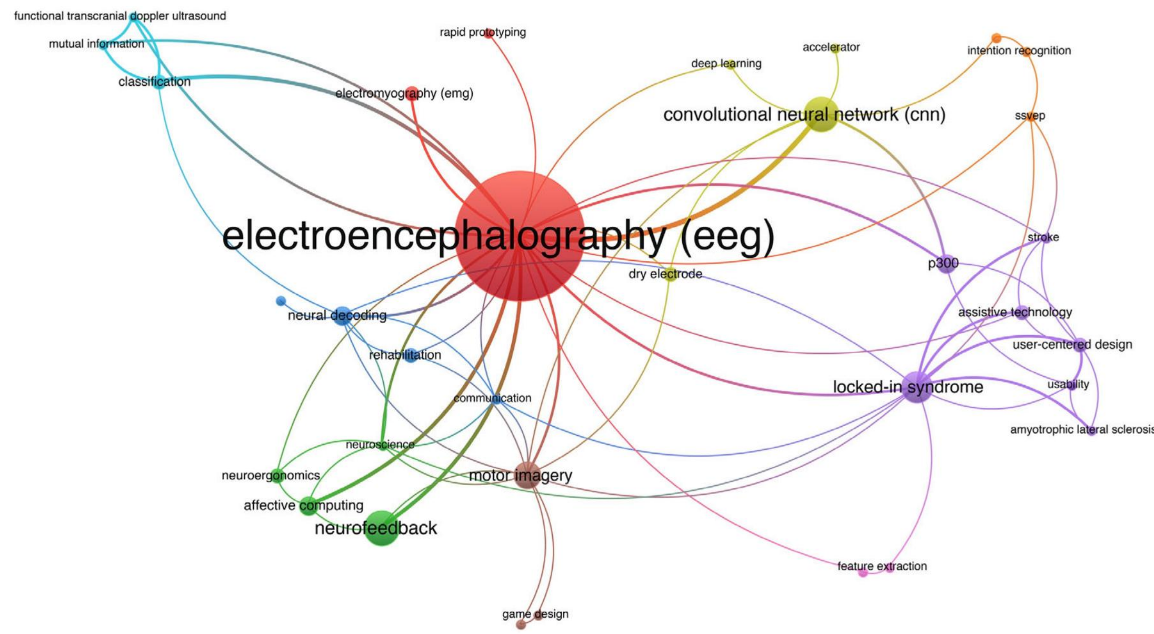

Figure 2. Co-occurrence network of authors' keywords.

Table 2. Groups of keywords derived from the co-occurrence network of authors' keywords.

No.	Color	Keywords
1	Red	electroencephalography (eeg) (31), electromyography (emg) (4), rapid prototyping (2).
2	Green	affective computing (4), neuroergonomics (3), neurofeedback (8), neuroscience (2).
3	Yellow	accelerator (2), convolutional neural network (cnn) (9), deep learning (2), dry electrode (3).
4	Purple	amyotrophic lateral sclerosis (2), assistive technology (3), locked-in syndrome (7), p300 (4), stroke (2), usability (2), user-centered design (3).
5	Dark Blue	communication (2), motor control (2), neural decoding (4), rehabilitation (3).
6	Light blue	classification (3), functional transcranial doppler ultrasound (2), mutual information (2).
7	Brown	game design (2), motor imagery (6), stroke rehabilitation (2).
8	Orange	intention recognition (2), pattern recognition (2), steady-state visual evoked potential (ssvep) (5).
9	Pink	feature extraction (2), filter bank (2).

Table 3. Themes of groups resulting from detailed thematic analysis.

Color	Keywords	Themes
Red	electroencephalography (eeg) (31), electromyography (emg) (4), rapid prototyping (2).	• Design Principles and Interactive Functionality • Development of Technology and Methods • Development of Tools and Resources • Monitoring and Analysis • Standardization of User Training Protocols
Green	affective computing (4), neuroergonomics (3), neurofeedback (8), neuroscience (2).	• Customization of User Experience • Monitoring of Emotions and Cognition • Alignment of Cognition in System Design • Enhancement of Interaction Efficiency and Intuitiveness
Yellow	accelerator (2), convolutional neural network (cnn) (9), deep learning (2), dry electrode (3).	• Advancement of Hardware Technologies
Purple	amyotrophic lateral sclerosis (2), assistive technology (3), locked-in syndrome (7), p300 (4), stroke (2), usability (2), user-centered design (3).	• Rehabilitation and Assistance
Dark Blue	communication (2), motor control (2), neural decoding (4), rehabilitation (3).	• Control and Navigation
Light blue	classification (3), functional transcranial doppler ultrasound (2), mutual information (2).	• Optimization of Signal Processing and Decoding
Brown	game design (2), motor imagery (6), stroke rehabilitation (2).	• Gaming and Entertainment
Orange	intention recognition (2), pattern recognition (2), steady-state visual evoked potential (ssvep) (5).	• Enhancement of Task Design and Paradigms
Pink	feature extraction (2), filter bank (2).	Same as Light blue

promote the development of BCI. BCI focuses on using neural signals, such as those from EEG, as inputs to realize the interaction between humans and computers. These papers originate from the "Red" group and primarily discuss the characteristics and development of BCI, leading to the naming of Principal Theme A as "BCI Characteristics and Development". Specifically, three themes delve deeply into the characteristics and development of BCI, addressing the design principles and interactive functions (characteristics of BCI), as well as the

Table 4. Identified themes and principal themes.

Principal Themes	Themes
A: BCI Characteristics and Development	A1: Design Principles and Interactive Functionality
	A2: Development of Technology and Methods
	A3: Development of Tools and Resources
B: BCI Practical Applications	B1: Control and Navigation
	B2: Rehabilitation and Assistance
	B3: Monitoring and Analysis
	B4: Gaming and Entertainment
C: BCI Optimization Techniques	C1: Optimization of Signal Processing and Decoding
	C2: Enhancement of Task Design and Paradigms
	C3: Advancement of Hardware Technologies
	C4: Standardization of User Training Protocols
D: General Interface Design and Interaction Efficiency	D1: Customization of User Experience
	D2: Monitoring of Emotions and Cognition
	D3: Alignment of Cognition in System Design
	D4: Enhancement of Interaction Efficiency and Intuitiveness

development of technology and methods, and the development of tools and resources (development of BCI).

A1: Design Principles and Interactive Functionality. The papers in this theme focus on the design of adaptive interfaces and unique control dynamics inherent in BCI systems. Central to this endeavor is the concept of neuroadaptive interfaces, which Hettinger et al. (2003) emphasize as systems that evolve in real-time to the user's cognitive and emotional states. However, the realization of such dynamic, responsive systems necessitates a standardized design framework, as proposed by Mason and Birch (2003), to ensure clear communication and comparability within BCI research. Additionally, addressing the unconventional control properties of BCI, highlighted by Williamson et al. (2009), requires a nuanced design approach that compensates for the limitations of BCI, such as limited bandwidth and variable delays. Together, these perspectives underscore the necessity of a multifaceted approach in BCI design to foster the creation of interfaces that are not mere tools but intuitive extensions of human intention and capability.

A2: Development of Technology and Methods. The papers in this theme examine a confluence of BCI technological refinement and methodological innovation, driving its transition from theoretical models to practical applications. Central to this progression is the enhancement of data acquisition and analysis, as evidenced by the advancements in real-time fMRI (Weiskopf et al., 2007), which have broadened the potential of BCIs in real-time analysis and neurofeedback. However, the realization of BCI's full potential hinges not only on technological prowess but also on interdisciplinary integration. The challenges in technology transfer (Nijboer, 2015) and the nuanced considerations in designing application-specific BCIs (Bocquelet et al., 2016) highlight the need for a holistic approach that encompasses usability, economic viability, and ethical considerations. Additionally, the exploration of BCIs in novel contexts, such as monitoring mental workload in software engineering (Kosti et al., 2018), underscores the expanding scope of BCIs beyond traditional realms. Collectively, these developments underscore a paradigm shift in BCI research, moving from a focus on technological capability to a multifaceted approach that integrates user-centered design, application specificity, and practical scalability.

A3: Development of Tools and Resources. The papers in this theme are emblematic of the broader trend in tech development, aiming to democratize access. This is evidenced by Crawford and Gilbert (2019) introduction of a novice-friendly, block-based programming environment for BCI application development, addressing the entry barrier for newcomers and acknowledging the initial learning curve they face. Complementarily, Chiesi et al. (2019) advance this democratization by presenting Creamino, a cost-effective, open-source EEG-based BCI system, which not only reduces financial barriers but also fosters a collaborative environment for innovation through its open-source nature. These developments underscore a strategic shift in BCI technology, emphasizing both the broadening of access for novices and the enhancement of research depth, reflecting a balanced approach to the democratization and advancement of the field.

B: The papers related to Principal Theme B primarily focus on the practical applications of BCI, and thus Principal Theme B is named "BCI Practical Applications". These papers explore BCI's practical applications across various domains: control and navigation, originating from the "Dark Blue" group; rehabilitation and assistance, from the "Purple" group; monitoring and analysis, from the "Red" group; and gaming and entertainment, from the "Brown" group. Consequently, this principal theme encompasses four themes.

B1: Control and Navigation. The papers in this theme discuss BCI practical applications in control and navigation. BCI is transforming assistive technology by providing new ways for people to control and navigate devices. On the control front, early work demonstrated that brain signals could control both a cursor and a keyboard (Wolpaw et al., 2003; Yang et al., 2013). In addition to computer accessories, BCI has been applied to controlling prosthetics (Benz et al., 2012; Chen et al., 2019; He et al., 2018; Müller-Putz & Pfurtscheller, 2008; Ofner & Müller-Putz, 2015). On the navigation front, the wheelchair developed by Kucukyildiz et al. (2017), which can be steered using both brain and muscle signals, is noteworthy. Puanhvuan et al. (2017) took a different approach by developing a navigation-synchronized multimodal control wheelchair, utilizing a combination of EEG and EOG. Overall, BCIs are becoming more intuitive and efficient, improving control over devices such as computers, prosthetics, and wheelchairs.

B2: Rehabilitation and Assistance. The papers in this theme focus on BCI practical applications in rehabilitation and assistance. These applications, tailored to the diverse needs of individuals with severe impairments such as stroke and multiple sclerosis, range from augmenting communication (Allison et al., 2007; Holz et al., 2015; Lesenfants et al., 2014; Ortner et al., 2017; Ron-Angevin et al., 2015) to integrating with assistive technologies (Kumar et al., 2022; Riccio et al., 2022). Additionally, rapid prototyping, as highlighted by Guger et al. (2001), expedites the transition from conceptual models to functional systems, enhancing the adaptability of BCIs. Together, these studies showcase BCIs, rooted in user-centered design as emphasized by Schreuder et al. (2013), not just as tools for functional rehabilitation but also as platforms for fostering autonomy and an enhanced quality of life for individuals facing the most challenging physical limitations.

B3: Monitoring and Analysis. The papers in this theme discuss BCI practical applications in monitoring and analysis. Within these realms, the precision and adaptability of such systems can significantly impact outcomes. Notably, Paulo et al. (2021) and Haghighi et al. (2017) contribute to this evolving field by addressing two critical applications: drowsiness detection and auditory scene analysis, respectively. In the former, EEG signals are harnessed to identify drowsiness levels, a major cause of accidents, by employing spatiotemporal image encoding for deep CNN classification. The latter study underscores the potential of EEG signals in auditory attention classification, suggesting applications in advanced hearing aids and augmented reality (AR) environments. These studies collectively make a significant stride toward more intuitive and responsive HCI, albeit with the necessity for further refinement in signal interpretation and system calibration to enhance reliability and user-specific adaptability.

B4: Gaming and Entertainment. The papers in this theme discuss BCI practical applications in gaming and entertainment. BCI applications, initially rooted in medical applications, have burgeoned into gaming and entertainment. Explorations, as discussed by Nijholt et al. (2009), advocate for a paradigm shift from conventional BCI applications towards more immersive, multimodal gaming experiences. This evolution is substantiated by Amin et al. (2022) and Jochumsen et al. (2022), who illustrate the potential of BCI in creating engaging, therapeutic gaming environments. Furthermore, Vasiljevic and de Miranda (2022) highlight the potential of BCI to enhance multiplayer interactions. Collectively, these studies encapsulate the transformative impact of BCI in gaming and entertainment, not only as a tool for enhancing user experience but also as a medium for cognitive development and therapeutic intervention, paving the way for a future where gaming transcends traditional entertainment.

C: The papers related to Principal Theme C primarily focus on the optimization techniques of BCI; therefore, Principal Theme C is named "BCI Optimization Techniques". These papers discuss BCI optimization techniques across various domains: signal processing and decoding, originating from the "Pink" and "Light Blue" groups; task design and paradigms, from the "Orange" group; hardware technologies, from the "Yellow" group; and user training protocols, from the "Red" group. Consequently, Principal Theme C comprises four themes.

C1: Optimization of Signal Processing and Decoding. The papers in this theme focus on BCI optimization techniques through a concerted effort to refine signal processing and decoding techniques, aimed at creating systems that are accurate, efficient, and engaging. This endeavor is exemplified through diverse research initiatives. Studies such as those by Higashi and Tanaka (2013), Zhao et al. (2021), and Borra et al. (2022) highlight the potential of machine learning techniques, such as CNN, in signal interpretation. Furthermore, hybrid approaches, such as the integration of functional transcranial Doppler ultrasound (fTCD) and EEG by Khalaf et al. (2018, 2019), and the integration of local field potential (LFP) and EEG by Feng et al. (2022), illustrate the benefits of combining multiple signal modalities for improved accuracy. This is complemented by research focusing on novel control paradigms and action classification methods. Such methods are investigated by Park et al. (2012), Abu-Alqumsan et al. (2017), and Young et al. (2019). Collectively, these studies focus on the optimization of signal processing and decoding to improve the accuracy, interpretability, and user adaptability of BCI systems.

C2: Enhancement of Task Design and Paradigms. The papers in this theme focus on BCI optimization techniques by refining task design and paradigms to enhance neurofeedback learning, user engagement, and system performance. Innovations such as McWhinney et al. (2018) goal-oriented task design and Pei et al. (2020) adaptable platform BrainKilter highlight the importance of engaging and customizable interfaces in enhancing training outcomes. These principles are further embodied in the work of Fazel-

Rezai et al. (2011), Kaufmann and Kübler (2014), and Markovinović et al. (2022). Complementing these are intuitive feedback mechanisms, like Hwang et al. (2012) LED keyboard, Smetanin et al. (2018) NFBLab, Duan et al. (2021) visualization feedback protocol, and Krogmeier et al. (2022) experimental story environment, which emphasize real-time, user-tailored training environments. Collectively, these studies demonstrate the field's commitment to leveraging sophisticated task designs and innovative paradigms to advance neurofeedback training and BCI performance.

C3: Advancement of Hardware Technologies. The papers in this theme focus on BCI optimization techniques in hardware technologies, which are evident in the shift towards more portable, user-friendly, and high-performing EEG devices. Pioneering studies, such as Casson et al. (2010), Frisoli et al. (2016), McCrimmon et al. (2017), Feng et al. (2022), and Chen et al. (2022), mark the transition from conventional, cumbersome EEG systems to next-generation wearable, wireless recorders. The evolution continues with dry electrode-based BCIs introduced by Guo et al. (2011), Pei et al. (2018), and Zhang et al. (2019), which eliminate the discomfort and preparation associated with traditional EEG systems, significantly enhancing user comfort and system portability. Additionally, the study by Konstantinidis et al. (2012) showcases the synergy between hardware advancements and computational power, facilitating real-time, emotion-aware applications. Collectively, these advancements focus on creating systems that are not only technologically advanced but also accessible, comfortable, and effective, thereby revolutionizing the interaction between human and BCI.

C4: Standardization of User Training Protocols. The papers in this theme explore BCI Optimization Techniques from the perspective of user training. The challenge of making BCI systems intuitive for users emphasizes the critical need for standardized user training protocols. The research by Mladenovic (2020) illustrates that BCI performance is markedly influenced by the initial methodologies employed. Additionally, Mladenovic (2020) sheds light on the diverse spectrum of interface designs and modalities in BCIs. The variability in interface designs and the inconsistency in user introductions to BCIs not only complicate the reproducibility of experiments and prediction of outcomes but also hinder the comparability of results across different studies. Advocating for a comprehensive standardization of protocol design for BCI user training paves the way for more consistent, intuitive, and effective user interaction with BCIs.

D: The papers related to Principal Theme D primarily examine the broader integration of neurodesign and HCI, not just limited to BCI; they pay more attention to general interface design and interaction efficiency. Thus, Principal Theme D is named "General Interface Design and Interaction Efficiency". Currently, this theme contains only a few papers. These papers cover domains such as customization of user experience, monitoring of emotions and cognition, alignment of cognition in system design, and enhancement of interaction efficiency and intuitiveness, all originating from the "Green" group. Principal Theme D comprises four themes.

D1: Customization of User Experience. The papers in this theme focus on the customization of user experience in general interface interactions, which stands as a paramount principle, ensuring interfaces not only meet functional requirements but also resonate on a personal, aesthetic level. For instance, Chew et al. (2016) explore the realm of aesthetic preference recognition through EEG, unveiling the capacity to decode individual aesthetic preferences for 3D shapes. Similarly, Fan et al. (2017) delve into the application of socially assistive robots for elder care, introducing a robotic coach architecture designed for both individual and multi-user settings. These studies collectively affirm the notion that tailoring user experiences through sophisticated understanding of individual preferences and needs not only fosters greater user satisfaction but also paves the way for innovative applications that can transform everyday interactions with technology.

D2: Monitoring of Emotions and Cognition. The papers in this theme focus on the integration of technology to monitor emotions and cognition in general interface interactions, which stands as a pivotal advancement. This notion is underpinned by the studies conducted by Rodríguez et al. (2013) and Siqueira et al. (2023), where innovative methodologies are employed to assess emotional and cognitive responses in virtual environments and gaming contexts. Rodríguez et al. (2013) delve into the use of portable EEG devices to evaluate mood changes induced by virtual reality (VR). Concurrently, Siqueira et al. (2023) showcase the potential of biosensors and artificial neural networks in identifying emotional responses without interrupting the user experience. These studies collectively underscore the critical role of integrating objective, real-time monitoring tools into user interactions, facilitating a deeper understanding of users' emotional and cognitive states.

D3: Alignment of Cognition in System Design. The papers in this theme focus on the alignment of cognitive processes in system design, as illuminated by Stanney et al. (2004) and Brocke et al. (2013). Stanney et al. (2004) propose a paradigm shift towards multimodal display systems, informed by behavioral and neurological foundations, aiming to optimize the information processing capabilities of users. Similarly, Brocke et al. (2013) advocate for the application of neuroscience in information systems design science research, highlighting how understanding the neurobiological determinants of perception can enhance the design of interfaces. Together, these studies underscore the potential of neuroscience and multimodal design principles to revolutionize the creation of intuitive, accessible, and efficient systems that seamlessly integrate with the human cognitive architecture.

D4: Enhancement of Interaction Efficiency and Intuitiveness. The papers in this theme focus on innovative approaches that significantly enhance interaction efficiency and intuitiveness, especially in complex systems such as immersive visualization environments and Computer-Aided Design (CAD). Research efforts, like those by Galati et al. (2021) and Cao et al. (2022), demonstrate innovative approaches to understanding and improving the user experience through physiological signals and immersive technologies. Galati et al. (2021) use functional near-infrared spectroscopy (fNIRS) and AR to measure internal and external user behaviors, offering deep insights into optimizing interface design for better cognitive alignment and efficiency. On a similar note, Cao et al. (2022) focus on utilizing EEG signals to facilitate a more intuitive and natural object selection process in CAD, addressing the Midas touch problem inherent in gaze-based interactions. These studies collectively highlight the importance of leveraging advanced technologies and cognitive insights to develop more efficient and intuitive interaction models.

After the comprehensive overview of themes in N-HCI, it becomes evident that the existing research focus is primarily on BCI. These studies include a thorough exploration of the characteristics and development of BCI, its applications, and optimizations. The advancement of BCI technology has not only broadened the scope of HCI but also effectively promoted deeper research into intuitive and natural user interfaces. This, in turn, expands our understanding of designing systems adaptable to human cognitive and perceptual abilities. However, it is noteworthy that HCI research beyond BCI, such as in fields involving general interface and interaction design with neural evidence, appears relatively underdeveloped. These studies address a broader range of HCI issues and have more common applications in daily life. Adopting neurodesign approaches could significantly enhance the ergonomics of conventional interfaces, making them safer, more efficient, and more appealing. To delve deeper into the N-HCI field, it is necessary to analyze aspects of neurodesign and HCI's focus. This involves exploring a conceptual framework of N-HCI through the combination of different deconstructed aspects, facilitating more refined research.

4.1.2. Conceptual framework of N-HCI

The multidisciplinary nature of neurodesign means that it encompasses various focuses, including user experience, systems design, product design, and marketing. However, the main things related to HCI are user experience, systems design, and environmental design, which can be summarized into three aspects: user, system, and environment. The "user" aspect focuses on the user's psychological and physiological responses, such as emotions, attention, memory, and perception. By understanding how the brain processes information and external stimuli, designers can create HCI that is more aligned with user needs and preferences. The "system" aspect involves the technical and functional aspects of HCI, including user interface, interaction logic, and information architecture. This aspect aims to design systems that align with human cognitive and processing capabilities, thereby reducing cognitive load and enhancing efficiency and satisfaction. The "environment" aspect considers the physical or virtual environment where users interact with the system. Environmental factors, such as light, sound, spatial layout, and sociocultural background, may affect users' psychological states and behaviors.

The interdisciplinary nature of HCI makes it focus on the integration of human capabilities and limitations, hardware and software potential, and interaction design principles. It can be distilled into three main aspects: human, computer, and interaction. The "human" aspect delves into cognitive psychology and ergonomics. This mainly includes designing interfaces that match human cognitive functions, designing accessible interfaces considering physical interactions, and creating multi-modal interfaces that accommodate various sensory inputs. Thus, this aspect can be further broken down into three sub-aspects: cognitive abilities, physical abilities, and sensory abilities. The "computer" aspect encompasses system design and engineering, focusing on constructing efficient and reliable hardware and software systems. It can be divided into two sub-aspects: hardware equipment, which comprises the physical components like processors and sensors, and software development, focusing on creating algorithms and user interfaces. Finally, the "interaction" aspect concentrates on interface design and multi-modal interaction methods. This aspect can be split into two sub-aspects: interface display, which covers the presentation of information, and interactive control, detailing how users input commands through devices or advanced methods like voice recognition.

Figure 3 shows a conceptual framework that integrates aspects of neurodesign focus with aspects of HCI focus. The horizontal axis in this figure represents the neurodesign focus, ranging from user to system to environment. The vertical axis represents the HCI focus, initially on human, computer, and interaction aspects, subsequently delving into sub-aspects like sensory abilities, cognitive abilities, and physical abilities. The key concepts in N-HCI shown in this framework are summarized from 15 themes. The distribution of these key concepts can help future researchers and practitioners position their work.

The conceptual framework of N-HCI shows that existing research covers many intersections between neurodesign and HCI. However, it also becomes apparent that certain intersections, particularly those involving the "user" and "environment" aspects of neurodesign, are underexplored. This observation underscores the potential for exploring

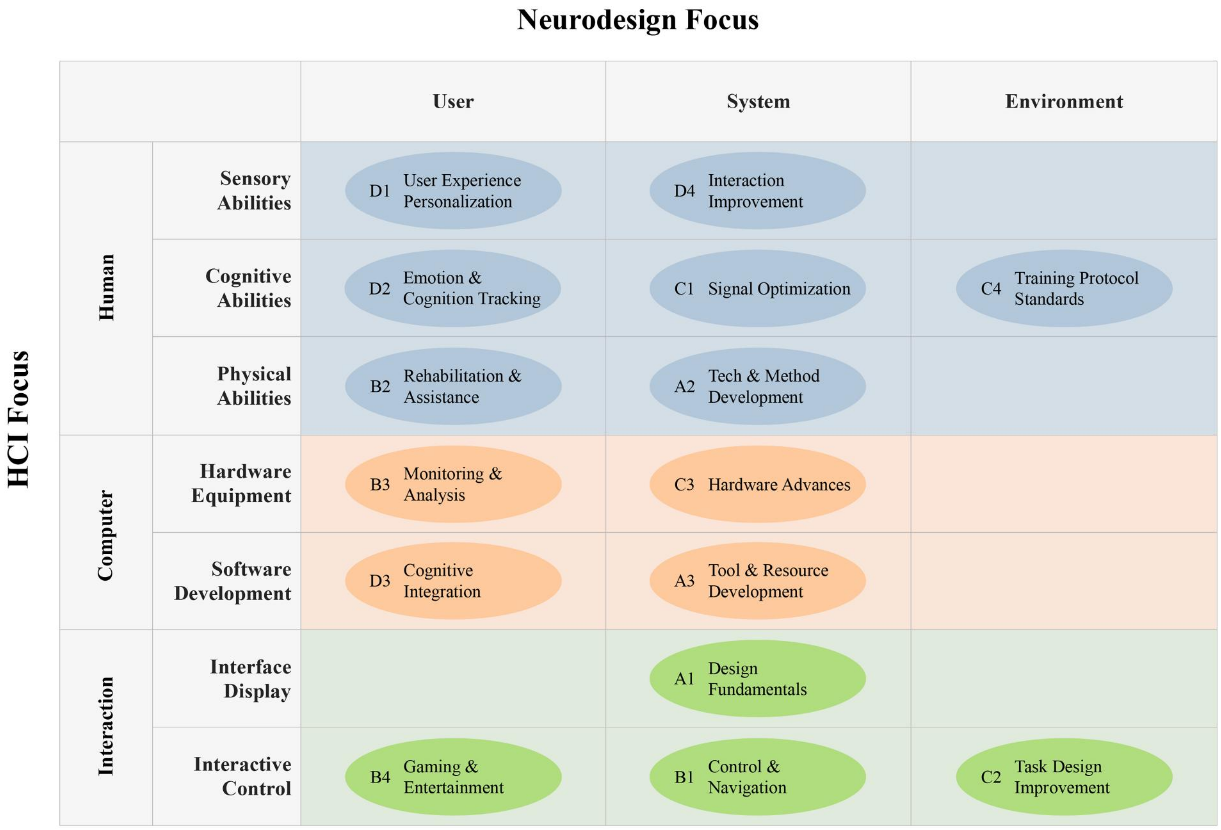

Figure 3. Key concepts in N-HCI.

intriguing research avenues that could enhance the coherence and richness of the discipline.

It is important to note that, due to the constraints of the selection criteria, some journal papers and other forms of scientific publications, such as conference papers and books, might not have been included. This also means that the 15 key concepts do not encompass the entirety of the literature. The blank intersections in Figure 3 may contain potential key concepts from literature not included in the review. For instance, the intersection of "user" and "interface display" is blank; however, significant research related to this intersection, including studies by authors such as Clifford et al. (2018), Iqbal et al. (2019), Hein et al. (2019), and Dou et al. (2022), has been conducted. These studies are conference papers and, therefore, have not been included in this review. The limitations of the final sample for this systematic review will be addressed in the conclusions section.

4.2. Future directions in N-HCI

Future directions in N-HCI can be explored in two main areas: first, strengthening existing research, and second, addressing research gaps. From the perspective of strengthening existing research, it is necessary to focus on existing themes that have been researched but are still insufficient. Current research themes are primarily concentrated on BCI. However, the integration of neurodesign with HCI extends beyond BCI alone. A broader range of HCI disciplines can benefit from employing neural evidence in interface and interaction design, thereby aiding designers in creating more user-friendly interfaces. Regarding addressing research gaps, there is a need to explore uncharted intersections within the conceptual framework. Specifically, there are significant research opportunities at the intersections of "user" and "environment" aspects of neurodesign with HCI. These intersections offer valuable avenues for exploratory research.

4.2.1. General human-computer interface design based on neural evidence

Among the four principal themes, three (Principal Themes A, B, and C) are focused on BCI. These works elaborate in detail on computer or mechanical control based on neural evidence, comprehensively discussing their characteristics, applications, and optimization, showing relatively mature research results. In contrast, the research on general human-computer interface design, represented by Principal Theme D, is not sufficiently comprehensive, both in terms of the number of papers and the depth of research. Clearly, this area requires more attention and in-depth study.

Currently, due to the lack of standardized guidelines, designers often rely on personal experience when designing human-computer interfaces. This reliance leads to inconsistent interface quality and challenges in evaluation. Establishing robust design and evaluation standards requires the support of neural evidence (Jung et al., 2022; Shukla et al., 2022; Sreetharan & Schutz, 2019). This evidence directly and reliably reflects the brain's response to the design, providing a scientific basis for setting design standards. Similarly, the general population, which does not use EEG

Table 5. Studies focused on general human-computer interface design.

Author(s)	Theme	Research method	Description
Chew et al. (2016)	D1	Experimental Study	Use of EEG signals to recognize aesthetic preferences for virtual 3D shapes, achieving high-accuracy classification of user preferences by employing algorithms such as SVM and KNN.
Fan et al. (2017)	D1	Experimental Study	The design of a robotic system aimed at helping elderly people, which adjusts its actions based on real-time analysis of human interactions and brain signals to offer personalized support.
Rodríguez et al. (2013)	D2	Experimental Study	Evaluation of VR as a mood induction procedure involves using portable EEG devices to measure emotional states.
Siqueira et al. (2023)	D2	Experimental Study	A new way to improve video games by using technology to understand players' feelings through their body signals, thereby making games more enjoyable by responding to these emotional cues.
Stanney et al. (2004)	D3	Theoretical Analysis	Enhancement of HCI by leveraging research on brain and behavior to inform design principles, thereby improving information processing and interaction efficiency.
Brocke et al. (2013)	D3	Theoretical Analysis	Development of IT artifacts utilizes neuroscientific approaches to align with users' cognitive and emotional processes.
Galati et al. (2021)	D4	Experimental Study	Combine VR with brain scanning technologies like fNIRS to help understand and improve how people process information and perform tasks in virtual environments.
Cao et al. (2022)	D4	Experimental Study	Creating an EEG-based model facilitates natural interaction in CAD. This model processes brain signals to better understand user intentions, solving issues with unintended selections in systems controlled by eye movement.

devices, shows more interest in the design elements and layout of interfaces. These users are concerned about how these aspects contribute to a satisfactory user experience, respond to emotions, and provide a logical structure. Establishing a user-centered design also requires the support of neural evidence. In fact, as listed in Table 5, only eight studies in the final sample involve general human-computer interface design.

The primary purpose of general human-computer interface design based on neural evidence is to achieve a user-centered design. As shown in Table 5, existing research primarily consists of experimental studies. The content focuses on user experience (Chew et al., 2016; Fan et al., 2017), emotional cognition (Rodríguez et al., 2013; Siqueira et al., 2023), system design (Brocke et al., 2013; Stanney et al., 2004), and interaction efficiency (Cao et al., 2022; Galati et al., 2021). Given the limited number of papers and the relatively infrequent use of theoretical analysis as a research method, it is imperative for future studies to not only deepen the investigation of content aspects such as user experience, emotional cognition, system design, and interaction efficiency but also to significantly strengthen the theoretical analysis. By addressing these shortcomings, researchers can contribute to a more nuanced understanding of how neural evidence can shape general human-computer interfaces.

However, it should be noted that this systematic review was exclusively focused on journal papers, which might have excluded other forms of research. This means that the eight studies listed may not fully represent the extent of neurodesign work in HCI. As mentioned earlier, the limitations of the final sample for this systematic review will be addressed in the conclusions section.

4.2.2. Integrating all neurodesign aspects with HCI

Table 6 highlights unexplored areas within the conceptual framework, including the integration of the "user" aspect of neurodesign with the "interface display" of HCI, as well as the integration of the "environment" aspect of neurodesign with five sub-aspects of HCI: "sensory abilities", "physical abilities", "hardware equipment", "software development" and "interface display". These integrations suggest promising avenues for future investigative studies.

The integration of the "user" aspect of neurodesign with the "interface display" sub-aspect of HCI suggests two pivotal research directions. The first is to study how different interface displays, such as visual, auditory, and haptic feedback, impact cognitive load and information retention among users with varying learning styles and cognitive abilities. This direction references studies by Corbett et al. (2016), Mason et al. (2019), and McAnally and Wallis (2023). These studies highlight the importance of sensory feedback in enhancing user interaction. However, they suggest a research gap in understanding the cognitive processes behind these interactions using neuroimaging techniques. The second direction focuses on adaptive interface designs that utilize neurophysiological measures like EEG to dynamically adjust to the user's emotions, attention levels, and cognitive states. This approach draws attention to the work by Seo et al. (2019) and Bao et al. (2023). Despite these advances, there is an identified need for deeper integration of real-time neurophysiological data to inform adaptive interfaces. This gap underscores the potential for future research to employ neuroimaging techniques to gain insights into the cognitive and emotional processes in HCI, aiming for more intuitive, efficient, and personalized interface designs.

The integration of the "environment" aspect of neurodesign with the "sensory abilities" sub-aspect of HCI highlights two forward-looking research directions. The first involves creating ambient intelligence environments that adapt sensory inputs like light, sound, and temperature to enhance cognitive and emotional well-being. This builds on initial findings by Schreuder et al. (2016), Lugo et al. (2019), and Iwashita et al. (2021). These studies point to the impact of

Table 6. Opportunities for integrating neurodesign with HCI.

Neurodesign Focus	HCI Focus	Opportunities
User	Interface Display	• Investigate how varying interface displays impact cognitive load and information retention in users with different learning styles and cognitive abilities. • Explore adaptive interface designs that dynamically adjust based on real-time assessment of user emotions, attention levels, and cognitive states.
Environment	Sensory Abilities	• Develop ambient intelligence environments that adaptively modify sensory inputs (light, sound, temperature) to optimize user cognitive performance and emotional well-being. • Study the impact of AR and VR environments on sensory processing and integration.
Environment	Physical Abilities	• Investigate the design of physical spaces and interfaces that enhance accessibility and usability for users with diverse physical abilities. • Examine the role of robotics and wearable technology in augmenting physical interaction within different environments.
Environment	Hardware Equipment	• Research into the development of environmentally adaptive hardware that responds to changes in its physical surroundings to optimize performance and user interaction. • Explore sustainable hardware design practices that consider the environmental impact of device production and usage.
Environment	Software Development	• Focus on creating software solutions that are sensitive to environmental contexts, such as location-aware applications or context-aware computing. • Investigate the development of software frameworks that enable the seamless integration of environmental data.
Environment	Interface Display	• Develop interface displays that dynamically adjust to environmental conditions to maintain optimal visibility and reduce strain. • Explore the use of AR and VR to create immersive environmental simulations that can be used for educational, therapeutic, or entertainment purposes.

ambient adjustments on well-being and cognitive function but note a gap in exploring the neural basis of these effects. The second direction examines the effects of AR and VR technologies on sensory processing and integration, particularly for individuals with sensory impairments. This is inspired by studies from Yu et al. (2019) and Diemer et al. (2015). These studies underscore the lack of integration of neuroimaging techniques to investigate how environmental and technological adaptations impact the brain. This suggests a significant opportunity to enhance the responsiveness and inclusivity of HCI systems through an improved understanding of sensory processing and neural engagement.

The integration of the "environment" aspect of neurodesign with the "physical abilities" sub-aspect of HCI offers two innovative research directions. The first involves exploring the design of physical spaces and interfaces to enhance accessibility and usability for individuals. This exploration leverages ergonomic principles for real-time adaptability and employs neurophysiological measures like EEG or fNIRS to understand their impact on cognitive and motor functions, as outlined by Sauer et al. (2020) and Hu (2023). The second direction examines the augmentation of physical interaction through robotics and wearable technology, focusing on rehabilitation and the enhancement of physical capabilities. It highlights the need for incorporating neuroimaging to understand how these technologies influence neural pathways, as discussed by Chen et al. (2015), Lessard et al. (2018), and Walsh (2018). Both directions underscore a gap in current research regarding the integration of neuroimaging techniques to explore the neurophysiological effects of ergonomic designs and assistive technologies. This presents opportunities for future studies to create more adaptable and effective HCI systems by understanding the neurocognitive implications of physical interactions within various environments.

The integration of the "environment" aspect of neurodesign with the "hardware equipment" sub-aspect of HCI presents two promising research directions. The first is developing environmentally adaptive hardware that optimizes performance and user interaction in response to physical surroundings. The second is exploring sustainable hardware design practices that minimize environmental impact. Research by Atif et al. (2015) and Ahmed et al. (2016) highlight the potential of IoT and smart environments in enhancing HCI, yet it lacks the incorporation of neuroimaging techniques to assess the neurophysiological impact. Similarly, studies by Oppong-Tawiah et al. (2018) and Celozzi et al. (2013) focus on green practices and energy efficiency without evaluating the neurophysiological effects of device production and usage. Future research should leverage neuroimaging methods to design adaptive and sustainable hardware that supports cognitive well-being and aligns with environmental sustainability. This approach fills the gap in current literature by marrying neurodesign with hardware development for enhanced HCI.

The integration of the "environment" aspect of neurodesign with the "software development" sub-aspect of HCI suggests two innovative research directions. First, developing context-aware software solutions that consider users' neurophysiological states, such as stress levels or cognitive load, for enhanced personalization. This direction is inspired by studies like those by Unger et al. (2016) and Li et al. (2020), which explore context-aware systems but lack a focus on neurophysiological feedback. Incorporating neuroimaging techniques could lead to applications that adjust in real-time to the user's cognitive and emotional states. Second, creating software frameworks that integrate environmental and neurophysiological data to adapt application behavior, aimed at optimizing user interaction. Research by Zheng et al. (2014) and Valero et al. (2014) shows the potential of adaptive applications responsive to environmental contexts but misses incorporating neuroimaging data for software adaptation. This research gap presents an opportunity to develop software that dynamically adjusts to both environmental conditions and the user's brain activity, enhancing engagement and satisfaction.

The integration of the "environment" aspect of neurodesign with the "interface display" sub-aspect of HCI highlights two key research directions. First, enhancing interface displays to dynamically adjust to environmental conditions (eg, lighting, noise) to improve user experience and neurocognitive compatibility. This has been explored by Tong et al. (2014), Orlosky (2014), and Ambeth Kumar et al. (2020), with a future focus on incorporating neuroimaging techniques for better cognitive load management. Second, leveraging AR and VR for immersive environmental simulations for educational, therapeutic, or entertainment purposes, as indicated by Ricci et al. (2022) and Fussell et al. (2019), with an emphasis on tailoring these simulations through neurophysiological feedback to enhance learning outcomes and emotional engagement. These directions suggest a gap in current research, emphasizing the need for integrating neurophysiological data into interface and immersive technology development. The goal is to create adaptive and immersive systems that cater to users' cognitive and emotional states for more personalized and effective technology interactions.

In conclusion, by integrating the aspects of neurodesign and HCI, The outlined research directions provide a roadmap for future investigations, unlocking the potential for more intuitive, efficient, and personalized HCI designs that not only enhance user experience but also contribute to the evolution of N-HCI. From enhancing interface displays with adaptive technologies that respond to users' cognitive and emotional states, to creating ambient intelligence environments and context-aware software that align with users' neurophysiological conditions, the potential for innovation is vast. Moreover, the exploration of sustainable hardware practices and the augmentation of physical interactions through advanced technologies emphasize the importance of a holistic approach that considers both the cognitive well-being of users and environmental sustainability.

5. Conclusions

The aim of this study was to first reveal the emerging research themes within N-HCI and second propose directions for future research in this field. This systematic review employed a rigorous methodology and adhered to PRISMA guidelines. It meticulously outlined the search strategy and setting, selection rationales, data extraction, and analysis methods, assessments of bias risk within included studies, and provided a systematic articulation of the results.

This systematic review uncovered four principal emerging research themes within N-HCI and constructed a conceptual framework that integrates key concepts and showcases the research landscape in this field. The results highlighted that N-HCI research predominantly focuses on BCI, with fewer studies exploring how neural evidence can improve general human-computer interface designs. Moreover, there was a noticeable gap in research that combines the "user" and "environment" aspects of neurodesign with HCI.

Considering these findings, the future directions of N-HCI are proposed to primarily focus on two main areas: First, strengthening and deepening existing research, especially in the theme that have been mentioned but not fully explored. Current research mainly focuses on BCI, and integrating a broader range of HCI with neurodesign holds great potential. This is significantly valuable in helping designers create more humanized interfaces. Second, making efforts to address research gaps. Within the conceptual framework, the intersections of the "user" and "environment" aspects of neurodesign with HCI offer important research opportunities that have not been exploited. These intersections open new pathways for exploratory research.

By offering a thorough understanding of the research themes and future directions in N-HCI, this review stands as a pivotal contribution to both the academic literature and industry practice. From a theoretical perspective, this review expands the theoretical foundations of N-HCI by providing a structured overview of current research trends and under-explored areas. By constructing a robust conceptual framework, it offers an invaluable scaffold for future research, providing clarity on the synergies between neural evidence, interface design, and user-environment interactions. Moreover, the identification of critical research gaps underscores a vital direction for scholarly endeavor, highlighting the theoretical richness and potential of integrating user and environment perspectives within HCI studies. On the practical side, this review underscores the crucial link between neurodesign research and practical advancements in HCI. By highlighting how neural evidence can revolutionize interface design, it offers a blueprint for creating more intuitive, user-centered interfaces that promise to enhance the way technology is experienced. Furthermore, as a comprehensive guide that delineates current research landscapes and future directions, this review serves as a pivotal reference for industry professionals. It not only inspires next-generation technology development but also sets a strategic direction for research and development initiatives, potentially leading to breakthroughs that redefine user interaction. Ultimately, this review catalyzes a symbiotic relationship between academic research and industry practice, facilitating the translation of theoretical insights into tangible, impactful technological innovations.

The limitations of this paper should also be noted. One primary limitation is the nature of literature reviews, which rely on Boolean operators in scientific databases and may not fully reflect the state of research in the field. For instance, relevant research by scholars not published in academic journals, but rather presented as oral reports or press releases, would not be considered, although including these types of work could provide a more comprehensive reflection of the overall research landscape in the field. Another limitation concerns the selection of the final sample, which relates to the choice of database, search descriptors, and database filters. Regarding the choice of database, the search was conducted only in the Scopus database. Although Scopus is considered one of the most comprehensive databases and has significant overlap with other relevant databases, it may still miss certain relevant academic papers. Regarding search descriptors, the use of specific descriptors could potentially omit publications using different terms. Unfortunately, this represents an inherent bias in systematic reviews. For instance, some papers might not label their work with "neurodesign" or its variants as key terms, resulting in their exclusion. Regarding database filters, only "Articles" and "Reviews" were included. Other types of publications, such as conference papers, book chapters, and reports, might provide richer information. The decision to exclude these types of publications was primarily due to time and human resource costs, as the study method involves qualitative analysis of documents, making the analysis of a sample twice the size nearly impossible. As mentioned in Section 2.1, the selected documents underwent a rigorous review process, thus ensuring higher quality and more typical representation. Despite these limitations, the achievement of the objectives proposed in this paper contributes to a systematic exploration of N-HCI and offers a broad perspective on research advancements related to N-HCI.

Addressing the limitations outlined in our review heralds a promising pathway to advance the systematic review process within N-HCI, ultimately fostering a richer and more nuanced understanding of this dynamic field. To transcend current boundaries and enhance the inclusivity and representativeness of research synthesis, future studies can concentrate on three aspects. First, future studies could incorporate a broader range of sources beyond academic journals, including more publication types such as conference papers, book chapters, reports, and even grey literature like conference presentations, press releases, and relevant social media content, to provide a more comprehensive view of the field. Second, diversifying the databases and search terms utilized in reviews could significantly reduce the risk of overlooking pertinent studies, thereby minimizing bias and ensuring a more exhaustive exploration of the field. Third, leveraging technology, particularly artificial intelligence, for data analysis could dramatically increase the feasibility of including a more diverse set of documents in reviews, thereby broadening the scope of findings without imposing undue burdens on the research team. Collectively, these directions not only aim to surmount the current limitations but also to push the boundaries of systematic review methodologies, making them more representative and inclusive of the entire research landscape in the field of N-HCI.

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Appendix A. Complete list of 122 reviewed documents included in the study

No.	Title	Link
1	Visual guidance for information navigation: A computer-human interface design principle derived from cognitive neuroscience	https://www.scopus.com/inward/record.uri?eid=2-s2.0-44949277658&doi=10.1016/0953-5438%2891%2990013-R&partnerID=40&md5=b87c11516f1c6695009853e58b419d97
2	3D Input Convolutional Neural Network for SSVEP Classification in Design of Brain Computer Interface for Patient User	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85131422701&doi=10.1155/2022/8452002&partnerID=40&md5=509b9f63589d1a32dcf1b642e97dd40e
3	The impact of goal-oriented task design on neurofeedback learning for brain–computer interface control	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85021953195&doi=10.1007/s11517-017-1683-1&partnerID=40&md5=bd8cb43ba0caa90569943381954b015f
4	Opening up the design space of neurofeedback brain-computer interfaces for children	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85041436204&doi=10.1145/3131607&partnerID=40&md5=513f6b1d4c841c71eb64b7e592b6cc9c
5	Deriving haptic design guidelines from human physiological, psychophysical, and neurological foundations	https://www.scopus.com/inward/record.uri?eid=2-s2.0-1942500408&doi=10.1109/MCG.2004.1274059&partnerID=40&md5=4ae04cba59f086d3489db05ebcb5641e
6	Firing-rate-modulated spike detection and neural decoding co-design	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85158021252&doi=10.1088/1741-2552/accece&partnerID=40&md5=4dc81162d73f0b1e0dd194de4a288c05
7	Application strategies for neuroscience in information systems design science research	https://www.scopus.com/inward/record.uri?eid=2-s2.0-84896997031&doi=10.1080/08874417.2013.11645627&partnerID=40&md5=9cd12d966b0e350fd109a04092bcdfd5
8	Design of a 3D platform for immersive neurocognitive rehabilitation	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85082502749&doi=10.3390/info11030134&partnerID=40&md5=62485f4c347a4a14cd35ff4996ca9c53
9	A Bayesian-optimized design for an interpretable convolutional neural network to decode and analyze the P300 response in autism	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85134429733&doi=10.1088/1741-2552/ac7908&partnerID=40&md5=2fbad5470f020602730e3e81d1512972
10	A paradigm shift in interactive computing: Deriving multimodal design principles from behavioral and neurological foundations	https://www.scopus.com/inward/record.uri?eid=2-s2.0-4043108412&doi=10.1207/s15327590ijhc1702_7&partnerID=40&md5=e0f804d7015595724dd5d10f90e6e96f

(*continued*)

Appendix A. Continued.

No.	Title	Link
11	Neurorehabilitation using the virtual reality based Rehabilitation Gaming System: Methodology, design, psychometrics, usability and validation	https://www.scopus.com/inward/record.uri?eid=2-s2.0-77956799027&doi=10.1186/1743-0003-7-48&partnerID=40&md5=79115b93e16570166a80d961567a0d6e
12	BrainKilter: A Real-Time EEG Analysis Platform for Neurofeedback Design and Training	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85082928476&doi=10.1109/ACCESS.2020.2967903&partnerID=40&md5=0d95a2e3e423833dc5704f68d3e3de22
13	Exploiting co-adaptation for the design of symbiotic neuroprosthetic assistants	https://www.scopus.com/inward/record.uri?eid=2-s2.0-67349094505&doi=10.1016/j.neunet.2009.03.015&partnerID=40&md5=0dbff48e427436e5230116736b12d9c7
14	Active sampling protocol (ASAP) to optimize individual neurocognitive hypothesis testing: A BCI-inspired dynamic experimental design	https://www.scopus.com/inward/record.uri?eid=2-s2.0-84978289154&doi=10.3389/fnhum.2016.00347&partnerID=40&md5=5eaae3d222325c9114adf62ca55333e8
15	Neuroadaptive technologies: Applying neuroergonomics to the design of advanced interfaces	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85011142180&doi=10.1080/14639220210000020918&partnerID=40&md5=a7bb1e9ab86b3d67d6f8cdf845013071
16	A neural network-based optimal spatial filter design method for motor imagery classification	https://www.scopus.com/inward/record.uri?eid=2-s2.0-84929103990&doi=10.1371/journal.pone.0125039&partnerID=40&md5=276792a325925a5a1869056ad77f118c
17	Design a Novel BCI for Neurorehabilitation Using Concurrent LFP and EEG Features: A Case Study	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85128801020&doi=10.1109/TBME.2021.3115799&partnerID=40&md5=8042935bdb14f504717a58024d3f3bc3
18	User-centered design in brain-computer interfaces-A case study	https://www.scopus.com/inward/record.uri?eid=2-s2.0-84886784445&doi=10.1016/j.artmed.2013.07.005&partnerID=40&md5=1dcab6e9a52d8b12029befcb0e59be21
19	An Efficient Model-Compressed EEGNet Accelerator for Generalized Brain-Computer Interfaces with Near Sensor Intelligence	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85140750618&doi=10.1109/TBCAS.2022.3215962&partnerID=40&md5=4a6641e37529fbc225db5a8986a1f430
20	Standardization of protocol design for user training in EEG-based brain-computer interface	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85101720611&doi=10.1088/1741-2552/abcc7d&partnerID=40&md5=e47cf2d88a98cc91f2c9a3ee0c67a138
21	Towards an affordable brain computer interface for the assessment of programmers' mental workload	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85043982317&doi=10.1016/j.ijhcs.2018.03.002&partnerID=40&md5=6d628d667e293d173b39892997aa66ed
22	Utilizing gamma band to improve mental task based brain-computer interface design	https://www.scopus.com/inward/record.uri?eid=2-s2.0-33749592391&doi=10.1109/TNSRE.2006.881539&partnerID=40&md5=c6ef189a539f22738a85dfbb872d970a
23	Exploring the Use of Brain-Computer Interfaces in Stroke Neurorehabilitation	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85109116680&doi=10.1155/2021/9967348&partnerID=40&md5=6358a3d0e66cec2f5286bc3bfcfa12e7
24	Goal-recognition-based adaptive brain-computer interface for navigating immersive robotic systems	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85020442770&doi=10.1088/1741-2552/aa66e0&partnerID=40&md5=02fbd71418a691d0faa3fd71625de861
25	Frontal alpha asymmetry interaction with an experimental story EEG brain-computer interface	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85136812601&doi=10.3389/fnhum.2022.883467&partnerID=40&md5=368c358a94d8e481eeaad2fb364dc40d
26	Towards optimal visual presentation design for hybrid EEG - FTCD brain-computer interfaces	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85053136031&doi=10.1088/1741-2552/aad46f&partnerID=40&md5=035bc40dda192d267b13ae84c712cc83
27	Next-Generation Wearable Wireless EEG Recorder: The future of accessible neural applications, from mental health monitoring to a noninvasive brain-computer interface	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85143255339&doi=10.1109/MSSC.2022.3202738&partnerID=40&md5=6f2a3af52e7ab6ba71e159590682b33c
28	A novel motor imagery hybrid brain computer interface using EEG and functional transcranial Doppler ultrasound	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85059120119&doi=10.1016/j.jneumeth.2018.11.017&partnerID=40&md5=459a181388642a6e0755b6330ed29c64
29	Beyond maximum speed - A novel two-stimulus paradigm for brain-computer interfaces based on event-related potentials (P300-BCI)	https://www.scopus.com/inward/record.uri?eid=2-s2.0-84907429733&doi=10.1088/1741-2560/11/5/056004&partnerID=40&md5=cde03d98919c58c58ef99e5cb06a6f60
30	A general framework for brain - Computer interface design	https://www.scopus.com/inward/record.uri?eid=2-s2.0-0038241238&doi=10.1109/TNSRE.2003.810426&partnerID=40&md5=7d45dc691980c9474b4c1f13709cb383
31	Turning shortcomings into challenges: Brain-computer interfaces for games	https://www.scopus.com/inward/record.uri?eid=2-s2.0-70749159695&doi=10.1016/j.entcom.2009.09.007&partnerID=40&md5=718fc070cbbc6a76c95e5954e61d5853
32	Rapid prototyping of an EEG-based brain-computer interface (BCI)	https://www.scopus.com/inward/record.uri?eid=2-s2.0-0034906326&doi=10.1109/7333.918276&partnerID=40&md5=23babc4456272bad548ccbcca51d19be
33	Key considerations in designing a speech brain-computer interface	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85026819152&doi=10.1016/j.jphysparis.2017.07.002&partnerID=40&md5=bfdf74b77391aaa4fc8ecf1c7409c9cf
34	The Wadsworth Center brain - Computer interface (BCI) research and development program	https://www.scopus.com/inward/record.uri?eid=2-s2.0-0041853788&doi=10.1109/TNSRE.2003.814442&partnerID=40&md5=1c1b65e607dffa8ebf9232d147b7ce64
35	NFBlab—a versatile software for neurofeedback and brain-computer interface research	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85077013443&doi=10.3389/fninf.2018.00100&partnerID=40&md5=2da2675863803d8e69a2ff7a755791cd
36	A comparison among several P300 brain-computer interface speller paradigms	https://www.scopus.com/inward/record.uri?eid=2-s2.0-83355169784&doi=10.1177/155005941104200404&partnerID=40&md5=63c48816e6609d787bfa2ef79af3b39f
37	Brain-computer interface systems: Progress and prospects	https://www.scopus.com/inward/record.uri?eid=2-s2.0-34447339625&doi=10.1586/17434440.4.4.463&partnerID=40&md5=ee49bc5ab8d48efe36b5844daecb379d
38	Designing for uncertain, asymmetric control: Interaction design for brain-computer interfaces	https://www.scopus.com/inward/record.uri?eid=2-s2.0-69949094187&doi=10.1016/j.ijhcs.2009.05.009&partnerID=40&md5=c8e1aa173e058e3299fd42397116a46d
39	BCILAB: A platform for brain-computer interface development	https://www.scopus.com/inward/record.uri?eid=2-s2.0-84885436573&doi=10.1088/1741-2560/10/5/056014&partnerID=40&md5=db90608b2cd854948037862b4be4fa52
40	Hybrid model-based classification of the action for brain-computer interfaces	https://www.scopus.com/inward/record.uri?eid=2-s2.0-84866253253&doi=10.1166/sl.2012.2284&partnerID=40&md5=8c4097dd4b1d2528e5731fd91b0a3a09
41	Performance Assessment of a Custom, Portable, and Low-Cost Brain-Computer Interface Platform	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85029918291&doi=10.1109/TBME.2017.2667579&partnerID=40&md5=213c981c56a2266290447a393c3ff220
42	Usability of a Hybrid System Combining P300-Based Brain-Computer Interface and Commercial Assistive Technologies to Enhance Communication in People With Multiple Sclerosis	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85133243264&doi=10.3389/fnhum.2022.868419&partnerID=40&md5=40530c6d10d448057f38042747abaee7
43	A brain-computer interface method combined with eye tracking for 3D interaction	https://www.scopus.com/inward/record.uri?eid=2-s2.0-77954217020&doi=10.1016/j.jneumeth.2010.05.008&partnerID=40&md5=53a89de9ab64042683f0008a803cbe9a

(*continued*)

Appendix A. Continued.

No.	Title	Link
44	A qualitative study adopting a user-centered approach to design and validate a brain computer interface for cognitive rehabilitation for people with brain injury	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85023778474&doi=10.1080/10400435.2017.1317675&partnerID=40&md5=e9ef53fbfe7920d56853b1a58af44dd8
45	Design considerations for the auditory brain computer interface speller	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85124377010&doi=10.1016/j.bspc.2022.103546&partnerID=40&md5=1e9b37b02c6418bd8c1253b81a543dbf
46	Technology transfer of brain-computer interfaces as assistive technology: Barriers and opportunities	https://www.scopus.com/inward/record.uri?eid=2-s2.0-84923563933&doi=10.1016/j.rehab.2014.11.001&partnerID=40&md5=cfd47a4086abc57ac9f1882250f5d147
47	Leveraging brain–computer interface for implementation of a bio-sensor controlled game for attention deficit people	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85135717949&doi=10.1016/j.compeleceng.2022.108277&partnerID=40&md5=7b3dab023e86f1cfea548b8eac228ef6
48	Comparing users' performance and game experience between a competitive and collaborative brain-computer interface	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85144012516&doi=10.1080/0144929X.2022.2152727&partnerID=40&md5=e9b855f54cf5ccd688209d618694e3bd
49	Design and Implementation of a Multi Sensor Based Brain Computer Interface for a Robotic Wheelchair	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85010931308&doi=10.1007/s10846-017-0477-x&partnerID=40&md5=6229d11be761ce1b7676b8ed059bae49
50	Brains and blocks: Introducing novice programmers to brain-computer interface application development	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85069513598&doi=10.1145/3335815&partnerID=40&md5=a1699fb44cb607bdcd4d664d38f7ad2d
51	Dry electrode based wearable wireless brain-computer interface system	https://www.scopus.com/inward/record.uri?eid=2-s2.0-84862974898&doi=10.1115/1.4005487&partnerID=40&md5=cad81adaed586fe787e4d53e1ffd9fb8
52	Portable brain-computer interface based on novel convolutional neural network	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85062558639&doi=10.1016/j.compbiomed.2019.02.023&partnerID=40&md5=80bb5a5e275aecbde63959cbddd17beb
53	An independent SSVEP-based brain-computer interface in locked-in syndrome	https://www.scopus.com/inward/record.uri?eid=2-s2.0-84901251496&doi=10.1088/1741-2560/11/3/035002&partnerID=40&md5=f89f405eec2a16d3b0d7cc0d34d3b7d4
54	An automated approach to estimate player experience in game events from psychophysiological data	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85140077738&doi=10.1007/s11042-022-13845-5&partnerID=40&md5=bc95e7cc82e3ff210e9388c411afd5a2
55	Building EEG-based CAD object selection intention discrimination model using convolutional neural network (CNN)	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85124218350&doi=10.1016/j.aei.2022.101548&partnerID=40&md5=9ca763e70d9d7c65ee7170c8ed3717e8
56	Error-Related Negativity-Based Robot-Assisted Stroke Rehabilitation System: Design and Proof-of-Concept	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85129820248&doi=10.3389/fnbot.2022.837119&partnerID=40&md5=8b86082f16edfcdd86c7fafbf63f5f8c
57	Implementing Performance Accommodation Mechanisms in Online BCI for Stroke Rehabilitation: A Study on Perceived Control and Frustration	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85143525388&doi=10.3390/s22239051&partnerID=40&md5=bb5586afa0d3bcc420bcb3201c09615b
58	CMOS-based area-and-power-efficient neuron and synapse circuits for time-domain analog spiking neural networks	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85148699485&doi=10.1063/5.0136627&partnerID=40&md5=9a50930e81116f6434e71a093936484b
59	Inception inspired CNN-GRU hybrid network for human activity recognition	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85126046806&doi=10.1007/s11042-021-11885-x&partnerID=40&md5=f4ca3862549451dc68fb16f33e4996f4
60	Two-branch 3D convolutional neural network for motor imagery EEG decoding	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85114034583&doi=10.1088/1741-2552/ac17d6&partnerID=40&md5=a80f0485537208c22009b106e0b19779
61	Exploring the SenseMaking Process through Interactions and fNIRS in Immersive Visualization	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85103253133&doi=10.1109/TVCG.2021.3067693&partnerID=40&md5=323e9f4c5f3a75a5d0efe83d59bab552
62	Cross-Subject Zero Calibration Driver's Drowsiness Detection: Exploring Spatiotemporal Image Encoding of EEG Signals for Convolutional Neural Network Classification	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85105843428&doi=10.1109/TNSRE.2021.3079505&partnerID=40&md5=38f13745234c7edea0f2454fb9542fb2
63	New approach for designing cVEP BCI stimuli based on superposition of edge responses	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85087528138&doi=10.1088/2057-1976/ab98e7&partnerID=40&md5=38238873adc0b9d9c350faa1908cf0a8
64	An Online Data Visualization Feedback Protocol for Motor Imagery-Based BCI Training	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85108360642&doi=10.3389/fnhum.2021.625983&partnerID=40&md5=b92d72a1e690ba9016c8ff60d24d3be2
65	SimBSI: An open-source Simulink library for developing closed-loop brain signal interfaces in animals and humans	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85085330123&doi=10.1088/2057-1976/ab6e20&partnerID=40&md5=01f9ae40a9b90bbc21d6936cab8a88ba
66	Filter bank convolutional neural network for SSVEP classification	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85118597659&doi=10.1109/ACCESS.2021.3124238&partnerID=40&md5=b020aa621b152f20aa6ea3dea7b03ea5
67	Optimizing a dual-frequency and phase modulation method for SSVEP-based BCIs	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85089433137&doi=10.1088/1741-2552/abaa9b&partnerID=40&md5=53fbd72118ac3326f87beae38d88cb2c
68	Introduction of human-centric AI assistant to aid radiologists for multimodal breast image classification	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85101049160&doi=10.1016/j.ijhcs.2021.102607&partnerID=40&md5=04058b0faf5cf54360bb0bd06d477a31
69	A study on CNN image classification of EEG signals represented in 2D and 3D	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85101703822&doi=10.1088/1741-2552/abda0c&partnerID=40&md5=cc9badd65410ccc4ba1779974039cf5f
70	Prediction of finger kinematics from discharge timings of motor units: Implications for intuitive control of myoelectric prostheses	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85062846097&doi=10.1088/1741-2552/aaf4c3&partnerID=40&md5=6954bf640ef76cc5802649b3bea38ec4
71	An Interpretable Performance Metric for Auditory Attention Decoding Algorithms in a Context of Neuro-Steered Gain Control	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85078333702&doi=10.1109/TNSRE.2019.2952724&partnerID=40&md5=bdd14e7d8effa90154d42258fe1291de
72	Facial expression recognition based on multi-dataset neural network	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85085131293&doi=10.13164/re.2020.0259&partnerID=40&md5=3241809a4e8495a1f680f53e30d1da74
73	Creamino: A Cost-Effective, Open-Source EEG-Based BCI System	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85051039724&doi=10.1109/TBME.2018.2863198&partnerID=40&md5=00c2e98acf5051f0426da11b3be81955
74	Wearable on-device deep learning system for hand gesture recognition based on FPGA accelerator	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85098009293&doi=10.3934/MBE.2021007&partnerID=40&md5=887cf72e0c05e6b354b837227fe350a4
75	Effectiveness of serious games for leap motion on the functionality of the upper limb in Parkinson's disease: A feasibility study	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85046040422&doi=10.1155/2018/7148427&partnerID=40&md5=83a82f887edfab21fc43147fb930102b

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Appendix A. Continued.

No.	Title	Link
76	Learning facial expressions with 3D mesh convolutional neural network	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85057576901&doi=10.1145/3200572&partnerID=40&md5=71e1c77f0d3938a58a8a175f01015566
77	Effects of an integrated neurofeedback system with dry electrodes: EEG acquisition and cognition assessment	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85054889617&doi=10.3390/s18103396&partnerID=40&md5=4113e44edf85e4a551f3415ee85aeca5
78	Factors that affect error potentials during a grasping task: Toward a hybrid natural movement decoding BCI	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85049861347&doi=10.1088/1741-2552/aac1a1&partnerID=40&md5=c2c415521d618fd7c7eb98e04332f54f
79	Brain-machine interfaces for controlling lower-limb powered robotic systems	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85042589463&doi=10.1088/1741-2552/aaa8c0&partnerID=40&md5=97069713d9736ed78b4bc38976e0f344
80	A Human-Humanoid Interaction Through the Use of BCI for Locked-In ALS Patients Using Neuro-Biological Feedback Fusion	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85028799937&doi=10.1109/TNSRE.2017.2728140&partnerID=40&md5=c7da2d3a3713365611bf70dc86beb2a9
81	A facial expression controlled wheelchair for people with disabilities	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85052210734&doi=10.1016/j.cmpb.2018.08.013&partnerID=40&md5=bbbaf42ee1402a2670fb2022e7f5edde
82	A graphical model for online auditory scene modulation using EEG evidence for attention	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85021821336&doi=10.1109/TNSRE.2017.2712419&partnerID=40&md5=c2121b74000a290ee6e68865c64ef830
83	Application of EEG and interactive evolutionary design method in cultural and creative product design	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85060808154&doi=10.1155/2019/1860921&partnerID=40&md5=0b204340245f3f049bef361a962fce92
84	A Virtual Reality Visualization Tool for Neuron Tracing	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85028695786&doi=10.1109/TVCG.2017.2744079&partnerID=40&md5=622414fce6aa7ec5e78191fb884e21ab
85	Closed-loop cortical control of virtual reach and posture using Cartesian and joint velocity commands	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85062836224&doi=10.1088/1741-2552/aaf606&partnerID=40&md5=e42d7ed7b3eb5805d34a340a0b60dce5
86	Assessment and communication for people with disorders of consciousness	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85027074196&doi=10.3791/53639&partnerID=40&md5=070457bc50d7f241970c3188ffc8c36d
87	A Robotic Coach Architecture for Elder Care (ROCARE) Based on Multi-User Engagement Models	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85029203778&doi=10.1109/TNSRE.2016.2608791&partnerID=40&md5=6cd30f9b9e671a2a4a7a7289ff9535b5
88	Navigation-synchronized multimodal control wheelchair from brain to alternative assistive technologies for persons with severe disabilities	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85012863710&doi=10.1007/s11571-017-9424-6&partnerID=40&md5=fe307db2b0688f68f89fce2425d4991a
89	Design and evaluation of action observation and motor imagery based BCIs using Near-Infrared Spectroscopy	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85006356576&doi=10.1016/j.measurement.2016.12.001&partnerID=40&md5=70dbe0bcab82cf54e68fad579f8d7152
90	Toward an open-ended BCI: A user-centered coadaptive design	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85029326201&doi=10.1162/NECO_a_01001&partnerID=40&md5=51be5e96d657919a0045b2ce8623aadb
91	New generation emerging technologies for neurorehabilitation and motor assistance	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85030787748&partnerID=40&md5=69af354516715a34d63fc1d028a64caf
92	Recasting brain-machine interface design from a physical control system perspective	https://www.scopus.com/inward/record.uri?eid=2-s2.0-84941939554&doi=10.1007/s10827-015-0566-4&partnerID=40&md5=de5b993bde91f0e3164113dcc9c325c4
93	A proposal for the development of adaptive spoken interfaces to access the Web	https://www.scopus.com/inward/record.uri?eid=2-s2.0-84930272093&doi=10.1016/j.neucom.2014.09.087&partnerID=40&md5=12f599e26d99d05b6effec8367c246e6
94	Initial test of a T9-like P300-based speller by an ALS patient	https://www.scopus.com/inward/record.uri?eid=2-s2.0-84937509604&doi=10.1088/1741-2560/12/4/046023&partnerID=40&md5=dc00618bd3232ac4cb18c7d35e951995
95	Aesthetic preference recognition of 3D shapes using EEG	https://www.scopus.com/inward/record.uri?eid=2-s2.0-84946107000&doi=10.1007/s11571-015-9363-z&partnerID=40&md5=03e4ad61cc5260392728eed05f6be545
96	Enabling Low-Power, Multi-Modal Neural Interfaces Through a Common, Low-Bandwidth Feature Space	https://www.scopus.com/inward/record.uri?eid=2-s2.0-84969884851&doi=10.1109/TNSRE.2015.2501752&partnerID=40&md5=ff5364583690496aac479b4363d46d05
97	Robust Brain-Machine Interface Design Using Optimal Feedback Control Modeling and Adaptive Point Process Filtering	https://www.scopus.com/inward/record.uri?eid=2-s2.0-84964781185&doi=10.1371/journal.pcbi.1004730&partnerID=40&md5=307a30c40e10b795779239f1e220a72b
98	A high-performance keyboard neural prosthesis enabled by task optimization	https://www.scopus.com/inward/record.uri?eid=2-s2.0-84919935236&doi=10.1109/TBME.2014.2354697&partnerID=40&md5=d76a434908170af87e2d346b1c5b8aed
99	Independent home use of Brain Painting improves quality of life of two artists in the locked-in state diagnosed with amyotrophic lateral sclerosis	https://www.scopus.com/inward/record.uri?eid=2-s2.0-84963540685&doi=10.1080/2326263X.2015.1100048&partnerID=40&md5=658bce68c87f77adc79367f5edae04a7
100	Towards an assistive peripheral visual prosthesis for long-term treatment of retinitis pigmentosa: Evaluating mobility performance in immersive simulations	https://www.scopus.com/inward/record.uri?eid=2-s2.0-84930195991&doi=10.1088/1741-2560/12/3/036001&partnerID=40&md5=c43ea605b286ffc21ef1cb5367887ded
101	Using a noninvasive decoding method to classify rhythmic movement imaginations of the arm in two planes	https://www.scopus.com/inward/record.uri?eid=2-s2.0-84923918117&doi=10.1109/TBME.2014.2377023&partnerID=40&md5=7262584f19cf38eb32f73537d2634a46
102	Designing implicit interfaces for physiological computing: Guidelines and lessons learned using fNIRS	https://www.scopus.com/inward/record.uri?eid=2-s2.0-84921448587&doi=10.1145/2687926&partnerID=40&md5=b4862d226ed6397e15877ae90e6a6d8f
103	Ten-dimensional anthropomorphic arm control in a human brain-machine interface: Difficulties, solutions, and limitations	https://www.scopus.com/inward/record.uri?eid=2-s2.0-84921809727&doi=10.1088/1741-2560/12/1/016011&partnerID=40&md5=2be24a45961b1d5183f86d67ca781732
104	A novel hybrid BCI speller based on the incorporation of SSVEP into the P300 paradigm	https://www.scopus.com/inward/record.uri?eid=2-s2.0-84875853575&doi=10.1088/1741-2560/10/2/026012&partnerID=40&md5=8d278bf58b7ac9531dbbc5bc8bb90731
105	Long term, stable brain machine interface performance using local field potentials and multiunit spikes	https://www.scopus.com/inward/record.uri?eid=2-s2.0-84885463082&doi=10.1088/1741-2560/10/5/056005&partnerID=40&md5=7d06592b0836cba8bbd8c8a90794d113
106	Simultaneous design of FIR filter banks and spatial patterns for EEG signal classification	https://www.scopus.com/inward/record.uri?eid=2-s2.0-84875517106&doi=10.1109/TBME.2012.2215960&partnerID=40&md5=221051566de65f55729b5a844e2b9226
107	Evaluating virtual reality mood induction procedures with portable EEG devices	https://www.scopus.com/inward/record.uri?eid=2-s2.0-84894257724&partnerID=40&md5=9205f1b1334084e65cdb9c7cbca425d1
108	Design of virtual keyboard using blink control method for the severely disabled	https://www.scopus.com/inward/record.uri?eid=2-s2.0-84880038955&doi=10.1016/j.cmpb.2013.04.012&partnerID=40&md5=d8dfaf5bdd509a70ab6629adde4b3d5e

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Appendix A. Continued.

No.	Title	Link
109	Interfacing with the computational brain	https://www.scopus.com/inward/record.uri?eid=2-s2.0-80054060411&doi=10.1109/TNSRE.2011.2158586&partnerID=40&md5=2f4625cb7625d935ab3a5bf4b8b4a673
110	Development of an SSVEP-based BCI spelling system adopting a QWERTY-style LED keyboard	https://www.scopus.com/inward/record.uri?eid=2-s2.0-84861333266&doi=10.1016/j.jneumeth.2012.04.011&partnerID=40&md5=7944728a4c4a3653426cf933e2c69a30
111	Assessment of executive functions in patients with obsessive compulsive disorder by neuro VR	https://www.scopus.com/inward/record.uri?eid=2-s2.0-84872041905&partnerID=40&md5=909c955c69748c7c934ebcf2bd413bfa
112	Real time emotion aware applications: A case study employing emotion evocative pictures and neuro-physiological sensing enhanced by Graphic Processor Units	https://www.scopus.com/inward/record.uri?eid=2-s2.0-84861199627&doi=10.1016/j.cmpb.2012.03.008&partnerID=40&md5=83e3aabae8a23c3bceef2dfce46f4795
113	Connectivity analysis as a novel approach to motor decoding for prosthesis control	https://www.scopus.com/inward/record.uri?eid=2-s2.0-84859011339&doi=10.1109/TNSRE.2011.2175309&partnerID=40&md5=f35d27624f1f33ad911182772e4621da
114	My thoughts through a robot's eyes: An augmented reality-brain-machine interface	https://www.scopus.com/inward/record.uri?eid=2-s2.0-74249106360&doi=10.1016/j.neures.2009.10.006&partnerID=40&md5=ca08ff54106c3f0a4552c02293a71310
115	Wearable electroencephalography	https://www.scopus.com/inward/record.uri?eid=2-s2.0-77952285184&doi=10.1109/MEMB.2010.936545&partnerID=40&md5=0a2b56c98807d43477c00e27eddc1341
116	A new concept of a unified parameter management, experiment control, and data analysis in fMRI: Application to real-time fMRI at 3 T and 7 T	https://www.scopus.com/inward/record.uri?eid=2-s2.0-52049088516&doi=10.1016/j.jneumeth.2008.08.013&partnerID=40&md5=df41af1dc7dfd2ee6458c2fa15761ab5
117	Control of an electrical prosthesis with an SSVEP-based BCI	https://www.scopus.com/inward/record.uri?eid=2-s2.0-37349003164&doi=10.1109/TBME.2007.897815&partnerID=40&md5=135c3a65b39e2abda92be88b969bf128
118	Real-time functional magnetic resonance imaging: methods and applications	https://www.scopus.com/inward/record.uri?eid=2-s2.0-33947140202&doi=10.1016/j.mri.2007.02.007&partnerID=40&md5=b7988bdc58dbe92e6eb7660fef9c05d0
119	Automatic user customization for improving the performance of a self-paced brain interface system	https://www.scopus.com/inward/record.uri?eid=2-s2.0-34447340116&doi=10.1007/s11517-006-0125-2&partnerID=40&md5=6925166464c3a3ed82220908d5d4f3cd
120	Prosthetic interfaces with the visual system: Biological issues	https://www.scopus.com/inward/record.uri?eid=2-s2.0-34247261632&doi=10.1088/1741-2560/4/2/R02&partnerID=40&md5=4aec1f68958319cb4decdb5760016edc
121	A virtual reality environment for designing and fitting neural prosthetic limbs	https://www.scopus.com/inward/record.uri?eid=2-s2.0-34248571894&doi=10.1109/TNSRE.2007.891369&partnerID=40&md5=02a797095c2beafb00343a1e8663335d
122	A complex-valued spiking machine	https://www.scopus.com/inward/record.uri?eid=2-s2.0-33646186926&doi=10.1007/3-540-44989-2_115&partnerID=40&md5=f477920a824f0e0aa71f7daadb6b4d79