Kullanıcı Deneyimi Değerlendirme Araştırmalarında Elektroensefalografi Kullanımının İncelenmesi

Literatür Makalesi/Review Article

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Özet— Günümüzde, bilgi sistemlerini değerlendirmek için İnsan-Bilgisayar Etkileşimi (İBE) alanında Kullanıcı Deneyimi (KD) değerlendirmesine artan bir ilgi vardır. Aynı zamanda, nörobilimsel ölçüm araçlarının KD çalışmalarında kullanımı sürekli artmaktadır. Bu çalışma kapsamında, 2010-2020 yılları arasında yayınlanan KD değerlendirme çalışmalarında nörobilimsel ölçüm araçlarından biri olan elektroensefalografi (EEG) kullanımına ilişkin sistematik bir haritalama yapılmıştır. Web of Science (WoS) veritabanı, Science Direct (Elsevier), IEEE Xplore Kütüphanesi, ACM Dijital Kütüphanesi'nden çalışma kapsamına uygun olarak belirlenip erişilebilen 89 çalışma incelenmiştir. İnceleme sonucunda bu çalışmalardaki genel eğilimlerin belirlenmesi ve KD değerlendirmesinde EEG kullanımının diğer KD değerlendirme yöntemleri ile beraber kullanımının mevcut durumunun ortaya çıkarılması hedeflenmektedir. Çalışma sonuçlarına göre KD değerlendirmesi için EEG ile toplanan veri türlerinin genellikle duygu ve dikkat olduğu, en yaygın olarak verilerin kullanım sırasında tek seferlik toplandığı tespit edilmiştir. EEG verilerinin analizine yönelik olarak yaygın kullanılan öznitelik çıkarma yönteminin destek vektör makinesi ve en sık kullanılan sınıflandırma yönteminin de olaya ilişkin potansiyel olduğu tespit edilmiştir.

Anahtar Kelimeler— kullanıcı deneyimi, kullanıcı deneyimi değerlendirmesi, eeg, duygu, dikkat

Review of the Use of Electroencephalography in User Experience Evaluation Research

Abstract— Nowadays, there is a growing interest in User Experience (UX) evaluation in Human-Computer Interaction (HCI) field to evaluate information systems. Meanwhile, the application of neuroscientific measurement tools in user experience studies is constantly increasing. Within the scope of this study, a systematic mapping is conducted on the use of electroencephalography (EEG), one of the neuroscientific measurement tools, in UX evaluation studies published between 2010-2020. 89 studies are gathered from Web of Science (WoS) database, Science Direct (Elsevier), IEEE Xplore Library, ACM Digital Library, according to the scope of the study, are examined. The aim of this study is to reveal the trends and the use of EEG with the other UX evaluation methods in UX evaluation research. According to the results of the study, the types of data collected by EEG for UX evaluation are emotion and attention, data is generally collected as single episodic experience. In addition, the support vector machine is used for the classification and event-related potential is used for the feature extraction of the EEG data.

Keywords— user experience, user experience evaluation, eeg, emotion, attention

1. INTRODUCTION

User experience (UX) which is once considered as a "buzzword in Human Computer Interaction (HCI) field" [1] has become an emerging research area since the midst of 2000. It becomes an umbrella term that denotes the design and the use of user interfaces and often is used as synonym for usability [2]. However, in contrast to usability

which is more focused on task-orientation, UX focuses also on hedonic qualities of use such as aesthetics, fun, pleasure, and positive emotions [1]. In addition, it focuses all these aspects of users before, during and after use of the system [3]. Ensuring UX in interactive systems has become essential for companies' competitiveness in the market [4] since satisfied customers of the product can recommend it [5]. It is seen that traditional usability evaluation methods or approaches are used for the UX evaluation in the literature [6,7]. Since the focus of UX is different than usability, the evaluation methods used for usability are not actually sufficient because they are based mostly on task efficiency and effectiveness. Although there is a satisfaction component in usability, UX's emphasis on users' emotions is much more.

Currently used evaluation methods for satisfaction such as questionnaires or user interviews are mostly based on users' self- reports. These methods generally include the subjective evaluations of the users about their experiences after the interaction. The results are based on the recall of the users and is limited by the users' memory [8]. Methods like think aloud can also be used for the experience of during use but this method has the disadvantage of interruption to the experience of user [9]. In addition, participants may be exposed to social pressure [10]. Therefore, it can be concluded that new approaches for evaluation of UX are needed to assess how the users feel [11]. On the other hand, in addition to these subjective methods used for UX evaluation, it is recommended in the literature [12,13] to use methods such as EEG (electroencephalography) since it has the potential to obtain instant information from brain signals objectively. EEG is one of the most convenient neuroimaging techniques that can be used to measure various UX concepts such as workload, attention, vigilance, fatigue, error recognition, emotions, engagement, flow, and immersion [14]. Thus, EEG can overcome the drawbacks of many UX evaluation methods.

In this study, a systematic mapping is conducted, to elicit the current state of the use of EEG in UX research in parallel with the other UX evaluation methods. Although there are several systematic mapping or systematic review studies on user experience evaluation, these mainly either cover UX evaluation methods in general or their examination periods are until the midst of 2010s. In addition, no systematic mapping has been performed on the use of EEG in user experience studies previously. Within the scope of the study, it is aimed to carry out a systematic mapping to cover both subjects. In line with this goal, it is aimed to give a general idea about user experience and EEG research areas. The main contribution of this study is the analysis and summary of how UX evaluation has been conducted by using EEG from 2010 to 2020.

1.1. Definition of User Experience

There are several definitions of UX in the literature but there is not any one common definition for the term [15-17]. The term is first coined in HCI literature by Donald Norman at Apple for user interface research [18]. One of the widely used definition of UX is given by ISO standard 9241-210 [19] as "a person's perceptions and responses that result from the use or anticipated use of a product, system or service". This definition focuses on the user's interaction with the system. On the other hand, Hassenzahl [20] defines UX as "a momentary, primarily evaluative feeling while interacting with a product or service". His definition focuses on hedonic aspects of use such as fun and pleasure rather than the task execution. Similarly, Schulze and Krömker's definition [21] emphasizes on emotions experienced in a specific context during and after use. All of these definitions are in line with the subjectivity of UX [16] and one of UX's key dimensions is revealed as emotions or feelings [11,22]. In addition, these definitions either covers its pragmatic aspects which are the utility and usability of the product or its hedonic aspects [23].

1.2. Usability vs User Experience

Usability and UX is considered to be very related to each other [3], [24]. Bevan [25] summarizes several views for this relation. Firstly, UX is considered to be an extension of usability since one of the dimensions of usability is satisfaction and it is similar to some hedonic attributes such as pleasure. On the other hand, it is considered as distinct because usability has a focus on user performance while UX focuses on users' emotions. However, a minimum level of usability is required for establishing a good user experience [26].

The aims of usability can be listed as to ensure effectiveness, efficiency, and satisfaction by providing easy to use and learnable products [27]. On the other hand, UX aims understanding the users with their needs and their emotions [25].

1.3. User Experience Evaluation and Methods

For the evaluation of the UX, it is generally seen that traditional usability evaluation methods, in which efficiency and effectiveness of the products are checked, are implemented [2]. However, UX evaluation is different and more difficult than usability evaluation since experience is a personal aspect [5,7]. While objective measures such as task completion time or number of errors can be used for the usability evaluation, these measures are not sufficient to measure UX. In UX there is a need to know how the users feel [3]. In addition to user's emotions, their other subjective aspects such as motivations, expectations, intellectual properties, or culture would affect the experience. Desmet [28] offered observations or self-reports to gather user's emotional responses. There are several assessment methods specifically developed for UX such as AttrakDiff [10]. However, users may find it difficult to express their feelings when asked directly and their responses can be affected by social pressure [29] or by their memory limitations [9].

Another important difference of UX evaluation is that it should consider all of the above-mentioned aspects in more than one episode. The evaluation is needed to cover overall UX such that before, during and just after the interaction as well as long term interaction with the product [7,24]. In addition, the real time evaluation is important because when data is collected after the experiment than there is a possibility that relevant information can be lost [5]. Physiology measurement methods including physiological sensors (GSR-galvanic skin response, ECG-electrocardiography, EMG - electromyography or HR heart rate) and neuroimaging (fMRI –functional magnetic resonance imaging, fNIRS – functional near-infrared spectroscopy, MEG – magnetoencephalography and EEG) can be considered as alternatives to existing methods to overcome these drawbacks [14].

Neuroimaging methods and applications have been widely used in HCI field under the scope of brain computer interfaces (BCI). Although there are counterarguments to its appropriateness [30], EEG has often been considered as a viable method since it is relatively cheap, portable, and noninvasive technique [14]. It is one of the methods that is used to monitor electrical activities of brain occurred in response to any stimuli. EEG can play an important role in revealing emotions directly from the brain [31,32]. Other constructs that can be revealed by EEG can be listed as workload, attention, vigilance and fatigue, error recognition and engagement which are all considered as UX related concepts [14].

1.4. Related Works

In the literature there are several studies that focus on UX evaluation methods, and these are generally conducted around the beginning of 2010s. These studies are grouped in two categories in this study as generic reviews and systematic reviews. Generic reviews are narrative/traditional literature reviews that do not mentioned any specific study selection mechanism whereas systematic review category follows a specific study selection mechanism like systematic literature reviews [33,34] or systematic mapping studies [35].

One of the examples of studies that can be considered in the first group is Vermeeren et al.'s [3] study that is conducted to collect UX evaluation methods from various sources including the literature, workshops and special interest groups' sessions and online surveys and 98 UX evaluation methods are determined as a result. In addition, the study reports several needs of UX evaluation methods which can be listed as the need of methods for the early phases of product development, methods for social and collaborative evaluation and more practical and good quality methods [3]. Scapin et al. [17], conducts a general review considering the underlying UX theory and their study reveals the origins of UX by explaining its scope and various definitions. They also investigate the UX evaluation methods and analyze these methods with respect to dimensions of UX. Rajeshkumar et al. [24] present a taxonomy for UX evaluation methods including parameters of research/study type, type of research, type of users/evaluators, development phase, time restriction factor and the period of experience based on the previous literature.

Some researchers focus on a specific category of UX evaluation methods. For instance, Frey et al. [9] focus on integrating neuroimaging techniques to UX evaluation as a more objective approach and report that EEG offered the best approach due to its practical use and cost, and many of the UX constructs such as workload, attention, fatigue, error recognition, emotions or engagement can be measured effectively. Similarly, Balters and Steinert [36] also focus on physiological measurement and explain various emotion-related physiological responses and their measurement methods which emphasize the need to dynamically integrate emotional states of users for understanding the user experience. In his thesis, Taffese [37] aims to provide an answer to the problem of how EEG and electromyography (EMG) tools can be used in user experience research and revelaed that EEG and EMG tools have a big potential in evaluating and improving user experience of products.

One of the studies that are considered in the second category is Bargas-Avila and Hornbaek's [2] study in which a review of 51 publications between 2005 and 2009 is conducted to investigate the ways how empirical research in UX is conducted and they report that studies mostly assess UX aspects of emotions, enjoyment and aesthetics and used methods known as traditional usability evaluation methods. Maia and Furtado's review [5] reveals those psychophysiological measures, which have the potential of real-time evaluation, are not yet widely applied for UX evaluation, and they consider momentary user experience. Rivero and Conte [7] investigate 227 papers that includes UX evaluation technologies by implementing a systematic mapping approach and the results of their study can be listed as the need for methods based on more qualitative data which would enable understanding the experiences of users and methods that would gather data at a wider time spectrum. Pettersson et al.'s [38] review shows that studies still implement pure usability evaluation methods however there is an increase in field studies rather than lab studies and triangulation of methods is begun to be applied. A more recent review [39] focuses on neurological and physiological measures of information systems and reports that there is an increasing interest on neurological and/or physiological measure for UX evaluation.

The summary of these review studies is presented in Table 1. As can be seen few of these reviews [14,37] are focused on UX evaluation that also implements the use of EEG together with other methods, but they are also generic reviews.

Table 1. The summary of the previous review studies

Reference Number	Number of articles examined in the study	Examination method	Topics evaluated	Year range covered by the study
[2]	51	Systematic Literature Review	The study investigates what kinds of products are used, which dimensions of experience are assessed and which methodologies are used in UX research.	2005-2009
[3]		Generic review	Study collects UX evaluation methods from various sources including the literature, workshops and special interest groups' sessions and online surveys and compiles UX evaluation methods	-
[5]	25	Systematic Literature Review	The focus of the study is how UX evaluation is conducted including issues such as the moment of evaluation, techniques used for evaluation, UX dimensions considered and the objectives of the evaluation.	2010-2015
[7]	227	Systematic Mapping	The main research question is what technologies are used for UX evaluations including methods, techniques, tools and other issues.	2010-2015
[14]	-	Generic review	The study examines how adding neuroimaging techniques can respond to the need of UX evaluation such as providing real-time and objective measures.	-
[17]	-	Generic review	The study investigates the UX evaluation methods and analyzes them with respect to dimensions of UX.	-
[24]	-	Generic review	The study categorizes UX evaluation methods according to research/study type , development phase, type of research, type of users/evaluators, time restriction factor and the period of experience.	-
[36]	-	Generic review	The study focuses on various emotion-related physiological responses and their measurement methods.	-
[37]	-	Generic review	The study reviews the implementation of EEG and electromyography (EMG) as an UX evaluation technique.	-
[38]	100	Systematic Literature Review	The study focuses on the UX evaluation techniques with a specific focus on whether triangulation is applied and how.	2010-2016
[39]	27	Systematic Literature Review	The study focuses neurological and physiological measures to evaluate the usability and user-experience (UX) of information systems	2003- 2019

2. METHOD

In this study, a systematic mapping is carried out to examine the use of EEG, one of the neuroimaging methods, in user experience research. Systematic mapping [40] is a kind of evidence-based software engineering method [34] that enables to reveal the general status of the subject and determine research trends by bringing together the findings of previous research studies. These studies are also called as scoping studies [35]. The search process adopted is defined by the determined topic area. Finally, its results report set of papers related to a topic area and counts of the number of papers in various categories [41]. The research steps proposed by Kitchenham et al. [33] is adopted and used based on the scope of this study. The study is designed as a three-phased study. These phases are planning, investigation, and reporting as can be seen in Figure 1. In the planning phase, research questions are determined. Next the search key words and search databases to be used and the inclusion and exclusion criteria for the studies to be included in the study are determined to define the boundaries of the study. In addition, a systematic mapping

protocol is prepared to be used in the investigation in relation to the research questions. In the investigation phase, the searches are conducted in the databases with the keywords determined and the publications are collected with respect to the selection criteria. Before examining all publications in this phase, to evaluate the adequacy of the systematic mapping protocol, a pilot study is conducted by randomly selecting 5 publications by the researchers. After the pilot review, the examination of all publications is completed by the researchers. In the final phase the findings are analyzed and reported.

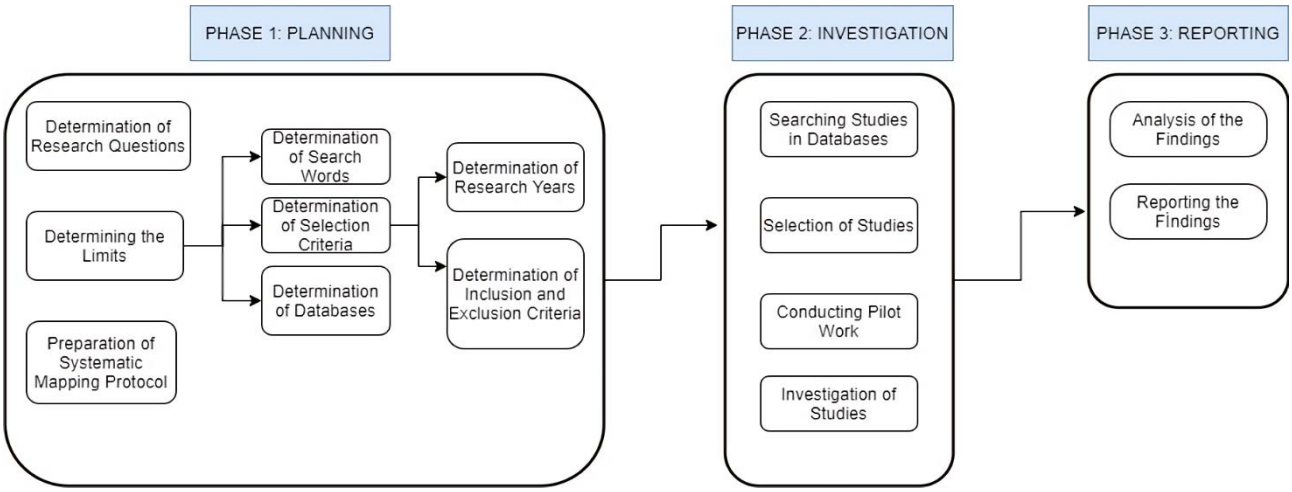

Figure 1. The three phases of systematic mapping procedure

2.1. Research Questions

Research questions of the study are grouped into three categories. These are general information, issues regarding UX evaluation and issues regarding the use of EEG. The details of the research questions and sub-questions are as follows.

General information of the studies
1. What are the publication types and publication years of the studies?
2. What are the methods of the studies evaluated?
3. What are the domains of assessment in the studies?
4. What are the applications used in the studies?

UX evaluation issues
1. What are the user experience evaluation methods used with EEG?
1.1. What are the empirical evaluation methods used with EEG?
1.2. What are the analytical evaluation methods used with EEG?
2. What is the scope of the User Experience assessment?

EEG measurement related issues
1. What type of data is collected by EEG for user experience evaluation purposes?
2. What are the emotions detected by the EEG?
3.What re the technical characteristics of the devices used to collect EEG data (Brand, number of electrodes)
4. What are the feature extraction methods and classification methods used in the analysis of EEG data?

2.2. Systematic Mapping Protocol

Articles are examined in order to reveal current trends in the use of EEG, one of the neuroimaging techniques, that can be used in user experience evaluation research. The results can provide guidance to other researchers who consider using this new technique in their UX research. Thus, they can use this as a starting point efficiently when deciding on to use which EEG device, how and when. For instance, identifying domain of the studies, or the type of applications it is used will be beneficial in terms of seeing where EEG provides more effective UX results. In addition, since it is recommended to be used with other UX evaluation methods as a complementary [13,42,43] it is important to know which methods it could be used together to provide rich data. In addition, there are various EEG devices in the market with a wide range of costs and it is important for researchers to know the characteristics of the alternatives during research design in order to conduct a cost-effective study. Finally, knowing the general trends in the methods and success rates used for EEG data processing will facilitate the work of new researchers. Therefore, a systematic mapping protocol is created according to the research questions determined. The protocol consists of 10 main sections. The sub-items used for mapping are adapted from previous research and are described in detail as follows.

1. Article general record: This section involves information related to the name, the year, publication type (conference or a journal), publication venue (name of the journal or conference), keywords defined for the article.

2. Methods of the articles: In this section, the methods of the evaluation studies is examined. Two methods have been used, namely the experimental research and the literature review which are determined in a previous systematic mapping study [7]. The articles are considered as an experimental research when they include UX evaluation by using a systematic method. The articles are considered as a literature review study when they report previous studies results on a particular subject.

3. Domain of the articles: The domains of the investigated studies are examined. The domains are designated as entertainment, information systems, health, education, and others.

4. Type of applications: In this section, the applications preferred for evaluation purposes in studies involving the use of EEG in user experience research are examined. The target applications in these studies are listed as computer games, web applications, mobile applications, augmented reality (AR) - virtual reality (VR) applications, custom software, marketing products and other software.

5. UX evaluation methods: Subcategories of user experience evaluation methods have been adapted from Te'eni et al. [44]''s studies. They examine the user experience evaluation methods in two parts, empirical and analytical. Empirical evaluation methods include laboratory experiments, observations, questionnaires and interviews whereas analytical evaluation methods are determined as cognitive walkthrough, pluralistic walkthrough, model-based evaluation, guideline based evaluations and heuristics based evaluations.

6. Assessment period: In this section, when the UX evaluations are conducted is examined. 4 periods are determined as single episodic experience, after use, cumulative episodic experience and before [7]. When UX evaluation is conducted before using the software, the user's expectations of the system can be revealed. When UX evaluation is only conducted during use of the system than this one is called as single episodic experience. When data is gathered after an episodic experience than user's reflections on the application is gathered. Moreover, when UX evaluation is conducted over time including collecting UX data before, during and after use, then this is called as cumulative episodic experience.

7. EEG data type: In this section, the types of data collected by EEG for evaluating user experience are examined. These data types are identified as emotion, attention, concentration / meditation, mental workload, and others.

8. Types of emotions: The emotions detected are analyzed in detail. Emotions are determined from both Russell's [45] dimensional emotion model and Ekman's [46] basic emotion model.

9. EEG data collection devices and their technical details: The devices used for EEG data collection as well as their technical properties are investigated. The name of the devices and the number of electrodes are noted.

10. EEG data processing methods: This section includes feature extraction and classification methods used in studies to interpret brain activity. The methods listed by Al Nafjan et al. [47] are adapted and used. Feature extraction methods included are listed as event-related potential (ERP), event-related synchronization/desynchronization, power spectral density (PSD), steady-state visually evoked potentials and Frontal EEG asymmetry. In addition, Support vector machine (SVM), Linear discriminant analysis (LDA), Deep Learning Algorithms, Linear Regression (LR), K-Nearest neighbors (KNN), Random forest (RF), Bayesian classifier, Thresholding are listed for the classification methods. Studies are mapped using above protocol by the authors independently first. Afterwards they come together to consolidate their results by reaching a consensus. Studies are assigned at least one category in each category, but they are also assigned more than one category whenever appropriate. Therefore, there is variance in the total number of articles mapped in each category.

2.3. Determination of the Boundaries of the Study

The systematic mapping covers the studies published between 2010-2020. For this purpose, the search process is first conducted in Web of Science (WoS) then it is extended to other databases respectively Science Direct (Elsevier), IEEE Xplore and ACM databases to obtain a comprehensive bibliography. The keywords "Electroencephalography", User Experience" and "User experience evaluation" are used in determining the studies. The search is also conducted with the use of their abbreviations of "EEG", "UX" and "UX evaluation" alternatively in order not to miss related studies. The final search strings are created using Boolean operators in each database. The articles are included with a two-step process. Only conference proceedings and journal articles are included in the study. In the first step duplicated articles gathered from different databases, articles written in languages different than in English are excluded. In the second step the articles are quickly investigated through their abstracts and the articles that do not mention about the use of EEG as a UX evaluation methodology are excluded. Table 2 presents the number of articles returned from each database as a result of the search string and the remaining number of articles after the first and second rounds. Total of 89 articles are included to be mapped as a result. A list of these studies is available on Google Drive[1]. Studies are identified by the ArticleID specified in the list.

3. RESULTS

Within the scope of this study, a systematic mapping of studies published in scientific databases about the use of

[1] https://drive.google.com/file/d/18JmOIVWOD2-dy1SW96hnL27uMKghn79O/view?usp=sharing

EEG in user experience research is carried out. Research studies conducted in a 11-year period are examined by using the research questions specified in section 4.1. The findings are reported under the sub-headings of general information, UX issues and EEG related issues in this section in accordance with the research questions.

Table 2. The number of studies determined based on the search results

Research Databases	Number of articles returned	Number of articles returned after phase 1	Number of articles returned after phase 2
Web of Science	78	75	54
IEEE Xplore	41	20	12
ACM	25	23	17
Science Direct	17	12	6
Total	161	130	89

3.1. General Information

3.1.1. Publication Types and Publication Years of Studies

The distribution of the mapped studies according to their publication type and publication year is presented in Table 3. The number of studies are less at the beginning of 2010s with one or two studies per year. However, at the midst of 2010, they reach higher numbers. This might be due to the widespread use of low-cost EEG devices in recent years. In addition, the number of conference papers (N = 47) is higher than the number of journal publications (N = 42). The reason for this distribution can be based on that, generally in conferences, it can be faster for the studies to turn into publications.

Table 3. Publication types and publication years of studies

Years	Scientific journal article	Conference papers	Total
2010	-	1	1
2011	1	2	3
2012	1	1	2
2013	2	2	4
2014	1	4	5
2015	3	7	10
2016	6	10	16
2017	2	5	7
2018	8	8	16
2019	7	5	12
2020	11	2	13
Total	42	47	89

Then the journals and conferences that frequently published this kind of studies are examined. It is revealed that generally journals that publish on human computer interaction, neuroscience and biomedical informatics and the conferences on the topics of human computer interaction, cognitive information and multimedia topics publish these studies. The names of journals and conferences, that publish the most research on this subject, are presented in the Table 4 and Table 5.

Table 4. Journals with more than one article

Scientific Journal Name	Number of articles
Frontiers in Neuroscience	3
Transactions on Computer-Human Interaction	2
Biomedical Informatics	2
International Journal on Interactive Design and Manufacturing	2
Sensors	2
Transactions on Human-Machine Systems	2

Table 5. Conferences with multiple publications

Conference Name	Number of articles
Conference on Human-Computer Interaction (HCI)	4
Symposium on Human Factors in Computing Systems (IHC)	3
Conference on Cognitive InfoCommunications	2
Conference on Quality of Multimedia Experience (QoMEX)	2

3.1.2. Methods of the Studies

Most of the investigated studies are experimental studies (N=78) in which EEG is used as an evaluation technique for UX research. However, there are several literature review studies (N=11) as well. The distribution can be seen in Figure 2. When the experimental studies are investigated in detail, it is seen that many of them (N=36) are user experience evaluation studies as seen in Figure 3. There are some studies that propose new UX evaluation frameworks (N=25) or some method comparison studies (N= 17).

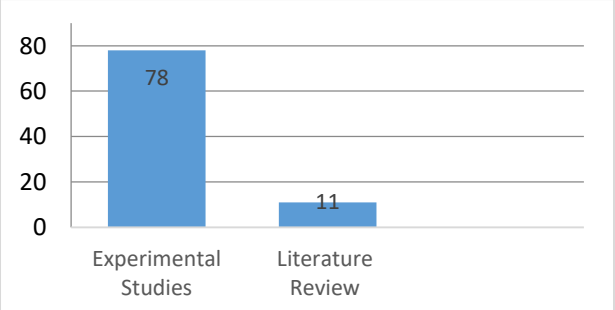

Figure 2. Methods of the studies

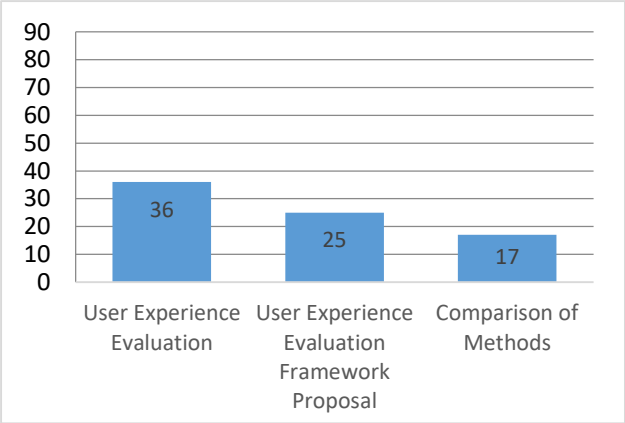

Figure 3. Methods of the experimental studies

3.1.3. Domain of the studies

The domains of the investigated studies have been examined and their domains are designated as entertainment, information system, health, education and others as presented in Figure 4. Many of the studies are conducted in entertainment (N=28). The number of studies classified in the field of information system (N = 22) also draws attention. Other studies are in health (N=12) and education (N=4) domains, respectively. There are several studies categorized in others domain such as automotive and marketing.

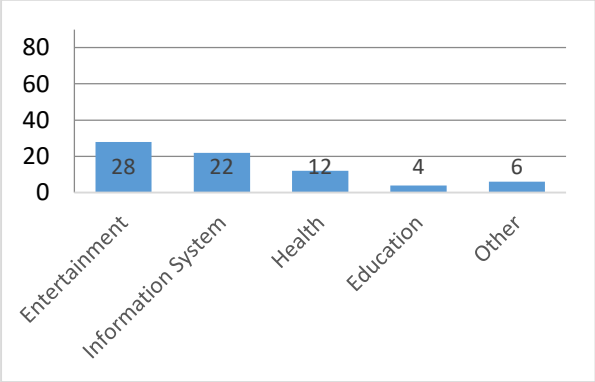

Figure 4. Domain of the studies

3.1.4. Types of applications evaluated in the studies

The UX evaluations are generally conducted on computer games, web applications, mobile applications, augmented reality (AR) – virtual reality (VR) applications, custom software, marketing products and some other software as presented in Figure 5. The frequently evaluated applications are computer games (N=15), custom software (N=13) and web applications (N=12) respectively. Various design products are evaluated in the studies and these are grouped in others category such as brain-controlled wheelchair, semi-autonomous vehicle, mobile phone, or a robotic needle steering.

3.2. UX Issues

3.2.1. UX evaluation methods used with EEG

In the studies, many user experience evaluation methods are used together with EEG as can be seen in Table 6. Empirical evaluation methods (N=175) are implemented more than analytical methods (N=46). Observation (N=50) is the most frequent UX evaluation method among the empirical methods. The other common methods are laboratory experiments (N= 58), survey (N=42) and interviews (N=22). Some studies implement more than one methodology as a triangulation purpose. On the other hand, cognitive walkthrough (N=21) is the most common and the next one is pluralistic walkthrough (N=15) as analytical evaluation methods. Model based evaluation, heuristics or guideline reviews are the least used methods in this category.

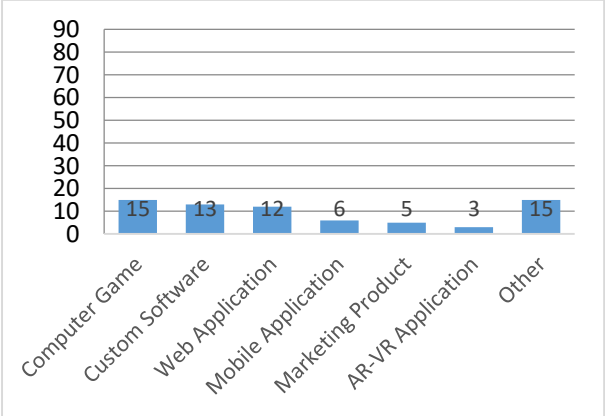

Figure 5. Types of applications evaluated

Table 6. UX evaluation methods used with EEG in studies

UX Evaluation Methods	**Number of implementation**
Empirical Evaluation Methods	175
Laboratory Experiments	58
Survey	42
Interview	22
Observation	53
Analytical Evaluation Methods	46
Cognitive Walkthrough	21
Pluralistic Walkthrough	15
Model Based Evaluation	5
Heuristics	3
Guideline Review	2

3.2.2. Assessment Period of UX evaluation

Assessment period of UX studies are investigated and it is seen that many of them is conducted as a single episodic experience evaluation (N= 59). This number is higher since EEG is used to collect real time data during experience in these investigated studies. On the other hand, few studies (N= 16) consider UX before system use. The details of the assessment period of studies can be seen in Figure 6. There are also some studies that are conducted as after use experience evaluation (N=33) or cumulative episodic experience (N= 22).

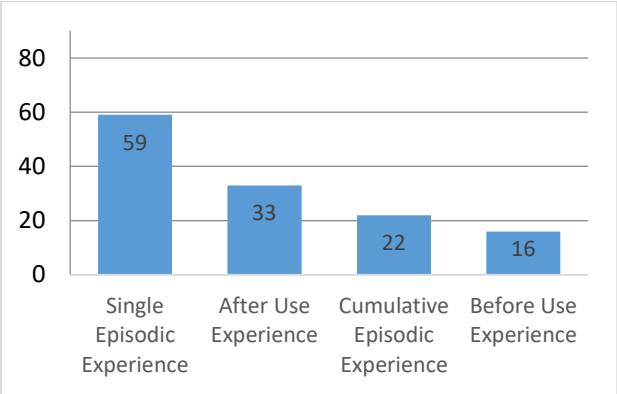

Figure 6. Assessment period of studies

3.3. EEG Related Issues

3.3.1. Type of EEG data to be used with UX evaluation

The studies are investigated to reveal the EEG data types that are collected for UX evaluation. The results are presented in Figure 7. Emotion (N=55) and attention (N=40) are the frequently used EEG data types. In addition, concentration/meditation (N=23) and mental workload (N=11) data are also analyzed in the studies. In the others category (N=8) head movement and mimics data are categorized.

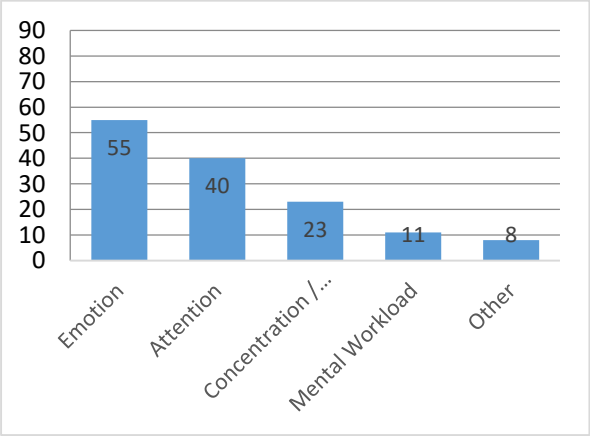

Figure 7. EEG data types collected for UX evaluation in the studies

3.3.2. Emotions recognized

Emotions of arousal (N=25), valence (N=17), happiness (N=10), liking (N=7) and excitement (N=5) are recognized in many of the investigated studies. In addition to these, Figure 8 presents other emotions such as fear, surprise, disgust, anger, sad, neutral, anxiety and dominance as well. As can be understood from these emotion types, various emotion models are referred. In some studies, (N= 18) Russell's [40] dimensional model while in some others Ekman's [44] basic emotions model (N=2) are specified clearly as a used emotion model. However, many of the studies do not clearly mention any emotion model.

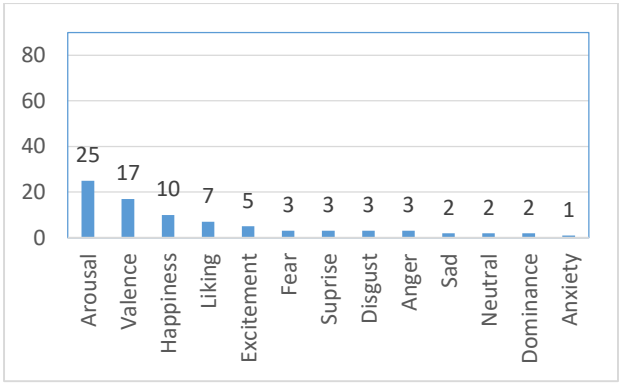

Figure 8. Emotions recognized in the studies

3.3.3. EEG data collection devices and their technical details

The studies are also investigated to reveal which EEG device collect EEG data and it is seen that Emotiv EPOC [48] (N=19) is used in many of the studies. Other second common device is NeuroSky MindWave [49] (N=9). This is mainly due to the low cost of these devices. Table 7 presents the other used devices. Other technical details of the used devices are also investigated such as number of electrodes. It is seen that the frequent number for EEG electrodes are in a wide variety from 5 to 256 as can be seen in Table 8.

Table 7. EEG devices used to collect EEG data in studies

Technical Characteristics of The Device Used	**Number of utilization**
EPOC (Emotiv Inc., San Francisco, CA, USA)	19
NeuroSky MindWave (NeuroSky Inc, San Jose, California, USA)	9
Quik-cap,NuAmps (Compumedics NeuroScan Inc.,El Paso,TX,USA)	4
Active-electrodes (BioSemi Inc., Amsterdam, Netherlands)	3
actiCAP, EASYCAP, BrainCap (Brain Products Inc., Munich, Germany)	2

3.3.4. EEG data processing methods

Feature extraction methods used for EEG data processing in studies are presented in Table 9. The most widely used method for feature extraction method is event related potential (N = 22). Others are event-related synchronization/ desynchronization (N = 15), power spectral density (N = 8), steady-state visually evoked potentials (N = 7), and frontal EEG asymmetry (N = 6) respectively.The commonly used classification method for EEG data is support vector machine (N = 10) as can be seen in Table 10. Linear discriminant analysis (N = 8), linear regression (N = 6), deep learning algorithms (N = 5) and K- nearest neighbors (N = 5) are among the other classification methods. It is observed that some studies conduct comparisons of these methods.

Table 8. Number of electrodes in EEG devices to collect EEG data in studies

Number of electrodes	Number of utilization
16 Channel	8
8 Channel	6
32 Channel	6
5 Channel	5
14 Channel	4
64 Channel	3
256 Channel	2
30 Channel	2
128 Channel	1

Table 9. Feature extraction methods used for EEG data

Feature Extraction Methods	Number of utilization
Event Related Potential	22
Event-Related Synchronization/ Desynchronization	15
Power Spectral Density	8
Steady-State Visually Evoked Potentials	7
Frontal EEG Asymmetry	6

Table 10. Classification methods used for EEG data

Classification Methods	Number of utilization
Support Vector Machine	10
Linear Discriminant Analysis	8
Linear Regression	6
Deep Learning Algorithms	5
K-Nearest Neighbours (KNN)	5
Random Forest	2
Bayesian Classifier	2
Thresholding	1

4. DISCUSSION

According to the results of this systematic mapping, it is revealed that the studies are frequently published in conference proceedings. The general methods of the studies is experimental research that includes user experience evaluation. This result is similar to the results of previous systematic research on general UX evaluation [7]. In addition, many of the studies evaluate computer games' UX and generally are in entertainment domain.

It is seen that empirical evaluation methods are used more than analytical methods in the investigated studies. Observation is the most commonly used method among empirical evaluation methods while cognitive walkthrough is determined to be the most frequently used method among analytical evaluation methods. Considering the assessment period of the studies, it is seen that many studies are conducted as single episodic experience evaluation while few studies also consider before use experience.

Emotion is determined to be the frequent and attention to be the second EEG data type that is collected for UX evaluation in these studies. This shows that user experience studies involve emotion recognition as well. In those emotion-based studies, Russel's [45] emotion model is frequently used. Emotiv EPOC and then Neurosky MindWave EEG devices are used in most of the studies to collect EEG data since their low cost and availability. In addition, it is observed that the number of EEG electrodes ranged from 5 to 256. Support vector machine as a feature extraction and event-related potential as a classification method are frequently used for the processing of EEG data.

Suggestions for open problems and potential ways of working for researchers working in the field of EEG-based UX are also revealed based on this systematic mapping study. These are summarized in Table 11. EEG data recording is mentioned as a challenging issue in EEG-based UX evaluation studies, since collecting data by EEG sensors from users is problematic and many of the EEG devices are uncomfortable for the participants for long-time exposure which might affect the UX evaluation data negatively [S22], [S34], [S35]. In addition, UX evaluation methods have some drawbacks mentioned as being subjective [S2], [S27], [S89] and there is a lack of correlation between the user's psychophysiological measures and the dimensions of the user's emotion [S22]. Using various sensors and various evaluation methods are generally suggested to overcome these issues.

There are several limitations to be mentioned for this study, too. For instance, one of the limitations in such studies is that the reliability of the results. Therefore, an iterative process is followed in the study. The researchers first map the studies independently and then come together to form a consensus on their findings. Thus, researcher bias is tried to be prevented. Another limitation is the possibility that not all publications are included in the study. However, to prevent this, many of the scientific databases in which publications on this subject are indexed are included in the study. It is planned to extend the mapping by including other study types such as book chapters and performing searches in other databases.

The study provides researchers with brief information about the goals of EEG in the context of UX research, the work done and what might happen in the future. It can be

used as a starting point for those who want to delve into detailed studies of EEG in the context of UX. Researchers can continue this study and examine the EEG in more detail. Thus, through further literature review, mapping and SLR studies, further classification, and analysis of EEG in UX research can also be made.

Table 11. The problems and suggestions

	Problems	Suggestions	ArticleID
EEG	Difficulty using EEG and other sensors.	Before the interaction, participants can be taken to the training process with the device.	[S22]
	Emerging human error during EEG data processing.	Automate the processing of data and eliminate the human factor from the measurement process as much as possible.	[S34]
	After long-term use, the EEG device increases user fatigue and causes connection problems.	The process should be evaluated by resting the user and checking the connection.	[S35]
User Experience	Traditional approaches to UX evaluation are often subjective.	To adequately evaluate user experience, both objective and subjective measurements need to be combined.	[S2], [S27], [S89]
	Lack of strong statistical correlation between user's psychophysiological measures and the dimensions of user's emotion.	More experiences are beneficial to further validate some correlations.	[S22]
	Inability of participants to express their emotions during user experience interaction.	Interaction with EEG and other sensors can be supported.	[S22]
EEG and User Experience	Findings from EEG-based user experience are uncontrollable.	Many methods can be used.	[S8], [S22]

5. CONCLUSION

Within the scope of this study, 89 studies published between 2010-2020 are examined through systematic mapping process in order to determine the research trends in studies involving the use of EEG for user experience evaluation. During the research process, Kitchenham et al's [33] proposed review framework is adopted according to the scope of the study. The process consisting of planning, examination and reporting phases is designed. A systematic mapping protocol is created according to the determined research questions and the investigation is carried out according to this protocol. It is believed that the results of this study would guide researchers working on this subject by revealing current trends in EEG use in UX evaluation studies.

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