Incorporating Cognitive Neuroscience Techniques to Enhance User Experience Research Practices

Anna Borawska
University of Szczecin / Institute of Management / Department of Decision Support Methods and Cognitive Neuroscience
Szczecin, Poland *anna.borawska@usz.edu.pl*

Adrianna Mateja
University of Szczecin / Institute of Management / Department of Decision Support Methods and Cognitive Neuroscience
Szczecin, Poland *adrianna.mateja@usz.edu.pl*

Abstract

User Experience (UX) involves every interaction that customers have with products, and it plays a crucial role in determining the success of a product in the market. While there are numerous methods available in literature for assessing UX, they often overlook the emotional aspect of the user's experience. As a result, cognitive neuroscience methods are gaining popularity, but they have certain limitations such as difficulty in collecting neurophysiological data, potential for errors, and lengthy procedures. This article aims to examine the most effective research practices using cognitive neuroscience techniques and develop a standardized procedure for conducting UX research. To achieve this objective, the study conducts a comprehensive review of UX research that employs cognitive neuroscience methods published between 2017 and 2022.

Keywords: user experience research, cognitive neuroscience methods, experimentation and study design

1. Introduction

In today's world, customers demand a superior level of satisfaction and a positive experience while using any product or service. The ability to use a product is referred to as usability, which includes human interaction with a product, system, or service [59]. The conventional definition of usability, which relates to user satisfaction, is now supplemented by the term User Experience (UX). User Experience encompasses the entire experience that a user has while using a product [66]. ISO 9241-210 defines user experience as "a person's perceptions and reactions that result from the use of a product, system or service" [29].

User experience is a larger concept, as it is not only about user satisfaction, but also about emotions and all the beliefs, preferences and behaviors that occur before, during and after using a product [58]. UX studies are becoming an integral part of the consumer-oriented design process. They focus on understanding the unconscious needs and motivations of users and enable creating products that match consumer expectations. User experiences determine market success [28]. They influence positively or negatively the desire to use the system or service again, which is important for the perception of the brand and its market position.

The popularity of the term "User Experience" has increased recently. In Google Scholar, the number of user experience-related papers published in 2010 was 20,800, and in 2016 it was 32,500, increasing by about 56% [54]. To illustrate the progress in the field of user experience, it is worth considering the amount of UX professionals in the world. According to Nielsen Norman Group's "User Experience Careers" report, from 1983 to 2017, the number of people working in the user experience design profession increased from 100 to about 1 million people

[63]. It is predicted that by 2050 there will be 100 million UX specialists worldwide, equivalent to 1% of the world's population, and that the main value factor in the future economy will be user experience [48].

The literature identifies many classic techniques and tools that can be used to study User Experience. The choice of the appropriate method depends on the specific information and data you want to obtain [65]. Among the most used classical methods in UX research are Usability Testing, Field Studies and Observation, Participatory Design, Focus Groups, Interviews, Prototyping, and Surveys and Questionnaires [25]. Many studies use more than one main method, additionally using various classic techniques at the same time. Focus groups can complement usability tests [16]. Interviews provide more precise data when journal protocols are additionally created [15].

Since understanding user behavior and preferences is a very complex and complicated process, researchers argue that traditional research should be supported by methods from the field of cognitive neuroscience [47]. Traditional user experience research methods are based on the declarations of the respondents and are therefore highly subjective. The results of the surveys depend on the consciousness of the respondents, and the collected data do not always represent the real feelings of the subjects, which makes considerable measurement errors [83]. Cognitive neuroscience methods measure a user's psychophysiological signals, so they are increasingly being used in user experience research as a natural extension of research into the emotional and formative factors of customer behavior [66]. Until recently, such research was quite rarely used in the UX research process due to the high equipment costs involved. Now that testing devices have become cheaper and more available; they are increasingly being used in research work. Cognitive neuroscience research has revolutionized the field of user experience design, as it has enabled a better understanding of user behavior and preferences [23]. Despite the progress and growth in popularity of cognitive neuroscience in the last decade, there are apparent difficulties in preparing studies using its methods [55].

The article discusses the importance of user experience (UX) research and the growing popularity of cognitive neuroscience techniques in the field. The article aims to analyze the best research practices using cognitive neuroscience methods and develop a generalized procedure to improve the process of designing and conducting user experience research. The procedure was created based on a literature review and includes a combination of classical and cognitive neuroscience methods.

2. Methodology

The methodology involved analyzing literature describing experiments on user experience research using cognitive neuroscience methods from the last six years (2017-2022) and selecting the most used cognitive neuroscience methods in the area. The date range was selected to include all research papers that are consistent with current research trends and technical capabilities. Relevant publications were searched using Google Scholar. The usefulness of this database in a literature review has been confirmed by research [22]. The search focused on articles relating to user experience (UX) and presenting research or experiments conducted and their results. The most used cognitive neuroscience methods in this area were selected based on a review by Zaki and Islam [83]. The keywords used in the search were defined as the expression: (“user experience” OR UX) AND (experiment OR research OR study) AND ((EEG OR electroencephalography) OR (fMRI OR “functional magnetic resonance imaging”) OR (fNIRS OR “functional near-infrared spectroscopy”) OR (GSR OR “galvanic skin response”) OR (EDA OR “electrodermal activity”) OR (HR OR “heart rate”) OR (ECG OR electrocardiogram) OR (EMG OR electromyography) OR “facial coding” OR eyetracking OR pupillometry).

For further analysis, were selected articles, which fulfil the following criteria:

- written in English;
- available as full texts;
- describing user experience research focusing on digital products (software, websites, mobile apps, interfaces, etc.).

Based on these assumptions, 64 publications were selected, which became the basis for

developing a generalized procedure for designing and preparing experiments, and to identify good practices for conducting user experience research using cognitive neuroscience methods.

3. Results

3.1. Analysis of selected experimental studies

The analysis of publications that met the criteria allowed for identifying current trends in user experience research using cognitive neuroscience methods. Figure 1 presents the distribution of publications on user experience from 2017-2022. During this time, there were between 7 to 14 articles published annually. Considering that the literature review was done in October and November of 2022, it can be concluded that interest in conducting this type of research is gradually increasing.

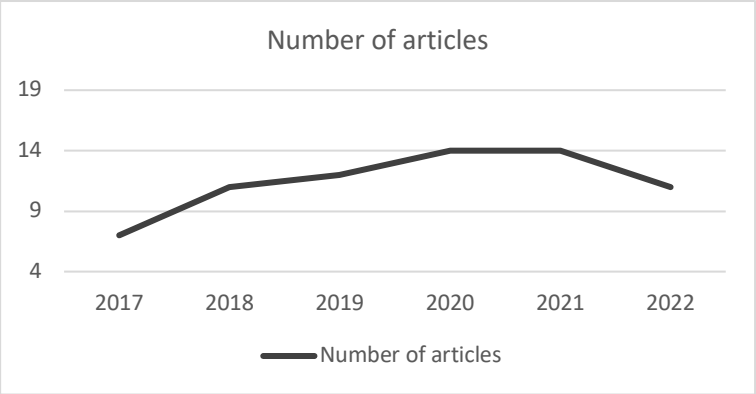

Fig. 1. Distribution of publications between 2017 and 2022.
Source: own study.

Based on the review of selected publications, the most popular cognitive neuroscience methods used in user experience research have been identified (see tables 1-4). The most used methods are eyetracking (ET) and pupillometry. Methods such as electroencephalography (EEG), galvanic skin response (GSR), and electrodermal activity (EDA) are also frequently used. Due to the relatively easy setup and analysis of collected data, facial coding (FC) as well as heart rate (HR) and electrocardiogram (EKG) measurements are also popular. However, the least commonly used methods in research are functional magnetic resonance imaging (fMRI) and functional near-infrared spectroscopy (fNIRS). Many experiments utilize multiple cognitive neuroscience methods simultaneously, allowing for the strengths of each method to be utilized while mitigating its limitations [76].

Table 1. Experiments related to user experience research on websites

Research subject	Neuroscience method	Classical method	Number of participants
online shops [7]	EEG, ET, GSR, HR	observation, interview, questionnaire	20
Aesthetics and usability of websites [69]	fMRI	questionnaire	8
Statical web application [5]	GSR	none	21
Advertisements on mobile websites [13]	EEG, GSR, ET	questionnaire	144
Visual design of the website [14]	ET, pupilometry, FC, GSR	questionnaire	15
University website [60]	FC	questionnaire	70
Online wealth management platform [4]	fNIRS, ET	questionnaire	12
Bank's website [17]	FC, EDA, pupilometry	none	57
Government website [20]	EEG, FC	questionnaire	30
Internet service with maps [34]	GSR	questionnaire,	24
Math learning portal [77]	ET	questionnaire, task completion time	35
Online education platform [80]	EMG	questionnaire	26
Website of the household appliances manufacturer [38]	EEG, EDA, ET	think-aloud protocol	20
Social media websites [40]	EEG	questionnaire	18
E-learning platform [41]	ET	observation, questionnaire	6

Research subject	Neuroscience method	Classical method	Number of participants
Distruptions when using a website [42]	pupilometry	questionnaire	40
Online shop [50, 51]	fNIRS	questionnaire	24
Video platform [52]	ET	none	10
Mobile version of the online shop [72]	ET	user journey,	14
Online information system (Fintech) [75]	EDA, FC, pupilometry	user action monitoring	38
473 different websites [19]	FC	none	12
Web service with interactive maps [33]	GSR,	think-aloud protocol	24
Automotive websites [43]	FC	hidden association test	160
Bank's website [70]	ET	questionnaire	22
Websites od food companies [1]	EEG, ET	delphi method	8
Static vs dynamic website [24]	ET, FC	test A/B, questionnaire	39
Digital library [31]	ET	questionnaire	30
Online shop [53]	EEG, GSR, ET, FC	none	32
Social networks [64]	FC	questionnaire, interview, observation	24
Web forms [68]	ET	mouse and keyboard tracking, questionnaire,	30
Mobile version of the online shop [71]	ET	user journey	16

A popular trend in research is to combine traditional methods with cognitive neuroscience methods. Besides cognitive neuroscience methods, questionnaires and surveys are most used in experiments. Other UX research methods such as interviews, think-aloud protocols, observation, and user journey mapping are less frequently used. Other methods (used in individual studies) include A/B testing, the Delphi method, IAT (implicit association test), and AAT (approach-avoidance task). In many studies, more than one method was used, as can be seen in Tables 1-4. Few publications have described studies and experiments that were conducted solely using cognitive neuroscience methods. Such a situation is rare. Generally, there is a tendency to combine classical and cognitive neuroscience methods to obtain the best overall picture of the user experience.

Table 2. Experiments on user experience research in games

Research subject	Neuroscience method	Classical method	Number of participants
Tetris [81]	EEG	questionnaire	44
VR games [30]	EEG	none	30
Snake [9]	EEG	questionnaire	6
VR game [3]	EMG, GSR	questionnaire	63
Game with exercises [27]	pupilometry, HR, GSR,	questionnaire	66
Educational video game [44]	pupilometry	none	20
VR games [11]	HR	questionnaire	80
Simulation game [49]	HR	questionnaire	15
Game in a VR [35]	EKG, GSR, EMG	questionnaire	31
Game with exercises [18]	EEG, EKG, GSR, ET	questionnaire	50
Mobile games [82]	EKG	questionnaire, in-game events	300
First person shooters (FPS) [39]	GSR, EEG, HR	questionnaire	14
Dota 2 [10]	HR, EEG, GSR	interview	31
VR game [12]	EEG, EDA, EKG	questionnaire	18
MOBA games [37]	EEG, EKG, GSR	questionnaire	53
VR games with exercises [79]	EEG	questionnaire	24
Video games [8]	EEG	questionnaire	10

In the analyzed experiments, the most frequently studies were websites and portals (31 publications) as well as games (17 publications) - both video and virtual reality games (Tables 1 and 2). Applications, both mobile and desktop (11 publications included in Table 3), were less frequently the subject of research. Less typical examples of studies on other digital products have been collected in Table 4. Among them, there are experiments on computer interfaces in cars and digital training materials.

Table 3. Experiments on user experience research in utility applications

Research subject	Neuroscience method	Classical method	Number of participants

Mobile communicator [57]	ET	questionnaire	40
End-user development software [73]	ET	questionnaire	10
Knowledge testing system [45]	EEG	questionnaire	82
Ideation software [56]	EEG	Approach-Avoidance Task, questionnaire	12
Business information system [32]	EDA, FC, ET	none	15
Archaeological VR application [67]	EEG	questionnaire	16
Email client [6]	GSR, HR, ET	think-aloud protocol questionnaire	45
Text editor [26]	ET	think-aloud protocol questionnaire	84
Mobile application [36]	ET	none	30
3D software [2]	ET	interview	15
Mobile applicatio [84]	ET, EEG	questionnaire	16

Table 4. User experience research experiments in other digital products

Research subject	**Neuroscience method**	**Classical method**	**Number of participants**
Electronic voting system [61]	ET	questionnaire	18
Warning window design [74]	fMRI, ET	none	16
Autonomous car interface [21]	GSR	questionnaire, interview	48
Automotive on-board computer interface [62]	EEG	questionnaire	13
CAPTCHA [46]	fNIRS	none	25
Digital training materials [78]	ET	questionnaire	15

3.2. Generalized procedure for designing and conducting experiments

Based on the analysis of research descriptions included in the reviewed articles, a generalized procedure for designing and conducting experiments using traditional (classical) and cognitive neuroscience methods has been developed. The proposed procedure is practical and focuses on the technical aspects of experiments, independent of the chosen research subject and set of methods used.

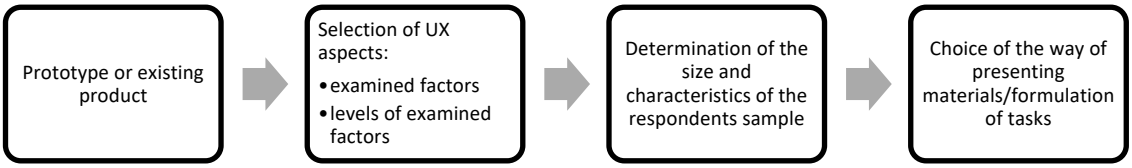

Fig. 2. Generalized procedure for designing experiments in user experience research.
Source: own elaboration.

The four main stages of designing an experiment are depicted in Figure 2. To begin, a prototype or an existing product, system, or service should be chosen for research. Then, the specific aspects of the user experience that will be examined and the factors that will be analyzed and their levels should be determined. The appropriate measurement methods, whether traditional or cognitive neuroscience, should also be selected based on the nature of the product being studied and the areas of interest. Based on these decisions, the number and characteristics of the study participants should be identified and divided into subgroups according to the variations of the studied materials. At the end of the preparatory stage, the method of presenting the materials to the participants should be chosen, and depending on the study's nature, tasks for the users during the experiment should also be formulated.

After designing the study, the experiment can be conducted. Its detailed procedure depends on the study and the methods selected for data collection. Based on the analyzed literature, 12 steps were identified that apply regardless of the choices made during the research design stage. The generalized procedure developed by the authors is presented in Figure 3.

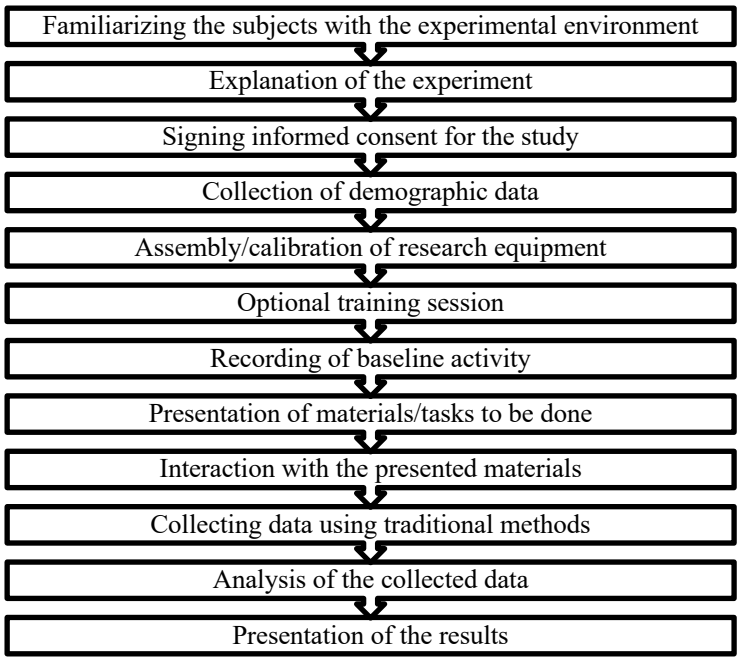

Fig. 3. Generalized procedure for conducting experiments.
Source: own study.

Conducting the study should begin with familiarizing the participants with the experimental environment and discussing the course of the study. After being familiarized with the procedure, the participant should provide written consent to participate in the scientific project. If necessary, after obtaining consent, demographic data about the participant is collected. The next step is the assembly and calibration of the research equipment depending on the cognitive neuroscience methods chosen for the study. Optionally, a training session may also be conducted at this stage to familiarize the participants with the use of the devices. After starting the experiment, the measurement equipment records the baseline course of the participant's psychophysiological signals in the resting state. The next part of the study is followed by the presentation of stimuli or the user's performance of tasks related to the selected subject of the experiment. During the participant's interaction with the presented materials, psychophysiological data is collected. The recorded signals can be supplemented with data from traditionally used methods of studying user experience. This stage concludes the practical part of the study, followed by the analysis of the collected data considering both subjective and objective measures. The procedure ends with the interpretation and presentation of the results.

3.3. Best practices for conducting experiments in UX research

The use of cognitive neuroscience methods in research requires appropriate preparation and attention to the conditions that must be met to ensure a successful experiment and valuable data collection. Based on published studies several key issues related to the application of cognitive neuroscience methods were identified. They are not mostly directly related to the procedure of designing and conducting experiments but can be considered good practices that improve the quality of conducted research.

One of the first decisions made when designing experiments is to determine the size of the study group. Due to the specificity of cognitive neuroscience methods, few studies are conducted with such many participants as with the use of traditional user experience research methods. The number of participants usually ranges from 20 to 40 people. The median is 24 and the average value is 36.7. There are examples in the literature of studies that use cognitive neuroscience methods with a large number of participants (over 100 people, see [13, 43, 82]), but these are very rare situations due to the time required to test a single person, including the assembly and calibration of necessary equipment. Good practice in this area may involve determining the number of participants using appropriate software, such as G*Power 3.1 [36]. It allows for determining the sample size of participants so that it is possible to obtain an appropriate effect size in the further statistical analysis of the obtained data.

In the next stage, which involves conducting experiments, it is necessary to ensure appropriate conditions. This includes both the time and place where the research is to be carried out. In terms of time, it is recommended to choose suitable hours for conducting the experiment. It is generally accepted that the research should be carried out between 9 and 11 am, due to the peak of cognitive abilities of the participants [1]. The research laboratory room should have appropriately arranged and constantly monitored environmental parameters, such as temperature and humidity. This is advisable to minimize their impact on the collected data [33]. Additionally, when the experiment involves using devices to record pupil dilation, the research should be conducted in a room with regulated lighting levels to eliminate the impact of the environment on the participant's reaction [42, 44].

It is also important to properly prepare the participants. When using EEG registration, it is recommended that participants wash their hair to ensure better electrode contact with the skin (coconut soap can be used for this purpose, among others) [9]. When using facial expression recognition software, it is important to make sure that nothing is obstructing any part of the participants' faces [14]. When recording signals using an eye tracker, it is necessary to ensure that all participants have proper vision (natural or corrected) [14]. In the case of participants wearing glasses, it is worth asking them to switch to contact lenses. This will improve the quality of the recorded data. For the same reason, mascara should be removed from the eyelashes [73]. For some cognitive neuroscience methods, it is also necessary to determine whether the participant is left or right-handed. This is usually done based on a declaration or a specific questionnaire [13, 30]. This is important, among other things, in studies using the measurement of skin galvanic response, as sensors of measurement devices are attached to the non-dominant hand of the participant to minimize disturbances caused by movement during the operation of input devices used in the experiment [5, 33]. It is also worth remembering that the skin galvanic response is recorded with a delay, which should be considered when planning the experiment [14].

Implementing these best practices does not guarantee a successful experiment in user experience research and obtaining valuable data, but it significantly minimizes the risk of failure. Therefore, these recommended practices from the literature should be considered and applied in conducted research.

4. Summary

The constantly growing expectations of the market and consumers place high demands on companies. To achieve success, companies compete for customer interest by designing and creating products that meet real consumer expectations. Today's customers are no longer guided only by the functionality and price of product. They increasingly choose products that inspire and evoke positive emotions, expecting a high level of satisfaction and positive experiences when using a product or service. To deliver what they expect, there is currently a strong emphasis on designing the user experience, which encompasses all aspects of customer interaction with products and influences their market success. While there are many classic methods for studying user experience in the literature, traditional techniques do not account for the emotions that people experience when using a product. Methods using the measurement of psychophysiological attributes can fill gaps left by classical methods, as they provide insight into subconscious reactions and enable measurement of user's unconscious preferences. The most popular techniques of cognitive neuroscience include: eyetracking, GSR, EEG, and facial coding, which in combination with traditional user experience research methods provide valuable information. However, designing and conducting experiments using such techniques can be challenging due to the fact that collecting neurophysiological data is a difficult, error-prone, and time-consuming process. Nevertheless, many researchers take up this challenge.

A review of the literature allowed the identification of 64 experiments conducted between 2017 and 2022, which focused on studying user experience. Based on the descriptions of these experiments, a generalized procedure for designing and conducting such research was proposed. The analysis of the literature also allowed the identification of good practices, which apply regardless of the materials studied and the chosen cognitive neuroscience methods. The obtained results allow for a better understanding of designing and conducting user experience

research using cognitive neuroscience methods for those interested in this topic and facilitate the creation of their own experiments.

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