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Abstract

This chapter aims to offer a user-centred methodological framework to guide the design and evaluation of Brain-Computer Interface videogames. This framework is based on the contributions of ergonomics to ensure these games are well suited for their users (i.e., players). It provides methods, criteria and metrics to complete the different phases required by ae human-centred design process. This aims to understand the context of use, specify the user needs and evaluate the solutions in order to define design choices. Several ergonomic methods (e.g., interviews, longitudinal studies, user based testing), objective metrics (e.g., task success, number of errors) and subjective metrics (e.g., mark assigned to an item) are suggested to define and measure the usefulness, usability, acceptability, hedonic qualities, appealingness, emotions related to user experience, immersion and presence to be respected. The benefits and contributions of the user centred framework for the ergonomic design of these Brain-Computer Interface Videogames are discussed.

1. Introduction

A BCI videogame combines a Brain Computer-Interface (BCI) and videogame content. It mainly consists in using a BCI as one of the input devices that can interact with the game. This BCI can be used in an active way: to send control commands (*e.g.*, Lotte et al., 2008), in a passive way: to adapt the game content based one the user's brain activity (*e.g.*, George and Lécuyer, 2010), or both. In a BCI videogame, the user can play by means of brain activity and the available output device (mainly visual feedback) is used to provide a meaningful feedback to the user (Lotte et al., 2013). As explained in (Scherer et al., 2013), a game, including a BCI game, is a problem-solving activity performed with a playful attitude. The objectives of BCI videogames are multiple. Indeed, they can be used in the medical area: for example, Holz et al. (2013) suggested the BCI videogame "*Connect-Four*" which aims to entertain the severely motor restricted end-users in their daily life in order to increase their quality of life and decrease their depression. Connect-Four is "*a strategic videogame with two competitive players in which coins have to be placed in rows and columns with the goal to connect four coins*" (Holz et al., 2013, p. 113). A BCI videogame can also be a learning tool: for example, as a motivating and engaging way to learn to use a BCI, to later used it to control a neuroprosthetics, as in Müller-Putz et al. (2007). Obviously, a BCI videogame can be an entertainment app: for example, "*Mind the Sheep!*" is a single- or multi-player videogame which consists to fence a sheep in as quickly as possible by herding them with their dogs (Gürkök et al., 2013).

To design and evaluate these BCI videogames, two complementary approaches co-exist: a technocentric design and an anthropocentric design.

The technocentric orientation aims to design and optimize an innovative application by testing its technological possibilities and solving technical challenges. This research path hardly considers the characteristics of human activity. Typically, these studies aim to improve the performance of the BCI at detecting mental states, in terms of information transfer rate (Yang et al., 2010), classification accuracy or error rates, for instance.

The anthropocentric orientation aims to design an application which will be useful and usable by their end-users. This approach focuses on the characteristics, capabilities and resources of end-users, the context of use of the designed application and the users' activity (Rabardel and Béguin, 2005). In the context of BCI applications, the user-centred approach has already been introduced (*e.g.*, Kübler et al., 2013, Schreuder et al., 2013). However, its use is more recent for the design of BCI videogames (*e.g.*, Plass-Oude Bos et al., 2011; Van de Laar et al., 2011). This approach remains minor compared to the technocentric approach. One reason could be the absence of a methodological framework dealing with the ergonomic design of BCI videogames, compared to the research conducted in technocentric design.

The purpose of this chapter is to propose a user-centred methodological framework to guide the design and evaluation of BCI videogames. This methodological framework deals with the ergonomic design of these applications and suggests methods, criteria and metrics.

The remainder of this chapter is organized as follows. In the following section, the relevance of the user-centred design for BCI videogames is explained. The third section details the ergonomic methods which are used or advocated in the context of user-centred design of BCI videogames. The fourth section describes which ergonomic criteria could be introduced to user-centred design BCI videogames, and proposes metrics for each criterion. The contribution of the proposed methodological framework to the user-centred design of BCI videogames is discussed in the fifth section. The sixth section provides a general summary and conclusion.

2. User-centred design and design of BCI videogames

Designing emerging applications suited to end-users requires design models from the ergonomic literature. Among these models, a user-centred design is particularly promising for BCI videogames. Indeed, a BCI videogame is an interactive system that could benefit from the "*user-centred design*" model as any interactive system. This model is formalised in the ISO 9241-210 standard through four iterative phases: 1) Understand and specify the context of use, 2) Specify the user needs and the other stakeholders' requirements, 3) Produce design solutions (*e.g.*, scenario, mock-up, prototype) and 4) Evaluate the solutions at all stages in the project from early concept design to long term use to specify design choices. Consequently, it can be used to guide designers toward an anthropocentric design of these specific videogames.

Moreover, the term "*user-centred design*" is already known in the BCI community to evoke a concept which is assessed empirically (*i.e.*, evaluated by a user during the accomplishment of an experimental task). For example, in their study, Plass-Oude Bos et al. (2011) tried to evaluate users' preference for three mental tasks (inner speech, association, stressed or relaxed mental state) which are more adapted than traditional paradigms (*e.g.*, Motor Imagery, P300, and Steady-State Visually Evoked Potentials) considered too slow, non-intuitive, cumbersome or just annoying. They measured the relationship between recognition performance and the preferences of users. To do that, fourteen participants participated in five experiments consisting of playing World of Warcraft (WoW) for two hours and for five weeks. They were divided into two groups. A real-BCI group: they controlled their shape shifting action with their mental tasks, at least insofar as the system could detect it: *i.e.*, the users received feedback on the recognition of their mental tasks in the form of an orange bar in the videogame (the bar is small if the system had detected the mental task related to elf form, while it is large if the system had interpreted the mental task related to bear form). A utopia-BCI group: they pressed a button to shape shift when they decided by themselves that they performed the mental task correctly (in this group, a BCI system with 100% detection accuracy was simulated). After user test sessions, the participants filled out a user experience questionnaire. The results show that the users preferred the association tasks (*i.e.*, the user had to feel like a bear to change into a bear, and to feel like an elf to change into an elf) whereas the relaxed/stressed mental state seems to be disliked the most. However, in practice, such a BCI paradigm with which a user could imagine being a bear to turn its avatar into a bear is not necessarily realistic and robust, as such mental tasks cannot be reliably detected in EEG. Furthermore, it appears that recognition performance has a strong influence on users' preferences.

3. Ergonomics methods used or advocated in the context of user-centred design of BCI videogames

It is now known that the combination of ergonomics methods produces complementary data enriching three of these four phases of user-centred design (*e.g.*, Anastassova et al., 2005): specify the context of use (step 1) and the functionalities of the future videogame (step 2) and evaluate the designed solutions (step 3). Defining the future context of use and specifying the functionalities of the BCI videogames are closely related as both steps involve identifying existing and latent needs (3.1). Evaluating solutions at all stages in the project from early concept design to long term use to specify design choices implies using prototypes evaluation methods (3.2) and methods to analyse system appropriation (3.3).

3.1. Ergonomics methods to identify existing needs and latent needs in order to specify the future context of use and the functionalities of the BCI videogame

Ergonomics uses methods which allow the designers to understand the future context of use on the one hand, and to identify existing needs and anticipate latent ones in order to specify the functionalities of the BCI videogame, on the other hand. According to (Robertson, 2001), the existing needs correspond to:

- Conscious needs: *i.e.*, those clearly formulated by the (future) end-users,
- Unconscious needs: *i.e.*, those which exist but are not clearly formulated by users, because they are not aware of the potential of the chosen technology. The latent needs are

characterized by their not proven yet or undreamed nature (Robertson, 2001). These needs are an important issue for emerging technologies, like BCI videogames, which are still in development in laboratories and whose uses are still sought.

3.1.1. Identification methods of existing needs

Interview is a currently used or recommended method to identify relevant needs in order to suggest realistic expectations with BCI. For example, to design a suitable BCI system for domestic use by people with acquired brain injury in order to facilitate control of their environment, Mulvenna et al. (2012) have conducted interviews with disabled participants with acquired brain injury and participants without movement disabilities. Before imagining a videogame, designers can interview potential users about points such as:

- The context of use, *e.g.*, who are the users of the videogame (children, adults …)? Can you explain the context in which the videogame will be used (in a classroom, at home …)?
- The videogame, *e.g.*, what is the goal of the videogame (entertainment, learning, rehabilitation …)? Which actions can be done in the videogame? What the virtual environment could be composed of?
- The interaction, *e.g.*, do you prefer to imagine that your hand is moving or to focus in order to move the avatar? Which other interaction device can be used in addition to the BCI?

3.1.2. Anticipation methods of latent needs

Anticipating latent needs (*i.e.*, not "*existing*" for users at a specific moment) involves the use of creativity methods to widen potential uses, the functionalities and properties of the videogame (Burkhardt and Lubart, 2010). This kind of methods is particularly relevant for the design of all emerging technologies, specifically those designed for different users' profiles like a BCI videogame. Among these creativity methods, focus groups are often used. This method aims to create small groups of potential users of an interactive system, and to interact on a relevant topic for the study to achieve. As output, opinions, expectations, motivations and attitudes, from customs, practices, experiences of participants are usually collected. Indeed, focus groups have recently been used for the design of BCI applications in a study conducted by (Blain-Moraes et al., 2012). The purpose was to determine the barriers and mediators of BCI acceptance in a population with amyotrophic lateral sclerosis. The authors conducted a focus group which involved eight individuals with amyotrophic lateral sclerosis (having previously used a P300-based speller with a visual display) and their nine carers. The focus group consisted of open-ended questions asking participants' about their desires and concerns with the BCI. It was transcribed in full and data was thematically analysed. Focus group analysis yielded two categories of mediators and barriers to user acceptance of this technology: personal factors (*i.e.*, physical, physiological and psychological concerns) and relational factors (*i.e.*, corporeal, technological and social relationships with the BCI). This study showed that a focus group is a relevant method to evoke needs in terms of mediators and barriers concerning the use of BCI by people with amyotrophic lateral sclerosis. This result is encouraging for the use of a focus group to anticipate latent needs of potential users of BCI videogames to stimulate them to discuss together and imagine new ideas on the usage of the technology (*i.e.*, a person is able to imagine new needs through creativity generated within a group). For example, future users are able to co-create together a videogame scenario and to decide their preferred interaction paradigm (*e.g.*,, association task). In addition to these methods, ergonomics uses and recommends methods to accomplish the fourth phase of the user-centred design process which corresponds to the evaluation of prototypes (3.2) and the appropriation of the BCI videogame by users (3.3).

3.2. Evaluation methods of prototypes

Prototypes are a means to immerse users in the context in which the BCI videogame will be integrated. Users are able to evoke functionalities which were previously latent and unconscious. A simulation of the future situation is an opportunity for the designer to explore the real impact of the videogame on the users' activities, in particular for the BCI videogames in learning and medical areas. This simulation allows them to identify the improvements to be implemented so that the users have a real benefit from its use (Burkhardt and Lubart, 2010).

In a user-centred design of BCI videogames, prototypes can be evaluated through user-based testing (*i.e.*, a simulation to study the users' behaviour in front of the application) followed by questionnaires. This observation is illustrated with some studies detailed below. These studies provide an overview of the way the evaluation is carried out in the field of BCI videogame on three aspects: the number of participants, the location of the test and the evaluation objectives (objective evaluation of performance, subjective evaluation, etc.).

Badia et al. (2011) conducted a study aiming to explore the synergies of a hybrid BCI and a BCI videogame for neuro rehabilitation system. This study involved 18 participants and consisted of four phases based on a training task called "*Spheroids*"which is a videogame like task in which the user has to intercept incoming spheres by moving the arms of the virtual avatar. First, the BCI classifier was trained. Then, the "*Spheroids*" calibration phase was used to assess the level of control of the participants by asking them to drive the virtual arms to specific locations. Subsequently, participants played the "*Spheroids*" training videogame. Finally, all participants answered a 5-point Likert scale (1 lowest, 5 highest) of 23 questions covering different aspects: enjoyment of the experience, perceived performance learning during task execution, level of task ease, level of control of the virtual avatar, and appropriateness of the system configuration (for instance, if arms were too fast or too slow).

Van de Laar et al. (2011) have recently elaborated a standardised questionnaire, inspired by the Game Experience Questionnaire and the Engagement Questionnaire. This questionnaire can be used to evaluate the user experience in a BCI-based interaction for entertainment purposes. It offers optional items depending on the category of BCI (*e.g.*, passive BCI, active BCI). For passive BCI, items measure the degree of comfort and of distraction from the main task due to the BCI hardware. For active BCI, items measure the applicability of the mental tasks and perceived speed of the BCI on the users' actions.

In their study, Zickler et al. (2013) evaluated the usability of Brain Painting, an application for entertainment offering the user creative expression by painting pictures. For that, they compared Brain Painting with a P300 spelling application in terms of user satisfaction through three questionnaires (*i.e.*, Quebec User Evaluation of Satisfaction with assistive Technology 2.0, Assistive Technology Device Predisposition Assessment (ATD PA)), Device Form, the effectiveness (accuracy), the efficiency as measured by the information transfer rate and the subjective workload using the National Aeronautics and Space Administration Task Load Index. Even if the results globally showed a good usability, they revealed that the system operability and the EEG cap are the main obstacles for use in daily life. Concerning the last observation, Nijholt and Gürkök (2013) suggested reducing the complexity of gel-based electrodes installation by using wireless headsets and dry electrodes.

These studies show three elements. First, BCI videogames, even relatively immature, can be evaluated with a large number of users with highly varying skills and potentially very heterogeneous needs. This is a key element in the context of BCI videogames which must be adapted to users other than those who have been involved in the design. Second, these studies stressed the diversity of the implementations of user-based testing that can take place in laboratory conditions (*i.e.*, controlled situations) and in conditions similar to real situations of interaction (typically, playing videogames at home where the variables are not controlled). This suggests that user-centred evaluations of BCI videogames can take place under experimental conditions (in the laboratory) and in more ecological conditions relative to the future situation of use. These two ergonomic approaches are complementary and coexist for the design of these emerging videogames. This opens perspectives for users-based evaluations of BCI videogames for several types of applications (*e.g.*, medical, learning or entertainment applications). Third, it provides information about the questions properties: these questions are generally measured on Likert scales (5 or 7-point) and less frequently open-ended questions that allow the questioned person to express freely. The items covered in these questionnaires concern the system (*e.g.*, appropriateness of the system configuration, application responsiveness to initiated actions) and subjective elements perceived by the user (*e.g.*, enjoyment of the experience, level of task ease). Even if the questionnaire is a relevant method, it should not be used alone. From an ergonomics point of view, it must be complemented for instance by interviews that will justify the scores obtained in the questionnaire.

3.3. Analysis methods of BCI videogame appropriation

To study system appropriation, longitudinal studies can be used. They are usually implemented through observations, interviews and self-confrontation made at different periods (*e.g.*, at 0 month, 3 months and 6 months after the integration of the BCI application in a situation).

Longitudinal studies have already been conducted in the context of BCI to measure the influence of psychological state and motivation on the BCI performance (*e.g.*, (Nijboer et al., 2010)). In this study, six participants were trained for several months either with a BCI based on sensorimotor rhythms or with a BCI based on event-related potentials (*i.e.*, P300), or both. Questionnaires assessing quality of life, severity of depressive symptoms, mood and motivation were filled out by the participant before each training session. Results suggest that P300-based BCI must be a first choice for allowing severely paralysed patients to control a communication program based on a binary spelling system. Results also suggest that motivational factors may be related to the BCI performance of individual subjects and suggest that motivational factors and well-being should be assessed in standard BCI protocols.

This study illustrated that longitudinal studies have been conducted to measure the evolution of some parameters’ effects on the use of a BCI-based speller and thus to study the appropriation of the BCI application by users. This is necessary because the lack of training on these new tools and the lack of support are factors that may lead end-users to abandon their use. Typically in the context of BCI videogames, a longitudinal study may intend to measure the motivation and game engagement for several months. It can also be used to study how the user skills at BCI control evolve with time, in order to design adequate levels and content in the game that can match such BCI skill progress.

These methods can be used to design and evaluate usefulness, usability, acceptability, hedonic quality, sense of presence, immersion and user experience. In the next section, the ways in which these ergonomic criteria can be taken account in the context of a BCI videogame are presented.

4. Ergonomic criteria

4.1. Usefulness

In ergonomics, the term "*usefulness*" oscillates between two meanings: *purpose-usefulness* and *value-usefulness* (Loup-Escande et al., 2013).

Purpose-usefulness is the description of system features and its uses. This description can take many forms depending on the phase of the design process: concept (*e.g.*, a BCI videogame to entertain the motor restricted users in their daily life), specifications (*e.g.*, this BCI videogame must be multiplayers and could consist in a virtual ping pong activity, the interaction must be based on relaxed / stressed mental state), prototype (*e.g.*, the virtual environment is modelled, the ball passing task between two users is implemented, the BCI interaction uses the Neurosky MindWave), final application (*e.g.*, the prototype is improved with a new point counting functionality and the integration of the Emotiv Epoc instead of the Neurosky MindWave). Purpose-usefulness corresponds to the functionalities of a videogame. These features are determined at a given time, even if they can be subsequently modified by players.

Several metrics can be used to assess the BCI videogames' usefulness. A well-known metric, and common to all emerging systems, is the adequacies *versus* inadequacies between the features implemented in a system on the one hand, and those desired at a time T by the user on the other hand (Blandford et al., 2008). These adequacies or inadequacies are collected with the number of responses Yes *versus* No to the question: Do you think this functionality / information is useful? They are collected with metrics resulting from requirement prioritisation: nominal scale, ordinal scale, ratio scale methods (Loup-Escande and Christmann, 2013). In nominal scale methods, requirements are assigned to different priority groups. An example is the MoScoW method, which consists of grouping all requirements into four priority groups, such groups corresponding to the requirements that the project (must / should / could / will not) have. All requirements listed in a category are of equal priority, which does not allow a finer prioritization. Ordinal scales methods produce an ordered list of requirements; for example, the simple ranking where the most important requirement is ranked 'one' and the least important is ranked 'n'. Another known method called

Analytic Hierarchy Process asks users to compare all pairs of requirements. Ratio scale methods provide the relative difference between requirements (*e.g.*, the hundred dollar method asks users to allocate a sum of money to each requirement). In addition to an ordered list of requirements, this method also helps us to discover the relative importance of each requirement in relation to the others.

Value-usefulness is defined as a significant advantage of the videogame for players in activities mediated by a computer system; this advantage is always relative to: the objectives of the user, the existing tools, the use environment and the dependencies on other activities. Value-usefulness refers to improvements and benefits that the videogame provides to the players. In the field of BCI, these benefits are evaluated in the short, medium or long term. For example, Yan et al. (2008) conducted a study to evaluate the usefulness of a BCI videogame for treating children with Attention Deficit Hyperactivity Disorder (ADHD). In other words, they wanted to show that the virtual reality neuro-feedback training could improve sustained attention. This study involves 12 subjects with ADHD aged form 8 to 12 years old, who were trained at least twice per week with five virtual environment games for 25-35 minutes. During the training period, all subjects were requested to stop taking any medication and behavioural therapy. To measure children's attention, authors used the integrated visual auditory – continuous performance test (IVA-CPT) at the beginning of the treatment and after each one of the twenty training sessions. Results show that subjects' attention had been strengthened after 20 training sessions.

In order to evaluate the benefits and advantages for the user with respect to his goals, existing tools, the environment of use and dependencies with other activities, the used metrics are more specific to the domain for which the application was designed. For example, to evaluate the usefulness of a BCI videogame to support learning, the metrics are specific to the knowledge that can be learned with the system.

In a BCI videogame for entertainment, the value-usefulness can be measured by the degree of engagement in the game if we consider that the more engaged the users, the more useful the videogame for them (Brockmyer et al., 2009).

Both for the medical area, for the learning domain and for the entertainment field, the benefits provided by a BCI videogame can be measured using indicators of well-being, since the objective of the BCI videogame is to increase quality of life. Quality of life can be measured by the Schedule for the Evaluation of Individual Quality of Life (Holz et al., 2013). To measure game engagement, Brockmyer et al. (2009) have designed a questionnaire based on four dimensions:

- The psychological absorption describes the "*total engagement in the present experience*" (Brockmyer et al., 2009, p. 625): *e.g.*, time seems to stand or stop,

- The flow describes "*the feelings of enjoyment that occur when a balance between skill and challenge is achieved in the process of performing an intrinsically rewarding activity*" (Brockmyer et al., 2009, p. 625): *e.g.*, I play without thinking how to play,
- The presence is defined in terms of "*being in a normal state of consciousness and having the experience of being inside a virtual environment*" (Brockmyer et al., 2009, p. 624): *e.g.*, I play longer than I meant to,
- Immersion describes "*the experience of becoming engaged in the game-playing experience while retaining some awareness of one's surroundings*" (Brockmyer et al., 2009, p. 624): *e.g.*, I really get into the videogame.

4.2. Usability

In 1998, the International Organization for Standards published a definition of usability (ISO 9241-11): "*The extent to which a product can be used by specified players to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use*". Some authors add learnability and memorability to define usability in BCI context, *e.g.*, (Plass-Oude Bos et al., 2010). Usability is therefore a combination of five elements: effectiveness, efficiency, satisfaction, learnability and memorability (Plass-Oude Bos et al., 2010):

- Effectiveness concerns the fact that the software allows the user to achieve the specified goal,
- Efficiency is the capacity to achieve a task with the minimum of resources for user, *i.e.*, efforts. For instance, can the user achieve multitasking with the BCI and control another input at the same time?,
- Satisfaction is influenced by ease-of–use (*e.g.*, EEG sensors setup time, machine calibration time, etc.) and by non-instrumental qualities (*e.g.*, aesthetics aspects),
- Learnability is what allows a novice user to devote himself quickly to a task, reducing the time needed to learn how to use the application. The second aspect of learnability is how efficiently can the game train the user to reliably perform mental tasks to use the BCI (Plass-Oude Bos et al., 2010, Lotte et al., 2013),
- Memorability is what allows the user to perform the tasks after a period of non-use without having to re-learn the functioning of the application (*e.g.*, how well can a user perform the BCI mental commands from one day of gaming to the next).

Plass-Oude Bos et al. (2010) adapted the usability characteristics commonly used in human-computer interaction (*i.e.*, learnability, memorability, efficiency, effectiveness, error handling, and satisfaction) to the design of BCI videogames. The usability of BCI applications has already been evaluated in some studies. For example, Ekandem et al. (2012) conducted a study to evaluate the usability of two BCI devices: the Emotiv EPOC and the Neurosky MindWave. Authors compared user comfort, experiment preparation time (*i.e.*, total time from initial placement to final adjustment), signal reliability and ease of use of each BCI. This study involved 13 participants. Each participant completed a training phase before playing several simple videogames included with each system like Pong, Tetris, and SpadeA. After having worn the BCI device for 15 minutes, the participant completed a post-experiment questionnaire. Results show that the preparation time for the Emotiv EPOC is longer than for the Neurosky MindWave and that the majority of participants indicated that the Emotiv EPOC was comfortable whereas the Neurosky MindWave was not. Moreover, the MindWave provided an easier signal acquisition whereas the EPOC clearly had contact issues due to participants' hair. However, the signal was maintained and even improved during the session once the EPOC was connected and calibrated, while the MindWave experienced more signal fluctuations.

The previous study focused on the direct evaluation of a BCI device. Interestingly enough some of the studies concerned the usability evaluation of BCI-based interaction with another system. For example, Iturrate et al. (2009) aimed to evaluate a new brain-actuated wheelchair concept that relies on a synchronous P300 brain-computer interface integrated with an autonomous navigation system. The evaluation concerned the effectiveness and the efficiency of the BCI-based interaction and of the graphical interface.

In Lotte et al (2008), the usability of a BCI videogame in 3D (Figure 1) was assessed using questionnaires that measured the feeling of control, the fatigue, comfort and frustration induced by the BCI game, both for control commands based on real and imagined foot movements.

Figure 1: The "Use-the-force" application. The user had to lift up a virtual spaceship using foot motor imagery (©CNRS Photothèque/Hubert Raguet).

These studies suggested that the usability evaluation of BCI videogames can have different objectives. Indeed, it can concern either the BCI hardware (EEG cap), the BCI software (*e.g.*, the reliability of mental state detection) or the BCI-controlled application (*e.g.*, a robot).

A BCI controlled application is often evaluated in terms of effectiveness using for example the degree of accomplishment of the task, the distance travelled to accomplish the task, the task success, the total time taken to accomplish the task (in seconds), the number of missions to complete the task (Iturrate et al., 2009; Escolano et al., 2009).

To evaluate the efficiency of a BCI videogame, Holz et al. (2013) used the NASA-TLX to estimate the subjective workload experienced in a specific task and its main sources (*i.e.*, mental, physical and temporal demand, effort, performance and frustration). In addition, the efficiency of a BCI system is often measured using the Information Transfer Rate (ITR), which measures how much information can be conveyed by the system in a given time (*e.g.*, in Bits per second) (Wolpaw, 2002). Thomas et al. (2013) listed several metrics used to quantify the performance of a BCI and evoked the evaluation strategies employed to compare the performance of two or more BCI. They suggested the following metrics to measure the performance of BCI based on synchronised control (*i.e.*, the system is periodically available to the user when it is on, but does not support the non-control): accuracy (*i.e.*, classification error), kappa, bit–rate (Wolpaw or Nykopp), confusion matrix and task specificity. They recommended those to estimate the performance of BCI based on self-paced system (*i.e.*, the system is continuously available to the user when it is on, and supports non-control): hit-false difference, confusion matrix, task specificity, utility, efficiency, True Positive (*i.e.*, it quantifies the chance of correctly identifying intentional control states) and False Positive (*i.e.*, it quantify the chance of incorrectly identifying the non-control state).To evaluate the satisfaction evoked by a BCI videogame, the semantic differential scales corresponding to the following items, provided by (Hassenzahl, 2001), can be used: Understandable *versus* Incomprehensible, Supporting *versus* Obstructing, Simple *versus* Complex, Predictable *versus* Unpredictable, Clear *versus* Confusing, Trustworthy *versus* Shady, Controllable *versus* Uncontrollable and Familiar *versus* Strange.

To the authors' best knowledge, there are very little studies on the evaluation of learnability and memorability in the BCI field. An exception is the study of Jeunet et al (2014), which assessed the subjective learnability and memorability (among other measures) of standard BCI training procedures, using questionnaires. However this was not in a gaming context. In technological systems though, learnability is better assessed by comparing task execution time by a novice group (who has never used the application before) and task execution time by an expert group (who already used the application). If the time taken by the group of novices is inferior or equal to the time taken by the experts group, then the learnability of the application is good.

The learnability is linked with a specific phenomenon called "*BCI illiteracy/BCI deficiency*" (Allison and Neuper, 2010). Indeed, a given BCI system does not work for all users because several users cannot produce detectable patterns of brain activity necessary to a particular BCI approach (Guger et al., 2003).

Memorability is assessed by measuring task execution time at different times over a period of weeks. If the time obtained during the first week is superior or equal to the time obtained during the following weeks, then the memorability of application is good.

4.3. Acceptability

According to (Venkatesh et al., 2003), acceptability refers to an individual's perception of the system's value. To assess the acceptability, authors try to identify the intentions of individuals to use a system through questions. Thus, models of acceptability identify the variables that contribute significantly to the determination of intentions to use a technology. Among these models, the most complete is the UTAUT (Unified Theory of Acceptance and Use of Technology) by (Venkatesh et al., 2003). According to this model, behavioural intention is influenced by the performance expectancy, effort expectancy and social influence, use behaviour is influenced by behavioural intention and facilitating conditions. Previous experience with the system, the voluntariness or not of use, gender and age moderate the effects of direct determinants like performance expectancy, effort expectancy, social influence and facilitating conditions.

According to (Venkatesh et al., 2003), acceptability is measured by eight factors:

- Performance expectancy is defined as the degree to which an individual believes that using the system will allow him/her to gain in task performance (*e.g.*, gain speed in the achievement of the task, score a lot of points, be able toget in a relaxed / stressed mental state),
- Effort expectancy corresponds to the degree of ease associated with the use of the system,
- Attitude toward using technology corresponds to an overall affective reaction of an individual using a system,
- Social influence is defined as the degree to which an individual perceives that important others believe he/she should use the new system,
- Facilitating conditions are defined as the degree to which an individual believes that an organizational and technical infrastructure exists to support the use of the system (*e.g.*, BCI patients association or BCI companies which provide technical support),

- Self-efficacy corresponds to "*an individual's belief in one's capability to organise and execute the courses of action required to produce given attainments*" (Bandura, 1997, p. 3), (*e.g.*, does the player believe he/she can control a game efficiently by mental activities alone),
- Behavioural intention to use the system corresponds to the intention to use the system in the next months,
- Anxiety. (*e.g.*, is the player anxious that the BCI may read his/her mind without his/her consent).

Table 1 describes metrics (or items) for BCI videogames acceptability inspired and adapted from (Venkatesh et al., 2003).

Factors influencing acceptability	**Items**
Performance expectancy	I would find the BCI videogame useful Using the BCI videogame entertains me Using the BCI videogame enables me to learn / to treat / to rehabilitate
Effort expectancy	My interaction with the BCI videogame would be clear and understandable I would find the BCI videogame easy to use Learning to operate the BCI videogame is easy for me
Attitude toward using technology	Using the BCI videogame is a good idea Using the BCI videogame is fun I like using the BCI videogame
Social influence	People who influence my behavior think that I should use the BCI videogame People who are important to me think that I should use the BCI videogame
Facilitating conditions	I have the knowledge necessary to use the BCI videogame The BCI videogame is not compatible with other systems I use

Behavioral intention to use the BCI videogame	I intend to use the BCI videogame in the next <n> months I predict I would use the BCI videogame in the next <n> months I plan to use the BCI videogame in the next <n> months
Anxiety	I feel apprehensive about using the BCI videogame The BCI videogame is somewhat intimidating to me

Table 1: Items used to assess factors influencing acceptability

These items formalised in the form of positive affirmation are associated with the Likert scale on which the user notes the degree of agreement or disagreement.

Instead of questionnaires, some authors perform interviews with players after a test session. Gürkök et al. (2014) conducted semi-structured interviews with 42 players to investigate their opinions on control and playability of the BCI videogame based on the famous multiplayer online role-playing game "*WoW*". They used the answers to provide some general guidelines for the design and the evaluation of BCI videogame acceptability. For example, they observed that "*the experience of fun resulting from playing a BCI videogame once does not reliably represent the experience of pleasure that unfolds by playing the videogame*". Consequently, the authors suggested that the "*BCI videogames should be developed and evaluated for the pleasure rather than the fun they provide*". To do that, literature in ergonomics and psychology proposes to design and measure hedonics qualities and appeal.

4.4. Hedonic qualities and appeal

Hedonic qualities refer to the aspects of a BCI videogame that are related to a person's pleasure. The pleasure derived from the use of a BCI videogame is associated with its appealing characteristics and aesthetic.

To evaluate the hedonic quality of all applications including videogame, Hassenzahl (2001) suggested the following items using the semantic differential scales: Interesting *versus* Boring, Costly *versus* Cheap, Exciting *versus* Dull, Exclusive *versus* Standard, Impressive *versus* Nondescript, Original *versus* Ordinary, and Innovative *versus* Conservative. To evaluate the comfort and discomfort of BCI devices, Ekandem et al. (2012) used three indicators: the comfort of the device (very uncomfortable, uncomfortable, indifferent, comfortable and very comfortable), the time the participants felt they could comfortably wear the device (0–5 minutes, 5–20 minutes, 20–60 minutes, 60–120 minutes and more than 120 minutes) and the type of discomfort perceived (sharp, dull, itchy, heavy, throbbing, awkward, burning or other).

To evaluate the appealingness of these systems, Hassenzahl (2001) suggested the following items: Pleasant *versus* Unpleasant, Good *versus* Bad, Aesthetic *versus* Unaesthetic, Inviting *versus* Rejecting, Attractive *versus* Unattractive, Sympathetic *versus* Unsympathetic, Motivating *versus* Discouraging and Desirable *versus* Undesirable.

4.5. Immersion and Presence

Two additional dimensions can be specified to evaluate the BCI videogames: immersion and presence. Each of these dimensions has led to many definitions (*e.g.*, (Witmer and Singer, 1998; Brockmyer et al., 2009)). The following definition remains the most comprehensive: immersion corresponds to the degree with which the system interface controls the sensory inputs for each modality of perception and action. So, immersion can be described (but not only) in terms of specific devices: a common dichotomy derives from the opposition of "*immersive*" systems (Head Mounted Display, Cave Automatic Virtual Environment) and "*non immersive*" systems (desktop, mouse).

According to Sanchez-Vives and Slater (2005), immersion determines the sense of presence perceived by users through display parameters, visual realism, sound, haptics, virtual body representation and body engagement. The International Society for Presence Research (2000) ruled that presence is "*a psychological state or subjective perception in which even though part or all of an individual's current experience is generated by and/or filtered through human-made technology, part or all of the individual's perception fails to accurately acknowledge the role of the technology in the experience*". In others words, the sense of presence is experienced when the place illusion (*i.e.*, the sensation of being in a real environment) and the plausibility illusion (*i.e.*, the feeling that the virtual scenario is actually occurring) occur (Slater, 2009).

These links between immersion and presence appeared in the literature: immersion has been studied in the context of many studies on BCI and virtual environment. For example, an immersive environment can improve the sense of presence while carrying out navigational tasks through imaginary movements (Lotte et al., 2013). Donnerer and Steed (2010) observed that P300 can be used successfully in immersive virtual environments and Groenegress et al. (2010) proved that P300 based navigation lowered the sense of presence compared to gaze-based navigation.

In the field of BCI, this dimension was evaluated in some studies. For example, Hakvoort et al. (2011) conducted a study with 17 participants aiming to measure immersion in a BCI videogame named "*Mind the Sheep!*". Their experiment consisted in two different sessions: a BCI session and a non-BCI session. Each session was divided into three trials: a familiarity trial (*i.e.*, participants had to collect 10 objects which were placed across the playground), an easy trial (*i.e.*, participants had to park a small flock of 5 sheeps using the dogs) and a difficult trial (*i.e.*, participants had to gather 10 sheeps, which were more scattered across the playground, into one pen that was placed in the centre of the playground). After each session participants filled in a questionnaire on their perceived immersion in the videogame. The 31 questions dealt with cognitive involvement, emotional involvement, real world dissociation, challenge and control. Results showed that the BCI selection method was more immersive than the non-BCI selection method (*i.e.*, a mouse).

To measure immersion and presence during a videogame, Witmer and Singer (1998) designed a questionnaire which was used in numerous studies. In their approach, these authors evaluate the presence according to four categories that we adapted below for BCI videogames:

- The control factors correspond to the degree of control that a person has in playing with a BCI videogame, the immediacy of control (*i.e.*, the delay between the action and the result), the anticipation concerning what will happen next, whether or not it is under personal control, the mode of control (*i.e.*, the manner in which one interacts with the environment is a natural or well-practiced method) and the physical environmental modifiability (*i.e.*, the ability to modify physical objects in an environment)
- The sensory factors are the sensory modality (*i.e.*, visual information and other sensory channels), the environmental richness in term of information, the multimodal presentation to simulate completely and coherently all the senses, the consistency of multimodal information, the degree of movement perception (*i.e.*, the observer must perceive self-movements through the virtual environment) and the active search (*e.g.*, the observers can modify their viewpoints to change what they see),
- The distraction factors correspond to the isolation from the used devices (*e.g.*, head-mounted display), the selective attention (*i.e.*, the observer’s willingness or ability to focus on the videogame stimuli and to ignore distractions) and the interface awareness,
- Realism factors are the scene realism governed by scene content, texture, resolution, light sources, field of view and dimensionality, the consistency of information with the objective world, the meaningfulness of experience for the person and the anxiety/disorientation when users return from the videogame to the real world.

4.6. User experience

User experience is a consequence of an interaction between a user (with his characteristics) and a product (with its features and qualities) appearing after an evaluation process (Hassenzahl, 2001). The user experience is defined by the perceived usefulness, usability, hedonic quality, appealingness and the sense of presence and the emotional reactions. The emotions arise from subjective feelings, physiological reactions, motor expressions and cognitive appraisals (Mahlke et al., 2006):

- Subjective feelings can be evaluated and measured by the "*Self-Assessment Manikin*" defined as "*a non-verbal pictorial assessment technique that measures the pleasure, arousal, and dominance associated with a person's affective reaction to a wide variety of stimuli*". Pleasure is measured by the following items: Unhappy *versus* Happy, Annoyed *versus* Pleased, Unsatisfied *versus* Satisfied, Melancholic *versus* Contented, Despairing *versus* Hopeful and Bored *versus* Relaxed. Arousal is measured with these adjectives: Relaxed *versus* Stimulated, Calm *versus* Excited, Sluggish *versus* Frenzied, Dull *versus* Jittery, Sleepy *versus* Wide-awake and Unaroused *versus* Aroused. Dominance is measured with items: Controlled *versus* Controlling, Influenced *versus* Influential, Cared for *versus* In control, Awed *versus* Important, Submissive *versus* Dominant and Guided *versus* Autonomous.
- Physiological reactions can be estimated from peripheral (*e.g.*, muscle tension, heart rate, electro dermal activity), and central nervous system signals (*e.g.*, electroencephalogram) (Mühl, 2009),
- Motor expressions can be measured with electromyography of the two facial muscles associated with positive emotions (*zygomaticus major*) and negative emotions (*corrugator supercili*),
- Cognitive appraisals can be measured by the "*Geneva Appraisal Questionnaire*" which measures five appraisal dimensions: intrinsic pleasantness (*i.e.*, a stimulus event is likely to result in a positive or negative emotion), novelty (*i.e.*, a measure of familiarity and predictability of the occurrence of a stimulus), goal/need conductiveness (*i.e.*, the importance of a stimulus for the current goals or needs), coping potential (*i.e.*, the extent to which an event can be controlled or influenced), and norm/self-compatibility (*i.e.*, the extent to which a stimulus satisfies external and internal standards).

The user experience has been often evaluated in the context of BCI videogames. The user experience resulting from these technologies has been measured by its perceived usability, its hedonic quality, its appealingness and the sense of presence. Some studies on user experience in BCI and videogames are conducted to compare the user experience resulting from the use of different controllers (*e.g.*, BCI, mouse) and to understand the added-value relating exclusively to BCI control (Gürkök et al., 2013), or to find the differences between real and imagined movement in a BCI videogame in relation to user experience and performance (Plass-Oude Bos et al., 2010) using a user experience based on the Game Experience Questionnaire (Ijsselsteijn et al., 2013).

These studies are focused on the comparison of user experience according to paradigms and interaction devices, only in the videogame field. Thus, user experience was evaluated with a specific questionnaire dedicated to game experience.

4.7. Competition and collaboration, two relevant criteria for multi-brain videogames

In the entertainment area, some multi-brain videogames begin to appear (Figure 2): each player uses a BCI (*e.g.*, Bonnet et al., 2013).

Figure 2: Two users playing BrainArena in a competitive trial.

For these specific BCI videogames, it is important to provide and measure competition or collaboration (Nijholt and Gürkök, 2013). In multi-brain videogames providing competition, two players compete using their brain until one of them is the winner and the other is the loser, *e.g.*, (Hjelm and Browall, 2000). For example, in the "Brainball" game (Hjelm and Browall, 2000), two players have to compete by relaxing, their performance is measured by EEG, their brain activity is compared and the difference determines the direction of the ball (*i.e.*, moving into the direction of the player who is less relaxed).

In multi-brain videogames promoting collaboration, Pope and Stevens (2012) suggest to distribute the control of the input devices among the two players, *e.g.*, one player acts physically while the other uses his/her brain. According to Nijholt and Gürkök (2013), the evaluation of the collaboration level requires several metrics such as the tasks' repartition and the number of social interactions between the two players, and has to integrate the environmental context, *e.g.*, Are players co-located or distributed? Is there an audience? What does the audience see and is there any interaction between the audience and the players?

5. Discussion

Our framework suggested specific methods to be used to define and measure specific criteria (Figure 3). Overall our framework highlighted that usefulness, usability and acceptability are criteria that need to be considered both to identify and to anticipate user needs (*i.e.*, contexts of use and features) through interviews and focus group. These criteria have also been integrated in the evaluation phase to assess both intermediate solutions (*e.g.*, prototypes) with user based tests associated with questionnaires, and the system's appropriateness by conducting longitudinal studies. In the same way, our framework stressed that hedonic qualities, appeal, immersion and presence, emotions and more generally user experience also need to be measured in the evaluation phase through user based tests and questionnaires. Moreover, this framework recommended specific metrics associated with each ergonomic criterion. For example, in a questionnaire or in an interview's grid, some questions can allow to evaluate usability (*e.g.*, the degree of complexity), usefulness (*e.g.*, the order of priority of the suggested functions), acceptability (*e.g.*, the intention to use the system in the next 4 months), hedonic quality (*e.g.*, the degree of boredom), appeal (*e.g.*, the degree of appeal), emotion (*e.g.*, the degree of arousal), immersion and presence (*e.g.*, the degree of provision of visual aspects).

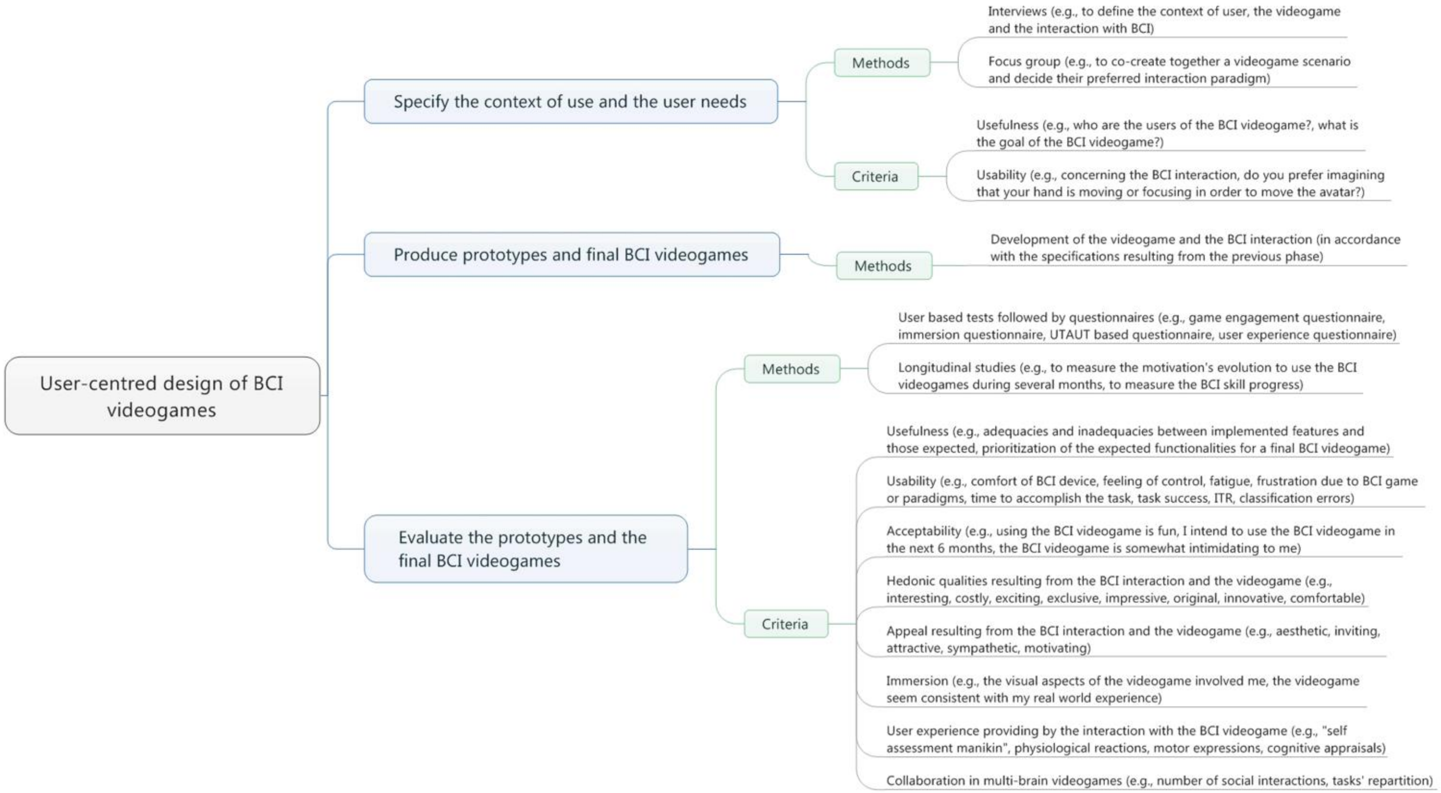

Figure 3: Methodological framework for the user-centred design of BCI videogames

The studies concerning the design of user-centred BCI videogames are uncommon compared to studies aimed to optimise the performance of these applications. One possible reason may be that research on BCI videogames requires technological developments before players can be confronted with the system in an actual context of use. However, integrating players from the early design phase to the use of application is necessary to design applications which will be suitable. Despite this, very few papers have focused on the methods, criteria and metrics for the ergonomic design of BCI videogames.

Concerning the studies on user-centred design of BCI (and not specifically BCI videogames), this chapter highlighted three observations. First, these studies concerned mainly the evaluation phase, *i.e.*, the evaluation of prototypes and of the appropriateness of applications (*e.g.*, (Nijboer et al., 2010)), to the detriment of the early design phase aiming to understand the context of use or to specify the user needs (*e.g.*, (Blain-Moraes et al., 2012)). Second, the majority of studies used only one method: the user based test is mainly used to evaluate the usability (*e.g.*, (Valsan et al., 2009)) and the usefulness (*e.g.*, (Yan et al., 2008)) ; the focus group to characterise the acceptability (*e.g.*, (Blain-Moraes et al., 2012)) and the questionnaire is used to measure the user experience (*e.g.*, (Van de Laar et al., 2011)) and, in longitudinal studies, to assess the application's appropriateness (*e.g.*, (Nijboer et al., 2010)). Third, the assessments of BCI videogames focused on a single criterion which was mainly the usability (*e.g.*, Holz et al., 2013; Gürkök et al., 2014) at the expense of other criteria such as immersion, presence (*e.g.*, (Hakvoort et al., 2011)) or usefulness (*e.g.*, (Yan et al., 2008)).

To overcome these observations, our framework suggests three guidelines. The first guideline insists on all phases of the user-centred design process for which ergonomics is equipped: understanding and specifying the context of use (phase 1), specifying the user needs (phase 2), evaluating the prototypes and assessing the appropriateness of applications (phase 4). Indeed, involving players from the identification of needs before the implementation of the application to the application's use allows designers to integrate the evolution of characteristics, needs and expectations of players. Our methodological framework is comprehensive in that it deals with every phase of the process, and not only the evaluation phase partially covered in the literature of human-computer interaction. The second guideline concerns the necessity to use several methods: interview and focus group to define specifications based on players' needs, user based testing, questionnaire and longitudinal studies to evaluate the BCI videogames. Indeed, using several ergonomic methods to study a criterion is advisable because they provide complementary data. Our methodological framework suggests implementing at least two methods to evaluate the same criterion. For example, to evaluate the usefulness of a BCI videogame, it is desirable to achieve (1) quasi experimentation-based longitudinal studies (*i.e.*, comparison between a group that uses the application and another group that does not use it, for a period of several months), and (2) after-use questionnaire tests with questions on the intention to use the BCI videogame in the future etc. The third guideline recommends defining and measuring several ergonomic criteria and underlines the importance of evaluating one criterion using several metrics. Indeed, designing a technological system suited to the end-user implies integrating several criteria and not just one: typically, a usable BCI videogame cannot be used if it is not useful for its players. The methodological framework incorporates several ergonomic criteria such as usefulness, usability, acceptability, hedonic qualities, appeal, immersion and presence, emotions and user experience, and several metrics for each of them.

6. Conclusion

The analysis of the BCI applications literature suggested that current evaluations of BCI videogames are mainly technocentric in order to technically improve the BCI videogames before using them in real contexts of use. However, some recent works tend to show the need to include characteristics, expectations and requirements of users in early design phases. To do so, methodological guidelines, from literature on ergonomics and human-computer interaction, are necessary.

In this paper, a user-centred methodological framework was proposed to guide the designers of BCI videogames so that the games are adapted to human characteristics, to the players' needs and to the context in which these applications will be integrated (*e.g.*, at home, in a classroom, during a medical consultation). For each user-centred design phase, our framework discussed methods, criteria and metrics to guide designers in the design and evaluation of the usefulness, usability, acceptability, hedonic qualities, appealingness, immersion and presence, emotions and more generally user experience associated with BCI videogames for therapy, learning or entertainment.

The implementation of this methodological framework to design and evaluate numerous BCI videogames could suggest several research perspectives. A first perspective could be to assess empirically the potential of a user-centred methodological framework, comparing one BCI videogame resulting from a technocentric design process (*i.e.*, as traditionally implemented to develop these applications) and an application resulting from a design process based on the user centred framework. A second perspective could be to improve the framework with the empirical results using it to design applications for different scopes (*e.g.*, BCI videogames for learning). An example of results could be the enhancement of the metrics' database for the usefulness criterion that is highly dependent on the applications' scope. Because one conclusion of the massive use of this framework could be a partial use depending on the application, a third perspective would be to develop a tool to assist in the decision-making concerning the selection of methods, criteria and metrics according to the scope of the application.

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Cross-references

BCI and player experience

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Keywords

Brain-Computer Interface; Videogame; Ergonomics; User-Centred Design; Evaluation