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Using Virtual Reality to Assess User Experience

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Objective: The aim of this article is to discuss how user experience (UX) evaluation can benefit from the use of virtual reality (VR).

Background: UX is usually evaluated in laboratory settings. However, considering that UX occurs as a consequence of the interaction between the product, the user, and the context of use, the assessment of UX can benefit from a more ecological test setting. VR provides the means to develop realistic-looking virtual environments with the advantage of allowing greater control of the experimental conditions while granting good ecological validity.

Method: The methods used to evaluate UX, as well as their main limitations, are identified. The current VR equipment and its potential applications (as well as its limitations and drawbacks) to overcome some of the limitations in the assessment of UX are highlighted.

Results: The relevance of VR for UX studies is discussed, and a VR-based framework for evaluating UX is presented.

Conclusion: UX research may benefit from a VR-based methodology in the scopes of user research (e.g., assessment of users' expectations derived from their lifestyles) and human–product interaction (e.g., assessment of users' emotions since the first moment of contact with the product and then during the interaction).

Application: This article provides knowledge to researchers and professionals engaged in the design of technological interfaces about the usefulness of VR in the evaluation of UX.

Keywords: user experience, virtual reality, virtual environments, technological interfaces, context of use

INTRODUCTION

The emergence of interactive technological products is accompanied by very explicit attention to user experience (UX). This trend is directing as well as engaging the industry and the scientific community's attention to the subject of UX. Despite its importance, a clear universal definition of UX is still missing. As stated by Hassenzahl (2004), today, this area can be seen as an umbrella used to motivate human–computer interaction research to focus on aspects that are beyond usability and task-oriented instrumental values. In fact, both concepts are often corresponded, however; although bad usability can aggravate human performance, good usability may be insufficient to create a good UX.

New trends recommend that the human factors' contribution to design should include the users' affective needs (Khalid, 2006). Most approaches on usability tend to underestimate the influence of emotions; however, the product's aesthetic appeal, as well as the pleasure and the satisfaction offered to the user, determines products' success in the market (Helander & Khalid, 2006).

Considering that UX occurs as a consequence of the interaction between a user and a product within a physical, social, and cultural context, researchers must be aware that, depending on the context at hand, users can have different experiences with the same product. Therefore, the ability to find and create adequate contexts is a huge challenge. However, this matter is not easily controlled in laboratory settings. For instance, more-elaborate experimental situations intended to increase a study's ecological validity may increase costs (time and money) and can result in a loss of experimental control. Furthermore, keeping the researcher and confederates' verbal and nonverbal behaviors under strict control is extremely difficult, if not impossible, to accomplish.

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In this context, virtual reality (VR) can assist in this problem by enabling the creation of realistic-looking virtual environments (VEs) with the advantage of providing greater control of the experimental conditions while granting good ecological validity. Another advantage of VR is the availability of avatars and/or embodied agents, which can assume the researcher's or confederate's role but with rigorously controlled behavior. In addition, with VR, near-exact replications of studies are possible.

First, we present the concept of UX and the most important methods and tools used to evaluate it. Second, the concept of VR, as well as its advantages and problems, is presented. Finally, a framework whereby VR can be used to assess UX is presented.

UX

Most definitions of UX include the user's qualitative experience while interacting with a product (McCarthy & Wright, 2004). The ISO 9241-210 definition goes farther in that UX focuses not only on the user's responses during the interaction (e.g., subjective evaluations and action tendencies) with a product but also on the reactions (e.g., physiological reactions) that occur during the interaction (International Organization for Standardization, 2010). Since these responses and reactions are affected by the user's expectations, beliefs, preferences, perceptions, feelings and emotions, and accomplishments, evaluators of UX should adopt methodologies that allow one to understand all of these aspects.

With such a wide-ranging view of UX, researchers are encouraged to consider a global perspective of UX that integrates the role of the product in the user's life. For example, the interaction with a particular product, such as a mobile phone, can be, occasionally, the most significant activity in the user's life, for example, when one receives a text message letting one know that one's baby has been born or that one has been promoted. Nevertheless, the interaction with this same product in another context assumes a less important meaning regarding the user's needs and desires, for example, when one receives a text message from one's cable TV provider offering product service.

The importance of UX differs according to the type of product as well as its intended use. Some products are developed with no expectation of forming a good customer relationship, whereas others are designed to provide an excellent UX. For example, with a disposable product, a user expects only a short-term effectiveness of its design that does not involve any strong emotion. In other cases, users expect not only the product's efficiency, that is, its ability to be easily learned and used, but also its attractiveness, challenge, enjoyment, and in some cases, its capacity to create status. In this context, UX is not only related to the product's attributes but is dependent on the user's requirements.

Designers who wish to extend a product's quality beyond its functionality, usability, and safety features (i.e., to meet the user's needs and thus make their designs more competitive in a global market) must also take into account aspects such as pleasure and appeal (Jordan, 2000) as well as emotion (Nagamachi, 2002). In this context, other factors, for example, apparent usability (i.e., the user's prior perception about a product's use; Kurosu & Kashimura, 1995; Tractinsky, 1997) and affective quality (i.e., a product's capability to elicit affective responses; Slovic, Finucane, Peters, & MacGregor, 2002) may be taken into consideration. For example, Seva, Gosiaco, Santos, and Pangilinan (2011), in a study involving mobile phones, have investigated to what extent product attributes (e.g., shape), during the design evaluation process, significantly contribute to affective quality, apparent usability, and desirability and found that product attributes related to shape are relevant in eliciting intense affect as well as perception of usability. The quality or accuracy of such assessments is not necessarily good since they may be prone to bias; however, they are still relevant because they may lead to irrational or impulsive behavioral actions (i.e., purchase).

It is worth mentioning that these evaluations are made when the product is seen for the first time, even before purchase (Khalid, 2006), and are based on feelings, which in turn are supported by related experiences with or collected information on similar products. Therefore, as argued by Forlizzi and Battarbee (2004), the

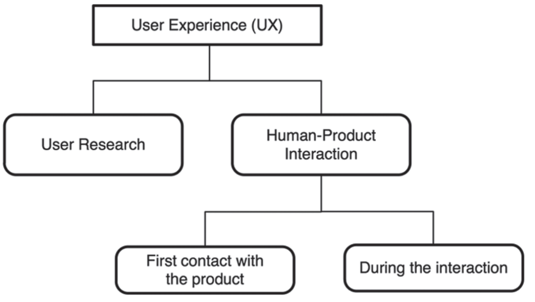

Figure 1. User experience dimensions.

UX is a dynamic process that takes place in the present, and it reshapes the experience and the user's future expectations.

Cultural aspects can also affect UX. Gorini et al. (2009) investigated the role played by the user's cultural and technological background in the emotional responses to VR. They analyzed the effects of being exposed to a relaxing, noninteractive, immersive VE (i.e., a mountain landscape around a calm lake) for the entire length of an ambulatory surgical operation. The effects were compared across two samples of participants characterized by vastly different cultural and technological backgrounds (i.e., inhabitants from a rural village, characterized by a very primitive culture, vs. highly civilized city inhabitants). Although the VR exposure produced positive relaxation effects on both groups, differences were found in physiological and psychological effects. More specifically, the urban sample reported a significant reduction in the self-reported level of anxiety, whereas the rural sample showed a reduction in physiological reactions but not in perceived anxiety.

In summary, UX includes the user's reactions and responses during the interaction with a product, from the moment one is confronted with it to the moment one is using it in a certain context. The emotional reactions and behavioral responses are dependent on the user's expectations and hence are strongly related to the user's cultural background and lifestyle. Figure 1 shows these two dimensions of UX: user research and human–product interaction. The main objective of the user research dimension is to determine the user's expectations through consideration of one's needs and lifestyle framed in a specific sociocultural context. The human–product interaction dimension may take place in two moments: the first contact with the product and during the interaction.

UX Evaluation Methods

Traditionally, product design mainly focuses on usability, which translates into usable, safe, effective, and comfortable interactions that are easy to learn and have a low level of error occurrence. The evaluation of these aspects can be achieved by observing and measuring the performance of users while they interact with a product, for example, by measuring parameters such as time to accomplish a task, number of errors, time to repair an error, and time to learn. Together with these performance parameters, the affective responses elicited by the product are also very important aspects to be considered, since the interaction should be enjoyable, engaging, and appealing (Jordan, 2000; Norman, 2004). Generally, these characteristics are based on a user's emotional state, which in turn is related to an emotional response involving a subjective experience and behavior (Gross, 2007; Larsen & Prizmic-Larsen, 2006). It is important to mention that users' responses are context dependent and dynamic over time (Law, Roto, Hassenzahl, Vermeeren, & Kort, 2009). The context can cause users to create expectations that may influence the UX with the product. In this scope, the user research dimension assumes a major role in UX.

The user research domain consists of understanding the user's expectations, needs, beliefs, and preferences. In the evaluation of this dimension, the most commonly used methodologies comprise ethnographic studies (e.g., Obrist, Bernhaupt, & Tscheligi, 2008; Tsekleves, Whitham, Kondo, & Hill, 2011), and their main objective is to assess how people interact with technology and their experiences. In the UX field, the investigation protocols are based on the observation of how and why people use their devices at home, workplaces, and public spaces. To obtain data fairly accurately, such studies should be developed across an extended period of time (Fetterman, 1998).

Regarding the human–product interaction dimension, several tools and methodologies have been used to evaluate aspects of UX that are activated by a product's attributes. Most of these tools measure the emotions experienced, the reactions to the product's appearance, and/or the sensory experience. These methods are related to prewired responses that are associated with specific patterns of bodily activation and expressive behavior, namely, facial expressions and feelings (Ekman, 1994). Scherer (2005), on the other hand, considers emotions as episodes of coordinated change according to five components: cognitive (appraisal), behavioral (action tendencies: approach or avoidance), expressive (facial and vocal expressions), physiological (autonomic activity), and subjective (feelings).

Most tools are based on subjective parameters and measure only one dimension of these components, often related to feelings or expressive behavior. Questionnaires usually measure the subjective feeling component of emotion and, for such a purpose, make use of a set of rating scales or verbal protocols. In such cases, the specialist provides the participants with standardized lists of emotion labels, with distinctive answer formats, to obtain information on the qualitative nature of the affective state experienced. The disadvantages of this procedure are associated with the probability that the participant is not familiar with some of the labels and/or that he or she may want to respond to a category that is not provided on the list. To avoid such problems, some researchers use protocols with a free-response format, requesting participants to choose a short expression that, in their opinion, best describes the nature of the state they experienced. The main limitation of this procedure is the individual differences in the variety of the vocabulary, which may restrain the responses of some participants. To avoid this problem, Laurans and Desmet (2008) used the Geneva Emotion Wheel (Scherer, 2005), which includes 20 emotion families, to evaluate affective responses regarding two consumer products.

A major limitation common to these tools is that they were developed to assess only the sensory experience after static exposure to a product, thus making it difficult to measure emotion over time, that is, during the interaction with the product. To control this limitation, Laurans and Desmet (2006) have proposed the self-confrontation method, which enables the collection of extended data on UX without interfering with the interaction. Another option could be the use of nonverbal instruments that measure either the expressive behaviors or the affect-related physiological activity.

The expressive behavior reaction (postural, vocal, and facial) is based on the assumption that each emotion is associated with a particular pattern of expression (Ekman, 1994). Facial behavior expression tools are based on the Facial Action Coding System (Ekman, Friesen, & Hager, 2002) and the Maximally Discriminative Facial Moving Coding System (Izard, 1979), which link expression types to different emotions. Regarding this subject, Kaiser and Wehrle (2001) have proposed a tool to measure facial visible expressions. Facial electromyography activity can also be used to provide information about the facial muscle activity associated with some emotional patterns (Nacke, Grimshaw, & Lindley, 2010). The main disadvantage of this type of method is the difficulty in recognizing subtle facial expressions.

Full-body behavior action measures offer insights on the interaction with a product and therefore can reflect a UX. Some body language, such as moving attention away from a product, physically moving toward a product, or noticing a specific element, can be observed and registered. In this area, Rebelo, Filgueiras, and Soares (2011) developed a video-based system whereby it is possible to define behavioral action categories and to register them while observing a video.

Vocal tools are based on theories that connect patterns of vocal cues to emotions (Johnstone & Scherer, 2001). These instruments measure the effect of emotion in multiple vocal cues, such as voice quality, articulation, speaking rate, intensity, pitch changes, and average pitch.

A considerable amount of research has focused on affect-related physiological activity measures, which are used to determine the affective response from users while they interact with a product. These include heart rate and heart rate variability, blood volume pressure, skin conductance, and electromyograms. Elevated arousal emotions will cause an intensification of the heart rate and will result in higher levels of skin conductivity variability. Heart rate variability contains information regarding vasoconstriction, which has been used to differentiate defensive reactions, such as fear, from offensive reactions, such as anger (Ekman, Levenson, & Friesen, 1983; Kahneman, 1973; Levenson, 1992). A diversity of wearable sensors designed by the Affective Computing Group at the Massachusetts Institute of Technology (Picard, 2000) have been used to gather multiple physiological signals while a person is experiencing an emotion.

The main advantage of these nonverbal instruments is that they measure objective parameters that are more “clean” when compared with subjective data obtained with self-report instruments. They are also less invasive and do not disturb participants in a significant manner during the interaction. Another advantage is that they are language independent; thus they can be used in different cultures. Nevertheless, working with these methods requires expertise and skill, and the data analysis is not trivial. Finally, these tools and proposed methodologies are typically used in laboratories, and consequently, the user’s behavior and perceptions may be influenced. As stated by Arhippainen and Tähti (2003), the context of interaction influences the user’s behavior.

Two psychology studies demonstrate, in a simple manner, that context changes people’s judgments. Dunn and Searle (2010) demonstrated that females’ decision about males’ attractiveness was influenced by the type of car that the men drove. The study participants were asked to rate the attractiveness of a young man sitting in a car, presented in a photograph. Half of the sample saw the man seated at the wheel of a Ford Fiesta (neutral-status motorcar), whereas the other half saw the man seated at the wheel of a Bentley Continental (high-status motorcar). Results showed that the man was rated as significantly more attractive when seated in the high-status motorcar (Bentley Continental) rather than the neutral-status motorcar (Ford Fiesta). In a second study, involving an affective priming task, evidence was found that an attractive face associated with a product can positively enhance its evaluation (Strick, Holland, & van Knippenberg, 2008).

In brief, the first study indicated the influence of a product on a person’s judgment (attractiveness rating), and the second one showed the influence of an individual (face) on a product judgment. The contexts in both of these studies involve spatial closeness to the objects and are represented by the car in the first study and by the face in the second one. These results highlight the extent to which context can influence a user’s opinions about a product and, at the same time, that the same user can have very different experiences with the same product, depending on multiple factors that are not product related. Furthermore, some contexts can be very difficult to recreate in a laboratory, which thus limits the access to valid experimental setups. VR, because of its characteristics, and when framed in adequate methodologies, can be useful in creating and controlling contexts of use that can represent real-life situations while assuring ecological validity, which is a key aspect in the evaluation of UX. In the following section, we discuss how VR is pushing the boundaries of the digital experience closer to a real interaction with a technological product.

VR

In a very broad sense, VR is a way of transporting a person to a reality (i.e., a virtual environment) in which he or she is not physically present but feels like he or she is there. According to the official encyclopedic definition, VR is

> the use of computer modeling and simulation that enables a person to interact with an artificial three-dimensional (3D) visual or other sensory environment. VR applications immerse the user in a computer-generated environment that simulates reality through the use of interactive devices, which send and receive information and are worn as goggles, headsets, gloves, or body suits. In a typical VR format, a user wearing a helmet with a stereoscopic screen views animated

images of a simulated environment. ("Virtual Reality," n.d.)

Burdea and Coiffet (2003) suggest that to ensure that participants feel involved in VR, three features are required. The authors call these criteria the VR triangle, in which the three vertices—interaction, immersion, and imagination—are interconnected in a systemic manner.

The VR Triangle

Interaction. Interaction (or interactivity) is communicated and connected with and between the user and the VR system. The capacity for detecting user motions and actions (user inputs) and refreshing the VE according to those inputs defines interaction (Rebelo, Duarte, Noriega, & Soares, 2011). Some of the main devices used for real-time interactivity are motion trackers and sensing gloves. These devices have embedded sensors that allow the computer to measure the real-time position of the user's hands (and sometimes wrists) as well as to register the bending of fingers, thus allowing natural gesture-recognition-based interactions to take place.

The gloves are mainly required for tasks involving the manipulation of objects. In spite of recent technological advances, the main drawbacks of these sensing gloves include the lack of tactile and/or haptic feedback, the need for a specific calibration for each user, and the difficulty in accommodating different hand sizes. For example, some gloves have devices that vibrate when the fingers are close to the objects with the intention of providing the user with the impression of having touched the virtual objects. The feeling of touching and grabbing simulated objects can be supplied by gloves equipped with a force feedback armature that conveys realistically grounded forces to the hand and arm and offers six-degrees-of-freedom tracking that accurately measures the translation and rotation of the hand in three dimensions. To enable tracking of movements of all body segments, there are solutions involving a set of sensors worn on a Lycra suit. These motion-capture suits, together with the VR gloves' sensors, allow the user to dislocate through the virtual world as well as to interact with the objects in a naturalistic manner.

Immersion. Immersion is associated with the feeling of being inside a VE. If one considers that information is processed predominantly by the auditory and visual senses, then what one sees and hears is very important to feeling immersed. Gutiérrez, Vexo, and Thalmann (2008) classified the types of immersion on the basis of the physical configuration of a VR user interface: fully immersive (head-mounted displays [HMDs]), semi-immersive (large projection screens), and nonimmersive (desktop-based VR). The physical level of immersion depends on how much of the real world the user can perceive. Thus, the lower the perception (see, hear, touch) of the real world, the greater the classification of immersion in VR. In this context, several devices can be used for visualizing VEs. HMDs are used for visualizing the VE in an immersive manner, since they visually isolate the participants from the real world. Some of them offer stereoscopic vision. The major differences between them are related to the field of view (FOV), which can range from 30° to 180° horizontally and from 30° to 60° vertically. A motion tracker can be associated with HMDs to measure the position and orientation of the user's head. The main disadvantages associated with these devices are related to the limitations of the FOV, the low image resolution generated, and the weight of some HMDs, which can be a factor of discomfort and intrusiveness for the participants.

Another kind of device used for visualizing VEs is the "CAVE." The CAVE consists of a room in which the VE is projected onto its walls and eventually its floor and ceiling. These environments are considered semi-immersive and can also be stereoscopic. The CAVE's main disadvantages are the high cost of the equipment and the limited space available for walking inside the room. Alternatively, LCD displays, also known as desktop-based VR, can be used to visualize the VE. Since such displays are nonimmersive, it is more difficult to ensure the participants' immersion, since they can see the surroundings of the real environment. Regardless of the device used for visualization, sound always plays an important role in increasing the level of immersion because it helps to increase the simulation's realism and the user's feeling of immersion.

However, it is important to notice that for a sound to be effective, it must be synchronized with the events that occur inside the VE, and it must be stereophonic, that is, it must remain localized in space and time, even when the user turns his or her head or dislocates himself or herself along the environment, and provide distance or depth perception (Rudmann & Strybel, 1999).

Imagination. Imagination is related to the user's capacity to perceive nonexistent things and the will to believe that he or she is in the VE, even while knowing he or she is physically situated in another environment (Burdea & Coiffet, 2003). Thus, the interactivity and immersion levels experienced by the user directly affect his or her imagination, which in turn is dependent on the type of equipment used, the degree of realism of the VEs, the tasks to be performed while in the VE, and the user's motivation to participate in the simulation.

Presence. Another important concept associated with VR is presence. Presence is a subjective concept, experienced by the user, related to the psychological state of being in the VE. When the brain processes and understands multimodal stimulations (image, sound, etc.) as coherent environments, where it is possible to act and interact, there is presence. Thus, presence is achieved when the user, deliberately or not, becomes conscious of being in a VE (Gutiérrez et al., 2008). Witmer and Singer (1998) developed a questionnaire to evaluate presence, which they define as the subjective experience of being in one place or environment even when one is physically situated in another. Presence refers to experiencing the VE rather than the actual physical locale. The necessary conditions for experiencing it are involvement and immersion. According to these authors, *involvement* is "the psychological state experienced as a consequence of focusing one's energy and attention on a coherent set of stimuli or meaningfully related activities and events," and *immersion* is the "psychological state characterized by perceiving oneself to be enveloped by, included in, and interacting with an environment that provides a continuous stream of stimuli" (Witmer & Singer, 1998, p. 227). Even though a video game played on a standard home television is in a nonimmersive environment, it may lead, nonetheless, to high levels of involvement. Involvement is related to the user's concentration inside the VE; thus any factor distracting the user can affect his or her involvement.

VR ADVANTAGES, LIMITATIONS, AND DRAWBACKS

Ideally, the interaction with a VE should resemble a real-life situation with a high-fidelity level—enough to make the participants believe that they are actually present in it as well as to afford an ecologically valid experience. However, current VR systems do not yet provide that level of verisimilitude and have limitations, mainly, adverse consequences associated with motion sickness and aftereffects, which in turn may lead to negative experiences, shorter duration exposures, and increased dropout rates.

VR Advantages

The advantages of using VR for research can be grouped into three main topics: availability, safety, and data provision.

Availability. VEs provide access to almost all locations, in specified environmental conditions and in a repeatable and systematic manner, without the time and the costs associated with a real-life setup. Furthermore, VR offers the possibility of allowing people with disabilities to participate in studies.

Safety. With VEs, research participants are able to experience the environment and interact with all sorts of products in a safe manner, even when exposed to controlled critical conditions. This advantage is relevant mostly when participants are required to interact with hazardous products and/or environments that may involve risk of injury, for themselves or for others, and property damage. For example, to evaluate UX with cars, or other motorized vehicles, participants may drive such vehicles in all sorts of road environments, in unfavorable weather conditions and/or at different speeds, without suffering or inflicting injuries as a result of their driving (e.g., crash, running over). Another example is the interaction with chemical products (e.g., household cleaners, pesticides), which can be handled safely without placing the participants' health and/or environment in danger.

In addition, VR eliminates the consequences and social effects of mistakes and errors, which are common during practice trials. For example, in the medical field, simulated surgeries may help surgeons learn and practice their techniques without hurting the patients. In the military field, simulated maneuvers allow soldiers to train in rescuing hostages without casualties. Moreover, some situational aspects that can affect participants' performance and the quality of UX, such as mental workload or induced stress, can be manipulated in a more accurate manner than would be possible in real-world situations. Therefore, with VR, UX can be studied in emergency situations (e.g., fire egress, terrorist attack) that otherwise would not be possible.

Data provision. VEs provide the opportunity to collect data from the early stages of the design process with a high accuracy and good ecological validity that are not easily available in real-life settings.

VR Limitations and Drawbacks

Most of VR's limitations and drawbacks are associated with the technology available, as mentioned earlier in this article. However, since a number of devices with different degrees of technological sophistication are available in the market, the severity of the inherent limitations depend on the quality of the technology that one can afford for undergoing such research and on the study's requirements. Nevertheless, it is expected that the majority of these limitations can be solved in the next few years.

Although VR technology is developing rapidly, its progress may be hampered by the side effects experienced by participants, which raises concerns regarding their health and safety as well as VR's overall effectiveness. Different VR devices and VEs may give rise to several symptoms of differing severity. Cobb, Nichols, Ramsey, and Wilson (1999) propose the term *virtual reality induced symptoms and effects* (VRISE) to distinguish cybersickness (CS) from simulator sickness (SS) and motion sickness (MS) associated with transportation. VRISE includes a variety of symptoms, ranging from vomiting, nausea, and disorientation to eyestrain or blurred vision as well as postural instability, which can occur both during and after participating in a VR simulation. Although the exact causes of VRISE are not always clear, its occurrence may be influenced by a large number of factors that involve technological issues (e.g., delay, limited sensorial cues), system design (e.g., user control strategies and scene content), and individual differences (e.g., age, gender, individual susceptibility), which are briefly addressed in the subsequent paragraphs.

Technological issues and display delay. People expect that whenever they move, the visual environment instantly changes accordingly, but in many VR systems, there is a temporal delay (e.g., update rates, processing times) between the participant's input (e.g., head movement) and the corresponding system's output (visual consequence on the scene displayed), which can lead to a sensory conflict, resulting in SS. However, results regarding the effects of delay on SS are inconsistent. DiZio and Lackner (1997) show that SS increases as a function of delay during an HMD-based search task. Similarly, Jennings, Reid, Craig, and Kruk (2004), who examined control and visual delays in helicopter HMD flight simulations, revealed that the addition of delays in both the control and the visual loops impaired the system-handling qualities and increased the magnitude of position maintenance error. In contrast, others have revealed no delay effects on SS (e.g., Draper, Viirre, Furness, & Gawron, 2001; Duh, Parker, Abi-Rached, & Furness, 2002; Moss et al., 2011; Moss & Muth, 2011).

FOV. The display FOV (DFOV) of an HMD is the FOV permitted by the physical dimensions of the display. Although restrictions in the FOV impair human performance (Toet, van der Hoeven, Kahrimanović, & Delleman, 2008), most previous research has suggested that the experience of SS is more prevalent with wider DFOVs (e.g., DiZio & Lackner, 1997; Seay, Krum, Hodges, & Ribarsky, 2001).

Immersion. In spite of the well-established importance of immersion on the quality of experience offered by the VR system, fully immersive HMDs (i.e., offering reduced vision or no vision of the external environment) have been found to be more sickening than less immersive systems, such as desktop VR. Moss and Muth (2011) assessed the effects of several display characteristics from diverse HMDs on SS and found that SS was greater when peripheral vision for the external environment was occluded than when it was not. Sharples, Cobb, Moody, and Wilson (2008) compared the prevalence and severity of VRISE symptoms across four display conditions (i.e., HMD, desktop, projection screen, and reality theater) with a controlled examination of viewing (i.e., active vs. passive viewing) and lighting (i.e., light vs. dark condition). They found increased reported symptoms with use of HMDs when compared with other display modes. No effect of lighting was found.

Furthermore, according to the postural instability theory of MS (Riccio & Stoffregen, 1991), a failure to maintain body control results in MS. It has been suggested that a light contact touch (e.g., touch of the fingertip) on a stable surface, in conjunction with proprioceptive signals about arm configuration, can strongly decrease postural instability and provide accurate body orientation information (Jeka & Lackner, 1995).

System design and navigation. The level of navigational control provided to the participants, the type of locomotion adopted, and navigational speed have been found to affect the levels of SS. Stanney and Hash (1998) found that complete control over the path of movement within the VE reduces the severity of CS symptoms when compared with a passive condition in which participants run a predetermined path of movement. Sharples et al. (2008) also found higher levels of reported symptoms in passive viewing when compared with active control over movement in the VE. Furthermore, Rolnick and Lubow (1991) found that when exposed to nauseogenic rotation, participants in control reported fewer MS symptoms than did participants playing the passive passenger role. Moreover, the levels of SS and the onset times of symptoms can be affected by the way in which participants explore the VE, as suggested by Howarth and Finch (1999), who investigated the nauseogenicity of two strategies for navigating within a VE (i.e., by head movement or by hand control). Results suggest an increased nauseogenicity when the head moved than when it was still. Similarly, Moss et al. (2011) found that users of HMDs with active head movements have increased SS.

An aspect that to some extent is related to the way participants explore a VE is the speed in which they navigate through it. So, Lo, and Ho (2001) found significant effects of navigation speed on the level of MS and on the onset times of MS symptoms.

Scene complexity. Visual scene complexity (e.g., rate of visual flow) has been found to influence both the incidence and severity of SS (e.g., Hettinger, 2002; Kennedy & Fowlkes, 1992; McCauley & Sharkey, 1992). Hettinger (2002) further suggested that the size of the visual field and the presence of movement in the background (i.e., periphery) influence vection. However, other studies failed to show a significant effect of scene complexity on SS (e.g., Pausch, Crea, & Conway, 1992; Stanney, Hale, Nahmens, & Kennedy, 2003). The presence of scene oscillation (i.e., compelling scene movements) made CS significantly increase when compared with no oscillation (Lo & So, 2001).

Exposure duration. Exposure duration has been found to affect the level of VRISE experienced. Longer exposures produce more symptoms of VRISE, but the total sickness tends to decrease after repeated exposures (e.g., Biocca, 1992; Kennedy, Stanney, & Dunlap, 2000; McCauley & Sharkey, 1992; Moss et al., 2011; Regan, 1995; Regan & Price, 1994; Stanney, Hale, et al., 2003). In previous research, a 20-min exposure increased VRISE symptoms in more than 60% of the participants, leading 5% of the participants to withdraw from the experiment before completing their 20-min immersion period (e.g., Cobb et al., 1999; Regan & Price, 1994). Nevertheless, by increasing the number of repeated exposures (habituation; e.g., Hill & Howarth, 2000; Howarth & Hodder, 2007), by providing frequent breaks, and by optimizing visual and vestibular cue fidelity, one can moderate this problem.

Age. Regarding age, toddlers (i.e., before the age of 2) seem to be immune to MS. Susceptibility increases until about the age of 12, at which point it declines again, with those older than 25 being half as susceptible as 18-year-old individuals (Golding, 2006). Although data on this topic are scarce, some authors suggest that elderly people might have an increased chance of suffering from SS (Arns & Cerney, 2005). Nevertheless, other studies have demonstrated that the use of VR with elderly people is quite feasible (e.g., Baños et al., 2011; Liu, Watson, & Miyazaki, 1999).

Gender. Literature reveals that females generally experience or report greater SS than males (e.g., Dobie, May, McBride, & Dobie, 2001; Kennedy, Lanham, Drexler, & Lilienthal, 1995; Kennedy, Stanney, Dunlap, & Jones, 1996; Stanney, Hale, et al., 2003). Biocca (1992) suggests that males might be reticent to report VRISE symptoms, but hormonal differences have also been considered as a possible explanation for such differences (Golding, 2006).

MS susceptibility. Some individuals are more susceptible to MS than others, and that susceptibility can be caused by individual factors, such as unstable binocular vision, individual variations in interpupillary distance, susceptibility to photic seizures and migraines, sensitivity to vection (Kennedy, Hettinger, & Lilienthal, 1990), drug and/or alcohol consumption, or overall state of health (Stanney et al., 1998). Previous exposures to provocative environments (e.g., simulators, roller coasters) influence susceptibility to SS (Stanney, Hale, et al., 2003). After repeated, intermittent, and short exposures to such environments, habituation may occur in which symptomatology decreases (McCauley & Sharkey, 1992), since individuals may learn adaptive behaviors that minimize adverse effects (Kolasinski, 1995). For a comprehensive review of the most important factors governing MS, see Golding (2006).

Fortunately, not everyone suffers from SS. Sharples et al. (2008) state that from data obtained from more than 200 participants, 80% of the participants across all experiments reported some experience of VR-induced symptoms. In addition, they reveal that 60% to 70% of the participants reported increasing SS symptoms, pre- to postexposure, for HMDs, projection screen, and reality theater viewing and higher reported symptoms in HMDs compared with desktop viewing (nausea symptoms) and compared with reality theater viewing (nausea, oculomotor, and disorientation symptoms).

Methods for Measuring VRISE

Subjective self-reports and questionnaires before, during, and after exposure as well as physiological measures are some of the most common methods for measuring VRISE. Cobb et al. (1999) used a combination of both types of method.

The Simulator Sickness Questionnaire (SSQ; Kennedy, Lane, Berbaum, & Lilienthal, 1993) is the most commonly used tool to assess SS. The SSQ consists of a checklist of 26 symptoms, each of which is designated in terms of degree of severity (*none, slight, moderate, severe*). The symptoms are grouped into three subscales (i.e., Nausea, Oculomotor Disturbances, and Disorientation) that help to better characterize CS. The final score, known as the Total Severity (TS) score, reflects the overall discomfort level.

The Motion Sickness Assessment Questionnaire (Gianaros, Muth, Mordkoff, Levine, & Stern, 2001) allows for measurement of MS as a multidimensional construct, since it differentiates MS symptoms according to four dimensions: gastrointestinal, central, peripheral, and sopite related. However, it may also be used to assess the overall experience of MS (total scores).

Shorter questionnaires are used to monitor the course of symptoms during exposure, for example, the Short Symptom Checklist, which is a short version of the SSQ (Cobb, Nichols, & Wilson, 1995); the Misery Scale (Wertheim, Ooms, De Regt, & Wientjes, 1992); or the Fast MS Scale (FMS; Keshavarz & Hecht, 2011). The FMS consists of a verbal rating scale, ranging from zero (*no sickness at all*) to 20 (*frank sickness*), which is responded to every minute instead of after the stimulus presentation. Participants are asked to focus on nausea, general discomfort, and stomach problems as well as to bear these parameters in mind when making their judgments. The potential effect of expectancy (i.e., the simple fact of expecting sickness to occur during the stimulus presentation) on the reliability of SS measurements—the occurrence of which was suggested by Young, Adelstein, and Ellis (2007)—can also be assessed. The Motion Sickness Susceptibility

Questionnaire (Golding, 2004), can be used to predict individual differences on MS.

In our opinion, although reliable, the evaluation of VRISE during exposure is limited by the fact that it distracts the participants from their task to focus on the symptoms and therefore disrupts immersion as well as interferes with the UX.

Physiological measures are one possible alternative to circumvent the questionnaires' limitations and can be monitored during and after immersion. Heart rate, salivary cortisol levels (e.g., Cobb et al., 1999; Kennedy, Drexler, & Kennedy, 2010), and postural stability (e.g., Cobb, 1999; Duh, Parker, & Furness, 2001; Mourant & Thattacherry, 2000) have been suggested as physiological measures related to SS. Postural stability, or postural equilibrium, refers to the individual's ability to maintain balance and postural control. Postural stability is usually measured with the use of floor-based tests, such as static postures (measuring how long a person can hold a static posture), and dynamic tests (monitoring the performance of a task, such as walking). These evaluations can occur before, during, and/or after exposure to a VR system (Kennedy & Stanney, 1996). Several studies reveal that postural instability precedes MS and may be reliable predictors of it (e.g., Smart, Stoffregen, & Bardy, 2002; Stoffregen & Smart, 1998; Villard, Flanagan, Albanese, & Stoffregen, 2008).

In summary, what is considered an effective and usable interactive VE poses new challenges, because traditional usability principles might not involve the unique characteristics of the VE, such as wayfinding quality, navigational techniques, object selection and manipulation, or the integration of visual, auditory, and haptic systems outputs. Furthermore, if the VE is not able to offer a relatively accurate representation of the real world, that is, have ecological validity, it might cause confusion and result in inappropriate behaviors. To help determine the VR system's quality, Stanney, Mollaghasemi, Reeves, Breaux, and Graeber (2003) suggest the Multi-Criteria Assessment of Usability for Virtual Environments system, which provides a structured approach for achieving usability in VE system design and evaluation.

In some cases, results from VR-based studies cannot be generalized because the VR systems' technological features and functionalities may interfere with the users' evaluation by either facilitating or hindering the interaction. For example, Yoon, Laffey, and Oh (2008) tested the impact that technology had on the user–system interaction and usability by comparing a web 2-D graphics system with an interactive 3-D graphics system used for product (i.e., furniture) demonstration and found that perceived usefulness and sense of presence both mediate the effect of the technology on usability outcomes, with a clear advantage for web 3-D.

Independent from a study's purposes, it is desirable that features of the VR system, as well as of the VE itself, do not prompt, among other aspects, discomfort or sickness in the users and, as a consequence, negatively affect their performance, presence, and enjoyment during the experiment. Moreover, since VRISE adversely affects the user in various ways, it is expected that depending on the level of sickness experienced, UX is negatively affected too. For example, Toet, van der Spek, and Houtkamp (2010) found that users suffering from CS misattributed their unpleasant feelings to the affective qualities of the VE. Performance, measured as the capability to execute, command, and control tasks, has been found to decline as MS develops. Dahlman, Sjörs, Lindström, Ledin, and Falkmer (2009) found that MS, induced by a rotating optokinetic drum, unfavorably affects short-term memory performance, and Muth (2009) found that exposure to severe uncoupled motion can degrade cognitive performance. As a consequence, outcomes related with dimensions of UX will be affected.

VR AS A TOOL FOR EVALUATING UX

VR can be used in both UX dimensions, that is, user research and human–product interaction. In both cases, the main advantage of using VR is that it offers the means to monitor the interaction, properly contextualized, while granting ecological validity.

1. In user research studies, VR can be used to gather insights on the users' needs and expectations. In this case, the users' behavior is evaluated during

the interaction with products and/or environments with accurate control.

2. Human–product interaction optimization focuses on UX evaluation with the use of a user-centered design (UCD) approach. In this case, the users' emotional reactions and/or behavioral responses are evaluated in controlled VEs.

VR in User Research Studies for UX Evaluation

UX is very much about expectations (Kraft, 2012). Expectations may depend on cultural differences, needs, preferences, and previous experiences and should be considered as a priority in the development of a product. Thus, designers of interactive systems must take into account how people use and understand new technology as part of their everyday activities and routines (Tolmie, Pycock, Diggins, MacLean, & Karsenty, 2002) in a given context of use (Hughes, O'Brien, Rodden, Rouncefield, & Viller, 2000). In the field of UX, ethnographic studies have been conducted to determine target users and their practices so that designers can use such information to better consider their needs in the design of a new system (Bell, Blythe, & Sengers, 2005). One possible alternative to overcome the ethnographic studies' limitation is through the use of the online 3-D Multi-User Virtual Environment (MUVE), which enables the systematic monitoring of users' behavior in a nonintrusive manner. In a recent study (Siriaraya, in press), the behavioral patterns of giving presents among 5,000 online users were studied with the use of MUVE. Regarding the type of gift and the frequency of giving, the results revealed distinct behavioral patterns between young and older users. Such behavioral patterns can be used in the design of products and help to establish mechanisms that improve interactions between the members of both age groups.

In MUVEs, one can write, talk, and interact with other avatars as well as use body language to communicate. In addition, it is possible to select clothes and accessories for the avatars, which discloses interesting information about how users project their identity. Moreover, users can also customize the VE they are in not only by selecting appliances but also by changing the overall decoration of the room. Such information, together with data about the level of attractiveness of some areas of the VE, can help researchers to better understand users' preferences and needs. Furthermore, the high realism of the avatars and the interaction offered prompt a high sense of presence (Jarmon, Traphagan, Mayrath, & Trivedi, 2009). All together, such features make MUVEs a tool that benefits user research studies. However, in spite of their potential, the use of 3-D MUVEs in ethnographic studies is still infrequent. Nonetheless, in other fields, particularly for training purposes, MUVEs have been successfully used to evaluate how male and female college students learn in Second Life (deNoyelles & Seo, 2012) as well as to improve nursing students' confidence in real-world clinical practice (Peck & Miller, 2010).

In summary, the use of 3-D MUVEs for observing users' behavior as part of an ethnographic study has some advantages when compared with conventional approaches, namely, the accurate manipulation of the simulated contexts of use and the possibility of carrying out an unobtrusive observation ("lurking") of the users' behavior. However, to ensure an ethical course of the study, researchers should inform MUVE users about the research and its purposes. This disclosure can be communicated, for example, by including the study's goal in the researcher's avatar profile and/or by providing the link for the research's web page.

MUVEs' disadvantages include the fact that users may not act as they would in real-world situations and instead use MUVEs to express their fantasies.

VR in Human–Product Interaction Studies for UX Evaluation

At this level, and taking into consideration the VR limitations regarding the sensorial stimulation, we can consider two different levels for using VR for human–product interaction in UX studies associated with the development of a product's (a) external features and (b) functional properties. According to a UCD approach, such measurements can occur in several stages along the product's design process from its first stages, when the concepts are defined, to its first drafts, and until the functional prototypes are developed.

External features. A product's external features are those that are more easily evaluated by the users in their first contact with the product and that may determine its attractiveness or repulsiveness. With VR, one can evaluate the users' initial reactions and responses to a product's visual or auditory features.

Several studies can be cited in this respect. Mobach (2008) used VR in a participatory design methodology and evaluated the relation between the changes made by the participants on a particular design of a pharmacy and to what extent such a design approach (operationalized on the results attained) affected staff satisfaction and construction costs. In the scope of road design, Heldal (2007) used VR to support the involvement of users in the selection of alternative solutions that should include consideration of a road's surroundings, with a particular emphasis on a cultural heritage site. In the field of interior design, Pacheco, Duarte, Rebelo, and Teles (2010) used VR in the design of indoor environments whereby a group of older adults selected wall colors.

With VR, subjective responses can be evaluated through the use of questionnaires with scales and/or "emocards." The use of input devices that require high visual-manual control (e.g., mouse and keyboard), either for purposes of interaction with the product or for data collection, should be avoided. Preference should be given to interactions that are mediated by realistically and directly controlled avatars. In this case, users can control their representation by immediately updating their avatar's body with the motion trackers (see Figure 2) that are attached to their own body.

Regarding physiological measures (e.g., heart rate, skin galvanic resistance), it is worth mentioning that although physiological measures may be used to assess individual differences in reactivity, particular attention must be paid to the methodology used. It is well known that physiological measures may be affected by many different causes: the methodology and the apparatus used (e.g., intrusiveness, discomfort), individual differences, and situational variables, among others. Therefore, an immersive VE may

Figure 2. Apparatus used at the ErgoVR–Ergonomics Laboratory of the Technical University of Lisbon to control avatars inside a virtual environment.

contribute to minimizing such aspects, that is, it prevents users from continuously visualizing the laboratory, the apparatus, and the researchers, thus making users feel apart from the real world. In addition, unwanted effects associated with extraneous variables in the context of use (e.g., lighting changes, background noise, presence of others), which are hard to control in real life, the field, and/or laboratory settings, can be easily controlled in a VR-based study.

Functional properties. At the moment, users have the opportunity to interact with a virtual prototype, in a controlled VE, to fulfill a given task. Here, the product's usability might influence the UX in a decisive manner, since the expectations of use are also being affected. The cinematic and/or dynamic aspects of the product must be considered as well as the navigational flows resulting from the users' actions in the VE. Authors of previous studies have used VR, with success, for similar purposes. For instance, Bruno and Muzzupappa (2010) defined a participatory design approach, supported by a VR system, to help designers in the involvement of target users in the design of product interfaces. This study showed no significant differences on the variables associated with usability and satisfaction between tasks performed with a real and a virtual microwave (virtual prototype). The main limitation of this study is the fact that the tasks were not performed in context. The inclusion of a probable context of use, such as everyday cooking activities, would have increased the study's ecological validity. Still in this scope, Antonya and Talaba (2007) demonstrate the practicality, flexibility, and versatility of VR technology in interactive design evaluations. The authors have connected VR with a simulator to demonstrate the cinematic and dynamic consequences of moving virtual mechanical structures. This study's main limitation was the computational problems that resulted from the real-time calculation required to change the mechanical structures.

From a methodological point of view, the use of VR for evaluating a product's functional properties in UX studies should privilege measures of behavior and satisfaction. The behavior-related measures are associated with performance, errors, and learnability. The satisfaction-related measures are linked to the subjective responses gathered after the interaction with the product. In this case, the behavioral measures are strongly correlated to usability and are mainly used to assess to what extent UX is affected by the circumstances of use. Therefore, the virtual contexts used for collecting data should be compelling, with scenarios and cover stories associated with it, including tasks in which specific actions involving the virtual objects are required and whereby modifications of the VE, according to the users' reactions, can be detected. Otherwise, if the evaluation is limited to a simple observation of the product's functional features, without enabling any user interaction, then such analysis must be conducted in a similar manner to the process used to evaluate the product's external features.

CONCLUSIONS

In the development of a product, UX must be part of a UCD methodology. Data collection involving this methodology usually depends on questionnaire-based tools, such as surveys or interviews, that do not favor the UCD process (Dinka & Lundberg, 2007; Luck, 2007). Besides this difficulty, if the solutions being assessed involve complex concepts, users may have difficulties in understanding them. Normally, the conception of physical prototypes, which are expensive and hardly modifiable, can solve this limitation (Nevalaa & Tamminen-Peter, 2004; Olsson & Jansson, 2005). VR, when framed in the contexts previously described, has the potential to overcome such problems.

As stated by Helander and Khalid (2006), emotions occur in context, whereas products communicate with users and can never be contextually neutral. Furthermore, situational factors (e.g., presence of noninteractive observers or facilitators) also affect the test participants (physiology and emotions) and the outcomes of the tests (Sonderegger & Sauer, 2009). Therefore, the context is a major aspect in product evaluation.

In this sense, we argue that VR can be a viable option, since it allows one to control the context in which the interaction takes place as well as ensures an ecological situation for the interaction. Previous researches have investigated this issue and have demonstrated that VR can provide adequate conditions for users to feel present in VEs. Villani, Repetto, Cipresso, and Riva (in press) in their research asked, "May I experience more presence in doing the same thing in VR than in reality?" To answer this inquiry, the authors evaluated the level of presence in two experimental conditions: an immersive VR job simulation and a real-world simulation that was identical to its VR counterpart (same interviewer, same questions) but with no technological mediation as well as without any social and cultural cues in the environment that could provide a better understanding of both the task and its social context. Results show that the level of presence was higher in the experimental condition with VR than in the real-world condition. This study suggests that the feeling of presence is a social construction, in which reality is co-constructed between actors and their environments through the mediation of physical and cultural artifacts. In this sense, presence is mediated by the VE's context, with the hardware assuming a less relevant importance.

Gorini, Capideville, De Leo, Mantovani, and Riva (2011) evaluated, using an HMD, the level of presence in four experimental conditions: with or without immersion and with or without a narrative context. Objects and avatars were perceived as more real in the immersive VE condition when compared with the nonimmersive condition. However, the immersion level alone was not enough to produce detectable changes in the participants' physiological reactions. The narrative context was considered an effective means to yield the sense of presence and was significantly different from the one attained in the condition without it.

In sum, when compared with conventional processes, VR definitely has many advantages for the evaluation of UX. However, its utility and application should be carefully considered. For this type of evaluation, it is crucial to ensure an immersive experience with the use of an HMD with stereoscopic vision that is supplemented with realistic sounds. The quality of the interaction is another critical issue for the success of this type of evaluation. In this respect, we can say that it is important to allow the interactions with the environments and the objects to be as natural as possible. However, some technological limitations still constrain the quality of the interaction, mainly in cases requiring complex motor actions, for example, typing a phone number into a virtual prototype of a mobile device. Yet this concern can be a false one, since, as mentioned before, devices with keyboards are being replaced by others controlled by voice commands or by simple and natural gestures, which can be easily mapped by sensors and used in VEs. Finally, imagination is the other major component required to ensure the feeling of presence in VEs. To achieve this purpose, it is fundamental to design tasks that are able to engage users while they are immersed and to place them in interesting challenges similar to those found in real-world settings.

We hope that this article will not only inform researchers and all experts engaged in the design of technological interfaces about research on UX, as well as the implications of using VR for such field of study, but also motivate them to incorporate VR to solve the main limitations that restrain UX studies.

In conclusion, we believe that human factors and ergonomics researchers and all experts engaged in the design of technological interfaces should consider the use of VR, framed in adequate methodologies, so as to improve UX. By highlighting recent research efforts conducted in this field, we hope to have been able to raise awareness about this new challenging approach.

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KEY POINTS

- Users' opinions are strongly affected by context. Therefore, user experience (UX) evaluations can benefit from using virtual reality (VR) as a tool, since it can provide the means to develop realistic-looking virtual environments with the advantage of providing greater control of the experimental conditions while granting good ecological validity.
- The main concepts of UX, the methods used in its evaluation, and its main limitations are identified.
- VR concepts, as well as its existing equipment, are presented. VR's actual or potential applications to overcome some of the limitations in the evaluation of UX are highlighted in light of the conceptual framework presented.
- The relevance of VR for assessing UX is discussed, and a framework for undergoing such an evaluation is proposed.

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