Bringing User Experience empirical data to gesture-control and somatic interaction in virtual reality videogames: an Exploratory Study with a multimodal interaction prototype

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Abstract
With the emergence of new low-cost gestural interaction devices various studies have been developed on multimodal human-computer interaction to improve user experience. We present an exploratory study which analysed the user experience with a multimodal interaction game prototype. As a result, we propose a set of preliminary recommendations for combined use of such devices and present implications for advancing the multimodal field in human-computer interaction.

Keywords
Multimodal interaction, user experience, virtual reality, somatic interaction, gesture interaction.

1. INTRODUCTION

Despite the huge interest and rapid expansion of new low-cost gestural interaction devices, in support of so-called "natural" user interfaces (NUI), there is a gap of knowledge about the experience of using these devices. The assumption that the interactions they afford are natural has been put into question, and with critical and empirical analysis exposing the high levels of artificiality they entail [Malizia12]. Consequently, there is little empirical basis for recommending ways to design, plan, specify, and implement systems that embrace somatic interaction, be it through gestures, large body movements or combinations of both.

We present new data about the user experience in immersive and augmented environments with multimodal somatic interaction (hand gestures and body movements). They were collected in high school environments, under testing and demonstration of a videogame prototype where a user was located aboard an immersive virtual reality XV-century ship while another used augmented reality to take the role of a frightening giant. Using gesture detection, the giant was inserted into the virtual reality of the ship.

User experience data was collected, characterized, and discussed, in order to identify problems, contribute to a better understanding of this field, and present a set of recommendations to support the development of systems that wish to incorporate these technologies. Attending to the early stage of the presented prototype in which both case studies were deployed, these are preliminary recommendations.

The remaining of this paper is organized as follows: section 2 presents an overview of user experience and multimodal human-computer interaction; section 3 addresses related case studies within this research field; section 4 describes the early stages of the developed prototype and the adopted devices; section 5 details the design and method used in the conducted case studies; the results of the exploratory study are discussed in section 6; the final section concludes the paper.

2. BACKGROUND

This section introduces the key concepts associated with user experience and multimodal interaction, which support the presented study.

2.1 User Experience

User experience (UX) consists of all aspects regarding the end-user interaction with a product or interactive system [Law09; Nielsen15]. UX is dynamic and related to emotions, beliefs, preferences, physical and psychological responses, behaviours, and achievements of users that occur before, during, and after the use of the product [Hassenzahl08; Law09; ISO10]. It is also related with project features and the overall context in which the interaction takes place [Hassenzahl06]. Therefore, it is important to assess user experiences, in a systematic way during all development stages of a system or product.

Although scientific literature provides numerous UX evaluation methods, few can be adopted to evaluate projects in their early stages [Vermeeren10]. The palette of methods is even thinner when focusing on multimodal interfaces [Bargas-Avila11; Wechsung14]. One of the few methods available is Co-discovery [Zimmerman07; Yogasara11], also known as "constructive interaction" [O'Malley84], which consists in the involvement of two participants (preferably friends), in exploration and simultaneous discussion of a prototype, while the researcher observes and gives necessary inputs [Jordan02]. Co-experience contributes to a holistic perspective of UX in its social context, through the construction of meaning and emotions between users using a system / product [Forlizzi04].

2.2 Multimodal Human-Computer Interaction

Human interaction with the world is inherently multimodal [Quek02]. Thus, there is a growing effort by the scientific community to leverage human communication skills through speech, gestures, touch, facial expression and other modalities for communicating with interactive systems [Turk14]. That is, since we humans interact with the world around us mainly through our main senses (i.e. vision, hearing, touch, taste, and smell), the objective of research in this area is to develop technologies, interaction methods, and interfaces to eliminate existing limitations, which use these senses together towards a more natural interaction by users.

Today, the word "natural" (in contexts such as NUI) is mainly used to highlight the contrast with classical computer interfaces that employ control devices whose operational gestures do not map directly to intended operations have to be learned [Malizia12]. Norman [Norman10] claimed that NUI are in fact not natural at all, since they do not follow the basic principles of interaction design (e.g. a clear conceptual model of interaction with the system). Although gesticulating is natural and innate, gestural interfaces, whose purpose involves achieving a so-called natural interaction, are based upon on a set of predefined gestural commands that must be learned as well.

Development of multimodal human–computer interaction tries to address problems like selecting gestures or gestural emblems that have similar meaning across a worldwide audience (due to the existence of various cultures), proposing the reduction of the number of misinterpretations by integrating existing types of interaction. This area has gained special relevance with the appearance of low-cost gestural and bodily movement detection/recognition devices associated to videogame consoles, such as EyeToy[1] (Playstation), Wii Remote[2] (Wii) or Microsoft Kinect[3] (Xbox). More recently, a diversity of console-independent equipment is becoming readily available, which can be purchased by end users and connected to various processing devices, with higher independence of manufacturers, but also more specialized in certain aspects of interaction and reduced cost. Examples of such devices include the Leap Motion[4] or Parallax Si1143[5] that enable the identification of finger gestures using images taken by infrared cameras, and the Myo[6] bracelet, which identifies gestures by detecting electrical activity in the muscles of the user's arm, a technique known as electromyography.

In parallel with low-cost gestural interaction, virtual reality and augmented reality have experienced a resurgence, via low-cost immersive displays and augmented reality glasses. Since the alpha release of the Google Glass[7] prototype, new proposals have been emerging in the market, driven both by technological appeal, and difficulties purchasing the actual Google Glass device. Some recently launched products, such as Recon Jet[8], are especially designed for outdoor activities, featuring GPS and sensors for speed, distance, and altitude. Others, like GlassUp[9], Optinvent ORA-S[10], and Vuzix M100[11], are essentially smartphone extensions, allowing the user to view emails, videos, social networking and other applications on one's own glasses. There are also devices like the Epiphany Eyewear, which are focused on video acquisition and streaming; Spaceglasses[12], Microsoft HoloLens[13], and castAR[14], which provide holographic interfaces that let users view and interact with virtual objects, and others. This includes low-cost virtual reality goggles allowing immersion in virtual 3D environments, with an extended field of view. Examples of such devices especially targeting games are Vuzix iWear[15] glasses and Oculus Rift[16],

[1] http://sony.co.in/product/playstation+eyetoy

[2] http://nintendo.com/wiiu/accessories

[3] https://microsoft.com/en-us/kinectforwindows/

[4] https://leapmotion.com/

[5] https://parallax.com/product/28046

[6] https://thalmic.com/myo/

[7] https://developers.google.com/glass/

[8] http://reconinstruments.com/products/jet/

[9] http://glassup.net/

[10] http://optinvent.com/see-through-glasses-ORA

[11] http://vuzix.com/consumer/products_m100/

[12] https://getameta.com/

[13] https://microsoft.com/microsoft-hololens/en-us

[14] http://castar.com/

[15] http://vuzix.com/UKSITE/consumer/products_vr920.html

[16] https://oculus.com/en-us/

but even lower-cost alternatives using simple lens on smartphones exist, such as Google's Cardboard[17].

The growing interest in the area, along with all these devices, leave open the creation of new multimodal interaction techniques and applications. The integration of devices from different modalities (e.g. vision, hearing) can potentially enhance a more natural interaction.

3. RELATED WORK

In the current technological ecosystem we are faced with several studies related to UX in multimodal environments. These might include a wide range of emerging devices: from somatic interaction to virtual and augmented reality, using both input and output modalities. Some researchers have started to explore and analyse existing solutions in order to understand the relevance, innovation and future prospects of this field.

Behand [Caballero10], is a means of interaction that allows virtual 3D objects manipulation on the mobile device through hand gestures. In this sense, the Behand is a way of interaction that uses a special camera at the rear of a mobile device to capture the image and the user's hand position when it points to the space behind the mobile device. The user's hand is transported to a virtual world on the mobile device, which takes advantage of its full capacity for manipulating 3D virtual objects. Regarding UX, they performed a case study, which reports that users consider this concept as "useful", "innovative", and "fun".

Ren et al. [Ren13] present two studies (formal / quantitative study in a laboratory and an informal/qualitative study in a primary school) comparing the gestural interaction (via Kinect) and the interaction by mouse and keyboard in a 3D virtual environment. In this sense, the objective is to enable effective interaction hands-free users without them having to use, wear or attach any device to their body. The user's body, by itself, can be considered an effective data input device, which enables a more flexible interaction. Furthermore, there were no significant differences in performance between the two types of interaction (mouse and keyboard), but the authors consider that these interactions when mixed with gestural interaction provide a more natural experience in both personal and public environments.

Online-Gym captures gymnastics motions of several users concurrently using one Kinect per user, and relays them remotely, allowing the users to see their motions within the same virtual world environment [Cassola14]. They implemented a quality of service management approach for relaying motion data over the network, by dropping older skeleton frames and attempting to keep users in sync.

González-Franco et al. [González-Franco10] conducted a study that reported the possibility of obtaining the ownership of an illusion of a body through a virtual mirror image, when using a synchronous communication between motor action and the participant reflecting in avatar movements in a mirror image. The only knowledge that the participants had, in this case study, was the avatar appearance: a virtual male body was used to represent male participants and female virtual models were used for female participants. The authors concluded that it was relevant to examine the impact of the illusion of real appearance between the face and the participant's body within the virtual representation.

Llorach et al. [Llorach14] reported the severity symptoms of Simulator Sickness (SS) that users may experience when using the Oculus Rift virtual reality headset to perform mobility tasks in virtual environments. They focused on HMD (Head Mounted Display), and point motion sickness problems, such as disorientation, nausea, headaches and vision problems. Such symptoms when caused by virtual simulators are known as cybersickness or SS. The authors showed that SS is significantly reduced when using a position estimation system, instead of the traditional gaming navigation controller. Following the same line of research, Davis [Davis14] presented a systematic review of the cybersickness field to measure various symptoms, including nausea and disorientation. They designed a case study to address issues related to cybersickness, along with a set of guidelines, using questionnaires or psychophysiological measures. They also presented a report on the individual factors and the related devices, with the tasks that lead to certain unwanted conditions. The authors concluded that there remains a need to develop more targeted and effective measures to combat the impact that cybersickness has on the physical condition of a person.

A study where students could paint a book with augmented reality devices was presented in [Clark12]. This research explored the metaphor "pop-up book" and describes the process by which children draw and paint as input to generate and change the appearance of the book's content. This system is based on detection of gestures and image processing techniques that can be easily exploited to augmented reality applications. The authors believe that this technology is an added value for artists who want to create 3D content, but it is dependent on the graphics capabilities of computers. They also state that if the solution is combined with an automatic model of content generation, it can bring numerous advantages in the architectural design of rapid prototyping of 3D models.

Morgado [Morgado15] analyses Google's Ingress alternative reality game, and extracts suggestions for educational application of its dynamics using multiuser participation, location-aware mechanics, and reinterpretation of the physical reality around the users, should an Ingress game-development API become available (or a similar one developed).

Finally, Lo et al. [Lo12] describes a framework called i * Chameleon that focuses on multimodal design considerations for pervasive computing. Their solution is based in a framework as a web-service and uses an independent analytical co-processor for collaborative multimodal in-

[17] https://google.com/cardboard/

teraction by providing a standard and semantics interface that facilitates the integration of new elements of computer applications. In this regard, the authors evaluated, firstly, the overhead and maximum throughput. Secondly, the simulation of the generic interaction process for measuring the response time from the sensory input. Finally, the solution was measured using client resources and a co-processor. With the aim of validating hi * Chameleon, two studies were conducted: 1) control a robot car using the Wii console and using an iPhone; 2) control the Google Earth map using the Wii console.

4. THE "PRIMEIRA ARMADA DA ÍNDIA" VIDEOGAME PROTOTYPE

"Primeira Armada da Índia" means "First Fleet of India" - the fleet of the famed navigator, Vasco da Gama, as the videogame prototype for obtaining data in school environments was based on Portuguese history and culture. A Portuguese ship from the age of discovery, is approaching the Cape of Good Hope and faces the mythical Adamastor giant, who seeks to prevent the ship from crossing from the Atlantic Ocean into the Indic[18].

A two player game was developed in Unity3D[19]: the helmsman of the ship of Vasco da Gama and the Adamastor giant (Figure 1). The helmsman (Player 1) uses Oculus Rift to be immersed in a virtual reality environment: the rear deck of a XVI-century ship. In the current prototype, the player can only move his head to freely observe the richness of the scenery in 360°: the ship, the sea, and the Adamastor giant. The latter (Player 2) is stranded on the Cape of Good Hope, but moves his torso and arms in response to the body movements of Player 2, detected by a Microsoft Kinect 2.

[18] The inspiration for this theme was the recent celebration of the 800 years of the Portuguese language, since this confrontation with Adamastor is a classic moment in the XVI-century epic poem The Lusiads, by Luís Vaz de Camões, usually seen as Portugal's foremost poet. The current Cape of Good Hope in South Africa was originally named Cape of Storms in 1488 by Bartolomeu Dias, the first European sailor to reach it. Portuguese royalty later renamed it Cape of Good Hope as a display of optimism regarding the possibility of reaching India that way, as Vasco da Gama eventually did in 1497. In The Lusiads, this is depicted as a confrontation with the giant. Another foremost Portuguese poet, Fernando Pessoa, also wrote about Adamastor in his poem, "The Monster".

[19] http://unity3d.com/

Figure 1 - Players using the prototype: Player 1 is siting and using an Oculus Rift; Player 2 is standing in front of a Kinect 2 and moving his arm to control the Adamastor giant.

5. THE EXPLORATORY STUDY

The exploratory study was designed adopting a user-centred approach and conducted through two case studies, which are described in the following subsections.

5.1 Design and Method

Two case studies were designed to assess the user experience with the early versions of the prototype, through testing sessions with groups of students from different educational backgrounds (potential end-users). The objectives of the case study were to characterize the user experience of the players: helmsman and Adamastor.

In both studies we adopted the user experience collection procedure known as co-discovery or constructive interaction [Kemp96]. This is a qualitative method, based on exploration and simultaneous discussion of the prototype by two users, which may or may not be mediated by the researcher [Holzinger05; Yogasara11]. The tests were flexible and not fully controlled in this exploratory phase, not being able to predict the interaction outcome between the two users while using the prototype. The presented method was applied in an unstructured form - despite the existing mediation and small tips to better use the devices, users could freely explore it in an open space, according to their instinct, free will and choice, towards a more natural interaction.

5.2 Case Study 1

5.2.1 Participants and organization of physical space

The first study was conducted with 72 users, mostly students aged between 14 and 17, during a Science and Entrepreneurship week at the Sicó vocational training school[20]. Due to physical space limitations, the players were arranged in a diagonal (Figure 2). The helmsman player is seated (seen with the Oculus Rift headset on the right side of the figure, 3 meters away from the Adamastor player, standing in front of the Kinect.

[20] In Avelar, central Portugal. http://etpsico.pt/

Figure 2 - Disposal of the users in the first case study.

5.2.2 Structure of testing and data collection

The study was conducted for 6 hours, distributed over a day, during which a total of 36 users tests were conducted, of approximately 10 minutes each. In each test, two players freely experienced the prototype, talking to each other about what they were genuinely experiencing. The researchers' role was only to give small technical guidance on the use of the devices. In this first case study, each player only had the chance to experience one of the devices - the Oculus Rift or the Kinect 2. The data collection was made through the registration of direct observation and audio-visual recordings.

5.3 Case Study 2

5.3.1 Participants and organization of physical space

The second case study was conducted with 36 users, mostly students aged between 14 and 17 at the Upper High and Secondary School of S. Pedro[21], during an information session on college-level Science & Technology programmes available at the local university. In this case study there were also physical space limitations. Users were initially arranged diagonally somewhat similar to Case Study 1, with the helmsman player seated about three meters away but in front of the Adamastor player. However, during the session, the users who were waiting for their turn started surrounding the helmsman player, and the researchers realized that the interaction between the players was being affected by this issue. Thus, the session was interrupted for space reorganization. The position of helmsman player was changed by about 1.5 meters, to be nearer to the Adamastor player (Figure 3).

[21] In Vila Real, northern Portugal. http://escolasaopedro.pt/

Figure 3 – Disposal of the users in the second case study.

5.3.2 Structure of testing and data collection

The case study lasted 3 hours, during which a total of 25 tests were conducted, of approximately 7 minutes each. In each test, two players freely experienced the prototype, talking to each other about what they were experiencing. Unlike case study 1, each player had the opportunity to experience both devices - the Oculus Rift and Kinect 2 (reversing their roles as players).

In this second case study, the researchers mediated the conversation between the players, describing the scenario and encouraging the interaction between them. For data collection, an observation grid was used (developed after reflection about the first case study) to support the recording of direct observation. Audio-visual recordings were also made.

6. RESULTS AND DISCUSSION

Since both case studies have followed similar design principles and method, we combined their data into a single data set. We then classified the obtained results based on each player role, namely Helmsman's and Adamastor's.

6.1 Helmsman Player (Oculus Rift)

Some students reported feeling nausea, blurred vision, and/or headaches. We have not identified other symptoms, but all of these and more have been reported by the scientific community, such as disorientation, vertigo, vomiting, among others [LaViola00].

However, these symptoms were felt only momentarily, with little or no effect in the subsequent experience of the players, which proceeded with the exploration of the virtual environment. Only one user asked to stop the test, but ended up not reporting which symptoms he felt exactly. In an attempt to overcome such symptoms, some players squeezed the Oculus Rift, adjusting the device to the head. The animation of the ship's roll may be contributing to these feelings. The single case in which a user reported feeling the ship's motion and was asked if he felt unwell or sick, he answered that he was feeling good, so we have no data to support that hypothesis. Other factors may be involved in these symptoms, such as the duration of the exposure, the width of the field of view (FOV), the setting of interpupillary distance (IPD), among others [Llorach14]. Although the average IPD is about 63mm, the range of values may vary between 52mm and 78mm.

The Oculus Rift, with a IPD of 63,5mm, allows users to make adjustments exclusively in the virtual environment, but there are few improvements for people with an IPD far from the average when compared with what can be achieved with a physical change of the IPD (setting of the lens) of the headset itself.

We did identify some behaviours related to the sense of presence and immersion in the virtual environment. Some users extensively explored the environment, looking at every detail of the ship, the sea, the sky, the rocks and the Adamastor giant, to the point of reporting disappointment with the fact that they could not stretch their necks to appreciate the outside of the ship, or move freely to other areas of the ship. Also, we observed cases of unplanned physical feedback, when users were trying to touch virtual objects and ended up touching a physical item. For example, trying to touch the ships' floorboards, and ending up touching the floor of the physical space. Other cases of attempts to touch included stretching arms to reach the Adamastor giant, even though it was visually distant several miles within the virtual environment. In one case, a user looked around to locate Adamastor and afterwards became disoriented and lost its reference, not managing to find him again - some of his colleagues, from the exhibition space, oriented him in the physical space, based on the visual feedback provided by a monitor which streamed the player's viewport. Other senses were involved unexpectedly: in one case, some colleagues of the helmsman player waved their hands near his face, generating some flow of air, and the player reported the feeling of wind coming from the virtual environment. Another user reported sensing some bad smell coming out of the virtual environment.

Due to the contents and interaction modalities, expressive behaviour related to the emotional state of the user was identified. Some users were enthusiastic during the sessions, also observed in [Caballero10] UX case study. In a particular experience, a player went as far as laughing, shouting, and threatening Adamastor. Finally, two users actually claimed to be afraid of Adamastor.

6.2 Adamastor Player (Kinect 2)

Regarding the players playing the role of Adamastor, several didn't realize where they should be positioned in the physical space to improve interaction. Others were uncertain of when or how to gesture, in order to interact with the helmsman player. Such cases appear to have influenced negatively the user experience, leading to disinterest and confusion during the tests, especially in the first case study - where there was a high dropout rate in the last tests just a few seconds after players started.

To better understand what might be causing this problem, we identified some aspects that may contribute to the analysis. On the one hand, the organization of the physical space, the layout of the players, and the lack of visual feedback guidance. For instance, users would often turn to the physical world location of the helmsman player, rather than the Kinect 2 sensor. This would often cause the virtual Adamastor giant to stop moving. On the other hand, the role of the researcher as a mediator influences the interaction. This was demonstrated through some changes and interventions by the team of researchers in the second case study. In the first case study the helmsman players had their backs turned towards the Adamastor players, and the mediators only provided minor technical guidelines on the use of the devices. In the second case study, mediators placed the two players on their locations, and sometimes described the scenario or encouraged interaction, which led to greater acceptance by Adamastor players (no withdrawal was observed).

Furthermore, there were also problems regarding the movements of the Adamastor as visualized by the helmsman players. The arms sometimes behaved unexpectedly, with angular movements or low amplitude, not portraying believable movements. This might be related to an unrestricted range of motion of the character when exporting the 3D model.

7. CONCLUSIONS AND FUTURE WORK

Based on Primeira Armada videogame prototype, this exploratory study allowed a preliminary characterization of the user experience, identifying some of the problems and potential use of these devices in an integrated manner.

To reduce and/or eliminate symptoms such as nausea, blurred vision, and headaches, felt by some of the users who controlled the helmsman, adequacy and calibration of the Oculus Rift headset for each specific user should be a greater concern. Thus, it is necessary to adjust the IPD in each case and regulate the time that the user is exposed to the virtual environment in a better way.

Some possibilities for improvement were also identified regarding the level of presence and immersion. Since several users have extensively explored the scenario, it would be interesting to include new virtual objects in the environment, enabling a richer and contextualized user experience. For example, the inclusion of non-player characters (NPCs) such as the ship's crew, marine animals, including guns in the ship, and so forth. Through these new virtual objects, new interactions would also become possible. In our game design, the helmsman player will be able to fire a cannon towards rocks thrown by the Adamastor player. Another possibility, which we have now implemented in the prototype for further testing, is resorting to Leap Motion's VR Mount on the Oculus Rift headset, allowing the helmsman player to see virtual renderings hands and forearms inside the virtual environment, reproducing the motions of his own hands and forearms (Figure 4).

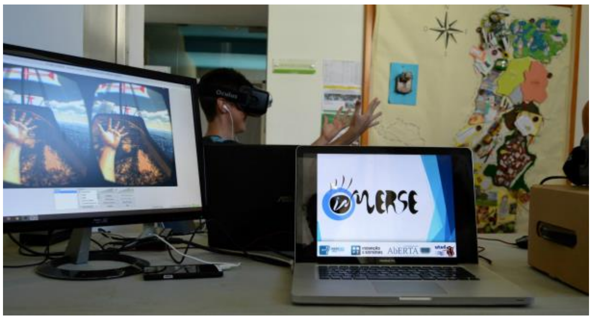

Figure 4 - Oculus Rift and Leap Motion combination, enabling the helmsman to see virtual renderings of arms and hands.

Regarding the disinterest and confusion observed on users who controlled the Adamastor giant, some proposed solutions were now developed in the prototype for follow-up testing. To provide orientation feedback, letting Adamastor know which way to turn, we have included Google Glass feedback. The Kinect 2 will capture of the Adamastor player's movement, and detect command gestures (e.g. grab and throw rocks), while Google Glass will show information regarding the current position of the ship and rocks in a physical world real-time compass, as well as instructions on how to act (Figure 5). Upon detection pull and push gestures, with Kinect 2, the player is now able to grab and throw rocks, with audible feedback via Google Glass.

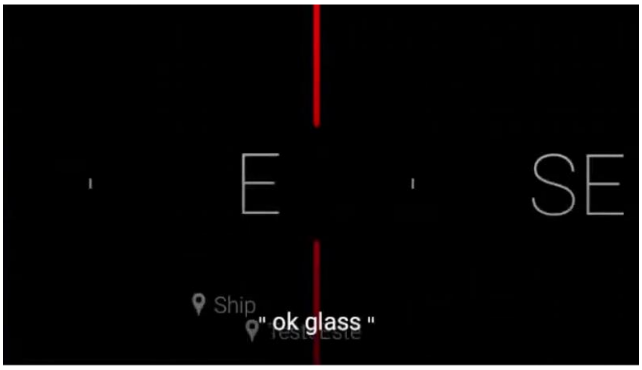

Figure 5 - Google Glass compass, showing the Adamastor player the locations of the ship and rocks.

As future work, it will be necessary to evaluate the effectiveness of these measures and their impact on the user experience of the Adamastor players. The inclusion of a new device (Google Glass) will bring also new challenges on interaction design, software, and hardware. For instance, during preliminary testing, Google Glass would overheat after few minutes of use. Besides annoying the user, this would shut down the device for quite some time, preventing extensive testing. Other interaction devices will also be explored, such as Myo bracelets, to enable gesture detection regardless of the player's orientation.

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