Usability assessment of natural user interfaces during serious games: adjustments for dementia intervention

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ABSTRACT

Serious games based rehabilitation program needs a comprehensive and people-centred design for a better efficacy. In most studies benchmarking the computer-interaction interfaces is a prerequisite for adjusting the most appropriate user input for the rehabilitation application. The present study examines a comparison between three natural user interfaces and two standard computer interfaces in two different virtual reality tasks. The results illustrate that the acceptance and user-friendliness of a device regarding the completion of a specific task strongly depends on the task itself and on the abilities of the users.

1. INTRODUCTION

Over the last decade, the field of virtual reality has been applied in various domains such as education, medicine, psychology and has been adapted to various target populations. The older adults are a common target for virtual reality technologies, since a virtual environment can be utilized for addressing some of the situations that they encounter in real life (Sawyerr and Pinkwart, 2011). For example, Morganti, Stefanini and Riva (in press) used a virtual reality-based procedure in order to assess deficits in spatial memory in the elderly. Virtual reality allows different functionalities and different interaction techniques. Smith, Salvendy and Koubek (1997) exposed two most prevalent interaction techniques in virtual reality with respect to the needs of elderly: how to navigate and how to select and manipulate objects in a 3D virtual environment. When implementing these techniques in a virtual environment, the usability of the interaction and of the input devices should be considered. The input devices are the tools used to implement the interaction techniques and they have to be natural, efficient and appropriate to work with a given technique (Smith, Salvendy and Koubek, 1997). Fisk et al. (2004) described the "usability" as the possibility and the facility to have access to a product in terms of learnability, efficiency, memorability, errors and satisfaction for older adults.

In line with Fisk, Holzinger, Searleand and Nieschelwitzer (2007) described three objectives when designing a new technology for older adults: the need to be adapted to the end user's physical impairments, the degree of familiarity and satisfaction with regards to the device, and the appreciation of the benefit when using this interface. The golden rule in order to interact naturally with a virtual environment is a natural user interface, which is an interface that is easy to use immediately, without the need for any training or previous experience (Steinberg, 2012).

Furthermore concerning the older adults, any changes with the main cognitive abilities due to aging, such as, perception, attention, memory and other functions involved in everyday life, should be taken into account in order to ensure the usability of a given interface (Gamberini et al, 2006). This last point is important for the special uses of virtual reality, like serious games based intervention for early dementia. Recently, there is an effort in literature to develop recommendations in order to design virtual reality for early dementia. Levels of difficulty, different layouts, errorless learning, simple and structured interfaces and scenarios, appropriate feedback and challenges are the common usability guidelines to design people centred rehabilitation using a virtual environment (Nor Wan Shamsuddin, Lesk and Ugail, 2011; Kaklanis, Moschonas, Moustakas and Tzovaras; Mader, Dupire, Guardiola and Natkin, 2012; Bouchard, Imbeault, Bouzouane and Menelas, 2012).

However all these studies above, although they investigate the usability of the game itself, do not evaluate the more appropriate interface to interact with the game.

The aim of the present study is to investigate how elderly can interact with three natural user interfaces and two standard input devices commonly used in the literature, as a first step to design a serious game based intervention for early dementia.

2. METHODOLOGY

2.1 Rehabilitation system

When working with the special target group of the elderly people, the ultimate goal is to support social interaction through customized user interaction scenarios and user interfaces. This requires strengthening their higher cognitive functions and everyday skills in realistic 3D VR environments. Our previous studies showed that Virtual Reality Daily Activities environments can be used to screen for persons with Alzheimer's disease early (Tarnanas et al, 2013) and if the diagnosis and treatment begins at a very early phase of the disease, they are able to manage their everyday activities longer and they suffer from less psychological and behavioural symptoms.

The 3D Memory Island virtual environment is a virtual reality journey back in time (auto-biographical memory) to landmarks that seniors have previously visited at their lives. We conducted an online survey regarding the most famous or visited cities or landmarks a typical Swiss senior might know or even have visited in his life. See figure 1 for examples of landmarks according to our survey. Based on the above, emphasis is given to tasks that have to be performed at the 3D Memory Island environment incorporating problem–based activities: for instance to prepare a virtual meal, to go shopping for ingredients, to navigate to the landmark etc. The aim of the 3D Memory Island is providing the users the capability of performing everyday activities with virtual reality by assisting the brain to find out alternative methods to execute functions, which are controlled by damaged brain regions. We also place a special focus on adaptive difficulty levels, allowing error-free learning that is expected to increase motivation, fun, and self-confidence.

Figure 1. *A virtual navigation at the 3D Memory Island until the user reaches the Parthenon landmark.*

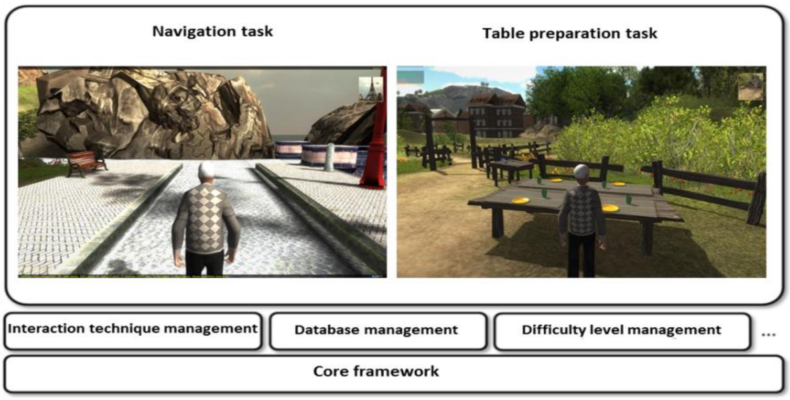

Figure 2. *A system framework of the 3D Virtual Memory Island.*

The proposed system: the 3D Virtual Memory Island is an immersive virtual reality platform which employs third-person view interaction. The current system consists of four main frameworks such as: Cognitive task and Interaction technique management framework, Database management framework and Difficulty level management framework (Figure 2).

2.1.1 Cognitive task and Interaction technique management framework. The Cognitive task management framework enables to manage two currently available training tasks such as the Table preparation task, and the Navigation task.

The therapist predefines the starting point and end goal for the Navigation task. The selected goal is displayed on the right-top of the main screen. A patient is required to reach the selected goal by using the connected interaction techniques. These interaction techniques enable the selection of 5 different types of interaction devices such as an optical natural user-interaction sensor, 2 magnetic natural user-interaction sensors, a Joystick and a Touchpad. Each interaction device is described in the section below.

If the patient chooses the wrong path on the way to the selected goal, the system recognizes the wrong path as error behaviour and indicates warning effect by changing the colour of the background of the screen.

2.1.2 Database management framework. The Database management framework enables the management of the system profile data, such as the task difficulty parameters as well as performance data that are collected during the applied cognitive task. This data set can then be visualized with various graphs and plots. This framework allows the patient and the therapist to monitor the progress of the applied training as well as to evaluate the effect of the task.

2.1.3 Difficulty level management framework. The Difficulty level management framework enables to manage the task difficulty. Currently, the task difficulty level is only changed manually by the therapist based on a patient's progress.

2.2 Study I

The goal of this study was to compare the usability of four interfaces using a navigation task. The following section describes the selected participants, the materials, the procedure and the data analysis of the first study.

2.2.1 Participants. 11 men and 9 women aged 60 to 86 were recruited through the Senior University of Berne to participate in this study (age M = 73; SD = 6.96). All subjects were used to handle computers; however none of them had experience playing video games.

2.2.2 Materials. The experimental setup consisted of a PC (Intel Core i7-3770 CPU with 3.40 GHz) with a 21" Asus screen (1920x1080, ASUSTeK Computer, Taïwan, CHINA) and 4 different interfaces (see figure 3): a Joystick (Logitech, Lausanne, VD, SUISSE), a Touchpad (Microsoft Corp, Seattle, WA, USA) and two motion and orientation detection game controllers, a Razer Hydra magnetic natural user-interaction sensor (Razer, San Diego, CA, USA), and a Kinect optical natural user-interaction sensor (Microsoft Corp, Seattle, WA, USA). The virtual environment was developed using the system Unity 3.4 which was the game development ecosystem.

To compare the different interfaces, the System Usability Scale (Brooke, 1996), a questionnaire developed to evaluate the effectiveness, the efficiency and the participants' satisfaction of different interfaces, was chosen. It includes 10 affirmations (i.e. "I thought the system was easy to use", "I found the system unnecessarily complex") and participants have to indicate their degree of agreement or disagreement on a 5 Likert scale. For the purpose of the study this questionnaire was translated to German.

2.2.3 Procedure. Each participant tried out all four interfaces in a counterbalanced order. The task was to guide an avatar through a pathway to reach a goal by following the navigation signs along on the way.

Two virtual scenarios were created to test the four interfaces. Both scenarios were set at 3D Memory Island, where the user starts from a give point and navigates freely in order to reach a modern or ancient landmark following the pathway explained above. The participants were instructed to reach those landmarks as fast as possible.

In one scenario, subjects were asked to reach a building which represented the Greek temple on the Athenian Acropolis, Parthenon (Snook et al, 2011) .The long-range-field-of-view optical sensor (Kinect) and the magnetic natural user-interaction sensor (Razer Hydra) were tested using this scenario. Subjects had to point their arms towards the desired direction to guide the avatar. Participants were asked to navigate the virtual environment by using only the mini joystick function of the Razer Hydra controller.

In the second scenario, subjects were asked to reach a group of four persons near to the Eiffel Tower with the use of the Joystick and the Touchpad. In order to guide the virtual character with the Touchpad, participants

Figure 3. *First Study experimental Setup (from left to right: the Razer Hydra, the Joystick, the Touchpad and the Kinect).*

moved their finger with several forward small movements. The Joystick was used without the need of using any additional button, as the three other devices.

Time to achieve the goal for each device was measured from the moment when the avatar started to move until the goal was reached. In both the scenarios, the goals were at the same distance from the starting point, which allows a comparison of the time between each interface. Moreover both the scenarios had the same paradigm, namely a navigation task, which allows the comparison of the satisfaction to use the devices, regardless to the scenario. Once one goal was achieved, the next interface was tried. After testing all four interfaces, participants filled out the System Usability Scale for each device individually.

2.2.4 Data analysis. Data analysis was performed using SPSS 20.0 for Windows (IBM corporation, New York, USA). As the data were not normally distributed and the satisfaction dependent variable was measured in an ordinal level, including a Likert Scale, a non-parametric analysis of variance (Friedman's ANOVA) was used to compare the mean score and the mean time among each interface. To adjust for multiple comparisons, the Bonferroni procedure was applied. A Spearman correlation was used to investigate if there is a link between the score on questionnaire and the time needed to achieve the goal.

2.3 Study II

The goal of this study was to compare the usability of two interfaces using a table preparation task. The following section describes the selected participants, the materials and the procedure. The data analysis was the same as the first study.

2.3.1 Participants. 11 men and 5 women aged 65 to 72 were recruited through the University Hospital of Tokyo, Japan to participate in this study (age M = 68; SD = 2.76). All subjects were used to handle computers; however none of them had experience playing video games.

2.3.2 Materials. The experimental setup consisted of a PC (Intel Core i7-3770 CPU with 3.40 GHz) with a 21" Samsung screen (1920x1080, Samsung corporation, Taegu, KOREA) and 2 different interfaces: a Razer Hydra magnetic natural user-interaction sensor (Razer, San Diego, CA, USA), and a LEAP motion magnetic natural user-interaction sensor (Leap motion Corp, San Francisco, CA, USA). The virtual environment was the same as in study 1.

As the table preparation needed other more precise measures to evaluate the task, the NASA-TLX was the chosen questionnaire for this task. Participant had to evaluate the task on 6 criteria in a 21 Likert scale.

2.3.3 Procedure. Each participant tried out the two interfaces in a counterbalanced order. The table preparation task was an exercise in order to prepare the kitchen table for two people dinner using the available kitchenware presented at the scene. The goal is to place the kitchenware at the correct positions at the table (accuracy) at the fastest possible time (executive functions / reaction-time). The table preparation task is shown at Figure 4.

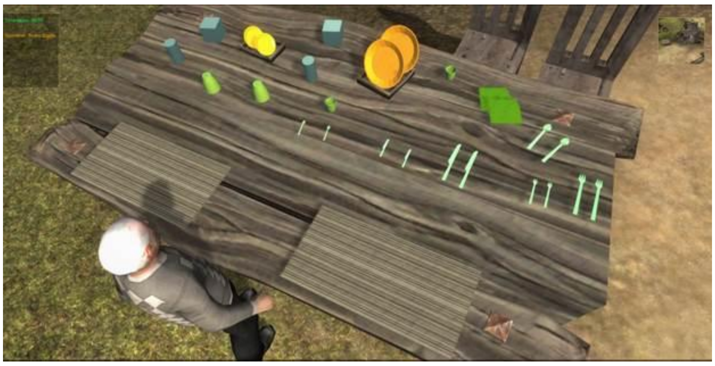

Figure 4. *Table preparation task.*

3. RESULTS

The number of participants, the mean score and the mean time per each interface are presented in table 1.

Table 1. *Mean score and mean time for each interface*

Interfaces	N	Score *		Time **	
		M	*SD*	*M*	*SD*
(a) Navigation task					
Joystick	20	86.36	(23.89)	214	(28.11)
Touchpad	20	54.62	(30)	213	(180.62)
Kinect	20	20.63	(19.63)	421	(143)
Razer Hydra	20	61.5	(28.32)	340	(71.42)
(b) Table preparation task					
Razer Hydra	16	3.16	(0.78)	67	(17.23)
Leap Motion	16	4.24	(0.78)	130	(33.48)

* Score from 0 to 100 for navigation task and from 0 to 7 for table preparation
**Time in seconds

First study Friedman's ANOVA revealed a significant main effect of score ($p < .001$) and of time ($p < .001$).

Orthogonal pairwise comparisons showed that the Joystick was significantly preferred (*M*= 86.38) than Touchpad (*M*= 54.63), Kinect (*M* = 20.63) and Razer Hydra (*M*= 61.50). No significant difference between the Touchpad score and the Razer Hydra score was found. The Kinect was significantly the less preferred in comparison to the three other interfaces. The goal was significantly reached earlier with the Joystick (*M*= 214) and the Touchpad (*M*= 213) than with the Razer Hydra (*M*= 340) and the Kinect (*M* = 421).

Only one negative correlation was found between the satisfaction to use the Kinect and the time to achieve the goal with the Kinect ($r = -.573$, $p = .008$).

Second study Friedman's ANOVA showed a significant main effect of score ($p = .003$). Subjects preferred to use the Leap Motion (*M* = 4.24) than the Razer Hydra (*M* = 3.16). A main effect of time was also found, ($p < .001$). Participants were significantly faster to complete the table preparation with the Hydra Razer (*M* = 67) than with the Leap motion (*M* = 130).

4. DISCUSSION

The aim of this study was to investigate what natural user-interaction interfaces are preferred by the elderly in a 3D virtual environment, as a first step to develop a serious game based intervention for early dementia. The Joystick was the favourite for the navigation task, while the Leap Motion was the favourite for the table preparation task. Fidopiastis, Rizzo and Rolland (2010) showed how important it is to choose a user centred design study that includes benchmarking for the efficacy of the virtual environment based rehabilitation programs, as it was in our study.

The present results show that the preferred interface is task dependent. Natural User Interfaces should be natural to use, which means representative of what we do in reality. They allow the user to directly interact with the computer. Leap motion and Kinect have the same principle which is to react to physical movements and gestures. The Razer Hydra controller can be related to widely used device such as the Wii and be used in two different ways, one is directly interacting and manipulating items on the screen via gesture recognition and pointing, the other is like a joystick, as it was done in the present study. But depending on the task and on the way to use it, the opinion and acceptance of the device was different. Navigation requires other movements and skills than table preparation and the interface should support the natural movements and skills to execute the task. The Kinect gestures we used were extending and pointing the arm forward in order to move the avatar forward which is not a natural movement for the human. As pointed out by Ball, North and Bowman (2007), the problem with a navigation task in 3D virtual environment is to immerse the user entirely in a virtual world and completely hide the physical world. When user's movements in the real-world accurately map the movement of the avatar in the virtual world then there is no feeling of disconnection. When it doesn't exist, disconnect arises when users must physically navigate in the real world in order to move in the virtual world. Physical navigation would have to be virtualized to match the virtual world, and this is difficult to fully achieve.

In contrast, the reality of the movement to take and displace an object was well represented by the use of the Leap Motion.

The literature shows many studies with the benefits of the Kinect and the Wii on elderly and clinical population (for Kinect see: Chiang, Tsai and Chen, 2012; de Urturi Breton, Zapirain and Zorrilla, 2012; Garcia, Felix Navarro, Schoene, Smith and Pisan, 2012; Obdrzalek et al, 2012 ; for Wii see: Clark and Kraemer, 2009; Fenney and Lee, 2010 ; Gerling, Schild and Masuch, 2010; Grosjean et al, 2010 ; Jung et al, 2009; Neufeldt, 2009). The general conclusion of all these studies is that the Wii and the Kinect support specific cognitive skills enhancements through the required physical movements. Moreover in patients' studies, they are found to be fun to use, which increases the level of motivation and encourages a long-term rehabilitation. Leap motion also seems to be a promising natural interface for virtual environment based rehabilitation programs. To our knowledge only one study used the Leap Motion with a virtual environment as a screening tool for early dementia (Tarnanas et al, 2013). Last decade the Joystick has been replaced by the motion and orientation detection game controllers in the field of virtual reality (Bowman, McMahan, and Ragan, 2012). A reason for that could be that Joystick is not as natural as the Kinect or the Wii to interact with virtual environment. Nevertheless, in the present study, it was popular among all participants.

According to Steinberg (2012) completion time is very important as "the users are impatient and do not want interfaces that take forever to navigate". The present results go partially with this idea because the Kinect was the interface with the longest time of achievement and the less liked. In line with the Fitts' law (1954), time indications and time of completion differences among all participants who used the same device can be a good indicator of the acceptance and user-friendliness of that device. The time standard deviation for the touchpad indicates that some participants used this device very easily whereas other had more difficulties. This difference can be based on experience that participants had with the touchpad of a laptop for example. In contrast, Joystick had a very small time standard deviation, all the participants used this device easily and didn't need any previous experience.

Furthermore Buxton (1994) considered technology in terms of the fidelity with which it reflects human capabilities on the physical, the cognitive and the social level. This is even more relevant when participants are old and not used to interact with technologies. Commercial-off-the-shelf (COTS) hardware used for this study, such as the Joystick and the touch mouse, are interaction devices with which older people have some familiarity because they are available to the public. Those devices manipulate position and orientation with two degrees of freedom. One the other hand, the magnetic and optical sensor natural user interfaces used enable 3D spatial interaction more efficiently than the COTS because they manipulate position and orientation with six degrees of freedom. All the interfaces had some usability freedom in terms of workspace and dexterity. Participants had the possibility to choose where they preferred to use the device and as each device required one hand to use it, participants were asked to use the preferred hand. The Joystick and the Razer Hydra were generally used directly in front the participants, whereas the Touchpad was usually used on the right or left side, depending on the participants' preference. The Kinect was either placed in the right side or in the left side, in front of the participant.

On the physical level, as elderly have reduced fine motor control but not reduced force control (Contreras-Vidal, Teulings and Stelmach, 1998), it is clear why they preferred to use the Joystick than the Touchpad or the Razer Hydra which required finer motor skills. Indeed the Joystick required more force but less fine control whereas the touchpad was used with small, accurate movements and the device was very sensitive. The Razer Hydra was also sensitive since participants had to be very precise in order to move the avatar straight forward. Even if the Kinect didn't require small and precise movements, the device was tiring for participants because of the unnatural gestures. In term of motor skills patient with early Alzheimer perform worse on tasks involving fine and complex motor function but not on gross motor tests in comparison to aged matched healthy adults (Kluger et al,. 1997).

5. CONCLUSION

This study provides the first comparison among five natural interfaces in two different virtual reality tasks and demonstrates that the goodness of a device with regards to the completion of an assigned task strongly depends on the task itself and on the abilities of the users. It confirms that the combination of several devices creates a range of interaction possibilities in order to suit with the needs of tasks and subjects (Hand, 1997).

Further studies in the field of user natural interfaces in 3D system are needed to allow interactions with the simultaneous use of two hands for input as it has been recognized as beneficial by Buxton and Myers (1986).

In conclusion, in order to create a serious game based rehabilitation program it is essential to take into account the usability of the involved devices, the patient's abilities and also the motivations to play of the target population.

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Unity 3D Game Development Tool, available at http://unity3d.com.