Design of virtual reality based physical and cognitive stimulation exercises for elderly people

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ABSTRACT

Elderly people are the most growing part of the population in developed countries (Europe, North America and Japan). This population is getting more and more alone and isolating this part of the population is the big issue of this century. This isolation can lead to a lack in physical and cognitive activity. Because virtual reality has given good results in health domain, we decided to design an application that combines physical activities and cognitive stimulation. The “Balade à l’EHPAD” application was then tested on different kind of population. Then, the expectations and needs of elderly people were collected and analyzed. The results clearly indicate that preconceived ideas exist in every people and also in professional caregivers who generally have a better knowledge of this population. Elderly people would like to have raw colors and virtually practice more violent sports (e.g., skiing, rugby). The overall study clearly indicates that more than for younger adults, the involvement of elderly people into the application design process is a prerequisite for the appropriation by this population.

1. INTRODUCTION

In France, 8.5% of the general population are elderly people (aged 75 or more); they will be more than 30% in 2060 (Blanpain and Chardon, 2010). This assumption is also true in other European countries as demonstrated by (Adveev et al, 2011). Aging is often accompanied by decline of cognitive functions, especially in case of dementia and Alzheimer Disease (AD) (Ankri, 2009), and is correlated with an increase of loss of autonomy (Bonnet et al, 2011). Recent studies showed the beneficial impact of physical exercise for older adults (Chodzko-Zajko et al, 2009), and on cognitive functions among people with Mild Cognitive Impairment (MCI) (Geda et al, 2010), whose deficits may be a precursor for dementia. In this context, different types of nursing homes for elderly dependent people frequently ask for new methods including information and communication technology for cognitive and physical stimulation approaches.

During the last years, the use of Virtual Reality (VR) in health domain has given positive results (Rizzo and Kim, 2005; Klinger et al, 2010). In MCI or AD contexts, VR can help respectively to assess dysexecutive functioning (Werner et al, 2009), or to detect navigational deficits (Cushman et al, 2008). VR-enhanced exercises can combine motivating game-like activities within virtual worlds and physical training; they considerably enhance health outcomes (Lange et al, 2010). Cassilhas et al demonstrated that resistant exercise had a positive impact on cognitive function in elderly people (Cassilhas et al, 2007). A recent study among 102 older adults tested the benefit of VR-based simultaneous cognitive and physical exercise on cognitive decline (Anderson-Hanley et al, 2012). The results showed that “cybercycling” training during 3 months has greater potential for preventing cognitive decline than similar effort on a traditional stationary bike.

In this context we designed the “Balade à l’EHPAD” project in early 2011, a VR-based application in which elderly people are involved in a bike ride within different virtual environments. During the ride, they are invited to participate to several simple games to stimulate some cognitive abilities (Figure 1). This application was rapidly designed based on discussion and a quick collection of car givers needs. They strengthen the fact that elderly people located in specialized care houses do not have a lot of physical
activities. We rapidly imagined the possibility to design a VR based application which would be driven by a physical interaction between the human and the machine.

The aim of this paper is to present a usability study of the first version of the “Balade à l’EHPAD” application which focuses on usability issues, participant interactions and behaviors. The purpose of the study was also to build recommendations for improving this first version.

![Figure 1](image1.png)

**Figure 1.** “Balade à l’EHPAD” provides an interfaced bike (A) for a virtual bike ride (B) in two different environments: the seaside (C) and a forest (D). The participants are suggested to be involved in simple cognitive exercises as collecting flowers (E).

### 2. MATERIALS AND METHODS

The evaluation of the “Balade à l’EHPAD” application was essentially carried out with usability testing (Hornbaek, 2006).

#### 2.1 Instrumentation

The “Balade à l’EHPAD” application is made of two parts: the software part consists of a all-in-3D application build using Unity integrated development environment (Guiping et al, 2011); the hardware part is made of a beamer and a bike interfaced with the computer running the application (Figure 2).

![Figure 2](image2.png)

**Figure 2.** Instrumentation of the “Balade à l’EHPAD” application. The application is made of a bicycle simulator interfaced with the computer running the VR-based application. The environment is displayed by a beamer on a 78” screen.

#### 2.2 Settings and Participants

Participants were recruited in three different populations: professional care givers, healthy participants and elderly people. Professional care givers are people working in the institution where the elderly people live (“Centre Inter-Générationnel Multi-Accueil”, CIGMA, Laval; “Polyclinique de Laval”; “Foyer Thérèse..."
Vohl, Laval). Healthy participants are safe subjects not directly related to the institution and elderly people are people living in one of the previously cited institutions. The panel contained 7 professional care givers (age between 20 and 36 Y.O.), 4 healthy participants (age between 22 and 52 Y.O.) and 15 elderly people (age between 82 and 97 Y.O.).

2.3 Evaluation Procedure

The “Balade à l’EHPAD” application invites participants to ride a bike simulator within virtual environments (VE) simulating natural spaces like a forest and the sea side (Figure 1 and Figure 2). The participant rides on a bike simulator with the illusion to move in the VE. In each virtual situation, simple cognitive exercises are suggested to the participant, like collecting flowers with specified colors (Figure 1E). A touchpad, fixed on the bike handlebar, allows the user to interact with the different items displayed in the VE by pushing three buttons with different colors: red, purple and blue.

Two different tests were carried out: a usability test with the “Balade à l’EHPAD” prototype followed by a questionnaire (test A) and a questionnaire without any usability test (test B). Test A was carried out among professional care givers and healthy participants. Because of the very preliminary version of the prototype and for safety issues of elderly people, this population sample carried out test B which does not include the bike ride.

Thus, test A questionnaire gathered information about 1) the adequacy between the prototype and the initial objectives; 2) the adequacy of the equipment and the expected audience; 3) the professional care givers needs and expectations, and 4) motivations and interests in the project. Finally, test B questionnaire was dedicated to collect needs, expectations, preferences and missing characteristics for elderly people.

2.4 Evaluation Criteria

An exhaustive list of the evaluated criteria was set in order to build the questionnaires. The retained criteria to evaluate the “Balade à l’EHPAD” application are listed in Table 1.

<table>
<thead>
<tr>
<th>Criterion category</th>
<th>Criterion</th>
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<tbody>
<tr>
<td>Content</td>
<td>Graphical User Interface (UI)</td>
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<tr>
<td></td>
<td>Virtual environments</td>
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<tr>
<td>Computer graphics</td>
<td>Graphical coherence</td>
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<td></td>
<td>Virtual environment</td>
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<td></td>
<td>Fonts</td>
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<td></td>
<td>First person representation</td>
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<td></td>
<td>Sound</td>
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<td></td>
<td>UI visibility</td>
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<td>Ease</td>
<td>For professional care givers</td>
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<td></td>
<td>For participants</td>
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<tr>
<td>Flexibility</td>
<td>Software</td>
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<td></td>
<td>Hardware</td>
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<td>Interaction</td>
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<td>Navigation artifacts</td>
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<td></td>
<td>Goal</td>
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<td></td>
<td>User control</td>
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<td>Hardware</td>
<td>Bike</td>
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<td></td>
<td>Touchpad</td>
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<td></td>
<td>Horn</td>
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<td></td>
<td>Screen</td>
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<td></td>
<td>Health impacts</td>
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<td>UX and satisfaction</td>
<td>Virtual User eXperience (UX)</td>
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<td></td>
<td>Satisfaction</td>
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<tr>
<td>Utility</td>
<td>Utility</td>
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<tr>
<td>Accessibility</td>
<td>Accessibility</td>
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<tr>
<td>Software performance</td>
<td>Performance</td>
</tr>
</tbody>
</table>
3. RESULTS

3.1 Usability Testing

The results of the usability test as provided by the test A are shown on Figure 3. The left part of the presented results (on a blue background) is related to the adequacy between the impressions of participants and caregivers and the objectives of the initial project. The following questions were answered:

- Adequacy with initial objectives
  - Does the application respond to the objective of allowing people physical activities?
  - Does the application respond to the objective of well-being for people riding?
  - Does the application respond to the objective of cognitive stimulation of people?

- Hardware
  - Is the bike appropriate for the objectives of the application?
  - Is the 3 buttons touchpad appropriate for answering questions?

- Cognitive stimulation exercises
  - Would it be useful to include usability familiarization activities?
  - Would you like to have different levels in the proposed cognitive activities?

The answers to these “test A” questionnaires are presented as a number of occurrences of each given term.

Let’s analyze the adequacy between the three principal objectives of the application (physical activity, well-being and cognitive stimulation of users) regarding to the feelings that had the testers during test A. We immediately see that participants and caregivers agree on their answers: when caregivers have an opinion on the currently considered criterion, the participants have the same. Despite it is clear for both samples that the prototype totally fulfills its role for allowing users to have physical activity, some caregivers and participants clearly indicate that the prototype does not give any well-being to the interrogated persons. The cognitive stimulation is badly considered by some of the testers estimating that the exercises are boring and that a goal could increase the motivation of users.

Concerning the hardware part of the instrumentation, the bike is roughly appreciated by the asked persons. Some of them strengthened the lack of comfort of the bicycle saddle. Thus it can be inappropriate for the targeted audience whose persons may have difficulties making movements. The height, the size and the shape of the bicycle saddle are actually not well suited to the physical conditions of elderly people. The same observations are made for the three-buttons touchpad. This touchpad is dedicated to answering questions given in the cognitive stimulation exercises provided to testers. The essential issue is the nearness of the three colors (magenta, blue and purple are close colors as indicated by the subtractive synthesis of the magenta and the blue colors giving the purple color) which can be confusing for people who may suffer of visual impairment (Ishihara et al, 2001; Hedge and Hustvedt, 2011).
Concerning the proposed cognitive stimulation exercises, the tested panel represented by the care givers and the participants do not really agree on the utility of a familiarization or training procedure before the activity. Care givers estimate that training is necessary despite participants do not think a training session would be useful. This is probably due to the two following facts: care givers are close to the elderly people and know their deficiencies especially towards all ICT stuff; participants were essentially ICT-advised people and are not sensitive to the technological break which exists between the young population and elderly people. Finally, the caregivers strengthened the necessity of multiple levels in difficulty for the proposed cognitive stimulation exercises.

3.2 Expectations and Omissions

Based on their evaluation of the “Balade à l’EHPAD” application that professional care givers and participants previously made, we asked them the following questions:

- Which elements seem to be crucial in the current prototype to fit the project initial objectives?
- Which absent elements are missing for the prototype to fulfill the project initial objectives?

The participants strengthened their answers on the bicycle simulator comfort, the virtual environment content in terms of 3D models and sounds. On the other hand, professional care givers were focused on the representation of the virtual bike handlebars, a kind of explanation during the cognitive stimulation exercises and usability simplicity.

Concerning the missing elements, both samples agree that a lot of work needs to be made for improving the cognitive stimulation exercises: adding difficulty levels, including ecological tasks and explanations, immersing the user into a motivating gameplay. Care givers who are aware on elderly people expectations think that the comfort and the accessibility of the bicycle simulator are missing as well as living VEIs.

3.3 Elderly People Preferences

Professional care givers, participants and elderly people were asked for their preferences concerning the following elements:

- Which kind of places elderly people would like to visit?
- Which kind of sounds elderly people would like to see?
- Which kinds of colors elderly people would like hear?
- Which kind of physical activities elderly people would like to practice?

The results to these “test B” questionnaires are depicted on Figure 4.

**Figure 4.** Results of test B concerning the collected preferences of elderly people as questioned to professional care givers, participants and elderly people.

Generally, professional care givers and elderly people agreed on places elderly people might like to visit, sounds they may like to hear, and physical activities they might like to practice. Notice that professional care givers did not answer for color preferences.

Concerning the places elderly people would like to virtually visit, we noticed that woods, countryside, gardens and the city are the most representative ones. Participants cited riverside, mountains, market places, famous places, historical places and imaginary places but they were not followed by elderly people themselves. This indicates that the participants sample had *a priori* concerning these preferences.
The a priori are much stronger when we look at the level of physical activities and colors. Concerning colors, participants estimate that elderly people would like to see warm and relaxing colors. Nevertheless, elderly people themselves prefer raw colors such as red, blue, green and so on rather than soft colors. Concerning physical activities professional care givers and participant thought that elderly people would like to be engaged in soft activities like soft fitness or aerobics, swimming, biking and walking. Actually, elderly people would like to be involved in skiing, rugby, tennis and soccer which are more violent sports. This clearly indicate that elderly people do not want to considered as other human beings able to practice equivalent physical activities.

3.4 Recommendations

Based on the results of tests A and B presented in the previous section, we proposed software and hardware design recommendations for the “Balade à l’EHPAD” application fulfill the expectations of professional care givers and elderly people. These recommendations are synthesized in Table 2.

Table 2. List of recommendations based on the evaluation of the “Balade à l’EHPAD” application.

<table>
<thead>
<tr>
<th>Ergonomic criterion</th>
<th>Recommendation</th>
</tr>
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<tbody>
<tr>
<td>Accessibility</td>
<td>Improve contrasts, use raw colors and increase elements sizes</td>
</tr>
<tr>
<td></td>
<td>Design an adapted bike for disabled people</td>
</tr>
<tr>
<td>Use assistance</td>
<td>Preserve use context in the same application</td>
</tr>
<tr>
<td>Conventions respect and understanding</td>
<td>Use classical standards in UI design</td>
</tr>
<tr>
<td>Satisfaction</td>
<td>Improve users comfort</td>
</tr>
<tr>
<td></td>
<td>Make the move of users in VEs more simple</td>
</tr>
<tr>
<td></td>
<td>Increase the users motivation in participating to the exercises</td>
</tr>
<tr>
<td>User control</td>
<td>Check the coherence between user actions and what happened in VEs</td>
</tr>
<tr>
<td>Efficiency and simplicity</td>
<td>Improve the ease of use</td>
</tr>
<tr>
<td></td>
<td>Provide a learning session to become familiar with the application</td>
</tr>
<tr>
<td>Terms used</td>
<td>Check that all terms used are understandable</td>
</tr>
<tr>
<td>Satisfaction</td>
<td>Satisfaction</td>
</tr>
<tr>
<td>Readability and perception</td>
<td>Improve the readability of software and hardware UI as well as exercises elements</td>
</tr>
<tr>
<td>Homogeneity</td>
<td>Check the coherence between buttons and instructions given to the user</td>
</tr>
</tbody>
</table>

We suggest increasing the accessibility of the all application by improving contrasts by using raw colors and increasing the sizes of some elements. As depicted in a lot of studies, elderly people suffer of visual impairment (Ishihara et al, 2001); the design should be adapted to this consequence of aging (Hedge and Hustvedt, 2011). This assumption is true for UI design but also for the bicycle simulator design. Using a bike bought in a traditional sport articles retailer is not sufficient for providing an adaptive solution for elderly people. We have to consider that elderly people might be equipped with a wheelchair and should be able to use the “Balade à l’EHPAD” application. On the other hand, the bike saddle should be adjustable considering that elderly people are often smaller than younger adults. It should also provide a better sustaining to avoid falls, limit their risks and improve users’ safety.

The satisfaction of the user is a crucial point in the appropriation of a new system including software and hardware parts. For this to be achieved, it is crucial to improve the user comfort by providing an adjustable smooth bike saddle. Results strengthened the fact that the cognitive stimulation exercises were boring; it is also crucial to improve the motivation of users in their participation to the exercises. Two ways were depicted: adding difficulty levels and a gameplay, make the VEs living by adding people, animations (traffic flow for cities, people on the beach for seaside VEs and so on …).

In terms of user control, we suggest to check the coherence between the user actions and what happened in the application. For example, it should be better having coherence between the bicycle rotation speed and the virtual speed of the avatar as seen on screen.

It was obvious that a training session should be implemented for the user to faster understand how to interact with the environment. This is very important to avoid the fail feeling a user may have if he did not succeed in reaching a certain place for example.
4. DISCUSSION

The present study represents the evaluation of usability of the prototype of a VR-based application combining physical activities and cognitive stimulation. This application involves the participant into a virtual bike ride in which he has to answer to simple questions. As it has already been demonstrated by several previously published studies, our discussion will not focused on the benefits of the association of physical activities with cognitive stimulation (Colcombe and Kramer, 2003; Colcombe et al, 2003; Kramer et al, 2003; Weuve et al, 2004; Hwan et al, 2005; Deary et al, 2006; Larson et al, 2006). We will focus our discussion on the methodology VR-based applications designers and developers should acquire to fulfill the expectations and needs of elderly people.

4.1 Stop considering Elderly People as “Soft People”

Therefore, as it is the case in designing products and interfaces for other audiences, the design process is emphasized when final users are involved in (Norman and Draper, 1986; Holzinger et al, 2007). The situation is not so different concerning elderly people. Our study clearly demonstrates that a lot of stereotypes are really present in younger people. As examples, elderly people are expected to like soft colors or soft physical activities and when they are asked they answer that they prefer to see raw colors and indicate that they would like to practice violent sport such as rugby, soccer or skiing. This result obtained on our study is in coherence with what showed Mitzner et al. They suggest that elderly people suffer of a negative image based on stereotypes. To dismiss this behavior, they suggest that involving elderly people into the design process (as it is often the case for younger adults) will allow the designers and developers to better fit their needs and expectations (Mitzner and Rogers, 2010). Moreover, studies have already suggested methods to involve elderly people and people with dementia into the design process (Lindsay et al, 2010).

4.2 Game Design and Adapted Hardware for Elderly People

One result of our study is the nature of the virtual experience proposed. It has been cited that the experience is boring, the environment is not really living and a people are lacking. We then suggest to really developing a game design for the cognitive activities proposed in the virtual experience. Game design is the process of designing the content and rules of a video game in the pre-production stage of a video game and design of gameplay, environment, storyline and characters during the production stage (Brathwaite and Schreiber, 2009). This is also true for elderly people cognitive activities such as (exer)games and it was already achieved in several studies (Ijsselsteijn et al, 2007; Facal et al, 2009). As an example, Gerling et al wrote several articles on (exer)game design for elderly users (Gerling et al, 2010). In addition to the adaptation of the game design to elderly people, the hardware part needs also to be adapted as depicted in this study by the fact that the bike simulator used was not adequate to allow elderly people to perform test A without any safety issues. This is also noticed in several studies using adapted Wii Balance Board (Neufeldt, 2009), Wiimote remote (Boulay et al, 2011).

4.3 Elderly People also bring their Own Background into VR Experiences

People bring their own background into a virtual reality experience. This assumption is also shown in our results in their preferences in term of environments, sounds and music and colors. As shown by North et al., it is crucial to take into account their expectations in term of design, thus improving their adherence (North et al, 1997). As mentioned by B. Lange and co-workers, the adherence to the therapeutic program will be increased if the treatment is fun, motivating and distracting (Lange et al, 2010). Wherever “Balade à l’EHPAD” is not a therapeutic application used in virtual rehabilitation, it must infer an adherence feeling for being efficient in improving quality of life, self-esteem and well-being of involved elderly people.

Finally, one important preconceived idea is that elderly people as disabled one do not care about their living environment and then can be immersed into virtual environments that do not fit to the rules of “beauty”. The cognitive mechanism which causes the relationship between aesthetics and usability exists and as depicted by Ilmberger et al., “what is usable is beautiful” (Ilmberger et al, 2008).

5. CONCLUSION

We presented in this paper a usability study of the first version of the VR-based “Balade à l’EHPAD” application which is dedicated to physical and cognitive stimulation among elderly people. Our focus was on usability issues, participant interactions and behaviors. Thanks to the results, we built recommendations for improving the first version of the prototype. Our study also confirms that co-design of a VR-based application is an essential part of the design process. Designers and developers must forget all their...
preconceived ideas on elderly people thoughts and listen carefully to their needs and expectations. They will bring into the virtual environments their knowledge of the world and their feelings. In a VR-based application, if the software or the hardware do not fit with these expectations, the application will never be appropriated and the objectives will not be fulfilled.

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