Study of the impact of added contextual stimuli on the performance in a complex virtual task among patients with brain injury and controls

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ABSTRACT

During the last years, researchers showed the feasibility and the interest of using Virtual Reality (VR) among patients with cognitive impairments for the recovery of capacities. While interacting, the VR system provides various kinds of information for different purposes: display of the virtual environment, understanding of the task, but also highlighting of functionalities or delivery of instructions. Generally, in order to improve the patient performance, additional cues are provided to enhance information saliency, such as arrows, change of colors. We define a “contextual Additional Software Stimulus” (contextual ASS) as any additional information delivered by the virtual system, related to the interaction whose absence in the virtual environment does not have an effect on the unfolding of the task. This work was designed to study the effects of contextual ASS on the performance in a daily living simulated task: purchasing items in the Virtual Action Planning Supermarket (The VAP-S). In this purpose, we started by implementing ASS in the VAP-S then we carried out experiments in which 23 healthy subjects (12 M and 11 F) and 12 patients with brain injury (12 M) took part. Results show that the deliverance of contextual ASS during the virtual task improves significantly some parameters describing the performance of healthy subject and patients with brain injury.

1. INTRODUCTION

After brain injury, cognitive rehabilitation aims to enable the autonomy of the patients in the instrumental Activities of Daily Living (iADL) (e.g., shopping, meal preparation). It refers to the therapeutic process of increasing or improving an individual capacity to process and use incoming information so as to allow increased functioning in everyday life (Sohlberg and Mateer, 1989). Executive Functions are defined as higher-order functions that are needed to perform organized goal directed behaviors. They include the capacity for initiative, formulating goals, planning, organization, reasoning, control, audit, abstract thinking and self-awareness (Meulemans, 2006). Many studies showed the feasibility and the interest of using Virtual Reality (VR) among patients with cognitive impairments for the recovery of capacities (Rizzo et al, 2004; Rose et al, 2005; Klinger et al, 2010). VR offers to the patient the possibility to experience simulated activities of daily living in which their performance in the task (e.g., cooking, shopping, road crossing, etc.) is observed and documented (Klinger, 2006a; Klinger et al, 2006; Klinger, 2008; Cao et al, 2009; Rand et al, 2009). In order to improve performance in virtual tasks, additional cues are provided to enhance information saliency, such as arrows, change of colors (Cao et al, 2010; Farran et al, 2012). We define a “contextual Additional Software Stimulus” (contextual ASS) as any additional information, delivered by the virtual system, related to the interaction whose absence of the virtual environment does not have an effect on the unfolding of the task.

A few works in the literature allow us to underline the relationship between the contextual ASS delivered by the virtual system and the performance of the subjects in the virtual task. In order to illustrate research works, we chose studies that cover both of auditory and visual modalities for the deliverance of ASS, since they represent the privileged modalities of information delivery in virtual environments (VE).

In the context of learning professional gestures, the CS WAVE was set up to train or evaluate people's welding motion skills (Mellet-d'Huart, 2002; Burkhardt et al, 2003; Mellet-d'Huart, 2004). The CS WAVE is a virtual environment that allows the trainee to perfect his hand motion accuracy and concentration through a
full range of exercises. It provides the trainers with an efficient support to follow-up and to assess the student evolution. It provides various guided information delivered as contextual visual ASS (texts and graphs), for example, visual marks to guide the learner not to overflow the area of welding.

Sanchez and colleagues developed the Audio-Based Environments Simulator (AbES) software that enables blind people to navigate through virtual representation of real spaces. Thanks to auditory cues, the system allows blind people to train their orientation and mobility skills in closed and unfamiliar spaces (Sanchez et al, 2009). The AbES consists of a two-floors building containing many rooms and different objects (furniture, etc.), and includes three modes of navigation and interaction: Free navigation, Path Navigation and Game Mode. In the free navigation mode, the patient explores freely the building. In the path navigation mode, the patient has to find a particular room in the building. The game mode task consists of a game in which blind participants have to find jewels and to bring them outside before that the monsters, randomly placed inside the building, steal the jewels and hide them elsewhere. Specific auditory stimuli are used to inform the blind participants about the presence of an enemy or a jewel. The system also delivers a verbalized audio of the cardinal direction of the user. When it is possible to move forward in the VE, the sound of a footstep is heard. When bumping against objects of the VE, another sound is heard indicating the collision. The system delivers also information that related to the location and the orientation of the user and about the task that must be completed. The experiments included six children (2 girls and 4 boys) whose ages ranged between 9 to 11 years old. Results show that the AbES is usable and highly understandable by blind people. The system allowed the blind participants to understand the dimensions and the spatial layout of the environment. The authors concluded that, if the users were clear on the locations of the walls and the doors, it would be possible to construct a more robust mental map of the space, allowing for a real training and rehabilitation exercise.

Cao and al. developed the Therapeutic Virtual Kitchen (TVK). The TVK is a virtual kitchen that is graphically very close to the Kerpape Center kitchen (Cao et al, 2010). Its various functionalities include behaviors of all the 3D objects that are required in coffee preparation or in the follow-up of all the activity of the participant. Coffee preparation is a complex task, including various steps that should be carried out in a correct way in order to prepare the coffee. Real sounds are provided according to the activated 3D objects, in order to increase the feeling of immersion within the virtual kitchen. During the task, contextual ASS can be provided by the therapist in order to help the participant to perform the task. These contextual ASS also bring information about the next step of the task. Besides, mouse visual stimuli are provided to facilitate the understanding of the interaction opportunities, like the modification of the mouse cursor according to user action (take, pour, activate, connect). In spite of the fact that the TVK is an VE with enriched information that provides various kinds of ASS, no work was set up, at present, to study the role of these stimuli on people with brain injury.

The quoted studies suggest the important role of the contextual ASS in the performance of subjects in the task. Let’s now consider the Virtual Action Planning Supermarket (VAP-S) (Klinger et al, 2004; Klinger, 2006b) that was designed to assess and train the ability to plan and execute the task of purchasing items on a shopping list. Operating the VAP-S includes a series of actions, described as a task, and allows an analysis of the strategic choices made by clients and thus their capacity to plan, such as the “test of shopping list” (Martin, 1972). Many studies showed the efficiency of the VAP-S as tool of cognitive evaluation for different populations such as Parkinson disease (Klinger et al, 2006), mild cognitive impairment (Werner et al, 2009), and schizophrenia (Josman et al, 2009). In order to use it in cognitive rehabilitation and to provide graduated modalities of intervention, we raise the issue of information saliency within the VAP-S, and in particular saliency of the items of the shopping list. In fact, these items are not specifically striking compared with the others items of the supermarket.

The objective of this work was: 1) to implement visual and auditory contextual ASS in the VAP-S; 2) to examine their impact on the performance in a complex virtual reality based task in the VAP-S among healthy subjects and patients with brain injury.

2. METHOD

2.1 Participants
To carry out the study, we included twelve patients with brain injury (12 males, mean age = 48±12) who attended the Rehabilitation Center of Kerpape and the hospital of Bordeaux in France, and twenty-three healthy subjects (12 male and 11 female, mean age = 29±6).

All of participants were right handed and only one of them has a little experience in video games.
2.2 Instrumentation

The VAP-S was designed to assess and train the ability to plan and execute the task of purchasing items on a shopping list. The VAP-S simulates a medium size supermarket with multiple aisles displaying most of the items that can be found in a real supermarket. It was already described in previous published studies (Klinger et al., 2004; Klinger, 2006a).

Purchasing items is a complex task that involves cognitive functions such as spatial capacities, attention, or executive functions. In order to highlight the items of the shopping list, we enriched the VAP-S with an additional layer that makes it deliver visual and auditory Contextual ASS. The visual contextual ASS is “Blinking of the list items” which occurs when the participant is close to an item of the shopping list. The auditory contextual ASS is an “Alarm beep”, which occurs in the same spatial condition as the previous ones.

2.3 Procedure

Subject were given a pre-trial session to be familiarized with the VAP-S. Then, they were engaged in the assessment session in which they had to purchase two lists of items (L1 and L2) in four conditions. Both lists contain four items belonging to the same categories of products and in the same geographic locations. For each participant, the task included the 4 following conditions: 1) purchasing the items of L1 without CAS (Condition C0); 2) purchasing the items of L2 without CAS (Condition C1); 3) purchasing the items of L1 with an auditory CAS (Condition C2); 4) purchasing the items of L2 with a visual CAS (Condition C3). To avoid any effect of learning, the participants started the task either with a condition with ASS or with a condition without ASS as described in Table 1.

2.4 Data analysis

Descriptive data analyses were used to study the population and the main variables representing the performance. To study the signification of the differences found in the tests, we used Student’s paired t test, with a 95% confidence interval.

3. RESULTS

We describe the performance of the participants in the VAP-S task thanks to the following variables: total distance in meters traversed by the patient (D), total task time in minutes (T), number of purchased items (NbI), number of correct actions (CA), number of incorrect actions (IA), number of pauses (NbP), duration of pauses (TP) and the number of intersection points in the curves representing the trajectory of participants in the virtual environment (Intersect).

Results are described with means and standard deviations; they are collected in Table 2 for patients and in Table 3 for healthy subjects. The third column of each table contains comparisons between participants performances in the conditions C0 (list L2 without contextual ASS) and C2 (list L2 with auditory contextual ASS), illustrated by the significance of the difference (p). The sixth column of each table contains comparisons between participants performances in the conditions C1 (list L2 without ASS) and C3 (list L2 with visual contextual ASS), illustrated by significance of the difference (p).

Results show that the performance of healthy subjects was significantly better in condition C2 compared to that in condition C0:

- Decrease of the distance traversed in condition C2 (128±18 m) compared to C0 (149±29 m), (p = 0.002)
- Decrease of the total time spent in the task in condition C2 (3.3±0.7 min) compared to C0 (4±0.8 min), (p = 0.000)
- Decrease of the number and the duration of pauses in condition C2 (5±2 stops and 0.8±0.3 min) compared to C0 (7±3 stops and 1.1±0.5 min), (p = 0.051, p = 0.008)
- Decrease of the mean number of point of intersection in the curves representing the trajectory of participants in the condition C2 (1±1) compared to C0 (3±3), (p= 0.001)

The same observation is also valid passing from the condition C1 to the condition C3:

- Decrease of the distance traversed in the condition C3 (121±12 m) compared to C1 (138±17 m), (p = 0.000)
Decrease of the total time spent in the task in the condition C3 (3.2±0.7 min) compared to C1 (3.9±1 min), (p = 0.000)

Decrease of the number and the duration of pauses in the condition C3 (5±3 stops and 0.9±0.8 min) compared to C1 (7±4 stops and 1±0.6 min), (p = 0.097, p = 0.607)

Decrease of the mean number of point of intersection in the curves representing the trajectory of participants in the condition C3 (1±1) compared to C1 (2±2), (p = 0.067)

Figure 1 shows two examples of curves representing two trajectories of a subject in two different conditions. The first curve, on the left, illustrates the trajectory realized in the task carried out under the condition C0. The second curve, on the right, illustrates the trajectory of the same subject under the condition C2.

### Table 2. Patients performances in the different conditions.

<table>
<thead>
<tr>
<th>Patients N= 12 (12 H)</th>
<th>Condition C0</th>
<th>Condition C2</th>
<th>p</th>
<th>Condition C1</th>
<th>Condition C3</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>48±12</td>
<td>48±12</td>
<td>-</td>
<td>48±12</td>
<td>48±12</td>
<td>-</td>
</tr>
<tr>
<td>NbA</td>
<td>4</td>
<td>4</td>
<td>-</td>
<td>4</td>
<td>4</td>
<td>-</td>
</tr>
<tr>
<td>BA</td>
<td>9</td>
<td>9</td>
<td>-</td>
<td>9</td>
<td>9</td>
<td>-</td>
</tr>
<tr>
<td>DP (m)</td>
<td>192±65</td>
<td>154±48</td>
<td>0.042</td>
<td>168±47</td>
<td>133±33</td>
<td>0.002</td>
</tr>
<tr>
<td>T (min)</td>
<td>8.1±3.1</td>
<td>6.1±2.8</td>
<td>0.01</td>
<td>6.3±2.2</td>
<td>5.1±2.1</td>
<td>0.007</td>
</tr>
<tr>
<td>MA</td>
<td>4±4</td>
<td>2±4</td>
<td>0.036</td>
<td>2±4</td>
<td>3±4</td>
<td>0.389</td>
</tr>
<tr>
<td>NbP</td>
<td>13±6</td>
<td>13±9</td>
<td>0.9</td>
<td>11±4</td>
<td>9±4</td>
<td>0.083</td>
</tr>
<tr>
<td>TP (min)</td>
<td>2.9±1.6</td>
<td>2.8±1.7</td>
<td>0.8</td>
<td>2.3±1</td>
<td>2±1</td>
<td>0.164</td>
</tr>
</tbody>
</table>

### Table 3. Healthy subjects performances in the different conditions.

<table>
<thead>
<tr>
<th>Healthy subjects N= 23 (11 F, 12 H)</th>
<th>Condition C0</th>
<th>Condition C2</th>
<th>P</th>
<th>Condition C1</th>
<th>Condition C3</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>29±6</td>
<td>29±6</td>
<td>-</td>
<td>29±6</td>
<td>29±6</td>
<td>-</td>
</tr>
<tr>
<td>NbA</td>
<td>4</td>
<td>4</td>
<td>-</td>
<td>4</td>
<td>4</td>
<td>-</td>
</tr>
<tr>
<td>BA</td>
<td>9</td>
<td>9</td>
<td>-</td>
<td>9</td>
<td>9</td>
<td>-</td>
</tr>
<tr>
<td>DP (m)</td>
<td>149±29</td>
<td>128±18</td>
<td>0.002</td>
<td>138±17</td>
<td>121±12</td>
<td>0.000</td>
</tr>
<tr>
<td>T (min)</td>
<td>4±0.8</td>
<td>3.3±0.7</td>
<td>0.000</td>
<td>3.9±1</td>
<td>3.2±0.7</td>
<td>0.000</td>
</tr>
<tr>
<td>MA</td>
<td>2±3</td>
<td>2±2</td>
<td>0.644</td>
<td>2±2</td>
<td>1±2</td>
<td>0.332</td>
</tr>
<tr>
<td>NbP</td>
<td>7±3</td>
<td>5±2</td>
<td>0.051</td>
<td>7±4</td>
<td>5±3</td>
<td>0.097</td>
</tr>
<tr>
<td>TP (min)</td>
<td>1.1±0.5</td>
<td>0.8±0.3</td>
<td>0.008</td>
<td>1±0.6</td>
<td>0.9±0.8</td>
<td>0.607</td>
</tr>
<tr>
<td>Intersect</td>
<td>3±3</td>
<td>1±1</td>
<td>0.001</td>
<td>2±2</td>
<td>1±1</td>
<td>0.007</td>
</tr>
</tbody>
</table>

Figure 1. Two examples of curves representing two trajectories of a subject in the conditions C0 (on the left) and C2 (on the right).

The comparisons show that the performance of healthy subjects was actually better when they performed the task assisted by the delivery of contextual auditory and visual ASS. In fact, once assisted by stimuli,
participants executed the task faster, crossed a shorter distance, made less incorrect actions and made less stops than unassisted participants.

This result is confirmed by the fact that 21 out of 23 subjects, considered that the contextual ASS delivered during the task helped them to better perform the task. Only 2 subjects felt that the delivery of the stimuli had no effects on their behaviors in the task. On the other hand, no subject considered that the delivered ASS disturbed him or that they had a negative effect on his behavior during the task.

The same observations are almost valid for patients whose performance was better in the condition C2 and C3 compared respectively to the conditions C0 and C1. In fact, they executed the task more rapidly and traversed a shorter distance in the conditions C2 and C3:

- Decrease of the distance traversed in condition C2 (154±48 m) compared to C0 (192±65 m), (p = 0.042)
- Decrease of the total time spent in the task in condition C2 (6.1±2.8 min) compared to C0 (8.1±3.1 min), (p = 0.010)
- Decrease of the mean number of point of intersection in the curves representing the trajectory of participants in the condition C2 (2±1) compared to C0 (4±4), (p= 0.094)
- Decrease of the distance traversed in the condition C3 (133±33 m) compared to C1 (168±47 m), (p = 0.002)
- Decrease of the total time spent in the task in the condition C3 (5.1±2.1 min) compared to C1 (3.9±1 min), (p = 0.007)
- Decrease of the mean number of point of intersection in the curves representing the trajectory of participants in the condition C3 (1±1) compared to C1 (2±2), (p= 0.007)

Thus, when they are assisted by visual and auditory ASS, patients execute the task faster and traversed a shorter distance. This increase in the performance of patients when they are assisted by contextual ASS is confirmed by the fact that 10 patients out of 12, considered that the contextual software stimuli delivered during the task helped them to better perform the task.

4. DISCUSSION

In this study, we wanted to assess the effect of contextual ASS on the performance in a simulated instrumental activity of daily living: a shopping task in the VAP-S. The experiments we carried out suggest that the contextual ASS delivered by the virtual system during the task have some potential effect. Indeed, when they were assisted by the contextual ASS, participants in both of populations performed the task more rapidly, traversed a shorter distance and found easier the virtual targets. Then, better performance can be achieved by assisting users using contextual visual and auditory software stimuli.

That was confirmed by the fact that about 93% of healthy subjects and 80 % of patients considered that the delivered software stimuli helped them to better perform the task and the rest of participants considered that it had no effect on them.

Besides, participants were not informed about the relationship between the delivered software stimuli and the virtual scene. This suggests that if participants were explicitly told about this relationship, their performance would have been better than that found in the experiments. We also compared our two groups of participants, and significant performance differences appear between the healthy subjects and the patient groups. But these results are not evoked in this paper because the two groups are not matched in age.

The results found cope with those of other works carried out in the context of spatial orientation tasks and object manipulation tasks. They prove the helping role of the contextual ASS for healthy subjects and patients with brain injury when performing virtual tasks.

5. CONCLUSION

Thanks to this work we succeeded in developing contextual stimuli in the VAP-S that had an effect on some parameters of the performance in the virtual shopping task. Healthy participants and patients with brain injury performed the task more rapidly, crossed a shorter distance and found easier the virtual targets. Nevertheless, the threshold of contextual ASS beyond which the performance starts to decrease is not specified in this work. In fact, stimuli which are source of information may also be source of confusion and disturbing if they are delivered in too big quantities. This issue is part of our future work.
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6. REFERENCES


X Cao, A S Douguet, P Fuchs and E Klinger (2009), Issues in the design of a virtual Instrumental Activity of Daily Living (vIADL) for Executive Functions exploration, In Virtual Rehabilitation, Haifa, Israel.


E Klinger (2006a); Apports de la réalité virtuelle à la prise en charge des troubles cognitifs et comportementaux; ENST; Paris.

E Klinger (2006b); Apports de la réalité virtuelle à la prise en charge des troubles cognitifs et comportementaux; ENST; Paris.


R Martin (1972), Test des commissions (2nde édition), Editest, Bruxelles.

D Mellet-d'Huart (2002), Virtual Environment for training : An art of enhancing reality, In Simulation based training, Spain, pp.48-89.

D Mellet-d'Huart (2004); De l'intention à l'attention. Contributions à une démarche de conception d'environnements virtuels pour apprendre à partir d'un modèle de l'_actions; Université du Maine; Le Mans.


A A Rizzo, M T Schultheis, K A Kerns and C Mateer (2004), Analysis of assets for virtual reality applications in neuropsychology, Neuropsychol Rehab, 14, pp.207-239.


P Werner, S Rabinowitz, E Klinger, A S Korczyn and N Josman (2009), The use of the virtual action planning supermarket for the diagnosis of mild cognitive impairment, Dementia and Geriatric Cognitive Disorders, 27, pp.301-309.