Effect of performance demands and constraints within virtual environments

Debbie Rand M.Sc\textsuperscript{1,2}, Rachel Kizony M.Sc\textsuperscript{1,3}, Hagit Brown B.O.T\textsuperscript{1}, Uri Feintuch Ph.D\textsuperscript{1,4}, Patrice L. (Tamar) Weiss Ph.D\textsuperscript{1}

\textsuperscript{1}Dept. of Occupational Therapy University of Haifa, Mount Carmel, Haifa, Israel
\textsuperscript{2}Beit Rivka Geriatric Rehabilitation Center, Petach Tikva, Israel
\textsuperscript{3}School of Occupational Therapy Hadassah-Hebrew University, Jerusalem, Israel
\textsuperscript{4}Caesarea Rothschild Institute, University of Haifa, Haifa, Israel

Abstract: In recent years, clinical studies have begun to demonstrate the effectiveness of virtual reality (VR) as an intervention tool in rehabilitation. There are, however, a number of important issues that must be addressed in order to determine how widely VR-based intervention should be applied, and the ways in which specific patient populations can benefit from its unique attributes. One of the unresolved issues relates to how the characteristics of a given virtual environment affect a user’s performance and therapeutic goals. The objective of this study was to compare the sense of presence, performance, and perceived exertion experienced by users when they engaged in two games performed within video-projected virtual environments that differed in their level of structure and spontaneity. VividGroup’s Gesture Xtreme (GX) VR and the rehabilitation-oriented application of GX marketed as IREX (Interactive Rehabilitation and Exercise) were used to deliver the virtual environments. Thirty healthy male and female participants, aged 21 to 35 years, experienced the same two virtual games on both platforms. A mixed design, within and between subjects ANOVA was used to examine the effect of movement constraint and gender as well as the interaction between these variables on the sense of presence, performance, and perceived exertion. No main effect or interaction effect was found for the sense of presence, assessed using the Presence Questionnaire (PQ), although significant differences were found for several of the PQ sub-scales. A main effect was found for perceived exertion for both games, but in the opposite direction. We conclude that it is possible to provide users with a satisfactory level of presence and enjoyment using both structured and non-structured paradigms. However, user characteristics such as gender, as well as the therapeutic objectives, should be taken into account when selecting a suitable application.

INTRODUCTION

In recent years, clinical studies have begun to demonstrate the effectiveness of virtual reality (VR) as an intervention tool in rehabilitation. Among its advantages is the opportunity for experiential, active learning which motivates the participant.\textsuperscript{1,2} VR also offers the capacity to individualize treatment needs while providing increased standardization of assessment and retraining protocols. Virtual environments can also provide repeated learning trials and offer the capacity to gradually increase the complexity of tasks while decreasing the support and feedback provided by the therapist.\textsuperscript{3}

METHODS

Participants

Thirty participants (14 men and 16 women) aged 21-35 years (mean age 25.4 ± 3), all university students, volunteered to participate in the study.

VR Platforms

The non-structured application was applied using VividGroup’s Gesture Xtreme (GX) VR system (www.vividgroup.com), a projected video-capture VR platform originally developed for entertainment purposes that has been adapted for use in rehabilitation.\textsuperscript{10} This system has been recently used in rehabilitation for the treatment of motor and cognitive impairments.\textsuperscript{7,8,10,11} Participants stand or sit in a demarcated area viewing a large monitor that displays games such as touching virtual balls, as shown in the left panel of Figure 1. A single camera vision-based tracking system captures and converts the user’s movements for processing: the user’s live, on-screen video image corresponds in real time to his movements. The users can interact with graphic objects as depicted in this environment. No additional equipment needs to be worn by participants and any part of body can interact with the VE, which allows the user to respond in a relatively unstructured and spontaneous manner.
The structured application was applied using the IREX platform Interactive Rehabilitation and Exercise (IREX), a rehabilitation-oriented application of GX. Since it was developed with the option to train a specific movement (such as shoulder abduction, in order to increase the range of motion of a specific joint or to increase the endurance) prior to the VR experience, a virtual model demonstrates the desired movement and again during the virtual experience (see the right panel of Figure 1). Once the user is familiar with the required movement, he is ready to engage with the VE. During the experience a graph comparing the desired movement to actual performance is located at the bottom of the screen in order to encourage the user to perform the desired movement. Since interaction should be only with the “affected” arm, the user wears a red glove on one hand and the movements are performed in a highly structured manner.

Virtual Environments

Two of the virtual environments (games) that were used are run on the GX and IREX VR platform, and have been described in detail elsewhere.\(^1\)

(1) Birds & Balls - wherein the user sees himself standing in a pastoral setting as different colored balls fly towards the user. Depending on the intensity of contact by any part of the user’s body, the balls will either “burst” or “transform” into doves and fly away. Performance was rated by the mean response time (RT) of touching the balls for the GX platform and percent of success for the IREX application.

(2) Soccer - wherein the user sees a video reflection himself as the goalkeeper in a soccer game. Soccer balls are shot at him, and his task is to hit them in order to prevent them from entering the goal area. Performance was rated by the percent success of repelling the balls for both applications. For these games, the third minute (out of a total of 4 minutes) of each VR experience was analyzed, since it should reflect the participant’s best performance (after participants had practiced but prior to the onset of fatigue).

Outcome Measures

Presence Questionnaire (PQ) (translated from Witmer & Singer, 1998)\(^1\) was used to assess presence. It is composed of 19 questions in which participants use a seven-point scale to rate various experiences within the VE; the maximum total score is 133 points. The items assessed different aspects of presence: involvement/control, intuitiveness, interface quality, and resolution.

Scenario Presence Questionnaire (SPQ), (based, in part, on a translated version of Witmer and Singer’s Presence Questionnaire\(^1\)) was administered after every environment. The six items assessed the participant’s (1) feeling of enjoyment, (2) sense of being in the environ-

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Figure 1. The Birds & Balls environments as used within the non-structured (left) and structured (right) applications.
ment, (3) success, (4) control, (5) perception of the environment as being realistic and (6) whether the feedback from the computer was understandable. Responses to all questions were rated on a scale of 1-5. These questions were combined to give a global response to the experience for a maximum score of 30. This 6-item questionnaire was formulated as an abbreviated alternative to the longer Presence Questionnaire.

Borg’s Scale of Perceived Exertion\textsuperscript{13} was used to assess how much physical effort the participant’s perceived that they expended during each VR experience. This is a 20-point scale that participants rated from 6 (no exertion at all) to 20 (maximal exertion).

**PROCEDURE**

Participants signed an informed consent and then filled in a demographic questionnaire. They experienced both games using the first application. After each game they filled out the SPQ and rated their perceived exertion on Borg’s scale for the specific scenario. After completing the two environments for a given VR application, participants completed the Presence Questionnaire. The same procedure occurred for the second platform while the order of the platforms was counterbalanced.

**DATA ANALYSIS**

A mixed design, within and between subjects ANOVA was used in order to examine the effect of the type of VR application (delivered via GX versus IREX) and the user characteristics (i.e. gender) as well as the interaction between these variables on the sense of presence, performance, and perceived exertion.

**RESULTS**

As a first step for analysis we examined whether the order of experiencing the VR platforms influenced the results. There were no significant differences due to the order in which the VR applications were experienced by participants for any of the outcome measures.

**The Sense of Presence**

No main effect or interaction effect was found for the total PQ, however for three of the four subscales of the PQ interaction effects were found: For the Involvement/Control PQ subscale, an interaction effect for application and gender was found (F(28)=6.7, p=.015); for the Resolution subscale, an interaction effect for application and gender was found (F(28)=4.3, p=.047); and for the Interface Quality subscale, a main effect for type of application (F(28)=15.3, p=.001) and an interaction effect for application non-structured movement

<table>
<thead>
<tr>
<th></th>
<th>Non-structured movement</th>
<th>Structured movement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>male (N=14)</td>
<td>female (N=16)</td>
</tr>
<tr>
<td>PQ total (19-133)</td>
<td>93.3 ± 15</td>
<td>95.6 ± 11.4</td>
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<tr>
<td>Involvement/Control</td>
<td>56.7 ± 9.1</td>
<td>60.2 ± 7.3</td>
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<td>natural (11-77)</td>
<td>12.4 ± 3.5</td>
<td>14.5 ± 2.6</td>
</tr>
<tr>
<td>resolution (2-14)</td>
<td>7.8 ± 2.8</td>
<td>8.8 ± 3.1</td>
</tr>
<tr>
<td>quality (3-21)</td>
<td>16.3 ± 3.7</td>
<td>12 ± 3.5</td>
</tr>
<tr>
<td>SPQ (6-30)</td>
<td>Birds and Balls</td>
<td>24.1 ± 2</td>
</tr>
<tr>
<td>Soccer</td>
<td>21.3 ± 3.4</td>
<td>21.7 ± 5</td>
</tr>
</tbody>
</table>

Table 1. Results from the Presence Questionnaire (PQ) and the Scenario Presence Questionnaire (SPQ) comparing participant responses when using virtual environments in non-structured and structured paradigms.
and gender was found \((F(28)=4.2, p=.048)\). The scores of the total PQ and its subscales for both the non-structured and structured movement applications appear in the table.

**Scenario Presence Questionnaire**

Birds and Balls - A main effect for the type of application was found \((F(28)=45.1, p=.000)\). Using the non-structured application, the participants felt a significant higher sense of enjoyment, control, and realism versus the structured mode while playing Birds and Balls (see Table 1).

Soccer - No main effect or interaction effect was found for playing soccer using a non-structured versus a structured application (see Table 1).

**Performance**

Due to technical difficulties and different outcome measures for the Birds & Balls game on the two platforms, comparison between the movement constraints within the VE was not possible. Therefore, only the percent of success playing Soccer was compared. A significant main effect for the type of application was found \((F(28)=159.7, p<.0001)\). Using the non-structured movement the percent of success of stopping the balls from going into the goal was \(49.8 \pm 9.7\) while the percent of success for using a structured movement was \(92.4 \pm 15.8\). This difference was found to be significant \((t(29)=12.6, p<.0001)\). Performance during Soccer for the structured application may have been higher since the balls are presented close to the user’s hand; they are not randomly distributed as for the non-structured application.

**Perceived Exertion (Borg Scale)**

A main effect for the type of application was found for both games (Birds and Balls \((F(28)=12.05, p=.002)\), Soccer, \((F(28)=16.02, p=.000))\) however in the opposite direction, as shown in Figure 2.

While playing Soccer using a structured application, a moderate positive correlation was found between the percent of success and the Scenario Presence Questionnaire \((r = .46, p<.05)\). In other words, the more the participant succeeded in blocking the soccer balls from entering the goal, the more enjoyment and control he felt. In addition, a moderate negative correlation was found between the perceived exertion while playing Soccer with a structured application and Scenario Presence Questionnaire \((r = -.38, p<.05)\) (i.e. the more the participant felt enjoyment, control, the less exertion he perceived while playing Soccer).

**CONCLUSIONS**

These results support the use of either structured or non-structured movement in therapy.
Selection of one or the other should depend upon the therapeutic goals for remediation of neuromuscular deficit. Both movement options used in this study, structured and non-structured, enhance the therapist’s repertoire of VR intervention tools to maximize rehabilitation. In addition, the results support the influence of user characteristics such as gender.

It is important to note that, in addition to the results presented here, our impression is that there are many subtle and not-so-subtle differences between the structured and the non-structured movement paradigms which may be relevant for therapy. For example, motor planning capabilities may only be evident when movement demands become more complex (i.e. when using both hands as well as other parts of the body). This is possible only via the non-structured applications (GX Platform) because it encourages the user to react to simultaneous, randomly distributed stimuli.

We have also noted that a more non-structured movement paradigm enables a therapist to identify underlying motor problems that would not be observed with conventional structured treatment and assessment. For example, the paretic limb of a patient who has had a stroke may be capable of movement when activated in isolation but become clumsy or slow when activated with the rest of the body. These and other issues will be examined in future studies.

Now that a variety of virtual environments are available for use in rehabilitation, it is imperative to identify how variations in performance demands and constraints affect their suitability for intervention of specific cognitive and motor deficits. This study is one of the first to address the effect of one important therapeutic parameter: the effect that ¾ spontaneity versus rigidity on ¾ performance has on participant responses and behaviors. The next step will be to examine these effects in patients with motor and/or cognitive deficits. It is possible to provide users with a satisfactory level of presence and enjoyment using both structured and non-structured movements. User characteristics such as gender must be taken into account since they, along with movement constraints, influence the user’s sense of presence. Further study is needed to explore interactions between performance and presence, and between perceived exertion and performance.

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CONTACT

Patrice L. (Tamar) Weiss
Department of Occupational Therapy
University of Haifa
Mount Carmel, Haifa, 31905  Israel
Ph: +972 4 828-8390
Fax: +972 4 8249753
Email: tamar@research.haifa.ac.il