Effect of movement constraint within virtual environments

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Key words: Virtual reality, purposeful activity, occupational therapy

Abstract

One of the difficulties faced by occupational therapists in physical rehabilitation intervention is the limited opportunity for implementing purposeful activities within traditional clinical settings. Virtual reality provides a medium suited to the achievement of the primary needs of rehabilitation intervention -- therapy that can be provided within a functional, purposeful, meaningful and motivating context in a reliable manner that can be readily graded and documented. The purpose of this study was to compare the sense of presence, perceived exertion and performance, experienced by healthy users when they engaged in two virtual environments performed within two video capture virtual applications that differed in their level of structure and the possibility to perform unconstrained movements. The participants in this study included 30 healthy participants.

The study instruments included the VividGroup GX and the IREX virtual reality (VR) applications, a demographic questionnaire, a Scenario Feedback Questionnaire, a Presence Questionnaire and the Borg Rating of Perceived Exertion Scale. The responses of the participants showed their enjoyment and high levels of presence in both VR applications, with no significant differences between them. The results of this study showed the potential of using both structured and non-structured VR applications to provide users with a satisfactory level of sense of presence and enjoyment.

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Introduction

Purposeful activities are goal-directed toward an objective and have personal, culturally meaningful characteristics (Katz, Marcus, & Weiss, 1994). The assumption that purposeful activity gives meaning and leads to a sense of competence and efficacy is a fundamental creed of occupational therapy (Katz, et al., 1994; Kircher, 1984; Lamport, Coffey, & Hersch, 2001). Although the literature suggests that specific impairments are best treated via functional, purposeful activity (Katz, et al., 1994; Sakemiller & Nelson, 1998; Weiss, Rand, Katz, & Kizony, 2004), techniques for implementing these strategies are not readily available. Indeed, one of the difficulties faced by occupational therapists in physical rehabilitation intervention is the limited opportunity for implementing purposeful activities within traditional clinical settings.

Conventional therapy also lacks the flexibility of grading and varying the biomechanical and physiological demands of a given movement. For example, it is often difficult to manipulate exercises or activities such that a patient is required to contract particular muscles concentrically or eccentrically, to perform these movements at higher or lower velocities, and to use only a specific limb or the entire body. Tasks performed within the real world are bound by the laws of nature and limited with the capabilities of the accompanying therapist.

In recent years, clinical studies have begun to demonstrate the effectiveness of virtual reality (VR) as an intervention tool in rehabilitation. Virtual reality provides a medium suited to the achievement of the primary needs of physical rehabilitation. Use of VR as a therapeutic modality can provide functional, purposeful, meaningful and motivating interventions in a reliable manner that can be readily graded and documented (Mantovani & Castelnuovo, 2003; Rizzo, Buckwalter, & Neumann, 1997; Rizzo & Kim, in press; Schultheis & Rizzo, 2001). Virtual reality offers the capacity to individualize treatment needs, while providing increased standardization of assessment and re-training protocols. Virtual environments can also provide repeated learning trials and offer the capacity to gradually increase the complexity of tasks while decreasing the feedback and support provided by the therapist (Schultheis & Rizzo, 2001).

The effectiveness of using virtual reality as an intervention tool for improving motor abilities of individuals with different disabilities has recently been demonstrated (Deutsch, Latonio, Burdea, & Boian, 2001; Holden, Dettwiler, Dyar, Niemann, & Bizzi, 2001; Kizony, Raz, Katz, Weingarden, & Weiss, 2003b; Reid, 2002; Sveistrup, et al., 2003). Deutsch et al., (2001) reported the use of the

Rutgers Ankle System (RARS) for the rehabilitation of ankle movement of patients with stroke. Holden et al. (2001) trained individuals with acquired brain injury to perform a movement (e.g., place an envelope in a slot, hit a nail with a hammer, move a ball through a ring, or lift a cup to the mouth). In this study, movements trained within the virtual environment via visual feedback from an electromagnetic motion tracking device were shown to transfer to the ability to perform better during real-world tasks. The clinical applicability of video capture VR has also been explored by several researchers. Reid (2002) used VividGroup's Gesture Xtreme (GX) virtual reality system for the training of postural control in children with cerebral palsy and Sveistrup et al. (2003) reported improvement of shoulder joint range-of-motion in patients with chronic frozen shoulder and for balance retraining in patients following a traumatic brain injury. Kizony et al. (2003b) described a usability study of an adapted version of the GX VR system with patients with spinal cord injuries who had balance deficits.

Despite these initial, encouraging results there are a number of important issues that must be addressed in order to determine how widely virtual reality-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 (e.g., type of interaction and meaningfulness) affect a user's performance, sense of presence and therapeutic goals. Many factors are thought to influence the user's sense of presence, including characteristics related to the computer and to the virtual environment (e.g., resolution, speed) as well as characteristics related to the individual (e.g., ability to adapt quickly, motivation) and to the task itself (e.g., how meaningful and realistic it is) (Nash, Edwards, Thompson, Barfield, 2000). Presence is thought to be a key feature in ensuring the efficacy of virtual training and transfer of that knowledge to real life situations (Mantovani & Castelnuovo, 2003).

Far less information is available about the effect that movement constraints within a virtual environment have upon users. Specifically, the effect of allowing a user to respond naturally with his entire body (i.e., non-structured movement) versus constraining him to respond with a specific limb (i.e., structured movement) has not yet been explored. The purpose of this study was to compare the sense of presence, perceived exertion and performance experienced by healthy users when they engaged in two games performed within two applications of a video capture VR platform that differed in their level of structure and the possibility to perform free movements: VividGroup's GX virtual reality application for the non-structured movement and the rehabilitation-oriented version of GX

marketed as the IREX (Interactive Rehabilitation and Exercise) application for the structured movement. In addition, the study aimed to determine the relationship between the user's gender, the type of the VR application and the type of the virtual environments and the sense of presence, the sense of exertion and performance.

Method

Participants

Thirty healthy university students (14 males and 16 females), aged 21 to 35 years (mean age 25.4 ± 3.0), volunteered to participate in the study.

Video capture virtual reality applications

The non-structured application was provided using VividGroup's GX VR (www.vividgroup.com), a projected video-capture virtual reality system originally developed for entertainment purposes that has been adapted for use in rehabilitation (Kizony, Katz, & Weiss, 2003a; Weiss, Rand, Katz, & Kizony, 2004). This system has been recently used for the rehabilitation of motor and cognitive impairments (Sveistrup et al., 2000; Kizony et al., 2003a; Kizony, et al., 2003b; Weiss, Bialik, Kizony, 2003). 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 graphical objects as depicted in this environment. These graphical objects serve as stimuli to the user and may be programmed to emanate from any location in the environment. No additional equipment needs to be worn by participants and the interaction with the VE can be via any part of body; the user, therefore, responds in a relatively unstructured and spontaneous manner.

The structured mode was applied using the IREX application, a rehabilitation-oriented version of GX (www.irexonline.com). It was developed to give the option to train a specific movement (e.g., shoulder abduction) in order to increase the range of motion of a specific joint or to increase the endurance. A virtual model demonstrates the desired movement prior to the virtual reality experience, and again during the virtual experience (see the small inset on the bottom left of the right panel of Figure 1). Once the user is familiar with the required movement, he is ready to perform within the virtual environment. 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
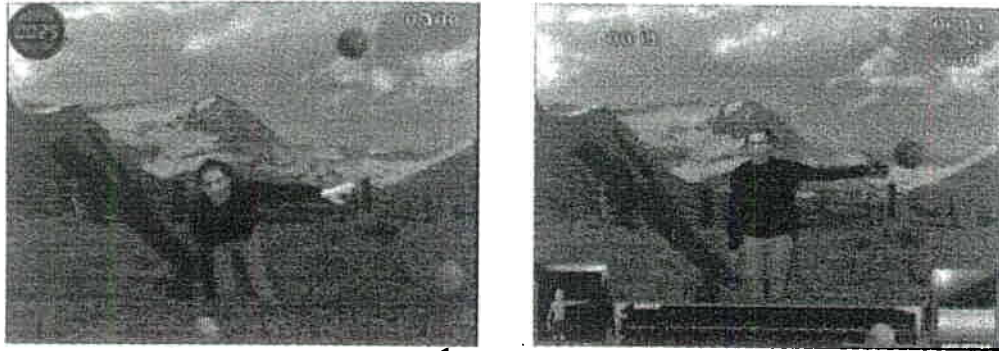
Figure 1: The Birds & Balls environments as used within the non-structured (left) and structured (right) applications

perform the desired movement at the maximal range. Since interaction should be only with the "affected" arm, the user wears a red glove on the affected hand and the movements are performed in a highly structured manner. In this application, the graphical objects (stimuli) are programmed to emanate from a specific location.

Virtual Environments

Two virtual environments (games) which are run via the GX and IREX virtual reality applications were used:

(1) Birds & Balls - the user sees himself standing in a pastoral setting where balls of different colors fly towards the user from all directions for GX, and from one direction for IREX. 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 application 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 virtual reality experience was analyzed, since it should reflect the participant's best performance, i.e., after participants had practiced but prior to the onset of fatigue.

Outcome Measures

Presence Questionnaire (PQ) (translated from Witmer & Singer, 1998) was used to assess presence. It is composed of 19 questions in which participants use a

7-point scale to rate various experiences within the VE; the maximum total score is 133 points. The items assess different aspects of presence and are divided into four subscales: involvement/control, natural, interface quality and resolution. The internal reliability of the PQ for the GX platform is ? = 0.88. (Witmer & Singer, 1998).

Scenario Feedback Questionnaire (SFQ), (Kizony et al., 2003a) (based, in part, on a translated version of Witmer and Singer's (1998) Presence Questionnaire) was administered after every environment. The six items assessed the participant's (1) feeling of enjoyment, (2) sense of being in the environment, (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. The internal reliability of the SFQ for GX platform for Soccer is á = 0.68 and for Birds & Balls is á = 0.47 (R. Kizony, personal communication, December 18, 2001).

Borg's Scale of Perceived Exertion (Borg, 1990) was used to assess the perceived physical effort the participants felt during each virtual reality experience. This is a 20-point scale that participants rated from 6 (very easy) to 20 (maximal exertion). This questionnaire has been shown to have a high level of test re test reliability (r =.80) (Bloch, Smith, & Nelson, 1989).

Procedure

Participants signed an informed consent and then filled in a demographic questionnaire. They experienced one of the games using the first application and then completed the SFQ and rated their perceived exertion on Borg's scale for the specific environment. They then experienced the second game after which they again completed the SFQ and Borg's scale. After experiencing the two games participants completed the Presence Questionnaire. The same procedure was then carried out for the second application; the order of the applications was counterbalanced.

Data Analysis

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

Results

We first examined whether the order of experiencing the virtual reality applications influenced the results. Since no significant differences due to the order were found for any of the outcome measures, these data were combined.

The Sense of Presence

Both virtual reality applications provided users with a high level of the sense of presence with no main or interaction effects when scores of the total PQ were compared. However, for three of the four PQ subscales, interaction effects were found. For the Involvement/Control subscale, an interaction effect for application and gender was found (F(28) = 6.7, p=.015); this score was significantly higher for women than for men using the GX application (t(15) = 2.82, p<.013). For the Resolution subscale, an interaction effect for application and gender was found (F(28) = 4.3, p=.047); for this subscale, the score was significantly higher for men using the IREX application (t(13) = -2.58, p<.023). For the Interface Quality subscale, a main effect for the type of application was found (F(28)=15.3, p=.001) such that the score for IREX was significantly higher than for GX, and an interaction effect for application and gender was found (F(28)=4.2, p=.048); for this subscale, men scored significantly higher while experiencing IREX (t(15) = - 3.81 p<.002). The scores of the total PQ and its subscales for both the non-structured and structured movement applications appear in Table 1.

While playing soccer using a structured application, a moderate significant positive correlation was found between the percent success and the Scenario Presence Questionnaire (r = .46, p<.05). That is, the more the participant succeeded in blocking the soccer balls from entering the goal crease, the more he felt enjoyment, control, etc.

Scenario Feedback Questionnaire (SFQ)

Birds and Balls. A main effect for the type of platform was found (F(28)=45.1, p=.000). Using the non-structured application, the participants felt a significantly higher sense of enjoyment, control, and realism than they did when using the structured mode while playing Birds and Balls (see Table 2).

Soccer. No main nor interaction effects were found for playing soccer using a non-structured versus a structured application (see Table 2).

Table 1: Results from the Presence Questionnaire (PQ) comparing participant responses when using virtual environments in non-structured and structured applications

	Non-structured movement (GX)			Structured movement (IREX)		
	male N=14	female N=16	total population N=30	male N=14	female N=16	total population N=30
PQ total (19-133)	93.3 ± 15	95.6 ± 11.4	94.6 ± 18.4	100.3 ± 17.3	92.5 ± 19	96.2 ± 18.4
involvement/control (11-77)	56.7 ± 9.1	60.2 ± 7.3	58.6 ± 8.2	59.6 ± 10.1	53.8 ± 11.07	56.5 ± 10.8
natural (3-21)	12.4 ± 3.5	14.5 ± 2.6	13.5 ± 3.2	13.7 ± 3.04	13 ± 4.2	13.3 ± 3.6
resolution (2-14)	7.8 ± 2.8	8.8 ± 3.1	8.4 ± 3	9 ± 3	8.7 ± 3.8	8.8 ± 3.4
quality (3-21)	16.3 ± 3.7	12 ± 3.5	14 ± 4.2	18 ± 3.2	17.1 ± 3.1	17.4 ± 3.1

⊾——————⊿ = significant differences (t-test) p<.05

Table 2: Results from the Scenario Feedback Questionnaire (SFQ) comparing partici-pant responses when using virtual environments in non-structured and structured appli-cations

	Non-structured movement (GX)			Structured movement (IREX)			P	t
	male N=14	female N=16	total population N=30	male N=14	female N=16	total population N=30		
SFQ (6-30)								
Birds and Balls	24.1 ±2	26.2 ± 2.5	25.2 ± 2.5	19.2 ± 3.8	19 ± 4.4	19 ± 4.1	.000	6.7
Soccer	21.3 ± 3.4	21.7 ± 5	21.5 ± 4.2	21.7 ± 4.5	24 ±4.6	23 ± 4.6	NS	

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) and Soccer (F(28)=16.02, p=.000)). Note, however, that these effects are in the opposite direction, as shown in Figure 2. That is, users reported that they exerted more effort while experiencing Birds & Balls with the structured application than they did with the non-structured application but less effort while experiencing Soccer with the structured application than they did with the non-structured application.
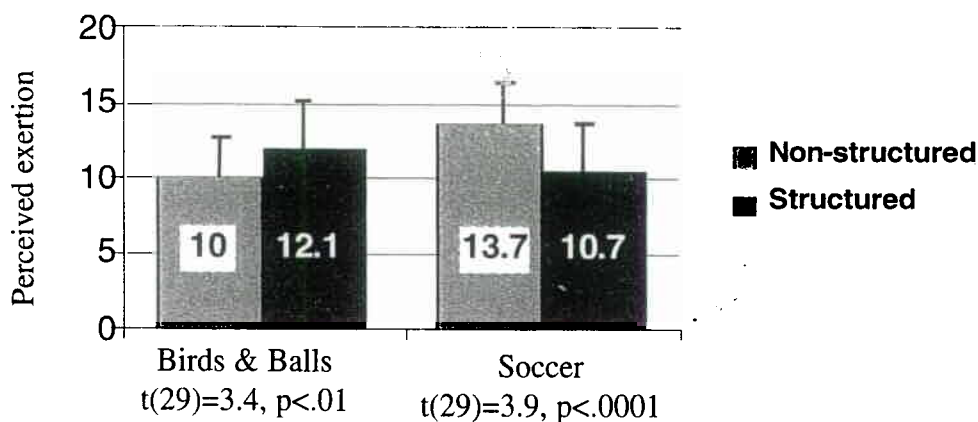

Figure 2: Comparison between the perceived exertion when using virtual environments in non-structured and structured applications

A moderate significant negative correlation was found between the perceived exertion while playing soccer with a structured application and the Scenario Presence Questionnaire (r = -.38, p<.05) (i.e., the more the participant felt enjoyment and control, the less he perceived exertion while playing soccer).

Performance

Due to different outcome measures for the Birds & Balls, comparisons between the two applications were not possible. Therefore, only the percent success while playing Soccer was compared. A significant main effect for the type of applica-

tion was found ($F(28)=159.7$, $p<.0001$). That is, using the non-structured movement, the percent success of preventing balls from entering the goal crease was 49.8 ± 9.7 while the percent success when using a structured movement was 92.4 ± 15.8. While playing soccer using a structured platform, a moderate significant positive correlation was found between the percent success and the Scenario Feedback Questionnaire ($r = .46$, $p<.05$). That is, the more the participant succeeded in blocking the soccer balls from entering the goal crease, the more he felt enjoyment, control, etc.

Discussion

The objective of this study was to compare the sense of presence, perceived exertion and performance experienced by healthy participants when they engaged in two virtual environments performed via two video capture virtual platforms that differed in their level of structure and the possibility to perform free movements. The results demonstrated the potential of using both structured and non-structured virtual reality applications since they both succeeded in providing participants with a high level of presence and enjoyment. Therefore, they both have potential for use in therapy; the selection of one versus the other should depend upon the specific therapeutic goals. For example, motor planning capabilities may only become evident when the patient's required movement becomes more complex. This is possible only via the non-structured applications (GX) because it encourages the participant to react to multiple stimuli that are delivered randomly. This non-structured movement paradigm enables the 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 becomes clumsy or slow when activated together with the rest of the body. It is important to use the GX application in cases of motor practice where use of full bodily movement is required and which obligate an immediate reaction. Moreover, since such movements are closer to those performed during natural functional activities, it is important to use the GX application when a patient approaches the later stages of rehabilitation.

In contrast, use of the IREX application appears to be recommended while practicing specific movements with graduated intensity in order to develop motor skills of strength, endurance, and range of motion. The IREX application is suited for such therapeutic goals because it enables a therapist to specify the parameters of the virtual stimuli and to direct them at specific limbs.

Both movement options used in this study, structured and non-structured, have the potential to enhance a therapist's repertoire of rehabilitation intervention tools. Indeed, the feasibility of using both the GX and the IREX applications for rehabilitation has been demonstrated in a number of clinical populations. Cunningham & Krishack (1999) first used a GX system to treat elderly patients who were unstable and at high risk for falling. More recently, Sveistrup, McComas and colleagues (Sveistrup, et al., 2003) have used the IREX application for balance retraining. Patients with stroke who received VR intervention reported more confidence in their ability to "not fall" and to "not shuffle while walking". The same research group has also demonstrated that an exercise program delivered via the IREX system can improve balance and mobility in adults with traumatic brain injury (Thornton, Marshall, McComas, Finestone, McCormick, & Sveistrup, 2004) and the elderly (Bisson, Constant, Sveistrup, & Lajoie, 2004).

Kizony et al. (2003a) performed a feasibility study of the GX application to train balance of 13 people who had a paraplegic SCI. The results showed that this VR platform appears to be suitable for use with people who have paraplegia and that it was able to differentiate between participants with different levels of balance function. The same group examined the relationships between cognitive and motor ability and performance within the GX-virtual environments of 13 people who had a stroke (Kizony, Katz, & Weiss, 2004). The results suggested that higher cognitive abilities relate to higher performance within the VR but found no positive correlations between VR performance and the motor abilities.

In accordance with the results of previous investigations of GX VR (Kizony, et al., 2004), significant correlations between presence, performance and perceived exertion were found in the present study. Higher levels of performance in the soccer environment were associated with higher levels of enjoyment and a stronger feeling of presence within the environment, success, control, and perception of the environment as being realistic. These higher levels were also associated with a lowered perception of exertion. These findings are important since the soccer environment is one that was particularly meaningful to the participants, most of whom had previous exposure to the real game of soccer. Realism while experiencing the soccer game was high, enhanced by true-to-life sounds. For example, "hitting" the virtual balls caused an authentic thumping sound to be emitted, and the noise of the crowd cheering in the background was reminiscent of a real soccer game. It is encouraging to note that the addition of greater structure to the virtual task, as performed within the IREX version of soccer, did

not appear to detract from the user's perception of meaning and realism. The motivating and enjoyable aspects of this and other virtual games are apparently sufficiently engaging so as to overcome any negative response due to movement constraint.

In conclusion, evidence from the literature as well as the results of the present study, has shown the usability and the applicability of video capture virtual applications for rehabilitation. Both the GX and the IREX platforms expand the repertoire of intervention tools, providing opportunities to present purposeful, therapeutic activities that are meaningful and motivating to patients, and flexible and diverse for therapists. The judicious selection of more global body activation or a particular limb movement in accordance with specific treatment objectives will assure the provision of appropriate occupational therapy.

Acknowledgement

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