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Comparison of Two VR Platforms for Rehabilitation: Video Capture versus HMD

Abstract

In recent years, clinical studies have begun to demonstrate the effectiveness of VR as an intervention tool for a variety of neurological conditions. There remains, however, a number of important issues that must be addressed in order to determine how widely VR-based intervention should be applied, and the user and platform characteristics that may be important when using VR in clinical settings. One of the unresolved issues that must be addressed is the suitability of particular VR platforms in relation to the therapeutic goals one wishes to achieve. Studying and identifying the characteristics of each platform may assist the therapist in choosing a suitable VR platform for the patient's needs. The purpose of this paper is to describe the results of a study of healthy participants ($N = 89$) using 2 different VR platforms in combination with 1 of the 2 virtual environments that was designed to compare the sense of presence, incidence of side effects, perceived exertion, and performance. The data demonstrate significant differences in some of the key characteristics of both VR platforms and environments as they affect participants' sense of presence, performance, side effects, and exertion. We conclude that when seeking a suitable VR therapeutic application, the user's characteristics together with attributes of the VR platform must be taken into consideration since both appear to have an impact on key outcome measures.

I Introduction

Rehabilitation of patients with neurological deficits resulting from stroke, head trauma, spinal cord injury, or degenerative diseases such as multiple sclerosis is a complex process since they typically suffer from serious motor and cognitive impairments. These patients require extensive periods of rehabilitation in order to minimize the impairments resulting from their neurological deficits and to improve their functional level in the performance of activities of daily living as well as enable them to participate in community life. Thus, an essential part of the rehabilitation process is remediation of cognitive and motor deficits in order to improve the functional ability of the patient, and to enable him or her to achieve greater independence. It is thought that the functional relevance of therapeutic intervention is of paramount importance (AOTA, 2002). Moreover, the improvement in function must go beyond what

is achieved in the clinical setting, that is, it must be transferred to real-life activities. Unfortunately, such objectives are often difficult, if not impossible, to achieve via conventional therapy.

In recent years, clinical studies have begun to demonstrate the effectiveness of VR as an intervention tool for a variety of neurological conditions (e.g., Jack et al., 2001; Schultheis & Rizzo, 2001; Weiss, Naveh, & Katz, 2003). There remains, 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 that must be addressed is the suitability of particular VR platforms in relation to the therapeutic goals one wishes to achieve. Given the growing options available on today's market, including numerous flat-screen systems, a variety of head-mounted-display (HMDs) models, and projection-based platforms, it has become important for clinicians who are considering the use of VR to identify both the assets and limitations of each approach. Some platform comparisons are relatively straightforward (e.g., size, cost, ease of use) and depend primarily on the availability of space, budget, and technical support. However, other comparisons are more complex and involve the characteristics of the systems and interactions between these characteristics and their influence on the user.

To date, information regarding the characteristics of the VR system attributes that may be of major therapeutic importance is scarce, and there are a number of open questions. Does the donning of external devices such as goggles, gloves, or helmets disturb patient performance due to weight, discomfort, or isolation? What effect does the way in which the patient is represented in a virtual environment (e.g., as an avatar, in "first" person, in "third" person) have on the sense of presence and on performance? What effect does the way in which the patient navigates or manipulates objects within a virtual environment (e.g., via a tracker, joystick, natural limb movements) have on the sense of presence and on performance? With what frequency or severity does a particular VR platform and/or environment lead to cyber-sickness-like symptoms? Are certain segments of the

population (e.g., men versus women, elderly versus young, specific pathologies) more susceptible to such symptoms?

The answers to these and other questions could guide clinical decision making as to which platform might be best suited for specific assessment and rehabilitation tasks with different patient populations. The purpose of this study was to compare the sense of presence, level of performance, side effects, and perceived exertion of healthy participants who played virtual games or scanned a virtual office displayed via two different VR platforms. The effect of age and gender on these variables was also examined. This comparison on healthy participants was designed to provide important information about the relative assets and limitations of the two VR platforms so that the clinician may justify their use for therapeutic purposes.

2 Method

2.1 Participants

The study sample consisted of 89 healthy volunteer participants divided into two groups: 40 participants aged 16 to 35 years and 49 participants aged 60 to 75 years. As illustrated in Table 1, the participants were divided into two primary groups; one group experienced three virtual games on two different VR platforms (Gesture Xtreme [GX]-monitor and GX-Head Mounted Display [HMD] and the other experienced the Virtual Office via a GX-monitor versus an HMD platform.

2.2 VR Platforms

Two VR platforms that differed considerably in their features were used in this study, along with a hybrid platform that combined features from them both. VividGroup's Gesture Xtreme (GX) VR (www.vividgroup.com) is a projected video-capture VR platform, originally developed for entertainment purposes, that has been adapted for use in rehabilitation (Kizony, Katz, & Weiss, 2003). Participants stand or sit in a demarcated area viewing a large monitor that displays a

Table 1. *Distribution of Participants in the Study*

Virtual environment	Virtual games (N = 40)		Virtual office (N = 49)			
	Young		Young		Elderly	
Age group						
Mean (±SD) age	24.5 ± 4.4		22.1 ± 3.0		66.6 ± 4.0	
Gender	Male	Female	Male	Female	Male	Female
N	24	16	13	20	11	5

game or functional tasks, such as touching virtual balls. 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. The origins of this work can be traced back to Krueger’s seminal “Videoplace” application in the early 1970s, where it was observed that humans felt compelled to interact with graphic objects displayed in this format.

In the 1990s, VividGroup designed and marketed a series of single-camera vision-based applications as location-based arcade entertainment systems. Known as the Gesture Xtreme VR System, it uses a blue backdrop and a chroma key to separate the user’s image from the background. This system has now come to be embraced by rehabilitation specialists as a research and clinical tool for the treatment of motor and cognitive impairments (e.g., Kizony et al., 2003; Kizony, Raz, Katz, Weingarden, & Weiss, 2003; Sveistrup et al., 2003; Weiss et al., 2003). Its advantages include the fact that patients see themselves rather than being represented as an avatar. They do not have to wear special apparatus such as an HMD, which encourages the use of active movement and reduces their chances of experiencing side effects. Moreover, the user is not isolated from the real world, and the therapist is able to readily intervene during the session in order to support and guide the patient’s movements. Despite these many advantages, GX VR is still not widely used in rehabilitation facilities. One of the major reasons for this limited usage is the cost of the system, which keeps it out of the price range of many clinical settings.

Head Mounted Display Platform (Fifth Dimension Technologies, www.5dt.com) HMD 800 unit, is a lightweight (594 g) head-mounted display. The user is isolated from the real world, while his viewpoint is “first person”; he or she manipulates objects within the virtual environment via Intersense’s (www.isense.com) Inter-Trax2, a 3-degree-of-freedom, inertial orientation tracker used to track pitch, roll, and yaw movements of the head. The user navigates via two hand-held switches that enable him to move to the left or to the right within the virtual environment.

A combination of the two VR platforms that integrated features from the two platforms described above. This hybrid approach used the 5DT HMD to display the GX VR games scenarios to users. The goal of combining features from the two platforms was to strengthen the attributes of each (the natural movement from the GX-monitor with the isolation created by the HMD). The features of the two different VR platforms as well as the hybrid platform are listed in Table 2.

T2

2.3 Virtual Environments

Three of the virtual environments (referred to here as “games”) are normally used with the GX-monitor VR platform and have been described in detail elsewhere (Kizony et al., 2003). Briefly, they include:

1. Birds & Balls—wherein the user sees himself standing in a pastoral setting where balls of different colors emerge from peripheral locations and fly toward the user. Depending on the intensity of contact by any part of the user’s body, the balls will either

Table 2. *Characteristics of the VR Platforms as Tested*

Feature	GX-monitor	HMD	GX-HMD
Description	User faces large monitor (34") while video camera records movements in 2D world.	Wearing an HMD, user navigates in a 3D virtual world.	Wearing an HMD, users see images of their own movements in 2D world that the video camera captures.
Virtual environments	Three games: Birds & Balls, Soccer, Snowboard <u>OR</u> the "Virtual Office"	"Virtual Office"	Three games: Birds & Balls, Soccer, Snowboard
Encumbrance	No external attachments to user	User wears HMD, navigates with hand-held switches	User wears an HMD
Point of view	User sees himself as a mirror image (not an avatar)	User's viewpoint is "first person"	User sees himself as a mirror image wearing an HMD.
Interaction with environment	User can use any part of body to interact with the environment but mainly his hands	User can look around (full 360 deg) while navigating with two hand-held switches	User can use any part of body to interact with the environment but mainly his hands
Body movement in space	User can move freely—forward, back, left, right.	Standing or sitting, user can take a step or two; must be careful not to trip over HMD wires.	User can move around; must be careful not to trip over HMD wires.
Record of movement	Whole-body movement is recorded on videotape	Only head movement is tracked and recorded	Whole-body movement is recorded on videotape
Isolation	Moderate	Considerable	Considerable
Feedback	Visual, auditory	Visual	Visual, auditory
Side effects	Anticipated to be minimal	Anticipated to be minimal to moderate due to the HMD	Anticipated to be moderate due to incongruence between environmental cues and head movement
Treatment goals	To train both motor and cognitive aspects while engaged in a purposeful activity.	Primarily to train cognitive aspects (e.g., visual scanning or visual memory)	To train both motor and cognitive aspects while engaged in a purposeful activity and while isolated from real world.
VR leading to participation	Improved performance for daily tasks that require hand movement, balance, and visual search.	Improved performance for daily tasks that require visual search, memory, etc.	Improved performance for daily tasks that require hand movement, balance, and visual search.



Figure 1. Participant using the GX video-capture system for a virtual game.



Figure 2. Participant using the Virtual Office via the GX video-capture system.

“burst” or “transform” into doves and fly away. Performance was rated by the mean response time (RT) of touching the balls.

2. Soccer—wherein the user sees a video reflection himself as the goalkeeper in a soccer game. Soccer balls are shot at him from different locations, and his task is to hit them with different parts of his video-represented body in order to prevent them from entering the goal area. Performance was rated by the percent success of repelling the balls.

3. Snowboard—wherein the user sees a video-represented back view of himself mounted on a snowboard. As he skis downhill he needs to avoid obstacles by leaning from side to side or by moving his whole body. Performance was rated by percent success of obstacle avoidance.

For all these games, the 3rd minute (out of a total of 4 minutes) of each VR experience was analyzed, since it should reflect the participant’s best performance, that is, after participants had practiced but prior to the onset of fatigue.

F1

The three games were viewed by the participants using the GX video-projected VR platform via an enlarged monitor (referred to as GX-monitor) and also with the HMD (referred to as GX-HMD). In this case an HMD is worn so that the displays of the three virtual games

(Birds & Balls, Soccer, Snowboard) are viewed via this display rather than on the normal enlarged monitor. In both cases, interaction with the VE is the same; the participants use different parts of the body to interact with the graphic stimuli.

A fourth environment is the “Virtual Office,” which was developed for use with an HMD by Rizzo et al. (2002) at the University of Southern California’s Integrated Media Systems Center (<http://imsc.usc.edu>). The task of the participants in the Virtual Office, as used in this study, was to visually scan the office environment for at least 2 min and no longer than 5 min. In the office there are 16 different items; 8 of them are uncommon to a typical office (e.g., a dog, a fire hydrant), whereas the other items are typical of an office (e.g., a clock, a clipboard). Performance was measured as the number of objects (out of the 16-item list) that participants were able to name after they finished scanning the office. The number of background items (e.g., door, window, desk) that were named was also recorded.

The Virtual Office was used in its traditional way with the HMD but was also converted by us to be used via the GX-monitor platform. In this case, participants stand in front of the GX monitor and visually scan the Virtual Office (see Figure 2). Movement within the office is accomplished by “touching” one of two virtual arrows displayed on the screen. Touching the left arrow

F2

causes the environment to move to the left, thus enabling the participant to see what is on the left side of the office, while touching the right arrow reveals the right side of the office. The image of the office used with the Vivid platform is a 360-degree photo-surround of Rizzo et al.'s (2002) Virtual Office; 16 different, but conceptually similar (e.g., a "cat" instead of a "dog"), objects replace the 16 objects that populate the original HMD-version of the office in the counterbalanced condition.

2.4 Outcome Measures

A *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 assessed different aspects of presence: involvement/control, natural, interface quality, and resolution.

A *Scenario Presence Questionnaire (SPQ)*, (based, in part, on a translated version of Witmer and Singer's [1998] Presence Questionnaire) was administered after every environment. The 6 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. This 6-item questionnaire was formulated as an abbreviated alternative to the longer Presence Questionnaire. The participants were also asked whether they felt any discomfort during the experience.

A *Simulator Sickness Questionnaire (SSQ)* (Kennedy, Lane, Berbaum, & Lilienthal, 1993) was completed by any participants who reported discomfort (Question 7 as indicated above), and, at a later stage, by all of the participants, using a 4-point rating scale on a 16-item symptom checklist for each environment. The total score was calculated by adding the scores of the three subscales, Nausea, Oculomotor, and Disorientation and

multiplying the total by 3.74, as suggested by Kennedy et al. The score ranged between 0–224.4 points.

Borg's Scale of Perceived Exertion (Borg, 1990) was used to assess how much physical effort the participants 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).

2.5 Procedure

Participants signed an informed consent and were then assigned to one of two groups. One group experienced the three virtual games (4 minutes each) using both platforms (GX-HMD & GX-monitor) and the other group experienced the Virtual Office, using both platforms (HMD & GX-monitor) (up to 2 minutes each); the order of platform usage was counterbalanced. After experiencing each environment, participants filled out the SPQ. Due to technical problems during the first half of the study, only participants who reported feeling cybersickness-like side effects (e.g., dizziness or nausea) when asked about discomfort were requested to complete the SSQ. The remaining 31 participants were requested to complete the SSQ following their use of each platform regardless of their response to the question. (Note, however, that all participants were aware of potential VR-related side effects prior to the study since they were cautioned about this possibility when they read and signed the informed-consent form). Participants were also requested to rate their perceived exertion using the Borg scale. After completing all environments for a given VR platform, participants completed the full Presence Questionnaire.

2.6 Data Analysis

A mixed design, within and between subjects ANOVA was used in order to examine the effect of the type of the VR platform (i.e., HMD, GX-Monitor) and the user characteristics (i.e., gender, age) as well as the interaction between these variables on the sense of presence, performance, and perceived exertion. Due to the small sample size of the participants who completed the SSQ we used a *t*-test rather than an ANOVA to explore

the differences between the platforms in the virtual games, and the nonparametric Mann-Whitney test for the Virtual Office.

3 Results

As a first step for each 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 platforms were experienced by participants for any of the outcome measures. The results for the virtual games will be presented first followed by the results for the Virtual Office.

3.1 The three Gesture Xtreme Games

3.1.1 Presence and Scenario Presence Questionnaires. *Presence Questionnaire* (total score)—A significant main effect was found only for type of platform ($F(1, 37) = 37.6, p < .0001$), while no significant main effect was found for gender or for the interaction between gender and type of platform. The participants' sense of presence was higher when using the GX-monitor platform than when using the GX-HMD. When the PQ was subdivided into its four subscales, a significant difference was found for the involvement/control subscale between the GX-monitor platform and the GX-HMD ($t(38) = 3.6, p < .001$) and for the quality/interface subscale, for the whole population ($t(38) = 5.5, p < .0001$). The results of the Presence Questionnaire and other outcome measures for the virtual games are listed in Table 3.

Scenario Presence Questionnaire—For Birds & Balls and Soccer, no significant main effects were found either for type of platform or for gender, nor was the interaction significant. That is, the participants felt similar enjoyment, success, control, and so forth, when playing the games with a monitor or while wearing an HMD. The total SPQ score for Birds & Balls was somewhat lower than those given for Soccer. For the Snowboard game, a significant main effect was found for gender only ($F(1, 37) = 10.8, p < .01$). *T*-tests between males and females within each platform revealed that for both platforms, scores for the

male group were significantly higher than scores for the female group ($t = 3.5, p < .01$, for the GX-monitor) and ($t = 2.1, p < .05$, for the GX-HMD).

3.1.2 Performance. *Birds and Balls*—A significant main effect was found for the type of the platform ($F(1, 34) = 8.5, p < .01$) but not for gender, nor was the interaction significant. The mean response time when the participants played Birds & Balls with the GX-monitor was 3.7 ± 0.6 s as compared to 4.0 ± 0.7 s for the GX-HMD.

Soccer—A significant main effect was found only for gender ($F(1, 35) = 25.7, p < .0001$), while no significant main effects were found either for type of platform or for the interaction between gender and type of platform. The percent of success in Soccer for male participants was significantly higher than for female participants when played with the GX-monitor ($t(36) = 4.4, p < .0001$) and with the GX-HMD ($t(35) = 4.2, p < .0001$).

Snowboard—No significant main effect for type of platform and gender or the interaction between them was found. In both platforms the participants' percent of success was high.

3.1.3 Side Effects. Of the 40 participants who experienced the virtual games, only 22 completed the SSQ for both platforms. The differences between the total SSQ score for GX-monitor (10.1 ± 11.2) was significantly lower than for the GX-HMD (36.2 ± 27.3) ($t(19) = 4.4, p < .0001$). These SSQ scores for both platforms were very low compared to the maximal SSQ of 224.4.

3.1.4 Exertion. No significant main effects were found in the Borg scale either for the type of platform or for gender, nor was the interaction significant. The score ranged from a high of 13.4 (out of a maximum of 20) for Soccer to a low of 8.3 for Snowboard.

3.2 The Virtual Office

3.2.1 Presence and Scenario Presence Questionnaires. *Presence Questionnaire* (total score)—A main effect between participants was found for gender

AQ: 2

AQ: 1

T3

AQ: 3

Table 3. Summary of Results of the Three Virtual Games Played on GX-Monitor and GX-HMD

	GX-Monitor			GX-HMD		
	Male N = 24	Female N = 16	Total N = 40	Male N = 24	Female N = 16	Total N = 40
PQ total (19–133)	99.1 ± 12.3	107.3 ± 15.7	102.6 ± 14.2	92.6 ± 13.7	97.3 ± 10	94.5 ± 12.4
Involv./cont. (11–77)	59.5 ± 7.7	63.1 ± 9.5	60 ± 8.6	57.6 ± 8.3	58.1 ± 6.5	57.8 ± 7.5
Natural (3–21)	13.4 ± 3.6	15.8 ± 3.3	14.4 ± 3.6	13.3 ± 4.2	16.2 ± 2.7	14.5 ± 4
Resolution (2–14)	9.5 ± 2.3	10.3 ± 2.7	10 ± 2.5	9 ± 2.5	10.2 ± 2.6	9.4 ± 2.6
Quality (3–21)	16.5 ± 3.3	18 ± 3.3	17.2 ± 3.3	12.7 ± 3.2	12.6 ± 3.1	12.7 ± 3.1
Scenario presence						
Questionnaire (6–30)						
Birds and Balls	23.6 ± 3.8	26 ± 2.6	24.6 ± 3.5	24.3 ± 3.5	25.6 ± 3	24.8 ± 3.3
Soccer	21.7 ± 3.7	22.4 ± 4.1	21.8 ± 3.8	21 ± 5	21.6 ± 4	21.2 ± 4.5
Snowboard	23.0 ± 4.0	26.8 ± 2.6	24.5 ± 4	23.3 ± 5.1	26.3 ± 2.2	24.6 ± 4.4
Performance						
Birds and Balls	3.6 ± 7.1	3.9 ± 6.3	3.7 ± 0.6	3.7 ± 6.2	4.3 ± 0.7	4.0 ± 0.7
Soccer	64.0 ± 10	48.5 ± 12	57.8 ± 13.4	62.6 ± 12.0	45.2 ± 12.7	40.1 ± 15
Snowboard	95.4 ± 6.5	99.5 ± 1.4	97 ± 5.6	96.7 ± 6	97.1 ± 2.7	97 ± 5
SSQ (16–224.4)	11.5 ± 12.4	8.3 ± 10	10.1 ± 11.2	36 ± 28.2	36.5 ± 28	36.2 ± 27.3
Borg scale perceived exertion (0–20)						
Birds and Balls	9 ± 2.6	9.1 ± 2.8	9.0 ± 2.6	9.5 ± 3.03	9.8 ± 2.8	9.6 ± 3
Soccer	13 ± 2.2	14.1 ± 2.2	13.4 ± 2.2	13.1 ± 3.4	13.6 ± 2.8	13.3 ± 3.1
Snowboard	8.6 ± 2.3	8.1 ± 2.7	8.4 ± 2.5	9.4 ± 3.2	9 ± 3.04	9.2 ± 3.1

↑↑ = significant differences (*t*-test or paired *t*-test)

($F(1, 45) = 7.6, p < .01$) and an interaction effect was found between age and type of platform ($F(1, 45) = 4.8, p < .05$). *T*-tests were carried out to interpret the interactions; although within the GX-monitor platform there were no significant differences between the two age groups, when they viewed the Virtual Office via an HMD the older group felt a significantly higher sense of presence than did the younger group ($t(47) = 3.9, p <$

$.0001$). Significant differences between males and females were found only for GX-monitor (males: 91.8 ± 15.1 versus females: 82.5 ± 14.0) ($t(47) = 2.2, p < .01$). The results of the Presence Questionnaire as well as other outcome measures for the Virtual Office are listed in Table 4.

When the PQ was divided into its four subscales for each of the age groups, significant differences between

Table 4. Summary of Results of the Virtual Office—GX-Monitor versus HMD

Age group	GX-Monitor		HMD	
	16–35 years N = 33	60–75 years N = 16	16–35 years N = 33	60–75 years N = 16
PQ total (19–133)	85.7 ± 13.5	89.8 ± 18.1	83.5 ± 12.7	98.4 ± 11.6
Involvement/control (11–77)	55.5 ± 7.8	57 ± 9.2	52.4 ± 8.5	59.3 ± 8.4
Natural (3–21)	10.6 ± 4.4	13.5 ± 4.7	10.9 ± 3.1	15.5 ± 4.2
Resolution (2–14)	7.6 ± 3.3	9.06 ± 3.2	7.5 ± 3.1	10.2 ± 2.6
Interface quality (3–21)	12 ± 3.7	10.2 ± 3.5	12.6 ± 3.07	13.3 ± 3.5
Scenario presence questionnaire (6–30)	23.8 ± 3.1	22.0 ± 3.6	21.4 ± 3.9	25.1 ± 2.8
Performance				
Visual scanning	9.7 ± 2.8	6.8 ± 2.5	8.2 ± 2.2	5.4 ± 1.5
Naming of background objects	5 ± 2.2	4.7 ± 2.7	5.5 ± 2.4	6 ± 2.03
Scan time	3.6 ± 1.2	2.9 ± 1.13	4.1 ± 1.1	4.1 ± 1.4
Borg scale of perceived exertion (0–20)	9.12 ± 3.0	7.2 ± 1.4	10.2 ± 2.2	7.5 ± 1.8

↕↕ = significant differences (*t*-test or paired *t*-test)

the platforms were found for the elderly group for the Interface/quality subscale ($t(15) = 2.5, p < .05$). Differences in the natural PQ subscale were found between the age groups within the Virtual Office when viewed via an HMD and GX-monitor, whereas the involvement subscale was found to have a significant difference between the age groups when viewed via the HMD only. Thus, the older group had higher scores on the natural subscale than did the younger group for both the GX-monitor ($t(47) = 2.0, p < .05$) and for HMD ($t(47) = 2.6, p < .01$). Moreover, the older group had a greater sense of involvement/control when using the Virtual Office with an HMD than did the younger group ($t(47) = 4.2, p < .0001$).

Scenario Presence Questionnaire—A significant main effect for age was found ($F(1, 30) = 5.0, p < .05$) but

there was no significant interaction. *T*-tests were carried out to analyze the main effect and the results showed that for the HMD a significant difference was found between the young and the older participants ($t(33) = 2.62, p < .05$), but no significant difference was found when using the GX-monitor.

3.2.2 Performance. Visual Scanning—A main effect was found for age ($F(1, 45) = 18.3, p < .0001$) and for the type of platform ($F(1, 45) = 11.7, p < .001$) but no significant interaction effect was found. Significant differences between age groups were found for the number of objects named by the younger participants when compared to the older participants for both the GX-monitor ($t(47) = 3.4, p < .001$) and the HMD ($t(47) = 4.4, p < .0001$). Participants from both age

groups were able to name significantly more objects when using the GX-monitor platform (younger, $t(32) = 2.9, p < .01$ and older, $t(15) = 2.4, p < .01$).

Naming of Background Objects—A main effect was found only for the platform ($F(1, 43) = 4.9, p < .05$), but no significant interaction effect was found. Significant differences were found between the background objects named after scanning the office via the GX-monitor (4.8 ± 2.4 for participants from both age groups) as compared to the number named using an HMD (5.6 ± 2.3 for participants from both age groups) ($t(46) = 2.1, p < .05$).

Scan Time—A main effect was found only for the platform ($F(1, 44) = 14.8, p < .0001$) while no significant interaction effect was found. A significant difference was found between the time participants took to scan the office presented via the GX-monitor (3.3 ± 1.2 s for the whole population) compared to the HMD (4.1 ± 1.2 s for participants from both age groups) ($t(47) = 3.8, p < .0001$).

3.2.3 Side Effects. A significant difference ($z = 2.6, p < .01$) was found in the total score of the SSQ for the GX-monitor (1.7 ± 3.06) as compared to the total score of the SSQ for the HMD (24.8 ± 28.2). Here too the scores were very low for both platforms, but it must be noted that only 6 participants filled in the SSQ after both platforms.

3.2.4 Exertion. A significant main effect was found for age group ($F(1, 41) = 9.3, p = 0.004$) but no significant interaction effect was found. For both the GX-monitor and the HMD, the younger participants perceived significantly more exertion while using the GX-monitor ($t(38) = 2.7, p < .001$) and for the HMD ($t(43) = 3.6, p < .001$).

4 Discussion

The objective of this study was to compare the sense of presence, level of performance, side effects, and perceived exertion of healthy participants for two different VR

platforms when they played three virtual games or when they scanned the Virtual Office. In addition, the relationship or effect of age and gender on these variables was examined. The results of this study have highlighted a number of significant differences in some of the key characteristics of the VR platforms and environments as well as user characteristics as they affect users' sense of presence, performance, side effects, and exertion.

4.1 Presence

A significant main effect for the sense of presence during the three virtual games was found only for type of platform. That is, presence was significantly higher for the GX-monitor, whereas for the Virtual Office, a main effect between the participants' sense of presence was found for gender and an interaction effect was found between age and type of platform. These findings highlight the fact that a participant's sense of presence is not influenced only by attributes of the VR platform; rather, by features of the virtual environment (e.g., type of games, extent of functionality) as well as characteristics of the individual user (e.g., age) and the task itself (e.g., scanning, movement), as suggested by Nash, Edwards, Thompson, and Barfield (2000). At least two other studies have compared the sense of presence reported by healthy participants when they used different VR platforms (Mania & Chalmers, 2001; Lo Priore, Casterlnuovo, Liccione, & Liccione, 2003). These studies did not find differences in the sense of presence between VR platforms; since they did not test for difference in other variables, as was the case in the present study, further comparison of the results are not possible.

In contrast to the PQ that was completed for each platform after participants had experienced all environments, the Scenario Presence questionnaire was completed following each virtual environment (i.e., after each game and the Virtual Office). The participants who played the virtual games felt similar enjoyment, success, control, and so forth, regardless of which VR platform they used. Gender influenced these variables only for the Snowboard game, which indicates that, at least for

Snowboard, the environment or task appeared to have a greater impact than did the type of platform.

In contrast, in the Virtual Office, a significant main effect for age was found; the older group preferred the HMD as compared to the younger group. This finding was unexpected since some of the elderly participants reported difficulty in focusing on the images while wearing the HMD, a problem that was particularly noticeable for the participants who wore bifocal glasses. From a clinical point of view, the ready acceptance of both the HMD and the video-capture technologies by elderly participants was encouraging since they are a segment of the population often in need of rehabilitation. Stanney, Mourant, and Kennedy (1998) have suggested that user characteristics that significantly influence VR experience should be considered. Characteristics such as prior VR experience, cognitive ability, personality, and age have been found to influence the virtual experience (Stanney et al., 1998). The results of the present study indicate that gender differences are also important. Since applications of VR as an intervention tool for rehabilitation are of great interest (Rizzo and Kim, 2005; Weiss, Kizony, Feintuch, & Katz, in press), future studies should also examine the effect that disability and subsequent impairment (e.g., motor, cognitive) have on participant performance in different VR platforms.

4.2 Performance

Performance during each of the three virtual games differed not only between the platforms (for Birds & Balls) but was also influenced by the gender of the participants (for Soccer). This finding again points to the importance of both the virtual environment and task characteristics for participant performance. It is interesting to consider why the male participants performed so much better during Soccer than did their female counterparts. One possible explanation is that this scenario was more meaningful for the male participants, and they were therefore more motivated to achieve higher scores. The literature on the impact of meaningfulness of a virtual environment on VR performance is sparse (e.g., Hoffman, Prothero, Wells, & Groen, 1998) and should be further investigated.

Performance for the Virtual Office environment did differ between the platforms. Moreover, for this environment, there was an interaction effect on performance between the type of platform and age. After scanning the office via the GX-monitor, participants from both age groups were able to name more objects from the list of 16 embedded items, but fewer background objects than while scanning the office via the HMD. The flat-screen monitor appeared to encourage quicker and easier visual scanning, perhaps because the objects were located horizontally within the office's panoramic 2D on-screen image. In contrast, visual scanning via the HMD was slower perhaps due to the greater complexity of the 3D image.

The decreased performance of the older group in both types of platforms points to the validity of the tasks performed within these VR systems since we expect to see differences as a function of age. A decline in visual acuity (e.g., Stanney et al., 1998) as well as perceptual-cognitive abilities such as memory (e.g., Josman & Hartman-Maeir, 2000) could lead to the decreased performance demonstrated in this study. The performance of the older group may also be influenced by the task characteristics, as indicated above.

4.3 Side effects

Since the potential for VE-related side effects (cybersickness) is considered to be a key potential ethical consideration for the use of VR for rehabilitation (Rizzo, Schultheis, & Rothbaum, 2002), different studies have addressed this issue in healthy and in patient populations (e.g., Pugnetti et al. 1998). The extent of the side effects experienced in this study on both platforms was quite low and no participants requested to terminate their participation in the study. This fact is encouraging, especially when one is interested in using the various platforms in rehabilitation. Although the exposure times in this study were consistent with typical treatment protocols (successive 2- to 4-minute trials separated by 2- to 3-minute breaks), they were still relatively short. Thus our negative findings with respect to side effects should be considered carefully as it may be that for longer exposure times the likelihood of side effects would increase. For example, participants in

studies conducted by Howarth & Finch (1999) were assessed for side effects every 2–5 minutes during a 20-minute exposure. An increase in nausea as time progressed was found; approximately 40% of the participants reported at least one cybersickness symptom after 20 minutes' exposure.

Although, overall, the incidence of side effects in the present study was low, there were significant differences between platforms. Participants reported side effects more frequently while using the HMD as compared to the GX-monitor. This finding is in accordance with the literature, which suggests that HMDs have a greater potential for causing short-term side effects, especially oculomotor symptoms (Lo Priore, et al., 2003). Our findings also demonstrated that side effects experienced while wearing an HMD depended upon the type of environment—fewer participants complained of side effects while experiencing the Virtual Office as compared to the virtual games. This result may be explained, in part, by differences in the extent of active movement within the two environments. The virtual games encouraged participants to move their limbs, and even their entire bodies, while attending to the traveling stimuli. In contrast, stimuli within the Virtual Office environment were static, and participants scanned the environment with small head movements rather than moving within it. The differences in occurrence in side effects in this study may also be due to the fact that total exposure times to the virtual games (3–4 min each for 6 games with 2–3 min breaks between games) was longer than for the Virtual Office (up to 5 min). It should be noted that for the virtual games, the HMD was connected to the GX platform to create a combined platform (GX-HMD). The HMD was not built originally for this use, which may have caused more side effects (see Table 2 for further description of this platform).

4.4 Exertion

The participants' perceived exertion while playing the virtual games was not influenced by either platform or gender. Thus any encumbrance associated with the HMD, due to its weight or cables, did not add to the effort experienced by the participants as compared to their effort via the GX-monitor. In contrast, the type of game/task played

did affect the level of perceived exertion, a finding that is likely due to difference in the physical effort required by the different games. The level of exertion ranged from “very light” for the Snowboard game to “somewhat hard” for the Soccer game as measured with Borg's scale (Borg, 1990). Thus, participants responded to the virtual stimuli with large, relatively rapid movements of the whole body and extremities during the Soccer scenarios but only shifted their weight gently from side to side during Snowboard. The level of perceived exertion for Birds & Balls and Soccer was higher than that perceived for scanning the Virtual Office, which ranged from “extremely light” for the younger group to “very light” for the older group. It may be that the scores were lower since scanning the Virtual Office environment did not require much movement of the body. A significant main effect was found between age and level of perceived exertion. Surprisingly, Borg-scale scores from the younger participants while scanning the Virtual Office were higher than the scores for the older group, a finding that may be related to the fact that the older group enjoyed this task more than did their younger counterparts and thus did not pay as much attention to their effort.

4.5 Conclusions

These results highlight the need to investigate the use of alternate platforms, environments, and tasks when creating protocols for rehabilitation to target therapeutic objectives (e.g., motivation, performance, and effort). It is anticipated that continued cross-platform and cross-environment comparison studies will provide further insight into their different characteristics, especially when expanded to include participants across a range of impairments. The results of this study underscore the importance of collecting data regarding the performance of different healthy populations (gender, age groups, etc.) in order to determine which tasks and platforms have the best usability and relevance for patients during the rehabilitation process. Future work should be directed at examining the responses of patients with different cognitive or motor deficits as well as a greater number of elderly participants in order to clarify their needs and behaviors when using both platforms.

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AQ1—*SM/RG* texp following hd3 OK? (so that “Presence questionnaire” falls at beginning of ¶ to ¶ “Scenario Presence Questionnaire” on p. 13

AQ2—*SM/RG* See query previous pg.

AQ3—*SM/RG* See query p. 11

AQ4—*SM/RG* See query p. 11

AQ5—*SM/RG* Form for refs to article in this issue?

AQ6—*SM/RG* correct form for ref to “this issue”?

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