Virtual reality based intervention in rehabilitation: relationship between motor and cognitive abilities and performance within virtual environments for patients with stroke

R Kizony[1], N Katz[2] and P L Weiss[3]

[1,2]School of Occupational Therapy, Hadassah-Hebrew University, Jerusalem, ISRAEL

[1,3]Department of Occupational Therapy, University of Haifa, Haifa, ISRAEL

[1]rachelk@zahav.net.il, [2]noomi.katz@huji.ac.il, [3]tamar@research.haifa.ac.il

ABSTRACT

The objective of this study was to provide experimental data to support a proposed model of VR-based intervention. More specifically our goal was to examine the relationships between cognitive and motor ability and performance within virtual environments. Thirteen participants who have had a stroke participated in the study. They each experienced three virtual environments (Birds & Balls, Soccer and Snowboard) delivered by the GX- video capture system. After each environment they complete a scenario specific questionnaire and Borg's scale for perceived exertion. Their cognitive, motor and sensory abilities were measured as well. The participants' responses to the VR environments showed that they enjoyed the experience and felt high levels of presence. The results also revealed some moderate relationships between several cognitive abilities and VR performance. In contrast, the motor abilities and VR performance were inversely correlated. In addition, there was a relationship between presence and performance within the Soccer environment. Although these results support some components of the proposed model it appears that the dynamic nature of the virtual experiences would be more suited to comparisons with different measures of motor ability than those used in the current study.

1. INTRODUCTION

Stroke is a major cause of disability for adults and the elderly, often resulting in motor and cognitive impairment, and functional disability (Woodson, 1995). Various studies have found relationships between functional disability and both cognitive and motor deficits. Thus a major goal of the rehabilitation process is to improve these deficits (Katz, et al.1999).

Virtual Reality (VR) has recently begun to be used for rehabilitation of patients with stroke. Piron, et al. (2001) used VR to train reaching movements, Broeren, et al., (2002) developed a VR haptic device for the assessment and training of motor coordination and Jack et al. (2001) and Merians et al. (2002) used a force feedback glove to improve range of motion, speed and strength of hand movement. The results of the latter study, which included three patients with stroke, showed VR to be useful for the improvement of upper extremity function in patients who are at a chronic stage. VR also appears to be beneficial for the training of safe street crossing using a desktop platform with patients who suffer from unilateral spatial neglect (Katz et al., 2003; Weiss et al., 2003).

The virtual reality experience is multidimensional and appears to be influenced by many parameters whose interactions remain to be clarified. A proposed model for virtual reality in rehabilitation is presented in Fig. 1. This model was developed within the context of the International Classification of Functioning, Disability and Health (ICF) (World Health Organization, 2001) terminology (Weiss et al., In Press) and consists of three nested circles, the inner "Interaction Space", the intermediate "Transfer Phase" and the outer "Real World".

As represented schematically in Fig. 1, two primary factors within the "Interaction Space" influence the nature of the interaction between the user and the virtual environment. The first of these factors relates to the user's personal characteristics. These include demographic factors (e.g. age, gender, cultural background), body functions (e.g. cognitive, sensory, motor) and structures (e.g., arms, legs). The second factor relates to characteristics of the virtual environment including both the type of VR platform and its underlying technology (enabling the flow of information to and from the user) and the nature and demands of the task to be performed within the virtual environment. The characteristics of the virtual environment may be either barriers or enablers to performance. The client interacts within the virtual environment, performing functional or game-like tasks of varying levels of difficulty. This enables the therapist to determine the optimal environmental factors for the client. Within the "Interaction Space" sensations and perceptions related to the virtual experience take place; here the user's sense of presence is established, and the process of assigning meaning to the virtual experience and the actual performance of virtual tasks or activities occur.

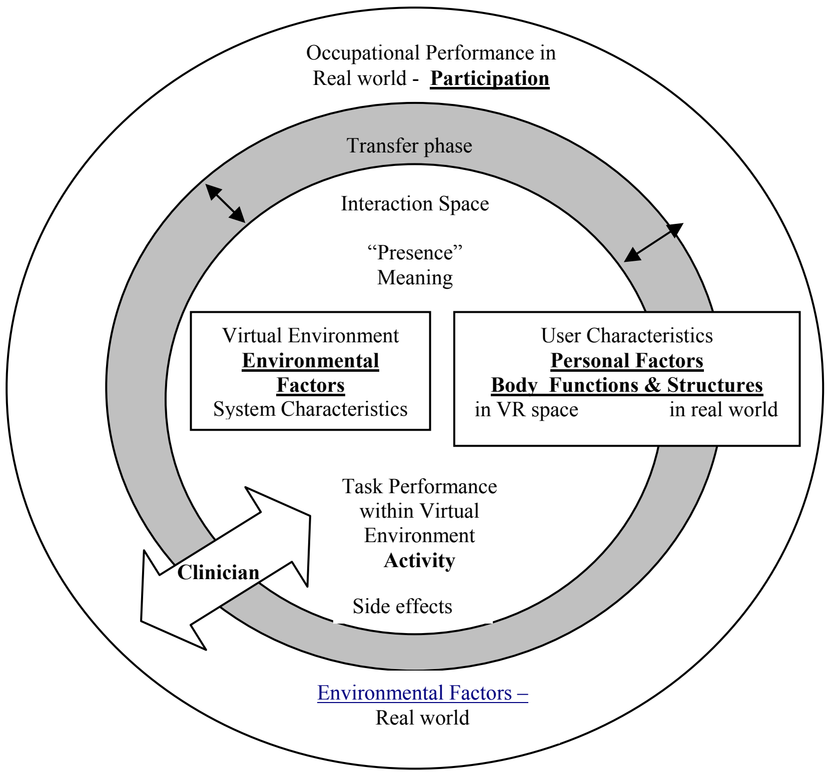

Figure 1: *A model of VR-based rehabilitation within the context of terminology from the International Classification of Functioning, Disability and Health concepts (indicated in bold).*

One of the undesired consequences of interacting within some virtual environments that could affect performance are side effects such as nausea and dizziness (Kennedy, & Stanney, 1996). For those users who are susceptible to this problem, such effects usually occur only in certain types of VR systems such as when using an HMD (Rand, et al., in press). Clinicians should be aware of this possible effect and ensure that clients who are susceptible to side effects avoid using a VR system and environment for prolonged periods of time.

From the Interaction Space (inner circle) we move to the Transfer Phase (intermediate circle) since our goal in rehabilitation is to improve daily function in the real world and this requires transfer of the trained skills or tasks as well as environmental modifications from the virtual environment to the real world. The "Transfer Phase" may be very rapid and accomplished entirely by the client or may take time and need considerable guidance and mediation from the clinician. Finally, the large, outer circle represents real world environments illustrating that the ultimate goal is to help the client achieve participation in the real world environment by overcoming, adapting to or minimizing the environmental barriers. The entire process is facilitated by the clinician whose expertise helps to actualize the potential of VR as a rehabilitation tool.

A key principle in rehabilitation is matching therapeutic tasks to the patients' abilities in order to enable them to improve residual capabilities without causing fatigue and frustration. Knowledge about the relationship between user characteristics, sense of presence and performance within the virtual environment would help clinicians achieve an optimal match, enabling them to select and customize environments and tasks so that they are more suited to patients' abilities. This would also enhance patients' involvement in the task. The application of this principle to people with stroke is particularly important since their disability is complex with both motor and cognitive components. Thus, a better understanding of the relationship between deficit and performance within virtual environments should lead to greater efficiency in the use of VR-based intervention.

The objective of this study was to provide experimental data to support the proposed model of VR-based intervention. We begin by an examination of the relationships between motor, sensory and cognitive abilities to performance within three virtual scenarios which, as indicated above, is an essential step for understanding the nature of interaction within the virtual environment.

2. METHODS

2.1 Participants

In order to establish the protocol and inclusion criteria for the current study, we first tested three participants with a protocol similar to one used in a prior study with patients who had spinal cord injuries (Kizony et al., 2003). Thirteen patients with stroke (4 female, 9 male) with a mean age of 66.3 ± 7.9 participated in the full study. Seven participants had a left hemispheric stroke and six had a right hemispheric stroke. Time between onset of the stroke and participation in the study ranged from 5 weeks to 11 months. All participants took part in rehabilitation services, either in hospital (11) or at an ambulatory day centre (2). Inclusion criteria included independence in ADL prior to the stroke, the ability to understand instructions and sign the informed consent and to move the affected upper extremity independently or with the aid of the non-affected arm.

2.2 Instruments

2.2.1 Virtual Reality

1. VividGroup's GX video-capture VR System has potentially important applications for the rehabilitation of children and adults with physical and/or cognitive impairment [www.vividgroup.com, www.irexonline.com] (Kizony, et al., 2003a,b; Cunningham & Krishack, 1999; Sveistrup, et al., 2003). The advantages of using this VR system with patients with brain damage has been described in detail elsewhere (Kizony et al., 2003a,b; Kizony et al., 2002) and includes its natural way of interaction and very low incidence of sides effect. Three virtual environments were used with this system:

Birds & Balls: The user sees himself in a pastoral setting and touches virtual balls (Fig. 2a). Performance in this environment was measured in terms of percent success (i.e., the number of balls touched out of the total numbers of balls) and response time (i.e., the time between the ball's first appearance on the screen until it was touched).

Soccer: The user is a goalkeeper and has to prevent the balls from entering the net (Fig. 2b). The performance in this environment was measured in terms of percent success similar to Birds & Balls.

Snowboard: The user is required to avoid obstacles as he skis downhill. Performance here was measured in terms on percent success (i.e. the number of obstacles avoided out of the total number of obstacles).

Figure 2a. *A participant within the Birds & Balls environment*

Figure 2b. *A participant within the Soccer environment*

For Birds & Balls and Snowboard, the third minute of each game was analyzed since it should reflect the participant's best performance, i.e., after participants had practiced but prior to the onset of fatigue. For Soccer, the second minute was analyzed since not all the participants were able to continue to perform at the same level during the third minute due to their motor impairments.

2. The Scenario Feedback Questionnaire (SFQ) is a 8-item questionnaire designed to obtain information about the subjective responses of the participants to the VR experience in each scenario. It queries the user's sense of presence, perceived difficulty of the task and any discomfort that users may have felt during the experience. The first six items of the questionnaire were formulated as an abbreviated alternative to the longer Presence Questionnaire developed by Witmer and Singer's [20]. These 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. The seventh item, queried whether participants felt any discomfort during the experience. A eighth item queried their perceived difficulty while performing the task. Responses to the first seven items were rated on a scale of 1-5 where 1=not at all and 5 = very much. Responses to the eighth item was also rated on a 1-5 scale where 1= very easy and 5 = very difficult.

2.2.2 Motor and Sensory Abilities. Active movement and coordination of the affected upper extremity was tested using the Fugl-Meyer Motor Assessment (Fugl-Meyer et al., 1975), muscle tone was tested with the modified Ashworth scale (Bohannon & Smith, 1987), touch sensation was tested and proprioception was tested with the Thumb test (Prescott et al., 1982). Balance was measured via the Functional Reach Test (Duncan et al., 1990) with its modification for sitting (Lynch et al., 1998). For this test we calculated a total score which is the sum of leaning forward when the left side is near the wall and leaning forward when the right side is near the wall. The perceived exertion during each task was measured via Borg's (1990) scale (scores range between 6 (no exertion) and 20 (maximal exertion)).

Cognitive abilities: Tests for visual search and attention included the Star cancellation test (Wilson et al., 1987) and the Mesulam symbol cancellation test (Weintraub et al., 1987). For each of these tests we calculated the number of correct symbols cancelled as well as the time it took to complete the test. Visual memory was tested with the Contextual Memory Test (Toglia, 1993), and thinking operations (i.e. categorization and sequence) with the Lowenstein Occupational Therapy Cognitive Assessment (Itzkovich et al., 2000) and executive functions with the Behavioral Assessment of Dysexecutive Syndrome (Wilson et al., 1996). (The latter results are not reported in the present paper.)

2.3 Procedure

Participants experienced each of the three virtual environments for 3-4 minutes, depending on fatigue. After each environment the participant completed the SFQ and the perceived exertion scale. The participant's motor and cognitive abilities were evaluated within approximately one week of the VR session.

2.4 Data Analysis

Descriptive statistics were used to describe the participants' responses to the SFQ, their performance within the virtual environments and their cognitive and motor scores. To examine differences between the scenarios regarding percent success, perceived exertion and difficulty we used either paired t-tests or Wilcoxon tests for related groups respectively. To examine relationships between virtual performance and cognitive abilities, motor abilities and sense of presence, Pearson or Spearman correlations were used depending on the nature of the scale of measurement (i.e. ordinal or interval). Due to the small sample, marginally significant values (e.g., $p<.053$) are presented as well.

3. RESULTS

3.1 Feedback on the VR Experience

The participants expressed their interest in having this therapy; indeed, the majority requested and received additional VR sessions following their completion of the study. Their responses to the SFQ showed that they enjoyed the experience and felt high levels of presence for the different environments with a mean ± standard deviation for Birds & Balls equal to 4.4 ± 0.4, Soccer equal to 4.1 ± 0.7, and Snowboard equal to 4.3 ± 0.5 out of a total score of 5. In addition, no cybersickness-like side effects were reported.

3.2. Performance within the Virtual Environments and Sensorimotor and Cognitive Tests

The participants' performance within the three environments is presented in Table 1. The participants performed significantly better in Snowboard than in Birds & Balls ($t=-3.5; p=.004$) and in Soccer ($t=-6.7; p=.000$). Performance in Birds & Balls was significantly better than in Soccer ($t=4.2; p=.001$). Their perceived exertion was significantly higher for Soccer then for Birds & Balls (t=-.2.43; p=032). The other differences for exertion were not significant. Perceived difficulty (from the SFQ) was significantly higher in Soccer than in Snowboard (z=-2.25; p=.024). The other differences for difficulty were not significant.

Table 1. *Performance within the three virtual environments (N = 13)*

	Birds & Balls Level 2[a]	Soccer Level 1[b]	Snowboard
Percent success	75.7 ±17.0	53.7 ± 22.8	91.1 ±6.2
Response time	5.7 ± 1.4	N/A	N/A
Exertion	9.3 ± 2.3	10.9 ± 2.7	9.5 ± 2.6
Perceived difficulty	2.0 ± 1.0	2.6 ± 1.1	1.8 ± 0.9

a. For Birds & Balls, level 2, four balls simultaneously approach the participant from different directions

b. For Soccer, level 1, one to two balls approach net simultaneously from different directions

Table 2 shows mean performance scores on the motor and cognitive tests. Participant scores on the cognitive tests were high with a relatively small variance. Although the variance was larger on the motor measures, ten out of the 13 participants had functional active movements in their affected upper extremity and sufficient balance to be able to reach out from their midline. Nine participants had increased muscle tone and four had normal muscle tone as measured during elbow flexion and extension movements. In the sensory measures it was found that 11 participants had intact touch sensation but only eight had intact proprioception.

Table *2.* *Performance on the cognitive and motor measures (N = 13)*

Measure	Mean ± SD	Range of possible scores
Cognitive		
Star Cancellation score	52.4 ± 2.1	0 - 54
Star Cancellation time (s)	107.8 ± 98.2	
Mesulam score	56.1 ± 5.0	0 - 60
Mesulam time	167.2 ± 86.4	
Contextual Memory Test	19.7 ± 7.4	0 - 40
Categorization	3.3 ± 0.8	1 - 4
Sequence	3.1 ±1.1	1 - 4
Motor and Sensory		
Functional Reach Test	70.0 ± 19.1	
Fugl- Meyer active movements	44.7 ± 15.5	0 - 60
coordination / speed	3.8 ± 1.2	0 - 6

3.3 Relationships between Sense of Presence and Enjoyment and Performance within Virtual Environment

Significant correlations were found between percent success in Soccer and the sense of presence as measured by the SFQ (r=.56; p=.05) and level of enjoyment also measured by the SFQ (r=.59; p=.03). The remaining correlations between presence, enjoyment and performance were not significant.

3.4 Relationships between Cognitive and Motor Abilities and Performance within the Virtual Environments

Significant correlations were found between several of the cognitive tests and performance within the virtual environments. The categorization test was correlated with both response time in Birds & Balls (r=-.61; p <.05) and percent success in Soccer (r=.57; p=.053). The Mesulam attention score was correlated with percent success in Snowboard (r=.56; p<.05) and the CMT memory test with percent success in Birds & Balls (r=.57; p<.05). These correlations indicate that the greater the cognitive ability, the better the performance in the virtual environments. With regard to the motor and sensory tests, the only significant correlations were found between the Fugl-Meyer coordination/speed test and percent success in Soccer (r=-.84; p=.001) and response time in Birds & Balls (r= 59; p=.54). Surprisingly, these correlations indicate that better motor ability is related to poorer performance in the virtual environments.

4. DISCUSSION

The model presented in the Introduction describes an Interaction Space which refers to a participant's performance within a virtual environment. Given appropriate conditions (e.g., feedback of sufficient quantity and quality), participants will feel "present" within the virtual world and it will become meaningful to them. The responses of participants in the current study attest to attainment of these two important reactions. The results of the short presence scores were similar to those of the patients with spinal cord injuries tested previously (Kizony et al., 2003b); their involvement within the environment appeared to encourage them to participate in what would otherwise be painful or boring therapeutic activities. There is already considerable evidence demonstrating that many VR-based interventions motivate routine therapy (Jack et al, 2001; Sveistrup, et al., 2003). The presence and enjoyment scores recorded in the present study provide additional evidence of this important VR asset (Rizzo et al., 2004). It also appears that, in addition to their motivational characteristics, these games encouraged participation by providing activities that were meaningful to the participants. . One participant remarked: "I like soccer the best since it reminds me of my grandson who plays soccer in a professional youth team".

Performance in an activity within the Interaction space is carried out within the context of a meeting between participants' personal characteristics and those of the task and environment. Thus one of the goals of the current study was to examine the relationships between cognitive and motor abilities and performance within the virtual environment. Although these results must be interpreted with caution due to the small sample size and the small variance of the tests scores, nevertheless, there appears to be a relationship between categorization which requires abstract thinking, visual contextual memory and visual attention and improved performance in the virtual environment. This last finding is in accordance with the nature of the virtual tasks used in this study which require participants to rely heavily on visual attention (i.e., searching for and responding to stimuli coming from all directions). The proposed model highlights the impact that user characteristics, such as ability to engage in visual attention tasks, have on performance within the virtual environment. It would therefore appear important to screen for such abilities prior to selecting a given virtual scenario. In order to further test the importance of user characteristics, we are currently analyzing the relationships between higher cognitive functions such as executive functions and VR performance.

In contrast to cognitive abilities, there were very few correlations between motor abilities and performance within the virtual environments. This was perhaps due to the small variance in this sample with most of the participants having higher level motor abilities (i.e., an insufficient data spread to obtain adequate correlations). One of the motor ability/virtual performance correlations appeared to be anomalous. That is, participant coordination/speed was found to be inversely related to performance within the virtual environments. This may have been due to the way in which motor ability was tested relative to the way it was performed virtually; the test task required that the participant touch his nose with the affected arm in a controlled and precise manner. In contrast, movement within the virtual scenarios used in this study, especially in Soccer due to the speed of the approaching balls, entailed ballistic actions. Second, touching the targeted balls did not require precise movements. Moreover, participants were required to lean forward and to the side within the virtual scenario, movement types which, again, differed greatly from the tests of motor and sensory abilities. Finally, the motor/coordination test rates ability only of the affected upper extremity. In contrast, within the virtual scenarios, the participants occasionally used their unaffected arm as well as other body parts to interact. In contrast to the pre-VR tests of functional ability, the virtual experience is clearly dynamic, and entails the use of many cognitive and motor abilities simultaneously. In retrospect, it is clear that additional measures of motor ability are required in order to more accurately characterize the relationship between it and performance within the virtual environment.

The above discussion leads to an additional important question - should we expect performance demands, and hence their characteristics, within the real and the virtual worlds to be identical? It may be that differences in presence, motivation, or other factors influence the movement patterns. Viau et al (2004) found that the movements in a virtual task were similar to those in a comparable task performed in the real world. In contrast, Lott et al. (2003) found there to be significant differences between functional lateral reach when performed in the real environment versus a virtual environment delivered with the GX video capture system; in this case, movements in the virtual environment were of higher quality. We recommend that, in future, additional data on cognitive, motor as well as functional abilities be measured on a larger number of participants in order to perform multiple regression which will help to predict and explain the virtual performance.

Further data will also help to clarify the relationship between presence and performance which takes place within the Interaction space. The results of the present study provided some support for a relationship between presence and performance via the results from the Soccer game. This environment is the most difficult one to perform in, a fact that perhaps compels a participant to "be there" in order to succeed.

In addition to the Interaction space, the model also designates a Transfer Phase and a Real World space. Since the ultimate goal of therapy is to enable individuals to transfer the skills learned during rehabilitation to adaptive performance in the real world, it is essential that these two components be explicitly tested. Initial positive results showing the possible transfer of skills to the real world have been described by Jack et al. (2001) as cited above. We are currently carrying out such a study, using a single subject design on patients with stroke.

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