Playing games in Virtual Reality: Motivation of patients during neurorehabilitation

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Abstract— **The aim of this study is to describe the practicability and outcomes of using custom made virtual reality (VR) to augment the rehabilitation of arm manipulation after stroke. The patients were adults with spastic hemiplegia who were treated in a rehabilitation hospital during PC based therapy in addition to conventional rehabilitation. The patients participated in 3 x 5 minutes/day training sessions, 5 days/week for three weeks. Training of arm manipulation in repetitive tasks was based on playing PC games using VR in sitting position. Outcome measures used: Drawing Test (DT), Intrinsic Motivation Inventory (IMI), Fugl – Meyer Test (FM) and Modified Aschworth Scale (MAS). DT was assessed before and after 3-weeks of PC training, and at follow up. MAS and FM tests were evaluated before and after the therapy, while IMI was scored after the therapy only. The feasibility of using a PC based system in the rehabilitation clinic setting in addition to conventional rehabilitation was supported.**

Key words- PC, virtual reality, motivation, games, therapy

I. INTRODUCTION

From numerous clinical studies it is becoming increasingly evident that neurorehabilitation may provide full capacity of plausible recovery to the patient if he/she receives not only all the prescribed therapies, but takes an active role over time [1]. It means that the patient should have more responsibility for the quantity and quality of performed therapies. To meet these requirements the patient needs adequate motivation. The question is how we can establish what the right motivation is for the particular patient. In other words, we need to build more knowledge and understanding of what the right motivation for the patient is in order to become the main player in his/her own rehabilitation program.

The question of relevance in our study was to learn how to motivate patients to take the therapy program "into their own hands" during rehabilitation, to exercise without boredom, even with enjoyment. PC based rehabilitation, particularly Virtual Reality (VR) and games may be the adequate solution to that [2], [3] by providing meaningful movements [4]. Functional performance and safety must be taken into serious consideration as well.

It was well documented in a great number of clinical studies that intensive exercise promotes and speeds-up recovery after stroke [5], [6]; moreover, "two therapies are better than one". Motor rehabilitation favors task-specific repetitive exercise [7].

After stroke, individuals may not be able to use all the PC peripherals. To provide adequate patient-PC interface, various "tools" may be adjusted for specific VR activities or/and PC games. Outcomes of such technology supported rehabilitation are drawing more attention [8]-[10] and both, broader and focused knowledge, is wanted. In addition, technology supported rehabilitation may also save therapists' time.

Virtual reality systems typically involve hardware and software components. Users control an interface to enter a VR or setting for the simulation. Virtual reality systems offer clinicians the control over exercise duration, intensity, and environments that real-world tasks do not. Users in VR can perform tasks that they may not be able to execute safely or at all in real-world situations. Virtual reality systems have been developed specifically for rehabilitation of upper-extremity use, lower-extremity training, and gait retraining. Most of these systems are not commercially available and, when available, are very expensive.

In order to unburden therapists' time, physicians in the rehabilitation clinic "Dr Miroslav Zotovic", Belgrade, were enthusiastic to include new options in their rehabilitation program. Based on long history of collaboration with the Faculty of Electrical Engineering, Belgrade [11], [12], the clinicians agreed to test the feasibility and efficacy of using VR for individuals after stroke in a pilot study in clinical settings. Neither physicians nor therapists had any previous experience with this new exercise program, or deeper understanding of motivation and acceptance by patients. In this pilot study, a group consisting of acute, subacute and chronic patients exercised in a new therapy setup in addition to prescribed conventional therapy.

Here we report our experience of using PC based games for rehabilitation of arm manipulation. The system integrates drawing board and planar manipulandum in VR activities. The software, which provides an exercise program with real-world object manipulation, i.e. with context-specific sensory-motor input, was prepared by coauthors with a technical academic background, in collaboration with physicians, physical therapists and a psychologist. Two primary outcome measures were: Drawing Test (DT), to assess arm coordination [13], and Intrinsic Motivation Inventory (IMI,) to assess patients' motivation, [14], [15]. The two standard clinical scales Fugl-Meyer (FM) test, [16], [17] and Modified Aschworth Scale (MAS), [18] were evaluated for upper extremities, too.

II. METHODS

A. Patient characteristics

Six patients (4 male + 2 female) agreed to participate and signed informed consent. Mean age was 59.17 years (SD = 9.74). Mean post-stroke time was 16 months (SD = 12.86).

B. Setup for exercise

Patients were seated in a firm, comfortable chair with a trunk harness, which prevented any torso movement. The exercise station (adjustable table with digitizing board and planar manipulandum with a handle) was placed in front of them. Patients grasped the handle and moved the manipulandum over tablet to take part in a chosen activity in VR. Exercised planar movements were transferred from the board to a TV monitor via PC, Fig. 1.

Figure 1. Exercise station (Digitizing tablet, TV monitor and custom made manipulandum) used during therapy sessions when patients played games in Virtual Reality.

Patients' position was always adjusted for exercise. When she/he was sitting and holding the handle, the height of the table was modified so that the upper arm was relaxed in a vertical position and the elbow angle was approximately 90^o. If the user did not have enough grip strength to hold the handle, their hand was strapped to it.

The planar manipulandum was a custom made passive mechanical rig with low inertia and virtually no friction described elsewhere in detail [19]. The rig consisted of two pieces and a handle attached rigidly to the open end of one rigs' segment. Planar movement of manipulandum above table was performed by pushing/pooling the handle in different directions.

The movement of the handle was recorded with *Wacom Intuos4 XL* drawing board and cordless mouse. For the acquisition of data, we used the original board drivers and wrote a program in C++. The workspace was limited to the board active area (487.7 x 304.8 mm); the sampling rate was 100Hz and spatial resolution 1/200 mm. The screen used for exercise setup was a 22'' LCD TV with PC input. The center of the screen was roughly in line with patients' eyes at the distance of approximately two meters.

C. Protocol for exercise

In order to motivate patients during hand and arm therapy, three games (Games 1-3) were designed. Explanation of task, instruction, game description and therapeutic goal for each game is presented in the following section:

GAME 1

Task: Simple point-to-point (p-t-p) movement.

Instruction: "Touch the object with cursor".

Game description: After the user moves the cursor to the object, the object disappears and a new one appears in random location of the workspace. The workspace expands over time.

Therapeutic goals: Increase of upper extremity (UE) coordination while reaching across midline of the body; increase of hand – eye coordination.

GAME 2

Task: Complex p-t-p movement with "grasping" and manipulating an object.

Instruction: "Pick-up the object with cursor and throw it away in a trashcan".

Game description: After the user collects an object with the cursor and disposes it in a trashcan, the next one appears on a random position in a workspace. The workspace expands over time.

Therapeutic goals: Increase of UE motor control and endurance while reaching across midline of the body; increase of hand – eye coordination and attention.

GAME 3

Task: Complex tracking movement.

Instruction: Move the cursor through the canal (tube) without crossing the borders.

Game description: The goal for the user is to follow a path from start to end without drifting. The path becomes more complex over time.

Therapeutic goals: Increase of UE coordination, motor control and endurance while reaching across midline of the body; increase of hand – eye coordination, focus and attention.

The display of each of the three games in VR is depicted in Figure 2.

The patients played games in 3 x 5 minutes/day training sessions, 5 days/week for three weeks. Conventional therapy was as scheduled for each patient.

GAME 1
Task 1: Simple point-to-point (p-t-p) movement

GAME 2
Task 2: Complex p-t-p movement with "grasping" and manipulating an object

GAME 3
Task 3: Complex tracking movement

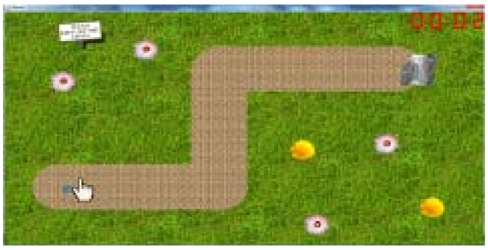

Figure 2. Display of the three games on TV/PC screen.

D. *Outcome measures*

The two primary outcome measures were: Drawing Test (DT), and Intrinsic Motivation Inventory (IMI).

1) *Drawing Test*

The task in the Drawing Test is to track the square on the digitizing board, as shown in Figure 3, upper panel. We calculated the following parameters: velocity, region deviation, line aberration. Velocity was calculated from the duration of a trial. Deviation of the region was defined as the outer surface of dotted square, presented in gray in Figure 3, bottom panel. Aberration of the line is determined as a difference between the line connecting two vertices and the drawn line, presented in red in Figure 3, bottom panel.

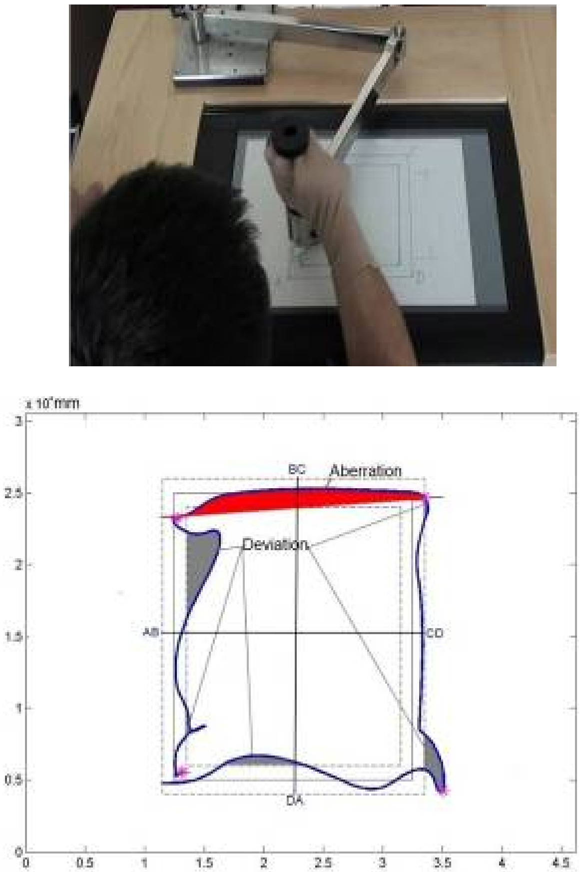

Figure 3. Upper panel: Patient at the start of Drawing Test. Bottom panel: An example of a Drawing Test. Line abberation and region deviation are marked with gray and red respectively. (AB, DA, CD and BC bisect points are used for calculation of devations.)

2) *Intrinsic Motivation Inventory*

The Intrinsic Motivation Inventory (IMI) is a multidimensional measurement device intended to assess participants' subjective experience related to a target activity in laboratory experiments. It has been used in various experiments related to intrinsic motivation and self-regulation. The full 45 items make up the 7 subscales.

The instrument assesses participants' interest/enjoyment (E), perceived competence (CO), effort (E), value/usefulness (U), felt pressure and tension (T), and perceived choice (CH) while performing a given activity, thus yielding six subscale scores.

Recently, a seventh subscale has been added to estimate the experiences of relatedness, although the validity of this subscale has yet to be established.

We constructed our own IMI according to the instructions. It included 26 items, relevant for this study, from the primary six subscales (E=5; CO=4; E=4; U=4; T=4; CH=5). These items were randomly ordered. Each item was scored on a 7-point scale (from incorrect to correct). We first reversed scores for the items for which an (R) was marked. Then, we calculated subscale scores by averaging across all of the items on that subscale. The subscale scores are then used in the analyses of relevant questions.

IMI was evaluated after the three weeks of therapy with playing games in VR.

The two secondary outcome measures, Fugl–Meyer assessed for upper extremity and Modified Aschworth Scale for spasticity of arm were estimated before and after the therapy with games.

III. RESULTS AND DISSCUSION

One example of progress in arm coordination and hand smoothness is shown in Figure 4 evaluated with DT before (top panel) and after (middle panel) the therapy with playing games, and at follow up (bottom panel) for patient #3.

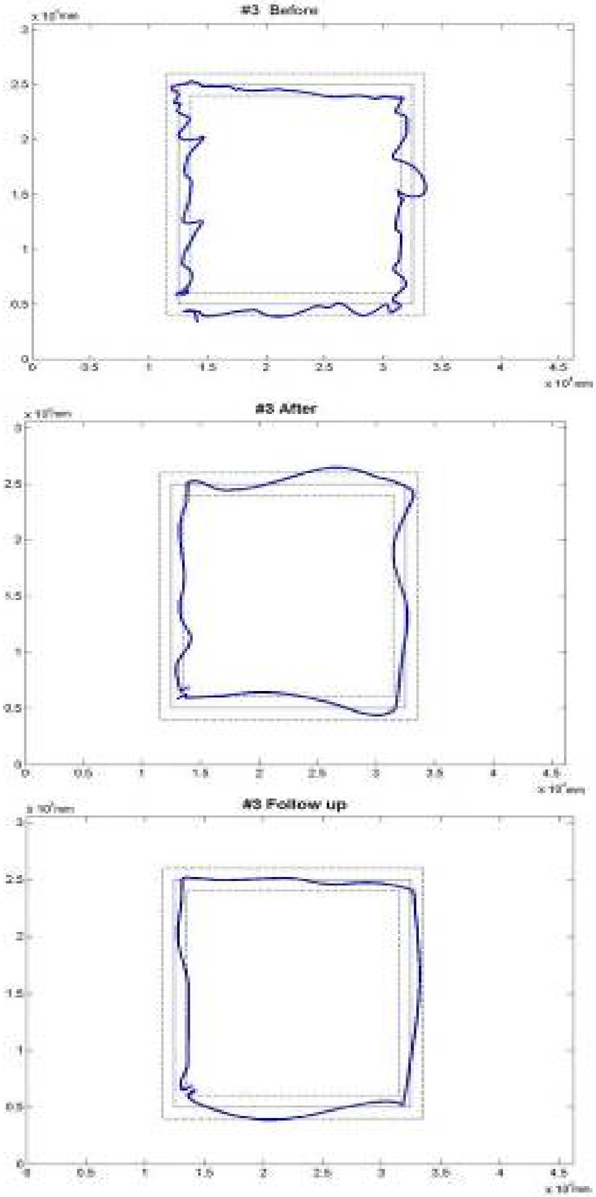

Figure 4. An example of DT for patient #3 before, after therapy and at follow-up. Improvement is noticable visually.

Parameters calculated from DT for all patients are presented in Table 1. They are presented in relative terms, in respect to initial results, recorded before the therapy. Smoothness of the hand movement improved if line aberration and region deviation decreased. Overall patients improved arm velocity and coordination.

Patient #3 declined in performed velocity after therapy, while patients #2 and #6 did this at follow up (grey). Patient #1 and #6 increased line deviation after therapy, while patients #3 and #4 at follow up (grey). Patient #1 and #6 increased line deviation after therapy, while patients #4 at follow up (grey).

TABLE 1. DT PARAMETERS (VELOCITY, LINE ABERRATION AND REGION DEVIATION) FOR 6 PATIENTS BEFORE, AFTER THERAPY WITH GAMES AND AT FOLLOW-UP.

	patient #	1	2	3	4	5	6
velocity	before	1.00	1.00	1.00	1.00	1.00	1.00
	after	4.42	1.37	0.98	5.77	15.83	1.08
	follow up	4.58	1.02	1.12	6.62	15.83	0.97
line aberration	before	1.00	1.00	1.00	1.00	1.00	1.00
	after	1.14	0.78	0.97	0.88	0.65	1.08
	follow up	0.93	0.64	0.94	1.24	0.59	0.87
area deviation	before	1.00	1.00	1.00	1.00	1.00	1.00
	after	0.91	0.83	0.09	0.19	0.37	0.84
	follow up	0.45	0.43	0.17	0.19	0.05	0.34

Arrows show positive trend in rehabilitation. Parameters in gray indicate deterioration in arm rehabilitation.

Averaged values of six IMI subscales for all patients were between 2.3 (SD = ±1.5) for pressure/tension and 7 (SD = 0) for perceived competence, Figure 5. Scores for other 4 subscales were of similar values (around 5). The interest/enjoyment subscale is considered the self-report measure of intrinsic motivation; thus, a higher score on this subscale indicates a relatively high motivation of patients for participation in this form of game therapy. Higher scores on perceived choice, perceived competence, and value/usefulness subscales, as well as a lower score on the pressure/tension subscale, all confirm relatively high patient motivation. In the follow up interview the patients gave useful suggestions about modifying the content of the VR games which could possibly motivate them more during rehabilitation.

Results for the two standard clinical scales are in agreement with medical expectations: small improvement in FM and no change in MAS, Table 2. Longer therapy might make the difference.

In this study we analyzed what the potential benefits are of rehabilitation based on hardware that integrates planar manipulandum with a digitizing board in a PC based virtual reality that may be used as a rehabilitation tool. Patients' motivation and system usability are to be further investigated [20].

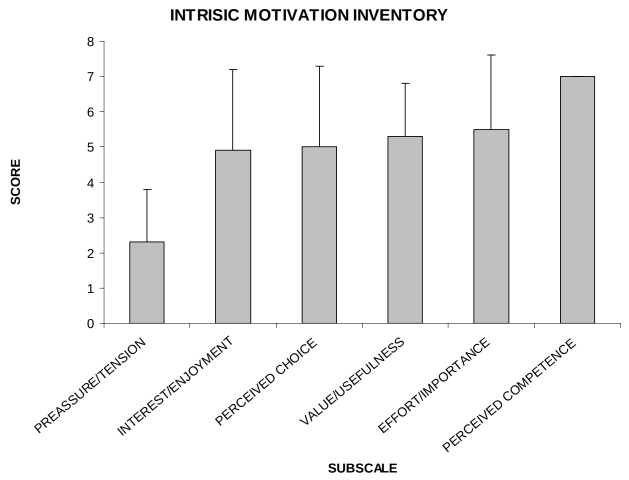

Figure 5. Score of Inventory Motivation Instrument for six IMI subgroups (maximum score 7 for each subscale).

TABLE 2. FUGL-MAYER AND MODIFIED ASCHWORTH SCALE FOR 6 PATIENTS ASSESSED BEFORE AND AFTER THERAPY WITH GAMES IN VIRTUAL REALITY.

	patient #	1	2	3	4	5	6
Fugl-Meyer	before	43	40	67	58	31	39
	after	44	46	68	59	NA	NA
Modified Aschworth Scale	before	1	1	1	1	1	1
	after	1	1	1	1	NA	NA

NA – not applicable

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