A Comparative Study on the Effectiveness of Adaptive Exergames for Stroke Rehabilitation in Pakistan

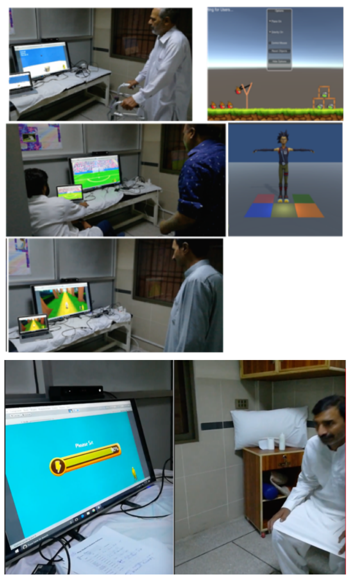

Figure 1: Top to Bottom: screenshots of adaptive games; Catch Fruits, angry birds-clone, Goal Shoot, Glowing Blocks, 3D runner, Sit to Stands.

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Abstract
Motion-based games for Health (MGH) are increasingly being adopted for stroke rehabilitation because of their inherent benefits [14]. In this paper, we present the initial results of a novel intervention study in Pakistan's context, that compares the benefits of prescribed manual therapy regarding motor functional improvements of 22 participants who participated in a randomized clinical trial that lasted for a period of 4 weeks with the pre-post intervention standard functional assessments (TUG, WMFT, ARAT). The results indicated that adaptive exergames are not just an alternative to manual therapy but can also provide the additional benefits of enjoyment and motivation (TAM, CEGEQ and informal interviews).

Introduction
With most developing countries' health budgets being spent largely on communicable diseases, there are inadequate resources left to invest in stroke rehabilitation. In Pakistan, where nearly 350,000 new stroke cases are reported each year [1], a 0.92 percent of GDP allocation to public health [2] is insufficient for stroke rehabilitation. Upon exploring the role of technology as an alternative to conventional

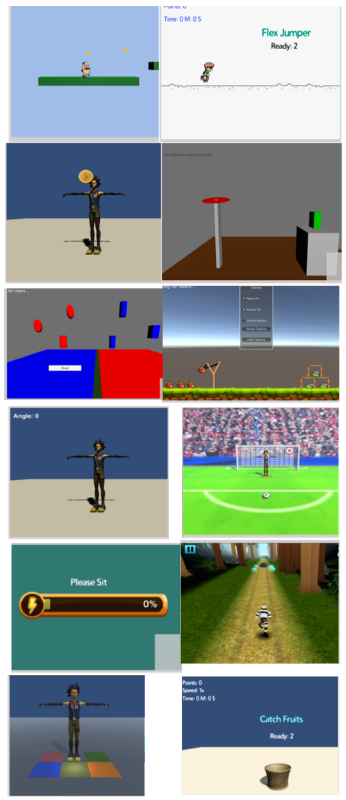

Figure 2. Screenshots of exergames in order as mentioned in Game Design Table 3 (a, b).

rehabilitation, exergames are proved to be an intrinsically rewarding framework which motivates stroke survivors in initiating and repeating specific exercises aimed at maximizing their physiological improvements [8,10]. In our study, we present an adaptive version of exergames platform called VRehab that could additionally facilitate our native users by catering to the complexities brought about by the lack of or a different nature of socio-technical infrastructure present in the developing countries, low literacy rates causing language barriers and unfamiliarity in the gameplay context and most importantly, shortage of resources[2,3]. By incorporating some existing recommendations for designing exergames for elders with our extensive features including Urdu based audio feedback prompts, user interface and familiar gameplay contexts, we have evidently facilitated average Pakistani post stoke patients, majority of whom are either devoid of health care and therapeutic facilities or are minimally aware of modern technology.

Tested in clinical conditions in Pakistan, VRehab offers 12 interactive exergames to assist hemiplegic patients with rehabilitation (Table 3 [a, b]). This study involves pre and post-experimental standard rehabilitation assessments such as Wolf Motor Function Test (WMFT), Action Research Arm Test (ARAT) and Timed Up and Go test (TUG) [4] that gauged spatiotemporal conditions of upper and lower extremity for patients of Randomized Clinical Trail (RCT). The exergames experimental group is expected to show better or at least on par improvement compared to manual therapy with the additional features of adherence and motivation for rehabilitation. By considering the age related sensorimotor deficits in the elderly group, we have adapted some pre-established guidelines that assert the need of a dynamic and uninvolved interaction mechanism that can be altered by the users according to their requirements and varied demographical needs, thus is more visually appealing and engaging to a specific audience [7]. By implicitly modifying the parameters and adjusting the accuracy required to acquire a target according to the abilities of the users, exergames can be made more enjoyable and easier for all kind of patients with the help of skill assistance [6]. Difficulty adjustment is another feature that ensures the selection of difficulty level in a game according to its intended audience [8,9]. Players are allowed to adjust the difficulty level manually; dynamic algorithms involve performance based difficulty adjustment.

The Core Elements Gaming Experience Questionnaire (CEGEQ) and the Technology Acceptance Model (TAM) questionnaire [5] successfully validated the inclusion of the aforementioned features by giving positive results on usability and game experience and overall acceptance of VRehab among the elderly and the semi-literate.

Our contributions include a medically validated and culturally relevant adaptive exergames platform that facilitates in functional improvements and its empirical evidence lies in patient's attitude and willingness towards playing exergames for rehabilitation. Our gameplay and game art recommendations, projected on a number of rehabilitative exercises database for upper and lower limbs extremities, ensure a low learning curve and high adherence level.

Method

Exercise Plan

The exercise plan focused on the strengthening and coordination of both limbs and was prescribed using FITT Principle (frequency, intensity, time, type). The sessions were started with low-intensity exercises

Exercise	Target Muscles
U1: Resistance training for elbow flexion.	Biceps femoris, brachioradialis
U2: Resistance training for shoulder flexion and abduction.	Deltoid, supraspinatus, Serratus anterior, Rhomboids, Pectoralis Major, intrinsic muscles of hand
U3: Wheel exercises for upper limbs	Muscles: Supraspinatus, infraspinatus Teres minor, subscapularis
U4: Reach to Grasp - RTG (functional reach).	Deltoid, Serratus anterior, Rhomboids, Pectoralis Major, Anterior Fibers of Deltoid.
L1. Quadriceps chair exercises with variations including bilateral, simultaneous and alternate set	Biceps femoris, brachioradialis

Table 1. Prescribed stroke rehabilitation exercises and their target muscles.

(<40% HR Reserve) followed by moderate-intensity exercises (40-59 % HR Reserve). The exercises covered the physiological as well as functional movement patterns. The literature suggests that the benefits of exercise therapy were restricted to balance, functional weight-shifting and gait training in the lower limb. Four exercises for lower limb were selected considering the motor demands that included the anteroposterior and lateral displacement of the center of gravity and multidirectional steps (Table 1). Similarly, four exercises for the upper limb focused on movements appropriate to the orientation of the spheres and lowering the center of gravity (Table 1). Significance of the chosen exercises for rehabilitation of chronic stroke patients is mentioned in literature [11,12,13]. In the next phase, we developed the prototypes of multiple serious games. We have used Unity (5.6.0f3), as the game engine, and Kinect V2, as motion sensor camera. 12 exergames[1] that mapped to the manual exercises were developed to focus on the same muscles groups Table 3 (a, b) . There is a difference between the number of exercises and exergames because the gains in atomic exercise are not equivalent to functional outcomes of a single exergame except GU1 and GL3 of Table 3 (a, b).

Participants and Procedure

A total of 22 elderly post-stroke patients were selected in accordance with our inclusion criteria as; patient being able to stand and walk 3 meters independently and obligating at least 10 months of the post-stroke period prior to taking part in the study. Majority of the participants in our study did not receive formal education after high school nor did they have any prior experience of exergames. Participants were divided into control and an experimental group of equal strength with random assignment (Mean age; Control:50.4, Experimental:52.1) and were required to attend at least 16 out of 25 sessions from 1st to 31st August, 2017 conducted at Ghurki Trust Hospital and Arthritis and Pain Care Center Lahore respectively under the supervision of three physiotherapists. Participants of both groups were already under treatment for chronic stroke rehabilitation for at least 6 months and participants of the experimental group had minimal direct interaction with therapists except for the basic guidance regarding games during the intervention phase. Patients in experimental group were free to adjust the difficulty level, speed and accuracy of each game manually as well as games were also adaptive based on the past performance of patient. Daily rehabilitation sessions were of 40-50 minutes for each participant of experimental group and 30-35 minutes for each participant of control group. The study evaluated the elderly participants with the range of physiological (for functional outcomes) and psychological (including technology acceptance and gaming experience) measures. The quantitative difference in functional improvements for each patient were recorded through several tests that include the Wolf Motor Function Test - WMFT (17 Tasks) and the Timed Up and Go (TUG) test to measure functional abilities in time dimension, Action reach Arm Test-ARAT (19 tasks) to measure functional abilities in space dimension [4]. Participants belonging to the experimental group were asked to fill the Technology Acceptance Model (TAM) questionnaire at the end of the experiment in order to measure the acceptance of our technological intervention and to quantify the

[1] Details of exergames are available at https://goo.gl/RXdauH

L2: Sit to stand exercise on stable surface	Hip flexors, Extensors, core, quadriceps, hamstrings
L3. Frenkel's exercises, forward, backwards and sideways steps	Hip Abductors, Flexors, extensors, quadriceps, hamstrings, core
L4. Frenkel's exercises, forward, backwards and sideways walking	Hip Abductors, Core.

Table 1 Contd. Prescribed stroke rehabilitation exercises and their target muscles.

Item	Mean score ± (SD)
Perceived Usefulness(PU)	5.23 ± 0.37
Perceived Ease of Use(PEU)	5.31 ± 0.26
Perceived Behavioral Control(PBC)	4.47 ± 1.51
Subjective Norms(SN)	5.27 ± 0.56

Table 2. Mean scores of items in TAM out of 6 (± Standard Deviation) for experimental group.

Test	Pre-Intervention Mean ± SD	Post-Intervention Mean ± SD	MCID Stroke	MCID Exhibited
TUG – 3meters (Seconds)-EG	24.02 ± 3.18	21.89 ± 2.89	2.9 seconds	No
TUG – 3meters (Seconds)-CG	24.34 ± 3.75	22.44 ± 2.77		No
WMFT – 17 Tasks(Seconds)-EG	83.82 ± 7.87	70.56 ± 6.43	16% change	Yes
WMFT – 17 Tasks(Seconds)-CG	84.84 ± 8.36	74.52 ± 7.66		No
ARAT (max 57 points)-EG	36.09 ± 8.49	42.27 ± 6.72	Change of +5.7 points	Yes
ARAT (max 57 points)-CG	35.45 ± 7.54	40.91 ± 7.91		No

Table 4. Participants' pre experiment and post experiment quantitative outcomes for three motor function abilities assessments of experimental and control groups, explaining the pre and post intervention tests values with corresponding Minimal Clinically Important Differences (MCID – which is the most significant determinant to assess the effectiveness of rehabilitation plan) definition and evidence (EG: Experimental Group, CG: Control Group) [4]**.**

gaming experience (gameplay, ownership, control, frustration) of the participants of same group, we used Core Elements Gaming Experience Questionnaire (CEGEQ) [5]. Limitation of this study's sample includes a lack of female participants because of socio-cultural constraints of women in Pakistan that restrain them from participating in physiotherapy sessions with male physiotherapists.

Results

Table 4 explains the output of pre and post experiment functional measures (TUG, ARAT, WMFT). Mean improvement scores in individual categories of ARAT for experimental and control groups are; Grasp (Max 18) (E: +1.46, C: +0.98), Grip (Max 12) (E: +1.36, C: +1.27) Pinch (Max 18) (E: +1.82, C: +2.18), Gross Movement (Max 9) (E: +1.46. C: +0.97). For gaming experience and technology acceptance, patients in experimental group answered a Core Elements Gaming Experience Questionnaire [5]. Significant mean scores (85%+) in CEGEQ for positive latent variables seemed to indicate that the patients were satisfied with the game environment, gameplay, control, ownership, control whereas low (19.2%) scores for frustration and points towards the higher enjoyment level for gaming experience. Technology acceptance model (TAM) questionnaire [5] using a 6-point Likert scale was adopted. Users gave considerably high scores to all of the items of TAM questionnaire except for Perceived Behavioral Control (PBC) (Table 2).

Qualitative Results

The feedback received from the participants during informal interviews at the end of the rehabilitation sessions revealed that the participants of the focus group were very motivated to play these games and

Exergame	Mapping
GU1 - Flex arm to make character (kid) jump	mapped to **U1**
GU2 - Flex arm to make character (bean) jump	mapped to **U1**
GU3 - Raise hand above shoulder	mapped to **U2, U4**
GU4 - Functional reach1 (Place object)	mapped to **U3, U4**
GU5 - Functional reach2 (objects at diff heights)	mapped to **U4**
GU6 - Angry Birds	mapped to **U4**

Table 3 (a). Six exergames for upper limb extremities and their mapped manual exercises.

they not only accepted the system (TAM) but were willing to use it on a regular basis. For example, one participant (F6) stated "These games are very joyful and interesting – time flies, whereas manual therapy was difficult, time consuming and boring". Patients were more interested in seeing a known environment and gameplays. For example, one participant (F8) said, "my grandchild also plays this (3D runner and Angry Birds) type of games on phone and I know this because I watch him playing". Finally, at the end of the study, all the participants expressed the wish to use exergames system for rehabilitation even after the study.

Discussion

Overall, the patients in the experimental group, trained using our VRehab platform, performed better in all the functional tests than those in the control group and found the gaming experience useful and engaging and were certain that it offers long term benefits. However, in certain cases, our platform was unable to record the movements in a precise manner. For example, in the 'Pinch' category of ARAT, control group seemingly outperformed the experimental group due of KinectV2's inability in detecting fine hand movement such as writing. Low mean scores of PBC category in TAM can be attributed to the fact that the mean score to the question "I have the resources to use the exergames system. (~$350)" was as low as 31%, thus proving that the majority of the participants were not financially stable enough to afford such solutions at home.

We would now like to highlight the design decisions we took while developing the VRehab platform which might help in designing better exergames for elderly in Pakistan: Game aesthetics can heavily affect the functional performance and motivation level of a patient. For example, all the patients in the experimental group preferred "Arm Flexion with kid" (where a kid was used as the avatar) to "Arm Flexion with Bean" (which was a counterpart of the above game with a slim bean character as the avatar). It shows that patients are interested in healthy and more realistic game avatars which represent the future they hope for. Use of angry birds' paradigm, Road Runner paradigm, Mario Run paradigm, etc. mapped on physical activities and these exercise helped in lowering the learning curve. Almost all the users explicitly highlighted that they already knew 'what to do to win these games' (highlighted in CEGEQ).

We selected the target muscles for the VRehab platform after extensive literature review, discussions with local neurologists and physiotherapists. And although the experimental group outperformed the control group because of the adherence factor, the resultant scores and MIs were significant in both the groups. This highlights the importance of choosing the right muscle groups for any exergaming platforms for rehabilitation. The muscles mentioned in our exercise plan section are very crucial for rehabilitations and daily life activities in the stroke patients' context.

The following limitations of this study might have impacted our research to an extent. The first limitation pertains to the fact that this is a medium scale pilot study which was run with a smaller sample size for only a month. Secondly, the results of this study are gender biased as no female was comfortable with participating in a rehabilitation session with a male physiotherapist. Third limitation was regarding the hardware as KinectV2 was not capable of tracking fine movements. We aim to address these limitations in future by running a long term study, adding a female physiotherapist on our research panel and by augmenting the current setup with more precise and

Exergame	Mapping
GL1 - Hip thrusters	mapped to **L1**
GL2 - Goalkeeping	mapped to **L1**
GL3 - Sit to stand	mapped to **L2**
GL4 - 3D Runner (side to side steps)	mapped to **L3**
GL5 - Glow blocks (place feet at glowing block)	mapped to **L3**
GL6 - Falling fruits	mapped to **L4**

Table 3 (b). Six exergames for lower limb extremities and their mapped manual exercises.

sensitive pressure sensors. Our platform evidently shifts the empirical workload of exercise supervision from rehabilitation professionals to an automated system. The same human resource can be used for other complex clinical tasks.

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