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Development of Rehabilitation Software with the Cooperation of Physiotherapists and Engineers: A Shoulder Rehabilitation Pilot Study

Fizyoterapist ve Mühendis İş Birliği ile Rehabilitasyon Yazılımının Geliştirilmesi: Omuz Rehabilitasyonu Pilot Çalışması

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ABSTRACT

The use of technological rehabilitation as a complementary approach has gained popularity in recent years. This study aimed to create serious games for shoulder rehabilitation and investigate their impact on patients with rotator cuff rupture in terms of pain, range of motion, joint position sense, and approximation force. Additionally, it aimed to showcase the collaboration between physiotherapists and engineers in developing technological rehabilitation software. The study involved 20 patients with rotator cuff rupture who underwent the Serious-Game Exercise (SGE) program twice a week for six weeks. All individuals were assessed before and after the treatment, and the results showed significant differences in all measured parameters ($p<0.05$). The study concluded that SGE is an effective therapy for patients with rotator cuff rupture, and serious games can be a viable alternative therapeutic approach.

Keywords: Exercise, Exergaming, Gamification, Rotator cuff

ÖZ

Teknolojik rehabilitasyon, son yıllarda popüler olan tamamlayıcı yaklaşımlardan biridir. Bu çalışmanın amacı omuz rehabilitasyonu için serious oyunlarının oluşturulması ve omuza yönelik tasarlanan bu oyunların rotator cuff rüptürü olan bireylerde ağrı, eklem hareket açıklığı, eklem pozisyon hissi ve aproksimasyon kuvveti üzerindeki etkisini incelemektir. Ayrıca fizyoterapistler ve mühendislerin iş birliği ile teknolojik rehabilitasyon yazılımlarının oluşturulması amaçlandı. Çalışmaya rotator cuff rüptürü olan 20 hasta dahil edildi. Katılımcılar 6 hafta boyunca haftada iki kez omuz rehabilitasyonu için geliştirilen serious oyun egzersiz programına alındı. Tedavi öncesi ve sonrası tüm bireylerin ağrı şiddeti, fleksiyon, abduksiyon ve eksternal rotasyon eklem hareket açıklığı, eklem pozisyon hissi ve aproksimasyon kuvveti değerlendirildi. Grubun tedavi öncesi ve sonrası tüm değerlendirme parametrelerinde istatistiksel olarak anlamlı fark vardı ($p<0,05$). Omuz rehabilitasyonu için serious oyun egzersiz programının rotator cuff rüptürü olan bireylerde etkili olduğu ve alternatif bir terapatik strateji olarak serious oyunlarının kullanılabileceği bulunmuştur.

Anahtar Kelimeler: Egzersiz, Exergaming, Oyunlaştırma, Rotator cuff

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INTRODUCTION

Video-based games played with game consoles, such as Microsoft (MS) Xbox and Nintendo Wii, have become widespread in rehabilitation in recent years. They are specified as a combination of games and physical motions designed to increase the physical activity and functionality of the person.[1] The components of the game consoles allow to track the movements of patients. For example, MS Kinect v2 is a component of the MS Xbox 360 game console with a two-dimensional (2D) RGB camera and a three-dimensional (3D) depth sensor. 3D locations of twenty-five joints in the skeleton can be accurately determined with the Kinect Software Development Kit. MS Kinect has a wide range of usages such as industry, health, informatics, and education sectors.[2,3] Nintendo Wii console Balance Board is a sensor used to measure the Center of Pressure (CoP) displacement of individuals. Balance board has shown to be valid and reliable and became a tool for assessing balance with CoP.[4]

There are two distinct approaches for video based gaming in physiotherapy: (i) Exergames and (ii) Serious games (SG). Exergames refer to the use of popular entertainment games in the context of rehabilitation.[5] Standard gaming consoles such as the Nintendo Wii, Playstation Move, and Kinect plus XBOX 360 have been utilized in rehabilitation. Serious games, on the other hand, are specifically designed and developed to target and improve a particular body function for rehabilitation purposes.. Serious games attract attention from the patients since they increase their motivation and enable the therapeutic exercises to be performed efficiently.[6,7] Therefore, it is necessary to develop specific serious games which are designed for a primary purpose to promote learning and behavior changes for pathologies. Physiotherapists and engineers should work together in the design of serious games and software development process.[7,8]

In the literature, there are many studies for video based game exercises for healthy and patient groups.[9,10] However, the number of serious game studies for shoulder rehabilitation is limited. Therefore, there is a need for serious game development with technology-based applications in shoulder rehabilitation.[11]

This study aims (i) to develop serious games for shoulder rehabilitation, (ii) to show the software development process with the corporation of physiotherapists and software engineers, and (iii) to examine the effectiveness of these games in the rotator cuff pathologies.

MATERIAL AND METHOD

Ethical Aspect of Research

The study enrolled 20 participants who had a partial rupture of the rotator cuff and met the inclusion criteria of the Department of Physical Therapy at Medipol University Hospital. The study was conducted according to the ethical principles stated in the Declaration of Helsinki for research involving human subjects, and the study protocol was approved by the Non-interventional Ethics Committee at Istanbul Medipol University. (Number: E-10840098-772.02-5248).

Participants

This study included participants who were diagnosed with rotator cuff rupture by a medical doctor and met specific criteria. The criteria included individuals aged between 40 and 60 who had been experiencing pain for more than 4 weeks and had not undergone any shoulder surgery. Individuals with neurological findings of cervical origin, those who were uncooperative, those with other orthopedic problems in the same shoulder, and those with neurological, vascular, or cardiac problems that could limit their function were excluded from the study.

Serious Games

Serious Game Development

The development of serious games for physiotherapy necessitates a close partnership between physiotherapists and software engineers. For software development in this study, the iterative waterfall model was employed. The initial step was to gather input from patients and physiotherapists to determine functional requirements by analyzing the specifications. We observed traditional therapy sessions to identify critical requirements, such as calculating range of motion (ROM) and pressure using sensors. The second step involved designing the serious game software, which included defining the major components of the system, their properties, interfaces, relationships, and interactions. We specified sensor components according to their measurement capabilities. User interface design was also crucial, and physiotherapists advised on game design elements such as color, shape, scoring criteria, and duration, as the games were developed for disabled people to increase motivation.The third step was the implementation of the serious games using C# programming language and Unity library. To collect sensor information, the software utilized application programming interfaces offered by the MS Kinect and balance board. The testing phase of software development consisted of individual code unit testing, comprehensive system testing, and acceptance testing. During the acceptance testing phase, healthy participants were initially tested, followed by real patients, with both physiotherapists and engineers monitoring the tests. Feedback from patients and physiotherapists was crucial, and modifications were made in the second development phase based on this feedback.

Instead of proceeding to the maintenance phase, the second iteration of the software development process began with the requirement analysis phase again. During this iteration, the requirement analysis, design, implementation, and test phases were repeated to make necessary changes to the software. There were some important points to note during software development, such as the need to test on unhealthy people and the necessity of modifying game elements after the test phase. The iterative waterfall model was useful for these modifications. Finally, the software and hardware were verified.

Becure Software Platform for Assessment and Serious Games

Becure™ is a web-based platform designed for physical therapy and rehabilitation, which includes both assessment tools and serious games. The platform utilizes various non-wearable sensors to gather quantitative data, such as motion, skeleton, and weight, which are then processed and stored in a database. This data can be used to generate development reports for each patient. In this study, four serious games were developed and integrated into the Becure platform, along with the Becure Balance and ROM Extremity systems.[12] More details about these systems and games are provided in the following sections.

Becure Balance System – Approximation Force Assessment

The Balance System software is utilized to quantify changes in the balance center, weight, position of the center of balance, and CoP (Center of Pressure). The balance board used in this study was linked to the Becure Balance System via Bluetooth. Participants in the study applied pressure to the balance board with their hands while standing or sitting, and CoP values were calculated based on the force exerted from their shoulders (as depicted in Figure 1). The board had four balance transducers, one at each corner, and the total CoP was calculated accordingly.,

$$CoP_X = \frac{L}{2}\frac{[(TR+BR)-(TL-BL)]}{TR+BR+TL+BL}$$

$$CoP_Y = \frac{L}{2}\frac{[(TR+TL)-(BR-BL)]}{TR+BR+TL+BL}$$

where TL is top left, BL is bottom left, BR is bottom right, and BL is bottom left transducer of the balance board. L and W are the length and width of the board, respectively. The Balance System offered three choices in terms of measurement parameters, which included the option to use or not use an ima-

ge, keep the eyes open or closed, and take intermittent measurements.

Becure ExtremityROM Measurement System

ExtremityROM is a software program that has been specially designed to analyze joint range of motion (ROM) and posture. It accurately determines ROM values using the 3D skeleton points of the MS Kinect sensor and calculates 11 parameters, including shoulder flexion/extension, shoulder abduction/adduction, shoulder internal/external rotation, elbow flexion, hip flexion/extension/abduction, and knee flexion. Proper detection of the patient by the MS Kinect sensor is crucial to ensuring precise measurement. Patients are instructed to stand in front of the sensor with their arms open, and joint angles are instantly displayed on the screen's lower right and left sections (Figure 2).

Serious Games

Balloon Game

The Becure Balloon is a therapeutic game that is created to improve the shoulder joint's range of motion by involving the patient in hitting incoming balls using arm movements from the shoulder. The game requires the patient to score goals by hitting the balloons with their arms. A sample screen of the Balloon game is shown in Figure 3a. The game employs real-time 3D skeleton information gathered from the MS Kinect sensor to calculate ROM degrees. Game parameters include level, left/right hand or both hands, minimum and maximum ROM degrees for the shoulder, balloon size, game duration, and target score.

Balance Pong

The game called Balance Pong was developed with the aim of improving shoulder muscle strength and the propri-oceptive system. It is played in front of a balance board device, with both hands on the board and hitting balls by transferring weight to the shoulders. The objective of the game is to hit the ball into the opposing team's goal.As the game progressed and the difficulty level increased, the number and speed of balls also increased. A sample screenshot of the Balance Pong game is depicted in Figure 3b.

Balance Surf

The Balance Surf game was designed to enhance anterior-posterior and lateral balance movements using the balance board sensor. The game requires players to collect stars while avoiding obstacles by directing the surfboard. As the levels progress, the speed of the surfboard and number of obstacles increase. Players interact with the game by placing their hands on the balance board and shifting their weight to move the surfboard left or right. Figure 3c illustrates this gameplay mechanism. The balance board is placed on a desk, and the game is controlled by pressing hands and shifting weight.

Balance Shooter

The game called "Balance Shooter" requires the player to move forward, backward, right, and left on the balance board in order to navigate a spaceship within the game.. Players use both hands to direct the spaceship and avoid obstacles, such as stones, in order to achieve higher scores. As the game progresses, the speed and number of obstacles increase, making it more challenging. Figure 3d provides a sample screenshot of the Balance Shooter game.

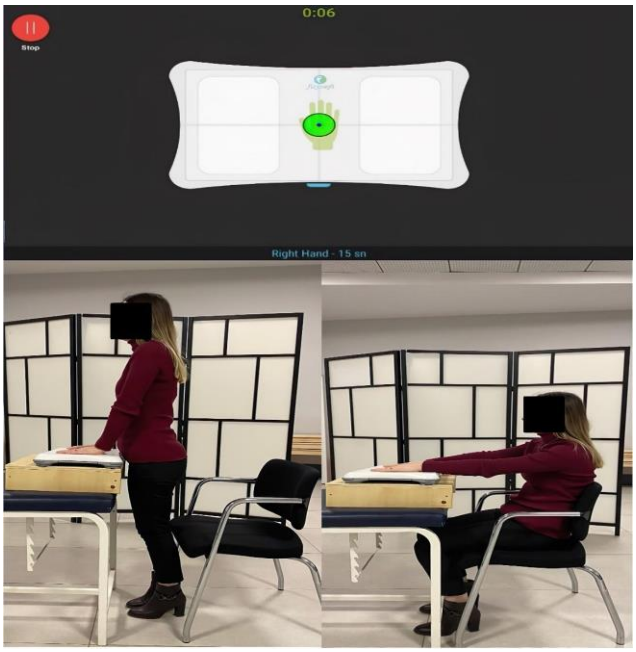

Figure 1. Becure Balance System

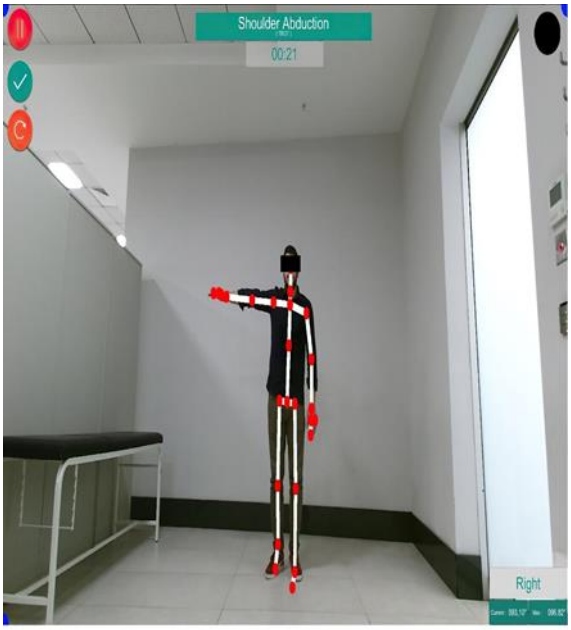

Figure 2. Becure Extremity ROM

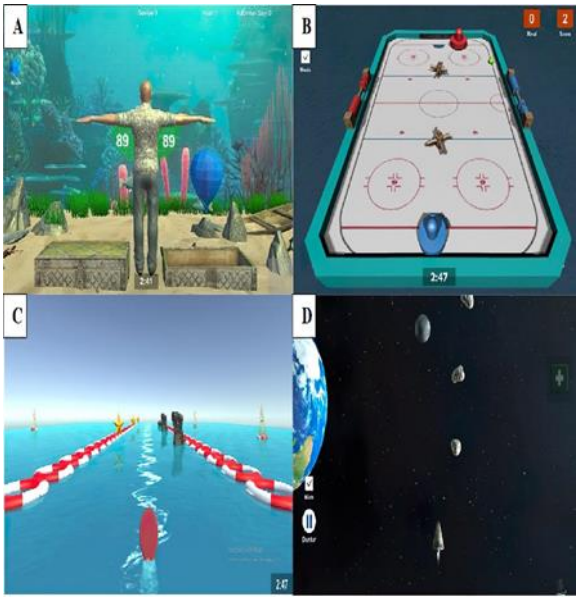

Figure 3. Serious Games

Intervention

The SGE program was applied to the individuals twice a week for 6 weeks. Balloon, Balance Pong, Balance Surf and Balance Shooter games were used. In order to increase patient motivation during games, different difficulty levels and scores were applied. Therefore, the patient tried to beat the previous score in each session. The games were played from easy to difficult levels while considering the pain and ROM of the participants. Under the supervision of a physiotherapist, individuals played these games designed for shoulder rehabilitation. Each game was played for 10 minutes for a total of 40 minutes.

In addition to the SG program, shoulder wheel exercises and wand exercises were also used to increase the ROM at the shoulder joint. Exercises involving the finger ladder were carried out five times, holding the endpoint for five seconds each time. For the limitation of movement, stretching exercises were conducted in both directions with 5 repetitions, keeping the position for 20 seconds at the conclusion. For six weeks, individuals performed the exercises twice a week.

Outcome Measurements

The evaluation parameters of the individuals participating in the study were evaluated pre and post-treatment.

The pain level was assessed using the visual analog scale (VAS) at rest and during activity. There was a 10-cm line on the scale. Participants were asked to rate their current level of pain on a scale, with higher numbers representing more intense pain.[13] Becure Extremity ROM was used to assess the ROM of the joint and joint position sense of the study participants. The patient performed the desired action while standing in front of the Kinect camera. The shoulder joint's flexion, abduction, and external rotation ROM were measured.[14] For the examination of joint position sense, subjects were initially instructed to elevate their shoulders to a certain degree and bring them to the same angle value while keeping their eyes closed. The shoulder angle difference while the eyes were open and closed were calculated for each individual.

The Becure Balance System was utilized to evaluate the shoulder approximation force. The participants were instructed to place both hands on the balance board and apply a downward force without relying on their body weight during the measurement process. The measurements were taken while the participants were standing and seated. (0° and 90°, respectively) (Figure 1).

Statistical Analysis

SPSS 22.0 software was used to analyze the data, which was presented in the form of percentages, means, and standard deviations. The normal distribution of the data was evaluated through the One-Sample Kolmogorov-Smirnov test. The effectiveness of the pre- and post-treatment programs was compared using the paired-sample t-test, with a significance level of $p<0.05$.

RESULTS AND DISCUSSION

Twenty-six individuals were included in the study. Four participants were excluded from the study because they did not meet the inclusion criteria and two participants were diagnosed with Covid during the treatment. The study was finally completed with 20 individuals. There were ten men and ten women subjects in the SGE program. The mean age of the participants was 47.7±7.1. When the affected shoulder area of the individuals participating in the study was examined, sixteen of the

individuals had right and four had left affected shoulder (Table 1).

Table 2 presents a comparison of the evaluation parameters before and after the treatment within the group. Upon comparing the pre- and post-treatment results, all measures showed significant improvements ($p<0.05$). The participants' VAS scores significantly decreased, and there was a determined increase in all ROM values and approximation force results. Additionally, all participants demonstrated a significant improvement in their joint position sense.

Table 1. Baseline Characteristics of the Participants

Participants (n=20)	
Age (yr), mean (SD)	47.7 (7.1)
Gender n (%)	
Male	10 (50)
Female	10 (50)
Shoulder Affected n (%)	
Right	16 (80)
Left	4 (20)

SD: Standard deviation

Table 2. Comparison of Changes in Outcome Measures Within Group

Outcome Measures	Pre treatment (Mean±SD)	Post treatment (Mean±SD)	p
VAS/resting	5.8±2.2	1.4±0.9	0.00
VAS/activity	9.1±1.1	3.2±1.2	0.00
ROM- Shoulder flex.	110.3±11.2	171.4±7.4	0.00
ROM- Shoulder abd.	71.7±15.5	149.5±17.8	0.00
ROM-Shoulder ER.	34.3±22	73.7±12.9	0.00
90° approximation force	4.4±2.3	8.2±2.5	0.00
0° approximation force	7.8±4	14.7±4.8	0.00
Joint position sense flex.	11.7±5.2	2.5±1.8	0.00
Joint position sense abd.	11±4	2.7±1.6	0.00

SD: Standard deviation; ER: External rotation; flex: flexion; ext: extansion; abd: abduction; VAS: Visual analogue scale; ROM: Range of motion.

Significant changes were observed in all parameters when the results of SGE were examined at pre- and post-treatment. Physiotherapy has witnessed a widespread use of SG for treatment with the advent of technology. Since 2007, there has been a surge in studies on exer-games. New treatment and evaluation methods are emerging with tech-

nological advancements. Becure Extremity ROM and Becure Balance System are examples of technology-based tools that provide accurate data for joint ROM, joint position sense, and approximation forces measurement in physical therapy. Despite this, few studies have evaluated shoulder approximation force in shoulder patients. Therefore, there is a need for more research in this area.[15]

Upon reviewing the literature, it was found that exergame interventions have been utilized across various medical conditions to improve balance, reduce movement disorders in Parkinson's disease patients, increase upper extremity function in hemiplegic patients, and enhance balance performance in geriatric patients with osteoarthritis.[16–19] It is underlined that there is limited research on the use of SGE for orthopedic issues.[20,21] Since the SG for orthopedic problems has not been deeply investigated so far, we specifically addressed the shoulder problems in this study.

A study compared exergame and home exercise programs and found that the exergame program had more significance than the home-based program.[22] Instead of using standard exergames, we chose to develop serious games specifically for shoulder rehabilitation in this study. Our results showed that SGE was effective in improving all measured parameters. We believe that this success is due to the fact that SGs designed for shoulder rehabilitation provide visual and sensory feedback, which can help reduce pain and increase patient engagement and perception during treatment. Alfieri et al. examined the use of games for musculoskeletal disorders rehabilitation. Results were on par with or better than those of traditional physical therapy or exercises performed at home. There was also the additional advantage of increased motivation for the exercise program. Also, improvements were seen in reported health status and the quality of life.[23]

In our previous study, we examined the effectiveness of video-based game exercise programs in rotator cuff injuries and reported that video-based game exercises improved pain, functionality and quality of life parameters. Three groups (a conventional exercise group, a structured closed kinetic chain exercise group, and a video-based game exercise group) were rehabilitated and the results showed that video-based game exercise group has better pain, functionality and quality of life parameters.[8] This study differs from in that we showed the SGE software development process and the games developed for shoulder rehabilitation.

In another study, exergame and serious game applications were compared in individuals diagnosed with Multiple Sclerosis (MS), and it was found that the dexterity parameters of individuals who were treated with serious games showed better improvement. According to this study, serious games tailored to an individual's needs are more beneficial than exergames. The rationale behind this is that while exergames are played for entertainment purposes, serious games are designed to improve specific functions required by the individual. They suggested that studies in this field should be carried out by increasing the number of participants.[24]

It was seen that the SGE were effective in approximation forces and joint position sense values measured at 0° and 90° in this study. The SGs created by physiotherapists and engineers included therapeutic exercises for daily life activities and were designed according to the needs of individuals. In addition, specifically moving the shoulder at certain angles with SGs positively affected the approximation force and joint position sense by stimulating the proprioceptive mechanism. We adopted that the physiotherapists should be included in the design processes of serious games so that SGs can be more therapeutically effective.

In another study, patient-specific features were often neglected when selecting and implementing game components. In conclusion, a holistic approach was required to increase rehabilitation compliance, supporting patients throughout the entire rehabilitation process by providing motivational game design elements based on patient-specific characteristics.[25]

In our study, the SG development process was also presented. Beristain-Colorado et al. [26] presented the standardization of serious game development according to patients' needs. In another study, a process framework for the development of serious games for motor rehabilitation therapy for cerebral palsy was presented.[27]As far as we know, there is no study in the literature involving physiotherapists in game development processes. It is important for the success of rehabilitation that physiotherapists and engineers work together for effective exercise selection in designing games for different disease groups.

CONCLUSION AND RECOMMENDATIONS

Numerous studies indicate that there is insufficient research on the use of exergames and serious games in orthopedic rehabilitation, and further randomized controlled trials are required to fill this gap.[28,29] We agree that there is a necessity for more investigation into the efficacy of video-based game exercise programs for shoulder conditions.

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