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Development of Shoulder Wheel with Adjustable Rotating Speed and Rotating Angle and Application Contents

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Abstract

The purpose of this study to improve the shoulder wheel that is used frequently during shoulder circumduction exercise in a park, to link the shoulder wheel to a game application comprising various shoulder circumduction exercise and shoulder ROM exercise, and to enjoy the game during the exercises. A step motor was added to the shoulder wheel, and the rotating speed and rotating angle, and rotating direction can be controlled. The shoulder height, different for different people, can be controlled as well, so that any user can use this device. The developed application content includes the game elements, to enjoy the repetitive and boring exercise with fun and interest, and the control to adjust the degree of difficulty. This was to help users heighten their desire to rehabilitate by inducing active participation during repetitive shoulder rehabilitation exercise because the game vests users with intrinsic motivation and immersion. If the shoulder wheel and application contents proposed in this study are used, shoulder diseases can be prevented in advance by performing muscle strengthening exercises required in an aging society. This study is expected to contribute to the field of research related to serious games and rehabilitation.

Keywords: *Shoulder Wheel, Shoulder ROM Exercise, Shoulder Circumduction Exercise, Application Content*

1. Introduction

We have to move our shoulders incessantly in daily activities. The shoulder is the only ball-and-socket joint in our bodies and can rotate 360 degrees. Because its movement span is large, it is often prone to injuries. In the shoulder, acromion (upper shoulder bone), scapula, arm bones and muscles, tendons, ligaments are organically connected and move. Any problem in any one of them can give rise to pain [1, 2]. The shoulder pain makes our daily life such as wearing clothes, taking a shower, drying hair, leisure activities, inconvenient. Thus, it is necessary to treat or rehabilitate in the early stage. Most of the shoulder pain comes from shoulder diseases like frozen shoulder, rotator cuff tear, calcific tendinitis, and so on. According to the statistical data on disease-sub classification and disease-fine classification by the Health Insurance Review and Assessment Service in 2021, rotator cuff injury and frozen shoulder, which are caused by degeneration of shoulder tendons,

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comprises about 75% of all shoulder diseases [3].

The diagnostic name of frozen shoulder is adhesive capsulitis. It is a disease of capsule hardening and adhesion, accompanied by the pain from inflammations occurring in the shoulder tendons or capsule. Generally, the symptoms of frozen shoulder are characterized by so much pain that one cannot lift the shoulder when washing face and drying hair. Rotator cuff injury occurs due to body aging. With tendon weakened, there is a high risk of damage when receiving a shock or lifting heavy things often. In addition, calcific tendinitis is a disease that calcifications occur in tendons. It became known that tendon cells change to cartilage cells, which is the cause of calcification. As such, the shoulder disease accompanying shoulder pain occur to workers, who use frequently their arms and shoulders, in courier service, construction, and beauty industry. They also occur to sports and leisure activists who use their upper limbs a lot. There are other causes like shoulder arthritis due to aging, brain disease (hemiplegia), and upper limb dysfunction. Another reason is due to the increase in the population using electronic devices like smartphones and mobile tablets [4-5].

Shoulder pain is caused by many reasons, and its treatment methods are also diverse depending on the cause of pain or the cause of shoulder disease (hot pack, ultrasound, physical therapy, laser, infrared, etc.). Sometimes, surgery may be needed. By the way, most shoulder rehabilitations are focused on the flexibility to recover the range of motion (ROM) of shoulder and the muscle strengthening around the shoulder [6-7]. This is to improve the flexibility by exercise to recover the range of motion of stiff shoulder. It is possible to prevent and rehabilitate the rotator cuff tear by muscle strengthening exercises. Good flexibility means that the shoulder has a complete ROM, and free and precise movement is possible. In other words, it is possible to improve shoulder ROM or prevent shoulder diseases with shoulder flexibility and muscle strengthening exercises. In particular, muscle strengthening exercises include: handstands, pull-ups, vertical arms lifts, arms behind the torso, cane exercises, wall exercises, and exercises using elastic bands and dumbbells.

However, the exercises above can reduce the will of patients to rehabilitate because the conventional exercises, being prescribed without considering the will of patients to rehabilitate, can be repetitive and no fun. This could make patients neglect or avoid the rehabilitation exercises they must carry out, and this could negatively affect the result [8-9]. Therefore, there have been studies to find effective rehabilitation exercise methods by producing game contents that can increase the patient's intrinsic motivation and immersion during conventional rehabilitation exercises [10, 11].

Some examples of such studies include VR games using Microsoft Kinect for occupational and physical therapy on patients with shoulder pain and injuries in out-patient physical therapy clinics and marker-less wearable AR rehabilitation game applications for which users have to wear auxiliary sensors, and so on [12, 13]. In addition, there are studies utilizing IMU sensors and smartphone applications to verify the validity of a treatment model in which wearable motion sensors are applied to help patients exercising at home in order to improve their rehabilitation exercise training compliance and accuracy of exercises [14]. By applying VR or AR to the existing rehabilitation exercise methods, existing studies tried to improve the rehabilitation effect by improving the patient's immersion during rehabilitation training.

Thus, in this study, the rotating speed, rotating angle, and rotating direction could be controlled with step motors and absolute encoders added to a shoulder wheel for shoulder circumduction exercise in an exercise facility in a park. This enables anyone to adjust the rotating speed and the rotating angle to meet his/her own shoulder ROM that is different for different people. In addition, it was designed to connect to application contents that can enhance the intrinsic motivation and immersion of patients during rehabilitation exercise. In particular, the shoulder wheel realized is not unfamiliar to users because it is an improvement of the existing

exercise equipment. It not only gives interest and fun by linking with various application contents, but also visualizes the performance result in a way that can be easily understood.

2. Building a Shoulder Wheel

2.1 Shoulder Wheel Design

As shown in Figure 1, a shoulder wheel was designed in such a way that a user can do shoulder circumduction exercise in sagittal, frontal, and transverse planes and shoulder ROM exercise including flexion/extension, abduction/adduction, and external rotation/internal rotation. A step motor was added to control the rotating speed, rotating angle, and rotating direction when a user does passive exercise. A gear reducer attached on top of the step motor increases the torque of the step motor. The absolute encoder, connected to the center axis of the step motor with a timing belt, was added to measure the user's rotating angle during active exercise to enhance the flexibility of shoulder ROM that was improved by passive exercise. The stainless-steel square pipes L1, L2, and L3 are 260, 200, and 220 mm long respectively. The total length is 680 mm. The pipes can be attached and detached. The maximum arm length, provided by the statistics of 8th Korean Anthropometric Survey, was adopted in the design. The length can be adjusted to fit the user's arm length [15]. Lastly, the folding hinge at the right side of the step motor was used to fix the shoulder wheel to the table as shown in Figure 2 (a) and (b).

Figure 2 shows the prototype shoulder wheel built. It shows that the shoulder circumduction exercise along the z-axis on the transverse plane (Figure 2(a)), and the shoulder ROM exercise and circumduction exercise along the y-axis on the sagittal plane (Figure 2(b)) are possible. Also, the shoulder wheel was installed on a table whose height is adjustable so that the height can be adjusted in the range of 1100 ~1600 mm to fit the shoulder height of Koreans [15].

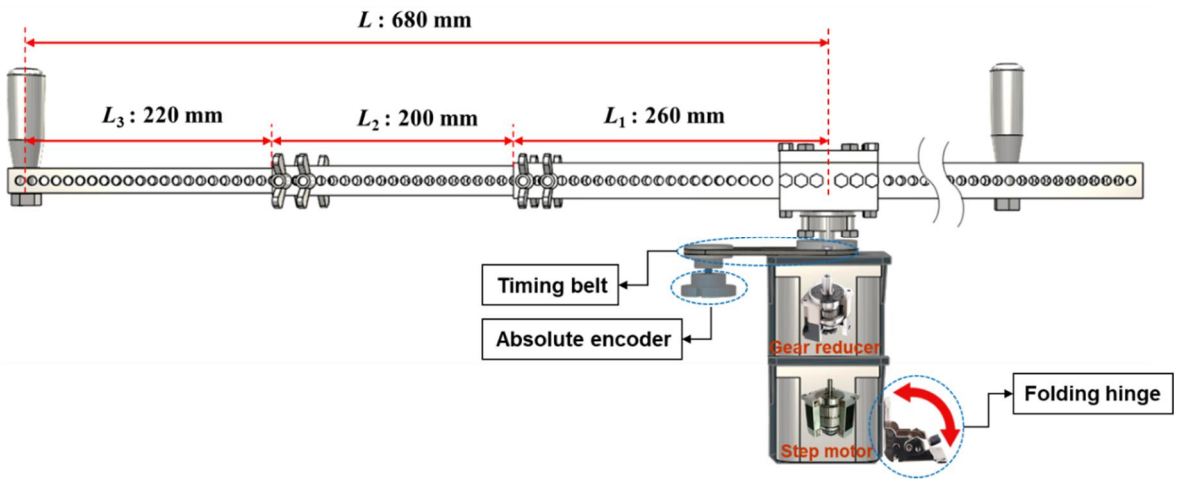
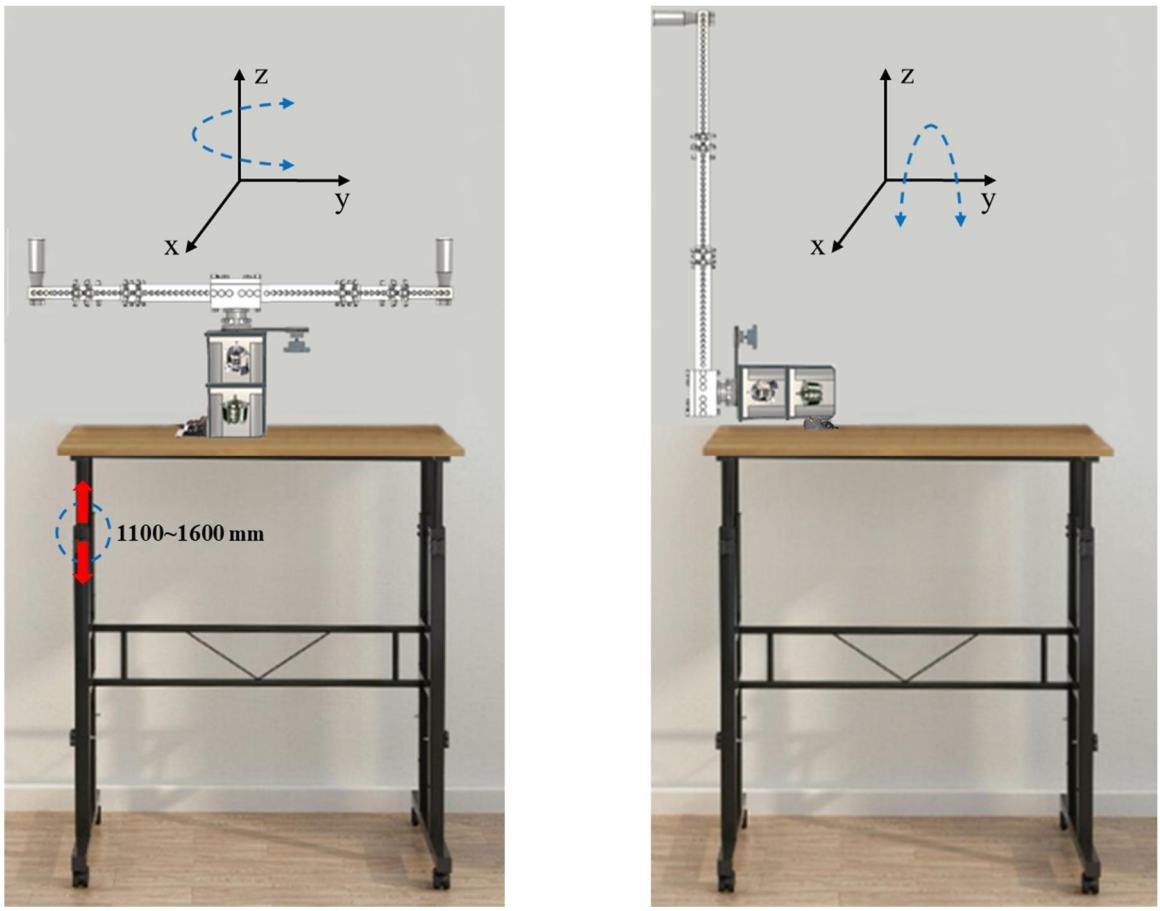


Figure 1. Shoulder Wheel Design

2.2 Shoulder Wheel System

The shoulder hardware was made of a step motor driver to control the rotating speed, rotating angle, and rotating direction during passive exercise, a Bluetooth wireless data transceiver, an absolute encoder to collect the information on the user's rotating angle during active exercise, and a foot switch for emergency stop in the

case of the user's shoulder pain.



(a) (b)

Figure 2. A Prototype of the Shoulder (a) Exercise on the Transverse Plane, (b) Exercise on Sagittal and Frontal Planes

It is very important that the step motor of the shoulder wheel controls accurately the shoulder rotating speed, rotating angle, and rotating direction. If the step motor rotates out of the user's range of shoulder ROM or faster than the set rotating speed, then the user's shoulder condition could be worsened. Thus, an experiment, of controlling the step motor at speeds of 0.25, 0.5, 0.75, and 1.0 rad/sec for 25 seconds per each speed, was carried out to check if an error occurs between the rotating angle and the rotating speed of the step motor. The rotating angle and the rotating speed of the step motor were measured with the absolute encoder connected to the center axis of the step motor. The measurement results are shown in Figure 3. The rotating angle of the step motor makes four sinusoidal waves for each step motor speed. This indicates that the actual rotating speed and the rotating angle are the same as the set values.

3. Realization of Contents

Various applications, that can be used to make the exercise fun while exercising using the fabricated shoulder wheel to measure the shoulder ROM and to prevent excessive exercise, were developed based on

Unity Engine.

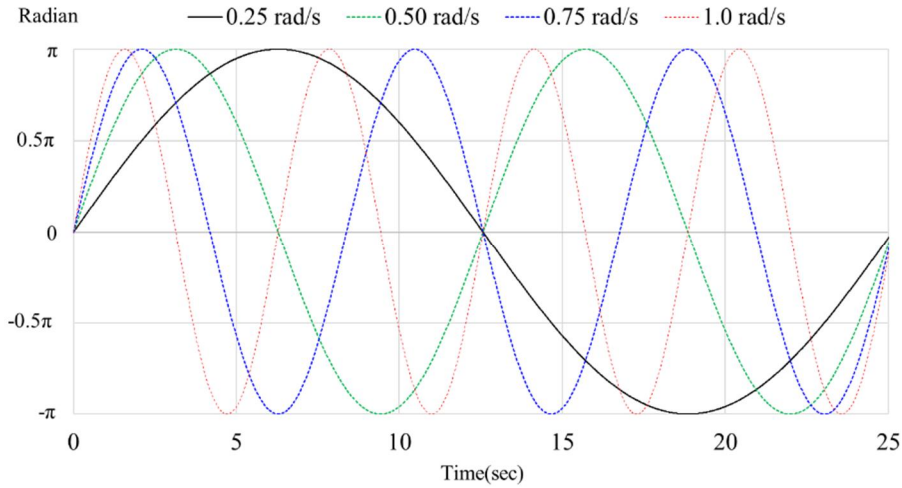


Figure 3. The Result of an Experiment to Control the Rotating Angle and Speed of the Step Motor

3.1 Content for Measuring Shoulder ROM

The shoulder ROM, if measured by hand, can be different depending on the rater [16]. In this study, therefore, the shoulder ROM was quantitatively measured using an absolute encoder. After the rotation axis of the shoulder wheel was aligned to the center of the joint, the ROMs of flexion/extension, abduction/adduction, and external rotation/internal rotation were measured while standing upright. The photographs of the postures during preparation and measurement, and the measurement screen are shown in Table 1.

After taking the posture identical to the measurement start position on the given measurement screen, the measurement of shoulder ROM ends when the user maintains for 3 seconds like the measurement posture within the ROM. These measurement result values will be used as parameters to be applied when playing the content tailored to individual users.

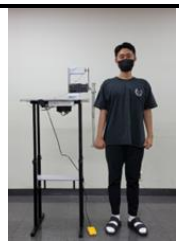
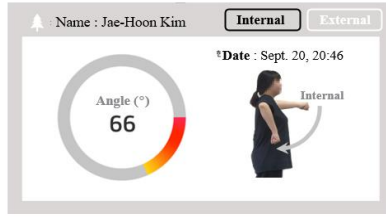
3.2 Application Content for Shoulder Wheel

An application was developed for users to do customized shoulder ROM exercise and circumduction exercise on the sagittal, frontal, and transverse planes using the shoulder ROM of the users as a parameter. The application also enabled both passive exercise and active exercise. The application has a setting screen where, if necessary, the user can change settings by adjusting the shoulder ROM and the rotating angle per second, as shown in Figure 4.

3.2.1 Application Content for Shoulder ROM Exercise. The exercise method to improve the shoulder ROM is to repeat raising arm slowly as high as possible. But such a repetitive movement can be boring so that users could be raising arms passively. This could limit the improvement of shoulder ROM. By linking an application to the shoulder wheel, repetitive shoulder ROM exercise became possible by providing users the elements of fun and interest while playing the application for accomplishing various goals. Here, the user's shoulder ROM value was limited to the maximum ROM so that the user would not do excessive exercise while

playing the application. The each posture while playing the application is identical to the postures for preparation and measurement shown in Table 1. The realized application content is shown in Figure 5.

Table 1. The Measurement of Shoulder ROM

	Ready Posture	Measurement Posture	Measurement Screen
Flexion			
Extension			
Abduction			
Adduction			
External Rotation			
Internal Rotation			

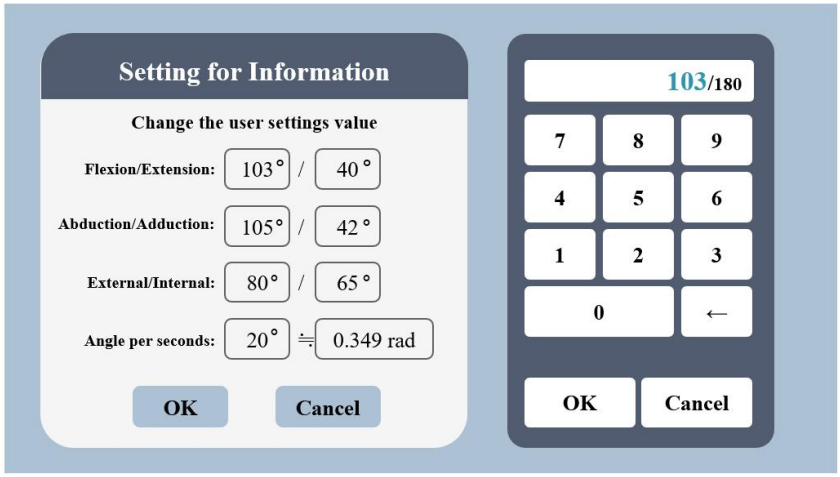


Figure 4. Screen for User to Change the Settings

Figure 5(a) shows the content of the application developed for flexion/extension exercise. In this content, a user repeats raising his/her arm forward and backward in a posture with his/her arm straightened and attached to the side of body as much as possible. The green avatar on the left side of the screen represents a user. By moving the avatar to avoid the birds flying from the right side to the left, the user can get a coin. If the green avatar collides with the birds three times, then the game automatically ends, and the user has to start the game again. The difficulty of the game can be adjusted by changing the numbers or the speed of the birds. As for the method of reward, when the user gets 20 coins and finishes the game, he can move on to the next level of the game. He is awarded with a star shaped coin as well shown (Figure 5(d)) in the upper right corner of the screen, so that he can plant a flower or a tree to make a garden. The game was designed to induce the user to participate actively through motivation and encouragement so that the user keeps training to get the reward and accomplish the goals by getting such awards [17]. Of course, although there are many things to give as awards, a simple example was presented in this study.

As shown Figure 4, when the user determines that his shoulder ROM has improved through repetitive exercise, he can measure his shoulder ROM again or change the limit on the shoulder ROM as needed. That is, when the user wants to improve the ROM slowly, he can change by 1 degree at least. It was designed that the shoulder ROM was allowed to change by 5 degrees at most in order to prevent injuries.

Figure 5(b) shows a game developed for abduction/adduction exercises. From a posture with his arms straightened and attached to his sides as closely as possible, the user repeats lifting his left/right arms. In the game, the user controls the bow in the bottom center of the screen and shoots alien characters flying down from the sky. If three aliens land on the ground, the game ends automatically, and the user should start the game again. When the user shoots down 20 aliens, he receives a reward. The reward and the method to adjust the difficulty of the game is the same as shown in Figure 5(a).

Figure 5(c) shows a game developed for external rotation/internal rotation exercises. From a posture with his arms straightened and attached to his sides as closely as possible, the user flexion and abduction his elbow at 90 degree angle and lifts his arm up and down. The user moves the black bar on the right side of the screen up and down and reflects the black ball on the left side of the screen and moving from left to right with the black bar to make the ball destroy the blue colored bricks. If the user misses the ball three times, he loses the game. If he destroys all the bricks, he wins the game and gets a reward. The reward and the method to adjust

the difficulty of the game is the same as shown in Figure 5(a).

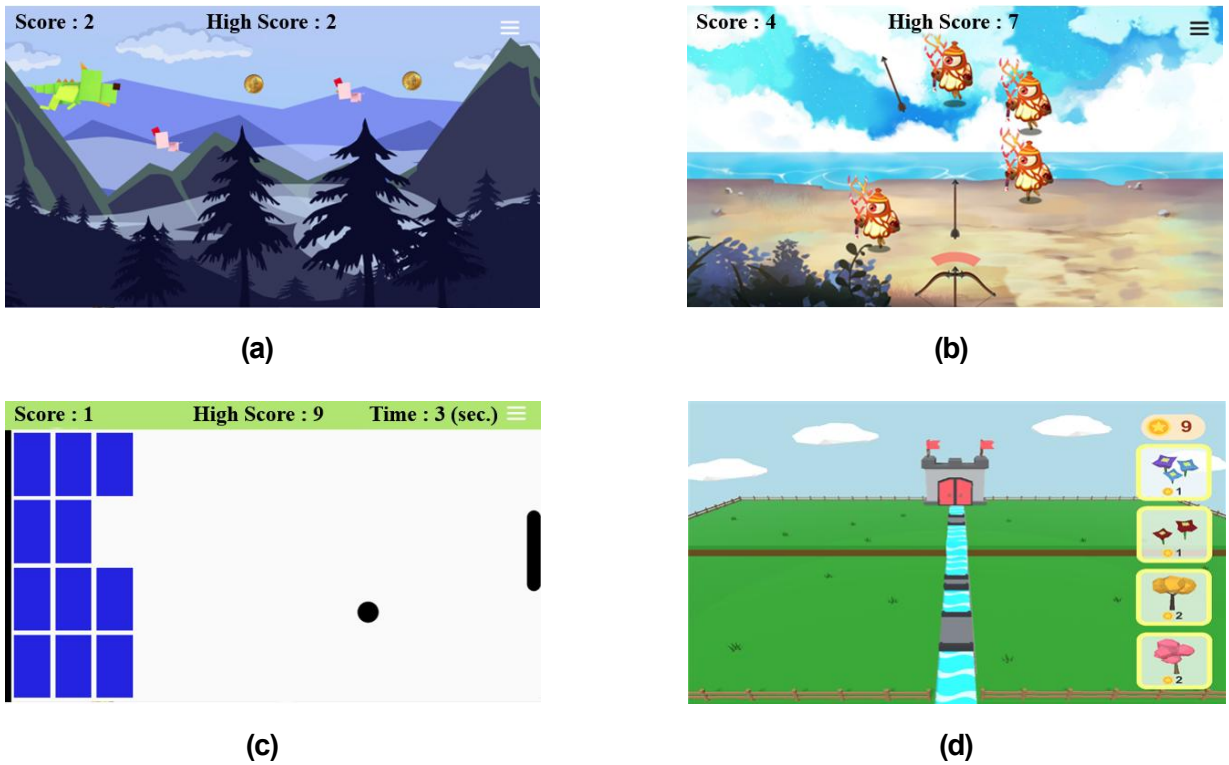


Figure 5. The Application Content for Shoulder ROM Exercise (a) Flexion/Extension, (b) Adduction/Adduction, (c) External Rotation/Internal Rotation, and (d) Gardening

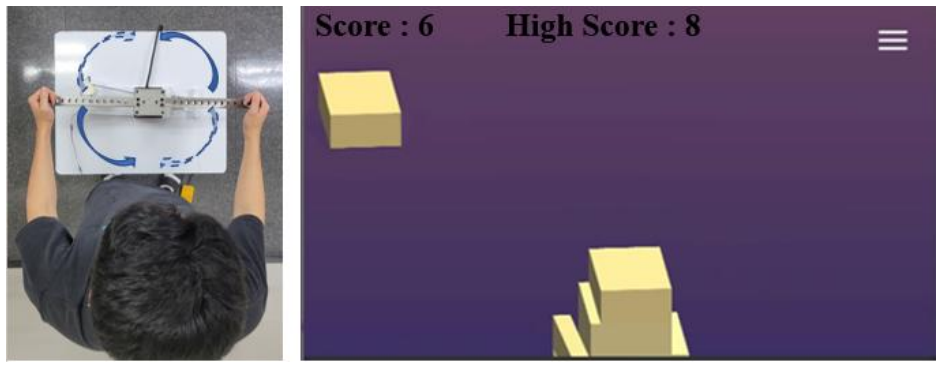
3.2.2 Application Content for Shoulder Circumduction Exercise. Not only the shoulder ROM exercise mentioned above, but also shoulder circumduction exercise can be done with the shoulder wheel made. The circumduction exercise can be done on frontal, sagittal, and transverse planes. The flexibility and the ROM can be improved, and the shoulder muscle can be strengthened through repeating movements.

The game developed for shoulder circumduction exercise in this study made repetitive shoulder circumduction exercise possible through the game elements, the degree of difficulty, and reward. Figure 6 shows the postures for shoulder circumduction exercise and the content of the game.

Figure 6(a) shows the posture for the exercise in the transverse plane with the elbow flexed at an angle of 90 degrees. As shown by the dotted lines and the solid lines, the user can rotate his arm forward and backward up to angle of 90 degrees. In the game developed for this exercise, the user controls the bricks falling down from the top to the bottom of the screen and builds a tower in the center of the screen with the transverse exercise. If the user fails to build the bricks three times, the game ends, and the user start the game again. The reward and the method to adjust the difficulty of the game is the same as mentioned above.

Figure 6(b) shows the posture for the exercise in the frontal plane in which the user can repeat the movement of rotating his arm up and down to an angle of 90 degrees as indicated by the dotted lines and the solid lines. The game for this is to get coins by driving the car in the center of the screen to the left or the right to avoid the obstacles on the road. When hit three times by the obstacle, the game ends. The reward and the method to adjust the difficulty of the game is the same as mentioned above.

Figure 6(c) shows the posture for the exercise in the sagittal plane in which the user can repeat rotating arms in the clockwise/counterclockwise directions. The game developed for this is that the user lines up the code numbers given in the left upper corner of the screen in to the dotted rectangle. If the numbers are not lined up in one minute, the game ends. If the numbers are lined up in the box, the reward is the same as in Figure 6(a). The user can control the difficulty of the game by adjusting the rotating speed of the disc moving in the right/left directions.



(a)

(b)

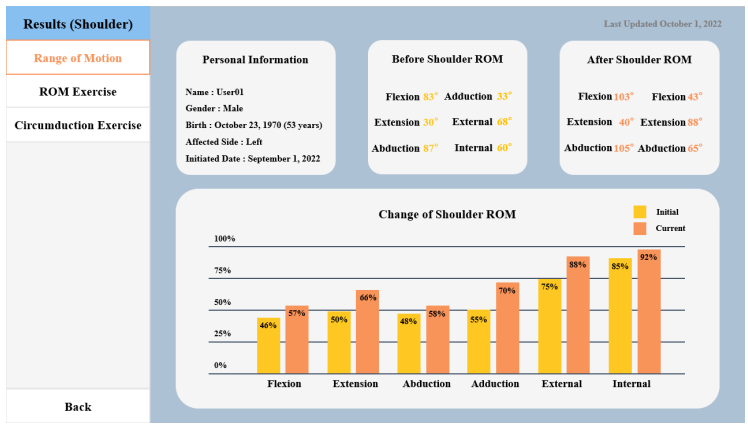
(c)

Figure 6. Application Content for Shoulder Circumduction Exercise (a) Exercise Posture on the Transverse Plane and the Game Content, (b) Exercise Posture on the Frontal Plane and the Game Content, (c) Exercise Posture on the Sagittal Plane and the Game Content.

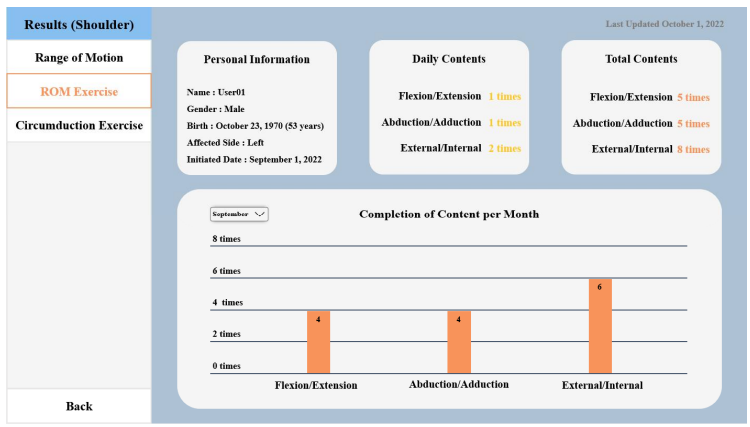
3.3 Display of the Results of the Games

As shown in Figure 7, the measurement values of shoulder ROM and the results of playing games are displayed for the users to compare intuitively to the values before the exercise. Figure 7(a) displays the shoulder ROM values measured before and after the exercise, and the rate of change in shoulder ROM by comparing the two values. This seems to raise the expectation on the effect of shoulder circumduction exercise by understanding easily the change in their shoulder ROM. For example, the flexion and abduction ROM show the lowest values. The user may decide that he needs to concentrate on the exercise to improve the values.

Figure 7(b) displays the result of playing the game for shoulder ROM exercise. It displays the number of completions on the day by the games played, the total number of completions by the games played, and the number of completions in the month. The user can grasp which game he plays the most intensively. For example in Figure (b), the user can see that he played the game for external rotation/internal rotation exercise the most intensively. The result of playing the game for shoulder circumduction exercise is displayed in the same screen.



(a)



(b)

Figure 7. Display or Visualization of the Result of Playing the Game Content (a) the Results of Shoulder ROM Measurements, and (b) the Results of Playing the Game Content of Shoulder ROM.

4. Conclusion

In this paper, a shoulder wheel, for mitigating the pain from shoulder diseases occurring due to various reasons or for shoulder rehabilitation exercise, was built, and application software was developed. The user can adjust the rotating speed and rotating angle because a step motor and a controller were added to the passive shoulder wheel which can be seen in parks or rehabilitation treatment centers. Generally, the flexibility of shoulder can be improved, and the shoulder can be strengthened only though repetitive exercises like shoulder circumduction exercise and shoulder ROM exercise. However, it is difficult to expect active rehabilitation exercise because repetitive exercise can be boring and no fun. Therefore, the objective of this study was to find an effective method that can give interest and fun by linking the shoulder wheel and a game.

The user can use this shoulder wheel according to his disease status by adjusting the shoulder height, which is different for different people, and the rotating speed and rotating angle during shoulder circumduction exercise and shoulder ROM exercise. The goal of this study was to propose a device for more effective rehabilitation exercise with improved intrinsic motivation and immersion by developing and linking an application to the repetitive rehabilitation exercise on this device.

The developed application is made of a content to measure the user's shoulder ROM quantitatively and a content of shoulder ROM exercise and shoulder circumduction exercise based on the measured shoulder ROM. All contents were intended to encourage active participation in the rehabilitation exercise by presenting various goals, in order to make the shoulder rehabilitation exercise more effective through game elements and the adjustment of the degree of difficulty, and by providing rewards for achieving goals. In addition, the change rate of the user's initial and present shoulder ROM and the results of contents for shoulder ROM exercise and shoulder circumduction exercise were displayed for the user to understand easily. This was intended to help the user to understand what exercise needs improvement the most by identifying the user's present shoulder condition and comparing the status before and after the rehabilitation.

5. Discussion

The shoulder wheel built in this study needs improvement with respect to the resistance exercise of repeating muscle contraction and relaxation for aging population who needs muscle strengthening during shoulder ROM exercise and shoulder circumduction exercise. An application liking to the resistance exercise also needs to be developed. This is because the prevention of shoulder disease in advance by doing muscle strengthening exercise is necessary as the aging of the society advances. It is also necessary to make the users participate more actively by utilizing various forms of content (for example, VR, AR, and metaverse) that can induce fun and interest. Additionally, there is a need to evaluate how much rapport is achieved through evaluation of usability or suitability for use regarding how much immersion the developed content of the application gives to users.

Acknowledgement

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