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Usability evaluation of a smart upper limb rehabilitation exercise device for individuals with disabilities

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User-friendly rehabilitation exercise devices can enhance health and quality of life through the convergence of information communication and medical technology. The development of rehabilitation exercise devices accessible to individuals with disabilities is important. We aimed to investigate the convenience, safety, and effectiveness of the developed rehabilitation exercise device for individuals with disabilities. A usability evaluation of the developed rehabilitation exercise device was conducted with five rehabilitation exercise experts and six athletes with disabilities using a questionnaire, the reliability of the revised questionnaire was $r=0.87$. Qualitative analysis was conducted using semistructured interviews following the testing of the upper limb rehabilitation exercise device by the two user groups. In the usability evaluation survey of the developed rehabilitation exercise device, the results were very positive, with an overall score of 4.25 out of 5. The highest score was assigned to the convenience of the device, followed by the effectiveness of the exercise and the safety of the device. The developed rehabilitation exercise device allows for three types of strength improvement exercises, including isometric, isokinetic, and isotonic exercises, all within a single device. Given that it is constructed with a wire system, it can be adapted to various exercise methods, depending on the type of disability. The device can be used by both nondisabled and disabled individuals, allowing for various exercise methods. The evaluation results indicate that the proposed device is highly versatile and practical.

Keywords: Disability, Rehabilitation exercise device, Usability

INTRODUCTION

Limited mobility in daily life can vary significantly depending on disability, leading to challenges in maintaining the physical strength required for overall well-being. Specifically, spinal cord injury (SCI) can result in secondary complications, including cardiovascular disease, due to the loss of motor and sensory functions and dysregulation of the autonomic body system (Myers et al., 2007). Individuals with spinal cord disorders have 20%–66% higher body fat levels than those without disabilities and are at increased risk of developing cardiometabolic diseases and sarcopenic obesity (Pelletier et al., 2016). Patients with paraplegia may enter a cycle in which reduced exercise capacity increases their risk of comorbidities such as metabolic syndrome and cardiovascular disease, further diminishing their exercise ability (Pelletier et al., 2016). Additionally, numerous studies have shown that individuals with disabilities who have difficulty with daily functioning need to perform regular upper limb exercises to maintain their health and avoid preventable medical complications (Kloosterman et al., 2009; Stromberg, 1986; Tweedy et al., 2017; Zimmerli et al., 2012). However, the high cost, time commitment, and intensity of regular exercise make it challenging for these individuals to adhere to such routines (Kowalczewski and Prochazka, 2011).

The ultimate goal for individuals with SCI is to regain the best possible function, mobility, and independence. Increasing muscle strength through strength training is crucial for maintaining health and posture (Santos et al., 2022). Enhancing upper limb muscle strength reduces shoulder pain, increases mobility, and improves function, thereby enhancing the ability to perform daily activities and improving the quality of life (Cheung et al., 2023; Melo et al., 2019).

For patients with paraplegia, upper limb strength training is an

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essential early rehabilitation exercise that enhances exercise capacity, the isometric, isokinetic, and isotonic contraction method were used throughout the rehabilitation process from single to multi joint movements. An all-in-one device that can perform isometric, isotonic, and isokinetic muscle contractions while providing resistance variation through motor control will enhance the effectiveness of exercise rehabilitation in the general population (Kowalczyk-Jurgiel et al., 2021).

Therefore, we have developed a rehabilitation device capable of performing three types of exercises in a single device. In this study, we aimed to address the limited mobility caused by varying degrees of disability in patients with paraplegia by developing equipment that can monitor each user's strength and exercise stages. This allows for modifications throughout rehabilitation, providing tailored exercises from a single device. Interviews and questionnaires were conducted with patients with paraplegia based on their first-hand experience with the developed device.

MATERIALS AND METHODS

Study design

This qualitative analysis was conducted using questionnaires and semistructured interviews following the testing of an upper limb rehabilitation exercise device by two user groups.

Participants

Five experts in exercise rehabilitation and six athletes with disabilities in sports participated in this study for the usability evaluation of the developed rehabilitation exercise device. Details are provided in Table 1. Along with the explanation of the developed rehabilitation exercise device, a usability evaluation questionnaire and interviews were conducted after the participants experienced the device (Fig. 1). All procedures in this study followed the guidelines of the Declaration of Helsinki and were approved by the Institutional Review Board of Gachon University (1044396-202110-HR-221-01).

Interviews with experts

An expert semistructured interview was conducted to assess the suitability of the device for individuals with disabilities and identify areas for improvement in exercise programs and overall device development. The interview included group discussions about the device, strength measurements, and coordination games. The entire process lasted approximately 90 min, from the beginning of the exercise to the end of the interview. The interview evaluated

Fig. 1. Developed rehabilitation exercise device. The staffs of Fig. 1 who participated in the study agreed to publish this study.

Table 1. Characteristics of the participants

Participant	Types of sports/major area	Types of disabilities	Major	Position
A (65 yr)	Wheelchair rugby	SCI: cervical 4–5		
B (50 yr)	Wheelchair rugby	SCI: cervical 5–6		
C (47 yr)	Wheelchair rugby	SCI: cervical 6		
D (63 yr)	Wheelchair tennis	SCI: thoracic 10		
E (65 yr)	Wheelchair tennis	SCI: thoracic spine 12		
F (57 yr)	Wheelchair tennis	Lower limb amputation		
G			Sports medicine	Professor
H			Mechanical engineering	Professor
I			Adapted physical activity	Professor
J			Sports medicine	Doctor
K			Sports physiology	Professor

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the performance of the equipment (immobilization, release, adequacy of support exercises, exercise performance, posture maintenance, and noise) and its ease of operation (monitoring operation, understanding and ease of use, applicability to persons with disabilities, and rope height adjustment). The recorded interviews were transcribed, and the accuracy of the transcriptions and interviews was confirmed. Additionally, the content of each expert's opinion was categorized and organized.

Questionnaire for usability evaluation

After experiencing strength measurement and rehabilitation exercises using the developed rehabilitation exercise equipment, the participants filled out a usability questionnaire about the device. The rehabilitation exercise device usability assessment questionnaire consisted of three main sections: safety of the appliance (postural retention, stability, movement speed, contact hazards, and exercise equipment and fixity), convenience of the device (suitability, explanation of device operation, noise, wheelchair accessibility, confirmation of exercise information, connectivity), and effectiveness of the exercise (effect of sensory exercise, suitability of exercise, operability, efficiency, exercise program). The reliability of the questionnaire was $r=0.78$. The questionnaire was divided into positive and negative categories, with higher scores for the negative questions indicating better equipment usability.

Statistical analyses

IBM SPSS statistics ver. 28.0 (IBM Corporation, Armonk, NY, USA) was used for data analysis. Descriptive statistics were used according to the study objectives. The collected data were analyzed using a text analysis method that involved coding and categorizing the data into upper and lower categories. The analysis employed "Domain Analysis" and "Taxonomic Analysis." The coding process included open, axial, and selective coding techniques for semantic understanding and conceptualization. The researchers continuously reviewed and confirmed the processes of describing, analyzing, and interpreting the data to better understand and convey the meanings of the participants' experiences.

RESULTS

Usability evaluation for people with disabilities

Users assessed the devices by grading them (1–5 points) according to various categories. The results of the usability evaluation are summarized in Table 2. The usability evaluation by users gave the highest scores for convenience of the device, followed by effectiveness of exercise. The lowest score was related to the safety of the appliance. In the subfactors, the highest score was exercise program in the effectiveness of exercise and equipment, exercise equipment and fixity in safety of the appliance, and wheelchair accessibility in convenience of the device. The lowest scores were assigned to the suitability exercise in effectiveness of exercise. The equipment allowed wheelchair users easy access because they could use it while remaining in their wheelchairs. Additionally, the pulley mechanism was smooth, allowing users to visualize their movements and balance between their shoulders. The equipment also allowed for easy directional changes and adjustments to the exercise in terms of repetition and sets according to individual needs. The results of the exercise, such as strength input, could be visually monitored on the screen, which positively impacted the usage of the equipment for upper body strength development. The following comments were made regarding the adaptability of users with disabilities:

"The adjustability and stability of the grip and gloves need to be improved."

"Height adjustments for each individual exercise scenario must become easier."

Table 2. Usability evaluation of rehabilitation exercise device for individuals with disabilities

Factors	Subfactors	Mean±SD
Safety of the appliance	Postural retention	4.00±1.10
	Stability	3.60±1.03
	Movement speed	4.10±0.75
	Contact hazards	3.80±1.47
	Exercise equipment and fixity	4.80±0.41
	Total score	4.10±0.58
Convenience of the device	Suitability	3.80±1.33
	Explanation of device operation	4.60±1.33
	Noise	4.60±0.52
	Discomfort	3.60±1.21
	Wheelchair accessibility	4.80±0.41
	Confirmation of exercise information	4.50±1.23
	Connectivity	4.30±0.80
	Total score	4.36±0.57
Effectiveness of the exercise	Effects of sensory exercises	4.50±0.55
	Suitability of exercise	3.50±1.38
	Operability	4.10±0.75
	Efficiency	4.30±0.52
	Exercise program	4.80±0.41
	Total score	4.20±0.58
Usability evaluation total score		4.25±0.50

SD, standard deviation.

"Wheelchair locking mechanisms, such as safety bars, must be installed during exercise."

"Locking belts for the wheelchair and legs need to be added."

Interviews with experts

Evaluation by professionals in the field indicated that equipment should provide individually tailored exercises while ensuring proper postural maintenance. However, maintaining the correct posture during upper body workouts requires an improved method for securing wheelchairs for individuals with paraplegia. Additionally, although equipment should support essential motions for upper body strength training, experts have suggested that incorporating different exercise routines could be beneficial. Their feedback included the following insights:

"I think we need additional reinforcement to hold the wheelchair in place."

"I think future development can utilize the three axes of motion in the sagittal, frontal, and transverse muscles."

Another response indicated that individuals with two- or one-handed disabilities might need a glove to hold the device, depending on the type of grip (straight handlebar and two-hand grips). If the person is moving to one side, they should be able to receive coaching or detailed explanations from the instructor to maintain their posture and balance the height of their shoulders by engaging their abdominal muscles. Their feedback included the following insights:

"If you have an upper body imbalance, initiate the exercise using a grip that is placed at a rotated angle. This exercise will be difficult without proper posture and correction, requiring the coach to provide accurate postural corrections and constant feedback."

The experts suggested that it is necessary to modify the button size, zoom function, screen items, and color differentiation, and to use simpler terminology on the screens used during operation. In addition, wheelchair users must use their hands to operate the tablet, which can be a risk factor. It would also be beneficial to number the different functions and use button-based controls instead of scroll-based controls to enable users to easily comprehend the exercise process. Their feedback included the following insights:

"First of all, the buttons on the monitor are too small. Even if it comes out on a tablet, I do not think they should be this small if they are aimed at people with disabilities. […] I think they should be color-distinguished."

"When I was exercising alone, I had to press a button and release the hand I was using to hold onto the equipment. I wondered whether it would be dangerous in the case of a malfunction during the process because of the control system of the motor. I think this should be corrected in the software."

The exercise program was designed to ensure that users could perform the desired exercises properly. Additionally, accessories were evaluated based on the user's disability and usability of the equipment, considering both single-handed and double-handed use. However, to properly perform such exercises, the height and angle of the handlebar should be adjusted according to the user's motion. The current wheelchair does not allow one-person adjustments, making it difficult for wheelchair users to make adjustments to their individual needs. Their feedback included the following insights:

"In the case of existing equipment, the arm length is often the same."

"I think it is a little difficult for people with visual impairments."

In addition, the developed equipment supports three types of muscle strength training: isometric, isokinetic, and isotonic, which are beneficial for users with disabilities. The equipment enabled effective exercise, with the intensity adjusted according to the individual user's range of motion and strength. The minimum and maximum loads can be adjusted, and the equipment, along with gloves, was specifically designed for users with disabilities. Key benefits include the ability to use the wheelchair in single- or double-handed positions, ease of access for wheelchairs, exercise data tracking and recording, and the option to watch personal exercises via video recording. Upper limb rehabilitation exercises using this device allow for individual strength evaluation, with large exercise-related data enabling the exercise load to be adjusted according to the degree and type of disability. Additionally, it can be used by people without disabilities, further increasing its usability. Their feedback included the following insights:

"I think it is applicable to a wide range of disability types."

"I think this is beneficial for people with disabilities. It is easy to use even for older adults, and I think it can be applied to them in the future because of the advantages of being able to freely adjust the load."

DISCUSSION

This study aimed to identify areas for improvement in rehabilitation exercise devices for effective use by individuals with disabilities through usability evaluation and to develop an inclusive exercise environment focused on upper limb strength training. Estimating a sample size of three to five users is sufficient for usability testing. Therefore, this study conducted a usability evaluation of the developed rehabilitation exercise device with five rehabilitation exercise experts and six athletes with disabilities.

Experts in the usability evaluation of rehabilitation exercise devices highlighted several areas for improvement: enhancing the

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locking mechanism between the equipment and the wheelchair, expanding the range of exercise programs, improving grip strength for single- and double-handed users with gloves, providing methods to correct users' posture, simplifying the use of the monitor and tablet by switching from scroll-based to button-based controls, and making exercise data more accessible with numerical displays. A significant observation was that although users with disabilities found it difficult to adjust the height and angle of the handlebar independently, the equipment's operation was manageable with coach assistance.

The expert evaluators noted that the developed rehabilitation exercise device allowed multiple exercises to be performed using a single device. The most significant benefit was the adjustable exercise weight, which could be tailored to the individual's strength data, making it suitable from the outset for users with disabilities. In addition, the device records each exercise session, enabling the collection of detailed data. The evaluator also highlighted that the adjustable load system could benefit various users, ranging from young to old, and for both those with and without disabilities.

Contact hazard and stability of the equipment received the lowest scores from the wheelchair users. However, the newly designed rehabilitation exercise equipment allows users to remain seated in their wheelchairs while using the equipment, making it more accessible for individuals with disabilities. When users were asked to reposition themselves after measuring their range of motion, there were instances in which their elbows and hands came into contact with the wheelchair. Additionally, during the exercises, users reported experiencing vibrations in the handlebar caused by the wire during the pulling motion. Wheelchair users also need to check the position of their wheelchairs to ensure that they can perform the exercise correctly before starting strength training.

To ensure that users with disabilities can perform the exercises as designed, it is essential to find the appropriate distance and position between the equipment and the wheelchair and to place a fixed footrest in the correct location (Jeoung et al., 2024). An additional safety bar was installed at the back of the wheelchair to prevent unwanted movements. Based on these results, the development of gloves to ensure secure contact between the users and the handlebar, as well as modifications to the design to prevent wire vibrations during exercise, is necessary.

The evaluation of the effectiveness of the planned exercise program revealed positive results regarding the perceived effect, efficiency, and motion of the exercise. However, as the level of disability increased, particularly in those with spinal cord disorders, exercise adequacy seemed to diminish. Two disability groups were evaluated by performing rehabilitation exercises with the same varying strength (40/100) for both cervical and thoracic spine impairment users. Although individuals with thoracic spine impairments usually have varying physical abilities depending on their level of physical activity, the user in this study was a para-athlete, necessitating a change in the load intensity. These results suggest that users with disabilities should check their specific types of disabilities and exercise intensity criteria before beginning rehabilitation exercises. Additionally, it would be helpful to include a strength training manual that provides step-by-step guidance from the beginning of rehabilitation, with an exercise program tailored to each individual. The low score for "suitability and discomfort" during the evaluation may have been due to the length of the device's handlebar. However, ease of access was highlighted as a positive aspect of the equipment. To maximize accessibility, the space between the equipment and the wheelchair was adjusted based on the wheelchair's design. Individuals with disabilities who use wheelchairs often find it challenging to perform upper body exercises while maintaining good posture and balance (Hicks et al., 2011); therefore, it is crucial that users maintain an appropriate range of motion and movement during these exercises.

Future iterations should include a fastening belt between the wheelchair and legs, which should be secured before starting the strength rehabilitation exercise program. Additionally, it is necessary to check the location of the wheelchair seat to ensure that target motions can be performed correctly. Exercise equipment designed for typical rehabilitation is often difficult for wheelchair users because they must transfer from their wheelchair to the equipment. To address the issue of limited accessibility and tailor the exercise intensity to each user's ability, the equipment was designed with individual strength measurements. Moreover, wheelchair users required gloves to hold the handles firmly during exercise, and fastening belts to secure the wheelchair and legs were necessary to maintain proper posture throughout the exercise (Toh et al., 2023; Yeh and Chou, 2023).

The equipment's visual inspection feature allowed users to monitor their exercise status on the screen, providing them with motivation and feedback. Maintaining and increasing physical capabilities is crucial for individuals with disabilities because they can considerably impact their daily lives (Willig et al., 2022). To gradually enhance the physical abilities of individuals with disabilities, rehabilitation exercises should be continuously and systematically monitored.

The present study has a few limitations that warrant consideration in future research. First, device evaluation involved a limited

number of professionals and users. Second, due to time constraints, feedback from evaluators on areas for improvement was somewhat uniform. To ensure a comprehensive understanding and identify areas for enhancement, future assessments should include diverse groups of wheelchair users with varying degrees of SCI, forms of impairment, and a range of physical abilities.

People with disabilities could visualize their exercise on video, and the monitor's ability to display exercise results helped motivate them to continue to exercise. Strength training for people with disabilities enhances daily movement and physical strength. Therefore, regular, systematic, and gradual strength rehabilitation exercises should be implemented by identifying the conditions under which the exercise can be performed effectively.

This study identified several factors that, if considered in designing future exercise equipment for people with disabilities, could lead to the creation of more suitable equipment than those currently available. This could significantly improve the quality of life for people with disabilities. The results indicate that exercise motion and the user's wheelchair dimensions should be considered when identifying the appropriate wheelchair position, allowing users to exercise while maintaining a correct posture. This information may be useful for further developing the proposed equipment. In addition, future iterations should include a tailored exercise plan based on users' physical abilities.

The rehabilitation exercise device was evaluated as an accurate tool for assessing the performance of three types of exercises: isometric, isotonic, and isokinetic (Jeoung et al., 2024). The rehabilitation exercise device developed here, capable of performing three types of exercises (isometric, isokinetic, isotonic) with a single piece of equipment, is the first of its kind, featuring a universal design that can be used by both disabled and nondisabled individuals (Rimmer et al., 2017; van den Akker et al., 2020). This device is particularly beneficial for individuals with spinal cord injuries because it helps maintain and control proper posture of the pelvis and torso (Caneiro et al., 2010; Hey et al., 2017; Sinderby et al., 1992; Troy et al., 2015). It allows for strength and endurance measurements and exercise performance using either one or both hands, potentially enhancing exercise effectiveness. Future studies should accumulate data using this device to validate its exercise effectiveness and improve usability.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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