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Interdisciplinary Co-Design Research Practice in the Rehabilitation of Elderly Individuals with Chronic Low Back Pain from a Senior Care Center in South Korea

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Abstract: The rehabilitation practices encounter multifaceted problems inherent in the current context of the elderly with chronic low back pain (LBP). We addressed a particular multifaceted problem in the current context using an interdisciplinary co-design research practice that consists of three phases: context exploration, patient-expert interaction, and patient-centered rehabilitation. Using an empirical study integrated with this practice, we investigated 30 Korean elderly patients suffering from LBP and introduced an exercise program design. In the context exploration phase, we found that the elderly patients neglected proper posture during work causing spine instability and resultantly developing chronic LBP. The patient–expert interaction phase explored latissimus dorsi (LD) and lumbar erector spinae (LES) muscles as the back trunk muscles that had caused LBP in most of these elderly patients. In the patient-centered rehabilitation phase, we designed an exercise program with exercise protocols and an exercise object for flexion and extension of trunk muscle relaxation and stabilization. Using electromyography (EMG), we found that the exercise program significantly increased the muscle activation levels of the muscles and reduced LBP. Our practice defines and addresses a multifaceted problem with several challenges both in healthcare design and the problem itself. This integrated approach can easily be expanded and adapted to other domain-related research projects that possess characteristics of complex problems.

Keywords: interdisciplinary co-design research; healthcare design; exercise; low-back pain; rehabilitation

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1. Introduction

Chronic low back pain (LPB) is a non-specific pain associated with muscle stiffness and backache located under the last rib and above the lower gluteus muscle folds [1,2]. In particular, the pain is specifically linked with intervertebral discs in the spine, facet joints, sacroiliac joints, fascia bones, nerves, and meninx. Chronic low back pain (LBP) is one of the most common chronic conditions in the aging population, with a 60–85% chance of occurrence at some point during a person's life [1,2]. The occurrence of chronic LBP is associated with a decrease in quality of life, and elderly people are the segment of the population more prone to physical disability [3]. Recent studies have reported chronic LBP as the most common affliction in the elderly population due to a decrease in their muscle mass (sarcopenia) and bone density (osteoporosis), the intersection of pain and multimorbidity, and muscle stiffness [4,5]. It is also expected to happen from fatigue in the lumbar region because of too much spine flexion or the momentary result of repetitive lifting tasks [6]. Laird et al. [7] documented that people suffering from LBP have reduced lumbar spine range of motion, and as a result, more difficulties in movement and physical activity are faced when compared with people without LBP.

Generally, chronic LBP is managed through a range of interventions, ranging from surgery to drug therapy to non-medical intervention. Previous studies have suggested the improvement of spinal flexibility and back strength via intensive training of muscle endurance using isokinetic back muscle strength [5,6]. In particular, Kim et al. [5] recommended lumbar stabilization exercises for older adult women to improve trunk strength and low back disability. Biering-Sørensen [6] suggested that isometric endurance of the trunk muscles can prevent low back trouble in older adults. Physical exercises show efficiency not only in improving the quality of life and decreasing the chances of disability in LBP but also in enhancing the mental wellbeing of patients [3]. Exercise therapies consist of a diverse range of interventions, ranging from aerobic exercises to strength and endurance exercises to stretching and muscle relaxation exercises [8]. Some studies have looked at the effects of standing aids on muscle activation patterns, which could help reduce or prevent LBP. Among them, Gallagher et al. [9] showed short-term gains from standing on incline and decline surfaces for trunk flexion angle and posterior rotation of the pelvic region. Gallagher et al. [10] found elevated surfaces to be more effective for lumbosacral lordosis flexion and decline surfaces for lumbar intervertebral joint flexion. Another study compared the effects of prolonged standing on 16° incline and decline slopes and a level surface to demonstrate decreased trends in LBP cases [11]. Fewster et al. [12] assessed standing interventions and showed that standing on elevated surfaces can flex the lumbar erector spinae (LES) muscle to reduce LBP in young or middle-aged people. They also showed the benefits of bending exercises for greater trunk flexion and posterior rotation of the pelvis on a decline in standing position, and their findings suggest that standing on an inclined slope leads to a greater trunk extension and anterior rotation of the pelvis. However, they did not study standing for long durations, and their interventions were designed for short periods with little evidence on the effects of standing interventions on individuals experiencing LBP. Exercise interventions target the muscles of the pelvic floor, transversus abdominis, oblique abdominals, quadratus lumborum, and lumbar region (L1–L5) to reduce LBP [13]. However, the latissimus dorsi (LD) muscle is not well recognized for its association with LBP. Nevertheless, the LD muscle should be considered in trunk muscle training [14] because it covers a considerable portion of the back, from wide-spread medial attachments to the spinous process of the lower six thoracic vertebrae, lumbar vertebrae, and sacrum [15]. The LES muscle can play an important role in standing upright postures for greater trunk stability [16] because it has various connected sites where some of the portions of the muscle have greater mechanical benefits to the spine than other parts [17].

In the current context, rehabilitation practice tends to include physical therapy and medical care offered by the medical community and general health services by senior care centers. Physiotherapists and medical practitioners provide clinical treatment and preventive medical interventions to meet each patient's specific health requirements [18]. However, individuals face significant challenges with current rehabilitation approaches. In most cases, patients become frustrated because of conservative treatment and extensive continuous therapies [19]. Furthermore, some healthcare professionals hold stereotypical views that undermine the dignity and autonomy of elderly patients [20]. Age-based discrimination has also been observed in healthcare institutes [21]. In most industrialized nations, healthcare systems focus more on high-cost procedures rather than practical disease management [22]. Standard care mostly consists of surgery and painkillers, which have several side effects, such as nerve damage, blood clots, infection due to surgery and dependency and addiction, inflammation, and stomachache due to medication [23]. The treatment phases in the current rehabilitation practice are traumatic, which causes feelings of denial and distress in subjects [24]. As such, patients abandon medical treatment and instead go to senior care centers. Senior care centers are mainly operated by medical personnel, therapists, and skilled nurses who offer a diverse range of exercise interventions—

from aerobic exercises to muscle-strengthening and stretching exercises [25,26]. Patients with weak muscles find these interventions difficult because of intensive and maximum exertion [27,28]. As chronic LBP often persists for longer in old age, elderly people with this condition can become more desperate for a solution, leading them to implement their own set of actions to maintain health [29]. Because of inadequate understanding of physiology and exercise, the actions taken by these individuals are often ineffective in the management of LBP [30].

Given the above context, rehabilitation practice may encounter a multifaceted problem: First, it might not properly define a particular problem of a rehabilitation situation due to a lack of both understanding and the development of domain-specific expertise; second, because of an absence of interdisciplinary expertise in healthcare design, design practice might not ensure the design of healthcare innovations. Traditional healthcare design projects incur limitations in tackling problems around the rehabilitation of elderly patients because the problems are complex and multifaceted, involving a diverse range of domain-specific expertise [31–33]. Using an empirical study integrated with the co-design research practice, this study aims to investigate elderly patients suffering from LBP in the current context of rehabilitation and introduce and test an exercise intervention program to support the rehabilitation practice. In particular, this integrated research practice consisted of three phases: context exploration, patient-expert interaction, and patient-centered rehabilitation. In the context exploration phase, we used contextual inquiry to observe the current rehabilitation practice, elderly patients, and stakeholders with the rehabilitation services for chronic LBP. In the patient-expert interaction phase, we conducted informal workshops among stakeholders and elderly patients to build mutual understanding around the problems associated with the current rehabilitation practice for chronic LBP. In the patient-centered rehabilitation phase, we arranged several discussion sessions with the stakeholders and patients to design an exercise program for chronic LBP with the principles of patient-centeredness. In this phase, we conducted detailed experimental trials with a pretest-posttest comparison group design and exercise training over five weeks to test the effectiveness of the program in the rehabilitation of elderly patients with LBP. During the trials, we measured the muscle activation levels of trunk muscles using Electromyography (EMG) procedure and perceived chronic LBP with repeated measures over a period of five weeks. We hypothesized that the higher the muscle activation levels of the trunk muscles, the lower the LBP score among elderly patients as the exercise program continued for five weeks.

2. Materials and Methods

2.1. Study Settings and Participants

This study consists of an integrated approach of co-design practice and an empirical study with a pretest–posttest comparison to develop and test a specific exercise program. This study was conducted in a senior care center and partially in a physiotherapy center, an orthopedic and spine center, and an exercise center in South Korea. Before commencing the study, we arranged several meetings with the senior care center staff regarding the enrollment of elderly individuals from the center. Given that the doctor, orthopedist, therapist, exercise trainer, and nurses accompanied the individuals in medical contexts, these experts were considered stakeholders for active participation in the study. Table 1 provides an overview of these stakeholders.

Table 1. Stakeholders' information.

Study Participants	Affiliation/Position	N
Stakeholder (expert)		Total (n = 6)
Medical doctor and Orthopedic specialist	Orthopedic and spine center	2
Therapist	Physical therapy center	1
Trainer	Exercise center	1
Staff (Nurses)	Senior care center	2
Elderly subject	Senior care center	30

As shown in Figure 1, the research process was composed of three key phases: context exploration, patient–expert interaction, and patient-centered rehabilitation development and testing. The research practice was divided into six sub-phases under the three phases (see Figure 1).

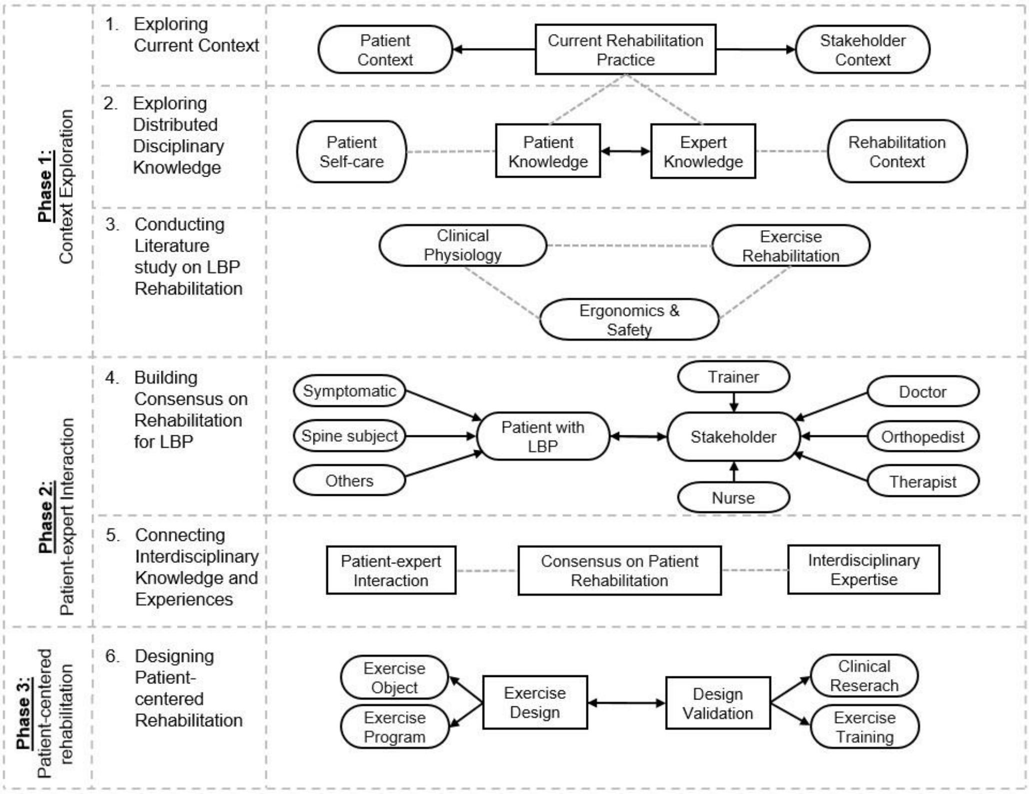

Figure 1. Schematic showing the research framework.

2.2. Context Exploration

In exploring the current context phase (Phase 1), we visited the senior care center, physiotherapy center, and orthopedic and spine center to observe the current rehabilitation practice with the patients and stakeholders. Using contextual inquiry, we observed the patients with the rehabilitation services offered by the centers and their self-care, including self exercises and motivation to perform physical activities inside the senior care center. In this way, we explored the current rehabilitation practice by interacting with the patients and the stakeholders.

In the phase that explored distributed disciplinary knowledge, we interviewed subjects about the current treatment as well as interviewed the stakeholders to gain expert knowledge about the current rehabilitation practice [34].

In the phase of conducting a literature study on LBP rehabilitation, three major fields were reviewed: clinical physiology to gain medical literacy on LBP, ergonomics, safety to identify the abilities and limitations of LBP subjects, and exercise rehabilitation to acquire exercise therapy knowledge.

2.3. Patient–Expert Interaction

In the phase of building consensus on rehabilitation for LBP conditions (Phase 2), patient–expert interaction was arranged to gain foundational knowledge of rehabilitation practice in LBP conditions from the key stakeholders, namely the doctor, orthopedist, therapist, and patients with LBP, including those symptomatic, spine subjects and subjects with other musculoskeletal conditions. The interaction was conducted through informal workshops among the stakeholders to discuss LBP management and build mutual understanding around problems associated with current rehabilitation for elderly patients.

All subjects agreed to a medical checkup and a radiographic examination of their trunk using X-ray imaging in a local clinic with the orthopedist. Among the 30 subjects, 20 were observed to exhibit chronic LBP conditions.

In the phase of connecting interdisciplinary knowledge and experiences, we built consensus based on all the stakeholders' knowledge and experience to find critical issues with current treatments for LBP management.

The qualitative data from interviews, informal workshops, and discussion sessions were analyzed using narrative analysis and interpreted with regard to the research settings and reported the results to express the views and voices of the research subjects, including the elderly patients and stakeholders.

2.4. Patient-Centered Rehabilitation

In regard to the phase of designing patient-centered rehabilitation (Phase 3), we studied the anatomy of the muscles specified by the doctor, orthopedist, and therapist, and conducted a literature review on training exercises for muscles around the spine (e.g., [35–37]). To gain further understanding of rehabilitation for LBP, we arranged several discussion sessions with orthopedists, the therapist, and the exercise trainer for a concise literature review on muscle stiffness of the trunk muscles. Given the previous studies (Schilling et al. [38], Rainoldi et al. [39], Nam et al. [40], and Ginn and Halaki [41]), along with several exercise trials with our subjects and patient–expert interactions, we sort to design an exercise program that included an exercise object and exercise protocols with the principles of patient-centeredness. For this purpose, we conducted detailed experimental trials and exercise training over five weeks. These trials were reviewed and approved by the ethics committee of our institutional review board and registered with the Clinical Research Information Service (CRIS). The trials were based on a pretest–posttest comparison group designed to test the effectiveness of the exercise object and the exercise program in the LBP rehabilitation of elderly patients. The experimenter described the purpose and procedures of the study to the subjects and explained that they could withdraw from the study at any time. Following a verbal explanation about the study, all subjects gave informed consent. Subjects were provided with loose clothes for exercise training throughout the study.

2.4.1. Study Design, Measures, and Instruments

In the initial screening of subject recruitment, a total number of 110 subjects were inspected in the senior care center for chronic LBP and trunk muscle fatigue. Half of them were hesitant to participate in the five weeks study and some had prior schedules due to which they refused to take part in the study. Moreover, some subjects had other major chronic conditions due to which they were not able to participate in the exercise training. Therefore, it was difficult to find only those subjects who were willing to voluntarily take part in the study and those who had only chronic LBP or other trunk muscle fatigue. Finally, we recruited a total of 30 subjects who voluntarily agreed to participate in the study. The inclusion criteria included elderly patients with LBP or trunk muscle fatigue. The exclusion criteria included a history of stroke and low back, hip, or leg surgery. The subjects underwent a medical checkup and radiographic examination using X-ray imaging in a local clinic. They had major and minor spinal deformations based on the medical reports. Among them, 18 subjects who only experienced LBP for a mean period of 2.3 years were chosen for this study. Subsequently, they were equally and randomly divided into two treatment groups: the control and experimental groups. The control group performed the exercise training in the level-standing position, and the experimental group completed the exercise training in the incline-standing position. Over the course of the study, two subjects withdrew from each group because of health problems (n = 1) or not following up (n = 1). Thus, 8 subjects in the experimental group and 8 subjects in the control group were included in the current analysis.

We arranged the main exercise training and experiments to last 5 weeks. The experimental group performed standing exercise training with the exercise object, and the control group completed the exercises without the object. Both groups performed training for 25 min daily, except on Saturdays and Sundays, with a 7-min break, for 5 weeks.

The LBP was evaluated at the end of each day's exercise training based on subjective response measures—feelings of pain in the lower back trunk. The LBP was measured using the Wong–Baker FACES Pain Rating Scale. This scale features faces ranging from a happy face at 0 indicating "no pain" to a crying face at 10 indicating "worst pain." The scale was obtained from the Wong–Baker FACES Foundation (For Wong–Baker Faces, https://wongbakerfaces.org/, accessed on 7 April 2022) in the Korean language.

To measure the muscle activation level of the back trunk during exercise, an electromyography (EMG) device (sEMG-4, PolyG-A, LAXTHA Inc., Daejeon, Republic of Korea) was used for recording EMG signals during the 5 weeks. Two pairs of Ag/AgCl surface electrode disks with a diameter of 11.4 mm were placed on the specified muscles at standardized sites after cleaning with ethanol. For the LD muscle, the electrode was placed 4 cm below the inferior angle of the right scapula. For the LES muscle, the electrode was placed on the right side of the vertebral column (L5) that extends alongside the lumbar portion of the spine. A reference electrode was placed over the seventh cervical vertebrae of the spinous process.

2.4.2. Experiment Procedure

Both groups performed maximum voluntary contraction (MVC) tests and had brief rest periods between sets to boost LD and LES muscle endurance. The MVC tests were conducted to determine maximum contraction in the LD and LES muscles. This test was also used for EMG signal normalization during exercise, where muscle activation levels were measured. The MVC signals for both LD and LES muscles were recorded for all subjects in both groups and followed by the training protocols. In total, two MVCs were measured and recorded for 10 s. There was a one-minute rest period between each MVC test, and the highest MVC was selected for further analysis. The MVC signals for the LD muscle were obtained as the subjects sat on a therapeutic table and performed a maximum isometric lat pull-down with fixed resistance from a rod held by the experimenter.

To obtain a successful MVC signal for the LES, the subject was asked to lie on a therapeutic table with their trunk extending over the edge of the table at the level of the frontal superior iliac spinal column while spreading the trunk to the resistance applied by the experimenter.

All MVC tests were 10 s in length. Subjects were asked to ramp up to maximum effort over the first 5 s while keeping maximum force for the remaining 5 s. Before the experimental setup, all subjects were taught the specified MVC technique and were verbally encouraged during the maximum isometric exertions. The purpose of these tests was to observe changes in LD and LES muscle activation levels during exercise as well as LBP scores over five weeks of the exercise program.

2.4.3. Data Processing

The raw EMG signals were processed in offline analysis using a bandpass filter and full-wave rectifier and smoothed using fast Fourier transform (FFT) to produce a bandwidth of 8–240 Hz. A notch filter was used with a filter cutoff frequency of 60 Hz. The sampling rate of the EMG signals was 512 Hz, and this was amplified using a common-mode rejection ratio of 90 dB with an overall gain of 210.084. The raw data were processed into the root mean square (RMS) with a window width of 78 milliseconds and the maximum EMG amplitude was calculated for the MVC of both muscles. The muscle activation level, expressed as a percentage of the MVC, of the LD and LES muscles during exercise was quantified. The recorded EMG signals during each exercise task were expressed as a percentage of the calculated RMS of the MVC. The maximum EMG values from MVC tests were used to normalize all EMG signals collected during each MVC test and expressed as a percentage of the calculated RMS of the maximum contraction. All raw signals were digitized using Telescan 2.89 software and a custom program in MATLAB.

2.4.4. Data Analysis

The purpose of the experiment was to measure whether there was a significant difference in the activation of the LD and LES muscles and LBP score between the experimental and control group when performing the exercise program for five weeks. For this purpose, first we used a mixed-design repeated-measures ANOVA (Analysis of Variance) test to calculate the mean muscle activation of LD and LES between the two groups (between-subjects factor = interventional group) with normal standing, lateral bending (180° upward extension, 30° right lateral flexion, and 30° left lateral flexion) and forward bending, and partial squatting (90° forward flexion, 45° downward flexion, and 35° eccentric squat extension) during the first week (W-1), second week (W-3), and the third week (W-5) of the exercise program (within-subjects factor = time). Second, we used a repeated measure ANOVA test to measure LBP score over time (W-1 to W-5) between the experimental and control groups. The Statistical Package for the Social Sciences (SPSS) version 22.0 (IBM SPSS Inc., Chicago, IL, USA) was used to calculate the mean score of LBP and mean muscle activation levels at $p < 0.05$.

At the end of the experimental trials and exercise training, we conducted post-trial interviews with eight subjects to discuss their general experience with the exercise program.

3. Results

3.1. Subject Anthropometric Characteristics

Sixteen elderly subjects from a senior care center participated in the study by completing the exercise program and subsequent experimental trials. The anthropometric characteristics of the subjects in both experimental and control groups are shown in Table 2. The subjects in the experimental group have a mean age of 72.21 (SD = 2.91) and subjects in the control group have a mean age of 71.81 (SD = 4.51); the age range was between 70–80 years.

Table 2. Subjects' anthropometric characteristics.

	Control		Experimental
		n	
Number of subjects	8		8
		Anthropometry	
Height, cm	151.82 ± 6.01		150.21 ± 3.62
Bodyweight, kg	53.52 ± 5.21		53.33 ± 5.33
Body mass index, kg/m^2	23.22 ± 1.81		23.61 ± 2.12
Age (years)	71.81 ± 4.51		72.21 ± 2.91
		Clinical	
Baseline LBP (0–10)	6.32 ± 0.92		6.11 ± 1.42

3.2. Context Exploration Results

We found that the elderly subjects had LBP due to musculoskeletal conditions. They had neglected proper posture while working, and this led to the loss of spine stability and contributed to the development of LBP. Most subjects made use of electrotherapy, manual therapy, and exercise rehabilitation. The subjects expressed anxiety that had been caused by spine surgeries and medication. Among the 30 subjects, five reported previous spine surgery, including for scoliosis, kyphosis, and spondylitis. Accordingly, they experienced mild pain in their trunk, which became acute during lifting tasks or carrying loads. They had difficulty following their existing exercises because of poor muscle endurance, which made it difficult to perform strength-based exercises.

Subjects reported side effects of conservative treatments and difficult exercises, such as discomfort and tiredness. Stakeholders reported four contributing factors to LBP: spine abnormalities due to age-related conditions, prolonged sitting, poor posture stability, and back muscle stiffness.

Studies were reviewed from the years 2000 to 2021 in which older adults were the reference population and LBP symptomatic subjects. We analyzed the contents, thematized them, and grouped them to articulate mutual patterns to construct further knowledge on LBP rehabilitation (see Table S1 in Supplementary Material A). From the clinical physiology studies, we determined experimental studies on muscle force, muscle growth, muscle fatigue, muscle movements, and muscle contraction. In the ergonomics and safety literature, we found empirical studies on muscle injury recovery, posture correction, standing conditions, and trunk muscle activities. From the exercise rehabilitation studies, we found studies on posture correction, muscle endurance exercises, standing aids, and sports activities.

3.3. Results of Patient-Expert Interaction

According to their medical reports, the patient–expert interaction revealed that some patients had major and minor spine deformations. Subsequently, the therapist and trainer interacted with the subjects and trained them using training manuals and exercise objects. They manipulated customized training objects for muscle-stretching exercises. After the training, we addressed the areas in which the patients felt fatigued during the training. The subjects were also observed by the orthopedists to trace the areas of the body with fatigue. These areas were traced by employing the existing methods to find appropriate muscles in the trunk that cause LBP due to spine abnormalities. These muscles were mainly latissimus dorsi (LD) and lumbar erector spinae (LES).

As reported by the doctor and the orthopedist, drug intervention in LBP is common, but the elderly often cannot take drugs for LBP for any length of time because they are already taking other medication for other health problems. The taking of multiple drugs simultaneously can have detrimentally interacting effects. The orthopedist and the therapist asked about the subjects' current health conditions in an open dialogue. These dialogues supplied us with important knowledge about a problem being explored from the viewpoints of experts and patients. The experts explained that LBP conditions were caused by prolonged sitting and sedentary activities. They added that the muscles of the trunk progressively become stiffened and strained with age. The subjects shared their concerns on current rehabilitation practices in LBP conditions—for example, that prescribed exercises pose problems because of their weak body muscles.

The activities and experiences from the interdisciplinary knowledge among the experts provided four practical insights into the challenges and opportunities in current rehabilitation practice for elderly patients. First, the patient–expert interaction endorsed a participatory research practice by exploring the knowledge and experiences of rehabilitation between the design team and other experts. Second, this practice brought all experts to the design process with uniform goals to define the multifaceted problem around rehabilitation practice. This ultimately explored design's ability to involve actual patients and key stakeholders in such a complex, multidisciplinary situation. Third, the interdisciplinary knowledge exchanges among the experts revealed invisible factors involved in the design process. These factors include awareness of physiological changes and medical requirements of the target users. Fourth, based on the integration of interdisciplinary knowledge and experiences among the experts, we reached an agreement on the design of exercise training for trunk muscles as an alternative treatment for LBP.

3.4. Results of Patient-Centered Rehabilitation

Firstly, we highlighted 15 types of exercise protocols that majorly included trunk flexion and extension exercises for muscle relaxation and stabilization. These exercises included sitting, standing, and lying down positions (plank, crunch, and bridge). The rationale behind each of these exercises was to design muscle exercises that can manipulate the back muscles (namely LD and LES) to keep the spine within normal curvature. The expected symptoms of LBP can thus be prevented. Our study subjects were also involved in this process, specifically in the development of the exercise program based on their previous experiences. Every step of the exercise was separately presented to them for approval.

The proposed exercise program caused severe fatigue, which hindered consistency in the participation among the subjects. We observed that the fatigue was caused primarily by prolonged standing with the standing exercise training and its longer duration (approximately 60 min). Subjects had difficulties in standing up from the lying down position to perform standing exercises, supporting the fact that this target population represents a vulnerable group with poor motor control abilities against postural stability and low fatigue resistance in standing positions [42]. Among the 15 protocols in the exercise program, we removed eight items that included lying down positions, as well as those that caused severe discomfort to other parts of the body. This also minimized the total duration of the exercise program from 60 min to 25 min, including a 7-min break. Table 3 lists the exercise movements and their timings; their details are presented in Supplementary Material B.

Table 3. Standing exercise program design.

Exercise	Procedure	Anatomical Position	Duration (5 Sets)
Normal standing position	Take a long breath for warm-up		30 s
Lateral bending Position	Stands with both hands up	 180° upward extension	2 min (Break until the next item: 1 min)
	Right lateral bending	 30° lateral flexion	3 min (Break until the next item: 1 min)
	Left lateral bending	 30° lateral flexion	3 min (Break until the next item: 1 min)
Forward bending and partial squat positions	Expands the hands forward	 90° forward flexion	3 min (Break until the next item: 2 min)
	Bends downward	 45° downward flexion	3 min (Break until the next item: 2 min)
	Bends forward slightly	 35° eccentric squat extension	3 min

Studies have revealed a positive effect of standing on an inclined surface in muscle relaxation as compared with standing on a horizontal surface [43,44]. The former type of standing is advantageous for the elderly with weak body muscles because it automatically leads to flexion and extension of the trunk without maximum exertion. Therefore, individuals do not need to make an extra effort to stretch their muscles. An inclined surface can create positive postural changes in both pelvic and lumbar spine angles, flexion rotation of the pelvis, and consistent improvement in lumbar spine extension [12]. The use of an inclined surface is thus more promising in posture correction than existing exercise methods. To increase the efficiency of our exercise program, we designed an exercise object with 10°, 15°, and 20° slope angles (see Figure S1 in Supplementary Material B). With this object, exercises could be performed by following the protocols in the exercise program.

3.5. Muscle Activation of LD and LES Muscles

For the normal standing posture, a mixed-design repeated measures ANOVA test determined that the mean muscle activation of LD muscle differed statistically significantly between the experimental and control group as the between-subjects effect (See Table 4). With a Roy's largest root correction, the test determined that the mean activation of LD and LES muscles differed statistically significantly with an interaction effect between the treatment groups and time. The detailed results are provided in Supplementary Material C.

Table 4. Mixed-design repeated measures ANOVA test results with the normal standing posture.

Dependent Variable	Effect	F Statistics	*p* Two-Tailed	η^2
LD muscle activation levels	Treatment groups (between-subject)	F (1, 14) = 34.5	0.02 *	0.71
LES muscle activation levels	Time (within-subject)	F (2, 28) = 7.02	0.03 *	0.33
LD and LES muscle activation levels	Treatment groups × Time	F (4, 56) = 3.27	0.03 *	0.19
LD muscle activation levels	Treatment groups Time	F (2, 28) = 3.07	0.041 *	0.18
LES muscle activation levels	Treatment groups Time	F (2, 28) = 0.22	0.34	0.016

Notes: LD = latissimus dorsi; LES = lumbar erector spinae; treatment groups = control and experimental groups; Time = five week of exercise training; * $p < 0.05$.

For lateral bending posture with 180° upward extension, the test determined that the mean muscle activation of LD muscle and LES muscle differed statistically significantly between the time (W-1 to W-5) as the within-subjects effect (See Table 5). With a Roy's largest root correction, the test determined that the mean activation of LD and LES muscles differed statistically significantly between the experimental and control group over time as an interaction effect. The detailed results are provided in Supplementary Material C.

Table 5. Mixed-design repeated measures ANOVA test results with the lateral bending posture (180° upward extension).

Dependent Variable	Effect	F Statistics	*p* Two-Tailed	η^2
LD muscle activation levels	Time (within-subject)	F (2, 28) = 3.16	0.04 *	0.18
LES muscle activation levels	Time (within-subject)	F (2, 28) = 8.38	0.02 *	0.37
LD and LES muscle activation levels	Treatment groups × Time	F (4, 56) = 5.56	0.02 *	0.28
LD muscle activation levels	Treatment groups Time	F (2, 28) = 4.88	0.03 *	0.25
LES muscle activation levels	Treatment groups Time	F (2, 28) = 0.78	0.21	0.06

Notes: * $p < 0.05$.

In the lateral bending posture (30° right lateral flexion), the mean muscle activation of LD muscle differed statistically significantly between the treatment groups as the between-subjects effect (See Table 6). With a Roy's largest root correction, a mixed design repeated measures ANOVA test determined that the mean activation of LD and LES muscles differed statistically significantly between the experimental and control group over time as an interaction effect. The detailed results are provided in Supplementary Material C.

Table 6. Mixed-design repeated measures ANOVA test results with the lateral bending posture (30° right lateral flexion).

Dependent Variable	Effect	F Statistics	*p* Two-Tailed	η^2
LD muscle activation levels	Treatment groups (between-subject)	F (1, 14) = 5	0.03 *	0.26
LES muscle activation levels	Time (within-subject)	F (2, 28) = 10.7	0.02 *	0.43
LD and LES muscle activation levels	Treatment groups × Time	F (4, 56) = 3.08	0.04 *	0.18
LD muscle activation levels	Treatment groups Time	F (2, 28) = 2.61	0.04 *	0.15
LES muscle activation levels	Treatment groups Time	F (2, 28) = 0.05	0.41	0.04

Notes: * $p < 0.05$.

In lateral bending posture (30° left lateral flexion), the mean muscle activation of LES muscle differed statistically significantly between the time (W-1 to W-5) as the within-subjects effect (See Table 7). A mixed-design repeated measures ANOVA with a Roy's largest root correction determined that the mean activation of LD and LES muscles differed statistically significantly between the experimental and control group over time as an interaction effect. The detailed results are provided in Supplementary Material C.

Table 7. Mixed-design repeated measures ANOVA test results with the lateral bending posture (30° left lateral flexion).

Dependent Variable	Effect	F Statistics	*p* Two-Tailed	η^2
LES muscle activation levels	Time (within-subject)	F (2, 28) = 7.10	0.02 *	0.33
LD and LES muscle activation levels	Treatment groups × Time	F (4, 56) = 2.98	0.04 *	0.15
LD muscle activation levels	Treatment groups Time	F (2, 28) = 2.43	0.04 *	0.14
LES muscle activation levels	Treatment groups Time	F (2, 28) = 0.21	0.31	0.10

Notes: * $p < 0.05$.

In forward bending posture (90° forward flexion), the mean muscle activation of LD muscle and LES muscle differed statistically significantly between the experimental and control group as the between-subjects effect (See Table 8). A mixed-design repeated measures ANOVA determined that the mean activation of LD and LES muscles differed statistically significantly between the experimental and control group. In particular, the univariate test with Huynh-Feldt correction showed that the mean activation of LD muscle differed between the experimental and control group over time. The test also showed a statistical difference in the mean activation of LES muscle between the two groups over time.

Table 8. Mixed-design repeated measures ANOVA test results with the forward bending posture (90° forward flexion).

Dependent Variable	Effect	F Statistics	*p* Two-Tailed	η^2
LD muscle activation levels	Treatment groups (between-subject)	F (1, 14) = 5.51	0.03 *	0.28
LES muscle activation levels	Treatment groups (between-subject)	F (1, 14) = 15.5	0.01 *	0.52
LD and LES muscle activation levels	Treatment groups × Time	F (4, 56) = 3.96	0.03 *	0.22
LD muscle activation levels	Treatment groups Time	F (1.87, 26.2) = 2.01	0.04 *	0.13
LES muscle activation levels	Treatment groups Time	F (2, 28) = 4.05	0.02 *	0.22

Notes: * $p < 0.05$.

In forward bending posture (45° downward extension), the mean muscle activation of LD muscle and LES muscle differed statistically significantly between the experimental and control group as the between-subjects effect (See Table 9). A mixed-design repeated measures ANOVA with a Roy's largest root correction determined that the mean activation of LD and LES muscles differed statistically significantly between the experimental and control group over time as an interaction effect. In particular, the univariate test with Huynh-Feldt correction showed that the mean activation of LD muscle differed between the experimental and control group over time. The test also showed a statistical difference in the mean activation of LES muscle between the two groups over time.

Table 9. Mixed-design repeated measures ANOVA test results with the forward bending posture (45° downward extension).

Dependent Variable	Effect	F Statistics	*p* Two-Tailed	η2
LD muscle activation levels	Treatment groups (between-subject)	F (1, 14) = 7.59	0.02 *	0.35
LES muscle activation levels	Treatment groups (between-subject)	F (1, 14) = 3.62	0.04 *	0.20
LD and LES muscle activation levels	Treatment groups × Time	F (4, 56) = 5.11	0.03 *	0.26
LD muscle activation levels	Treatment groups Time	F (1.51, 21.1) = 2.61	0.04 *	0.15
LES muscle activation levels	Treatment groups Time	F (1.6, 22.4) = 2.81	0.03 *	0.16

Notes: * $p < 0.05$.

In partial squatting posture (35° eccentric squat extension), the mean muscle activation of LD muscle and LES muscle differed statistically significantly between the experimental and control group as the between-subjects effect (See Table 10). A mixed-design repeated measures ANOVA with a Roy's largest root correction determined that the mean activation of LD and LES muscles differed statistically significantly between the experimental and control group over time as an interaction effect. The detailed results are provided in Supplementary Material C.

Table 10. Mixed-design repeated measures ANOVA test results with partial squatting posture (35° eccentric squat extension).

Dependent Variable	Effect	F Statistics	*p* Two-Tailed	η^2
LD muscle activation levels	Treatment groups (between-subject)	F (1, 14) = 17.2	0.01 *	0.55
LES muscle activation levels	Treatment groups (between-subject)	F (1, 14) = 9.72	0.02 *	0.41
LD and LES muscle activation levels	Treatment groups × Time	F (4, 56) = 2.94	0.04 *	0.13
LD muscle activation levels	Treatment groups Time	F (1.87, 26.2) = 2.11	0.03 *	0.12
LES muscle activation levels	Treatment groups Time	F (2, 28) = 1.98	0.04 *	0.11

Notes: * $p < 0.05$.

3.6. Perceived LBP Score

A repeated-measures ANOVA test determined that the mean score of LBP differed statistically significantly between the experimental and control group as the between-subjects effect (See Table 11). The test also showed that the mean score of LBP differed statistically significantly between the time (W-1 to W-5) as the within-subjects effect. However, there was no interaction effect between the treatment groups and time for LBP score. The detailed results are provided in Supplementary Material C.

Table 11. Repeated measures ANOVA test results in perceived LBP.

Dependent Variable	Effect	F Statistics	p Two-Tailed	η^2
Perceived LBP	Treatment groups (between-subject)	F (1, 14) = 12.4	0.01 *	0.47
	Time (within-subject)	F (2, 28) = 47.9	0.01 *	0.77
	Treatment groups × Time	F (4, 56) = 0.89	0.64	0.06

Notes: * $p < 0.05$.

3.7. Post-Trials Interviews and Insights

From the post-trial interviews, we noted most of the subjects suffered from fatigue at the start of the program. Some of them possessed pain in the lower trunk because of prior spine surgery. When they were asked about the trunk exercises using the proposed exercise design, they said that our exercise program was helpful and better than conservative treatments that involve complicated physiotherapeutic and clinical methods. We asked the subjects, (a) what did you expect from the 5 weeks exercise program?, and (b) what did you think you are likely to learn about your back pain condition and its intensity (low, high, or medium) after and before the exercise program? In responding to these questions, subjects F, G, and H reported the following answers (as translated into English translation):

Subject F noted:

> "I didn't even know what it was when I received the new one [new version of the exercise object], but it was so nice to try it. I didn't expect much at first. Normally, back pain doesn't affect much my daily life, but it was good for my back . . . ".

> "I thought my back would get better if I just do what the exercise program guided me to do so . . . ".

Subject G noted:

> "I hoped that my muscle strength would improve through the exercise program. I didn't expect anything but I just thought it would be better to do exercise to improve muscle strength, develop good posture, and give strength to my legs beside my back . . . ".

> "I didn't expect what I learned. My knee got a lot worse, but it got a lot better after this program. I thought it would be better if I do this program again . . . ".

And subject H noted:

> "I had a bend back, but I wanted to make my postures correct, and it seemed to straighten my back. I hoped my body would get better by exercising with the new exercise object. I wanted my body to have muscles and become lighter . . . ".

> "I didn't know what I learned, but I just wanted to do exercise with the object. My body feels refreshed when I perform the exercise program . . . ".

Overall, the subjects expressed favorable views about the exercise training along with the exercise object. According to them, the training helped decrease their LBP. Some of those interviewed also believed that training reduced their leg pain. They elaborated that the exercise object with a 10–15° slope angle benefits muscle relaxation and posture correction. Subjects requested to take the training object and the printed manual of the exercise program back to their homes to maintain the training in their domestic settings. They believed the training helped them with their knees, shoulders, and waist, and they also wanted to suggest the exercise training to their families and friends. To a large extent, we observed considerable improvements in the subjects' health conditions based on the current results with the exercise program. Table 12 below and Supplementary Material D present detailed descriptions of the revised exercise program design and its points of effect in the body.

Table 12. Revised exercise program procedure and the targeted areas of the body.

Step	Exercise Procedure	Target Body Areas
	Initiate a long breath— Breathe slowly with your nose. Exhale slowly with your mouth. Hold your breath for 3 s	
1	Normal standing position	Gastrocnemius muscle relaxation
2	Stretch up	Latissimus dorsi muscle relaxation
3	Stretch left	External oblique abdominal muscle Latissimus dorsi muscle relaxation
4	Stretch right	External oblique abdominal muscle latissimus dorsi muscle relaxation
5	Stretch forward	Hamstring muscles (semitendinosus, biceps femoris, semimembranosus), erector muscle of spine relaxation
6	Stretch under feet	Hamstring muscles (semitendinosus, biceps femoris, semimembranosus), gluteus maximus relaxation
7	Skate right foot	Meso gluteus relaxation
8	Skate left foot	Meso gluteus relaxation
9	Back S line (squat position)	Making the waist arched
10	Hands behind the head	Diaphragm, rhizomelic
11	Clenched fists	Cervical vertebral relaxation
12	Chin up	Cervical vertebral relaxation
13	Stretch neck to the left	Cervical vertebral relaxation
14	Stretch neck to the right	Cervical vertebral relaxation
15	Take off the exercise object	

4. Discussion

The integrated research practice in this study explored the current context of rehabilitation and patient-expert interaction and defined patient-centered rehabilitation. In particular, we found that neglecting proper postures during work causes spine instability, which develops chronic LBP in elderly patients. We also found that fatigue in the LD and LES muscles causes LBP in most elderly patients. Based on these findings, we designed an exercise program with exercise protocols and an exercise object for flexion and extension of LD and LES muscles to minimize the intensity of chronic LBP among elderly patients. The exercise program significantly influenced the muscle activation levels of the LD and LES muscles and LBP at $p < 0.05$. There was a significant increase in mean muscle activation and a decrease in the mean LBP score over time in the control and experimental groups. The results underlined a link between the activation of each muscle and LBP; the higher the muscle activation levels of the LD and LES muscles, the lower the LBP score as the exercise program continued for five weeks.

A progressive decline in the health and physical fitness of the aging population places substantial demands on health reforms. The integration of healthcare design with rehabilitation fields is required for a paradigm shift due to important limitations associated with the aging population, such as funding deficits, patient hesitation, and medicinal and clinical side effects. For elderly people, chronic disease and pain management require regular attention in addition to continuous visits to healthcare centers. This study reports the outcomes of an interdisciplinary co-design research practice to develop an exercise program for the management of LBP in the elderly. To address LBP management in the elderly, the design approach required understanding and responding to a broad range of issues, such as awareness of anatomical and physiological changes of aging, ergonomic and safety issues, exercise adaptability, the aesthetics of exercise objects, and medical literacy. We initiated our design approach with a comprehensive and in-depth research phase and relied heavily on direct feedback from elderly subjects and experts in the form of qualitative and quantitative assessments. Co-design with the elderly patients and experts and testing the design of an exercise object and subsequent experimental trials were vital. The design outcomes in each phase of the research process were built on the knowledge gained from the preceding phases, and the clinical and physiological aspects and trunk exercise considerations were shaped into a fully functional exercise program. The program was tested for its effectiveness in LBP management with elderly subjects in clinical trials. As the problem in our study was multifaceted and needed a profound understanding of LBP requirements, we explored the distributed disciplinary knowledge of the stakeholders by inquiring and analyzing the expert and subject knowledge. Our design approach contributed as a knowledge integrator to acquire better insights into the problem and in the process, transformed stakeholders' knowledge. The design practice needs to first initiate problem exploration by engaging experts and affected individuals regarding the problems, then lead the collaboration. Second, we extended the co-design process to further analyze and explore the patient–expert interaction for establishing consensus among the stakeholders. Our design approach mediated the knowledge created and negotiated among the stakeholders and connected interdisciplinary knowledge and experiences that emerged during the interaction. We obtained significant contributions from this interaction by analyzing stakeholders' knowledge and experiences to build consensus on patient rehabilitation. The mediating role in gaining this consensus thus facilitated our co-design process. The roles of initiating and leading the exploration of such a complex problem and mediating the knowledge and experiences of the stakeholders to address the problem can increase the pace of healthcare design expansion. Once incorporated into design practice, these diverse roles will, over time, gradually inform healthcare designers with other domain knowledge and expertise. This will, in turn, enable them to become more credible and genuine contributors in addressing complex problems in a distributed disciplinary environment.

The results of muscle activation and LBP supports that exercise training can increase muscle strength with changes in muscle activation patterns and alleviate LBP by standing postures on sloped surfaces [11]. Moreover, standing posture training on an inclined surface can flex the lower back and increase lumbar spinal extension. Similarly, Ingerson et al. [45] found significant improvements in LBP conditions with positive changes in muscle activation during flexion tasks. With regard to standing exercises for posture correction, Waongenngarm et al. [46] and Claus et al. [47] showed that postural changes due to standing flexion could improve blood circulation in the lumbar region and change the spinal curvature, making such exercise an effective intervention for patients with chronic LBP. These studies suggest that posture-correcting exercises should be investigated further for their benefits in manipulating trunk muscles to spinal curve balance. The results support that forward bending and partial squatting posture training are effective methods for increasing flexion and extension of the trunk muscles, including those in the thoracic and lumbar regions [48,49]. The evidence overall is that a strong LES maintains anteroposterior spinal integrity and contributes to spinal stabilization in squat posture training. In support of our results, Gorsuch et al. [50] showed that squat posture training improves the strength of trunk muscles due to a significant increase in muscle contraction. Cho et al. [51] observed a greater increase in lower extremity muscle activation with an increase in board slope from 5° to 10°. They concluded that an increase in board slope could be an effective method to influence trunk muscles. Moreover, Coqueiro et al. [52] stated that semi-squat postures could be utilized in trunk muscle strengthening exercises. The patterns of increase in muscle activation levels support the findings of Torres-Peralta et al. [53], who showed an increase in muscle contraction burst duration with exercise intensity due to muscle activation during standing exercises. Our results are further supported by Bruce-Low et al. [54] in that trunk muscle training with repetitive postures can induce greater EMG activity to increase trunk muscle activation.

Vincent et al. [55], Kuss et al. [56], and Hicks et al. [57] identified LBP treatment through different exercises to help improve functional performance in the elderly. Those studies suggested that the symptoms of LBP are common complaints related to functional limitations and frailty, and exercise rehabilitation is therefore broadly recommended to manage and reduce the prevalence of LBP in the elderly. In particular, Vincent et al. [55] and

Kuss et al. [56] showed that whole-body resistance training with lumbar extension and back extensor strength exercise alleviates LBP conditions and promotes functional movement in the elderly. Hicks et al. [57] reported a significant improvement in LBP conditions in elderly subjects through an exercise program that included stretching and trunk muscle training.

Besides the above studies, our results suggest that bending and squat exercises with a gradual increase in exercise intensity are effective methods for improving the flexibility of the lower back and can ultimately ease LBP in elderly individuals. Consistent with this, our exercise program is based on trunk flexion and extension through bending and squat exercises on the proposed design of the exercise object. Some studies have recommended mat-based Pilates, stretching, gymnastics, and traction therapy for lumbar rehabilitation to reduce LBP, such as in the studies by Rhyu et al. [58] and Menacho et al. [59]. Those studies used isometric exercises, such as mat exercise and I-Zer exercise, for pain relief and showed that I-Zer exercise based on traction is significantly effective for LBP and induces muscle relaxation. Traction exercise is a conservative treatment designed to reduce pain; however, it requires maximum muscle strength, which elderly people may not possess or be able to endure for a long period [60]. As a result, exercise methods majorly focusing on maximum trunk strength and endurance can negatively influence the muscles and ultimately decrease spinal stability in elderly people. Our results are further supported by Chanplakorn et al. [61] in that standing aids are significantly promising because they are associated with postural correction, spine stability, and sagittal alignment of the lumbar spine. In addition, Ibrahim et al. [62] suggested that standing and bending exercises for postural modifications are promising in reducing back muscle tension to ease LBP conditions.

5. Conclusions

Our research practice defines and addresses a multifaceted problem that consists of several challenges both in healthcare design and the problem itself. The design approach can easily be expanded and adapted to other domain-related research projects that possess characteristics of complex problems. The role of healthcare design is thus better purposed to initiate and mediate the co-design process along with creating to grapple with multifaceted problems in healthcare design projects. In defining a multifaceted problem, an initiating role means that the design approach gains leadership among other domain experts to define and recognize the root of the problem. A mediating role means that the design approach carries unique expertise from experts into healthcare design to generate better solutions with a focus on users' desires and use context. It is challenging to transform the traditional role of healthcare design. However, designers who develop interdisciplinary expertise are required to initiate this paradigm shift to tackle multifaceted problems. The design of patient-centered rehabilitation will help policymakers, healthcare designers, and rehabilitation researchers to embark on multidisciplinary research that challenges traditional rehabilitation practice to acquire new forms of interdisciplinary expertise in healthcare design.

The research practice in this study adopted for the current context of rehabilitation could present a platform for identifying and addressing complex problems by engaging the actual patients and relevant stakeholders. Undertaking this from various perspectives, such as healthcare design, clinical physiology, ergonomics and safety, and exercise rehabilitation, the practice presents the best opportunity to effectively address emerging elderly patients' health concerns. The insights gained from combining the above fields suggest that there are still challenges to address in enabling and supporting such interdisciplinary research to be combined with healthcare design. There is even such research needed to be done to develop an understanding of the role and purpose of design in these fields. There are, though, multiple prospects developed from embedding design in this interdisciplinary research environment, e.g., providing insights into the social and behavioral challenges to foster best practices for elderly patients' health implementation associated with chronic conditions. Assessing elderly views on challenges to lifestyle changes after their experiences in performing exercise training and responding to subsequent clinical trials in the qualitative studies will be of importance.

These outcomes of the integrated research practice provided a way to approach multifaceted problems by developing interdisciplinary expertise in healthcare design. The problem presented in this study highlighted the demand for further studies with a particular focus on interdisciplinary actions acquired by design at various phases of the design process because it is challenging to bridge multiple stakeholders with different backgrounds where consensus among them is difficult to build in each phase of the research process. More studies are required to explore robustly exchangeable understandings regarding the acquired interdisciplinary expertise in design and other diverse fields, which can address complex problems associated with the rehabilitation of elderly patients. Considering the study period of five weeks and the small number of research participants, the exercise program has shown partially positive results; however, there can be better outcomes if the study was conducted for longer periods, for example, five months with a considerable number of research participants. With this perspective in mind, future studies should consider the exercise program for longer periods with an appropriate and larger sample size of research participants to determine effective results. Conducting further studies to increase the program's applicability with different standing positions for trunk muscle activation and isometric muscle strength measurements, thus contributing to alleviating LBP in the elderly population is warranted.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/app12094687/s1, Figure S1: (a) Design concept of an inclined object for a standing exercise, (b) Creating a prototype of the inclined object; Figure S2: Latissimus dorsi (LD) and lumbar erector spinae (LES) muscle activation with normal standing posture over time; Figure S3: LD and LES muscle activation with lateral bending posture training for 180° upward extension; Figure S4: LD and LES muscle activation levels with lateral bending posture training for 30° right lateral flexion; Figure S5: LD and LES muscle activation levels with lateral bending posture training for 30° left lateral flexion; Figure S6: LD and LES muscle activation levels with lateral bending posture training for 90° forward flexion; Figure S7: LD and LES muscle activation levels with forward bending posture training for 45° downward flexion; Figure S8: LD and LES muscle activation levels with partial squatting posture training for 35° eccentric squat extension; Figure S9: Mean low back pain (LBP) score with time (weeks) in the control and experimental groups; Figure S10: Final exercise object with angle adjustment and folding mechanism; Figure S11: Images from the exercise program manual showing the different standing postures; Figure S12: Exploded view and assembly structure of the exercise object; Table S1: Literature inquiry matrix and mutual relationships between themes and elements; Table S2: Standing exercise program.

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