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Original Article

The Effectiveness of a Mobile-Based Educational Application on Recovery and Learning Rate of Corrective Exercises in Scoliosis Patients: A Pilot Study

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Abstract

Background: Proper performance of corrective exercises is crucial for treating scoliosis, a common musculoskeletal disorder. However, these exercises are often performed incorrectly, reducing their therapeutic effects. This study aimed to design a mobile-based educational application to increase adherence to corrective exercises among scoliosis patients and to test the hypothesis that the proposed application positively affects the recovery and learning rate of these exercises in scoliosis patients.

Methods: Information requirements were gathered to develop the application according to library resources and expert opinions. The mobile application was then developed using the latest available technologies in the world. Finally, the system was evaluated by measuring its impact on patient recovery rate and exercise learning using a case-control method, usability through a user experience questionnaire, and accuracy using a confusion matrix.

Results: Fifty-one information requirements were identified for the treatment of scoliosis, and seven rule-based reasoning processes were used in comprehensive decision-making rules. The system demonstrated 100% accuracy. The evaluation phase revealed a significant relationship between application use and recovery rate in the case group ($P=0.004$). Moreover, the use of the application had a positive effect on the rate of learning corrective exercises. The highest and lowest usability scores were observed in the "perspicuity" and "stimulation" dimensions of the app, respectively.

Conclusion: In low-income countries, the developed application can be used to construct broader, similar systems and programs in treatment management, patient monitoring, emergency response, personalized health monitoring, and improved access to healthcare information.

Keywords: Mobile application, Corrective exercise, Recovery, Scoliosis, Quasi-experimental

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Background

Scoliosis is one of the most common musculoskeletal disorders affecting the spine. If not diagnosed or treated early, this disorder can cause problems in patients' appearance and sitting positions, and in severe cases, may lead to lung diseases and heart complications.[1,2]

Physiotherapists and orthopedic specialists accordingly sought appropriate methods to treat this disorder. Among these, non-surgical procedures, particularly corrective exercises, have received greater emphasis.[3,4]

Performing these movements correctly during home exercises is challenging, and their proper execution is crucial. Since these exercises must be done repeatedly, patients often experience fatigue, which may make them avoid performing the exercises correctly, reducing therapeutic effects. Therefore, it is critical to motivate patients with spinal curvature, especially those with scoliosis, and monitor how they do such exercises.[5,6]

Nowadays, mobile health (mHealth) technologies assist rehabilitation professionals by providing decision support in healthcare, offering tools for monitoring home exercise programs, collecting reliable results or vital signs, giving feedback on body postures, mechanics, and delivering educational materials as well as motivational messages to patients. Therefore, they can improve treatment quality by enhancing patient adherence to healthcare strategies.[7,8]

Mobile health technology, due to its attractiveness, accessibility, ease of training, low cost, personalization, error prevention, and other capabilities, can be used as an effective solution for sensitive medical conditions that often require accurate guidance. Therefore, this technology can be used to teach corrective movements to patients with scoliosis.[9]

This study aimed to develop a mobile application to enhance adherence to corrective exercises in scoliosis patients and to investigate the hypothesis that the proposed application improves both recovery and the learning rate of corrective exercises.

Materials and Methods

The present study employed a quasi-experimental design and was conducted in three phases: information requirements engineering, design and development, and evaluation.

Information Requirements Engineering

Initially, the scoliosis treatment workflow was observed in some physiotherapy departments. To identify and determine the information requirements, relevant library resources were searched, and data on scoliosis management were collected. The gathered information was then provided to three physiotherapists and three technical experts (a programmer, a medical informatics specialist, and a health information management expert) in the form of a questionnaire used during focus group sessions. Focus group sessions were held in three sessions, each lasting one and a half hours, at the Faculty of Rehabilitation, Tabriz University of Medical Sciences, Iran.

The questionnaire consisted of four parts: (1) patient personal information, (2) patient clinical information, (3) disease management, and (4) application capability. Items were rated on a five-point Likert scale ranging from "very important" to "not important at all". During the sessions, participants completed the questionnaire and selected and approved the key information requirements. At this stage, both functional and non-functional requirements, as well as data elements of the application, were determined. In the present study, the rule-based reasoning was used to define decision-making rules based on domain knowledge derived from clinical guidelines and expert opinions using the "if-then" format.

Application Design and Development

In the design and development phase, the system was developed over a period of three months at no cost by the research development team, which included three technical experts (a programmer, a medical informatics specialist, and a health information management expert). An agile methodology was adopted, based on the knowledge extracted in the previous phase.

In the design phase, to establish the application content (appropriate exercises for scoliosis), the exercises were categorized into five areas: hanging, mobilization, shaping, stretching, and education. A physiotherapist specializing in scoliosis exercises performed the movements, which took 20 hours in total. A physiotherapy specialist monitored the correctness of the exercises. The exercises were recorded using a high-quality Sony FDR-AX33 camera and edited using Adobe After Effects CC 2017 v14.1 software. In addition to the videos, audio instructions were added for further learning purposes. Moreover, the system requirements were modeled by selected unified modeling language (UML) diagrams, such as use case and activity diagrams, created with Visual Paradigm software.

In the development phase, the user interface and database layers of the system were designed using Android Studio, Android SQLite, and the Java programming language. The resulting system was an Android-based mobile application.

When the system was installed and launched, it prompted the therapist to create a user profile. The system then required the therapist to register a new patient and enter the patient's code. In the next step, the system recommended a list of exercises based on the type of scoliosis selected by the therapist. The therapist then selected and assigned the desired exercises. The therapist was informed of the exercise by the patients. Moreover, the patients could also register in the system and enter the code. In the subsequent step, they could see and do the exercises. The exercise videos could be downloaded once and played multiple times. The system included features such as profile editing, reset, search, settings, navigation options, a status bar, exercise reminders, text and image guidance, educational videos, and step-by-step user assistance explaining how to use each section of the application.

Pilot Study and Evaluation

The evaluation phase of the study consisted of several parts. The first was an interventional evaluation to evaluate the effect of the system on patients' recovery rate and learning of corrective exercises in patients with scoliosis. For this purpose, scoliosis patients who visited the rehabilitation center affiliated with Tabriz University of Medical Sciences (Tabriz-Iran) from April 2020 to July 2020 were considered. After obtaining anterior-posterior imaging and grading their spinal curvature, individuals who met the inclusion criteria were invited to participate in the study. The inclusion criteria were as follows: female gender, idiopathic scoliosis with a Cob angle between 20-40 degrees, basic information literacy, age between 15-30 years old, having a smartphone with an Android operating system, and no history of spinal surgery or rehabilitation. Further, physiotherapists interested in collaborating in the study were also included, while others were excluded from the study. The sampling method used was convenience sampling. The Cobb method was applied to measure the spine curvature.

Participants were randomly assigned to case and control groups (n = 10 per group). The patients in the case group received their exercise programs through the mobile application. Both physiotherapists and patients were trained on how to use the application. In contrast, the patients in the control group received their exercises through face-to-face physiotherapy sessions at a clinic.

Then they received a worksheet containing exercise illustrations and were instructed to continue the exercises accordingly.

The exercises were performed 12 times per week, with each session lasting approximately 90 minutes. To assess the effect of the system on patient recovery rate, Cobb angles were measured before and after the intervention in both study groups. To evaluate the system's impact on exercise learning, both groups performed the exercises in the presence of an expert physiotherapist after the intervention, who qualitatively rated their performance as good, moderate, or poor. This evaluation was conducted in a double-blind manner.

The second part of the evaluation phase focused on assessing program usability. For this purpose, the User Experience Questionnaire (UEQ), which evaluates six dimensions (attractiveness, perspicuity, efficiency, dependability, stimulation, and novelty) was administered to participants in the case group after the intervention.[10] Finally, the application was evaluated in terms of accuracy. Data related to the classification of corrective exercise types were collected simultaneously by physiotherapists using paper forms and through the application. A confusion matrix was used to evaluate the accuracy of the classification model's predictions. The physiotherapist's opinion served as the gold standard for assessing the system's accuracy.

Statistical Analysis

All data were collected from the patients who referred to the rehabilitation center affiliated with Tabriz University of Medical Sciences (Tabriz, Iran) and met the inclusion criteria. Further, experts with more than three years of experience who were interested in collaborating were included in the study.

In the information requirements engineering phase, data collected through the checklist, which included information obtained from literature searches and focus group sessions, were entered into Excel software and analyzed qualitatively. Items rated as "important" or "very important" were selected for inclusion in the system design.

In the evaluation phase, data obtained from Cobb angle measurements were entered into SPSS Version 24.0 software and analyzed using the Wilcoxon signed-rank test. To measure the effect of the system on exercise learning in patients with scoliosis, the collected data were analyzed qualitatively according to expert evaluations, categorized as "good", "moderate", or "poor".

For the usability evaluation, the data were entered into Excel version 2019 software and analyzed using descriptive statistical methods. Finally, to measure system accuracy, the obtained data were entered into a confusion matrix and analyzed using the following equation, where TP refers to a true-positive rate, TN to a true-negative rate, FP to a false-positive rate, and FN to a false-negative rate.[11]

$$Accuracy = \frac{TP + TN}{Total}$$

Results

Three members of the focus group were physiotherapy specialists, and three were technical experts. All six participants worked at the university, and two had more than 15 years of professional experience. The mean age of the referred patients was 17.5 years. All 20 patients (100%) with scoliosis were female. In addition, most patients were single and held a diploma degree. Table 1 presents the characteristics of the focus group members and patients.

To determine the rules related to determining scoliosis types, the Schroth method was selected and validated among all available items. A total of 51 corrective exercises were identified for scoliosis treatment and divided into five main categories: Shaping, Stretch, Mobilization, Hanging, and Education. The information requirements used for developing the application are presented in

Table 1. Characteristics of the Participants

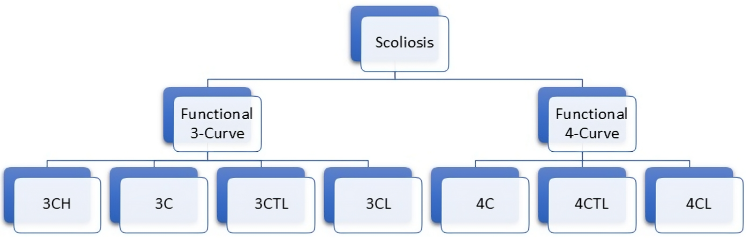
Items		Frequency (%)
Characteristics of focus group members		
Gender	Female	3 (50)
	Male	3 (50)
Age	20-30	2 (33.33)
	30-40	3 (50)
	40-50	1 (16.67)
Academic background	Bachelor	0 (0)
	Master	1 (16.67)
	Doctor	5 (83.33)
Organization	Company	0 (0)
	University	6 (100)
	Other	0 (0)
Job experience	<5	1 (16.67)
	6-15	3 (50)
	>15	2 (33.33)
Characteristics of the Patients		
Gender	Female	20 (100)
	Male	0 (0)
Age	10-20	16 (80)
	20-30	4 (20)
	>30	0 (0)
Marital status	Single	11 (55)
	Married	9 (45)
Academic background	Illiterate	0 (0)
	High school	3 (15)
	Diploma	10 (50)
	Bachelor	7 (35)
	Master	0 (0)
	PhD	0 (0)

Table 2. The extracted rules, comprising seven rule-based reasoning models, were implemented in the rule-based engine and were used for determining scoliosis type. Figure 1 illustrates the knowledge representation process as a decision tree.

Figures 2 to 4 show the functional requirements of the application, while Figure 5 shows a section of the developed application's graphic user interface module. The application supported multiple processes, including user login, patient registration, unique code generation,

Table 2. Areas and Types of Corrective Exercises for Scoliosis Patients

No.	Area	Type	Exercise
1	Hanging	3-curve	Butterfly, Air cycling, Pendulum legs, Abdominal muscle strengthening
		4-curve	Butterfly, Air cycling, Abdominal muscle strengthening
2	Mobilization	3-curve	Squat with wall-bar, Sagittal circling with the trunk, Diagonal circling with the trunk, Sagittal circling, Chest-straddle position on the chair, Raising hands while sitting on the floor
		4-curve	Squat with wall-bar, Raising hands while sitting on the floor, Chest-straddle position on the chair, Sagittal circling with the trunk, Sagittal circling
3	Shaping	3-curve	Great arch, Oblique traction, Neck posture corrective exercises, Grabbing the back of the seat from behind, Head under the desk, Rotational sitting with a Swiss ball, Rotational sitting, Side bridge (3-curve scoliosis), Putting the weight on one foot, Corrective rotation in the pelvis, Muscle cylinder exercise
			Shaping with wall-bar, Raising the right sulcus shaping (3-curve scoliosis), Lowering the right sulcus in the standing position, Hip shift correction
		4-curve	Great arch, Rotational sitting with a Swiss ball, Head under the desk, Grabbing the back of the seat from behind, Neck posture corrective exercises, Oblique traction, Correction of lumbosacral curvature (4-curve scoliosis), Side bridge (4-curve scoliosis), Correction of lumbosacral curvature 2 (4-curve scoliosis), Raising the right sulcus, Shaping with wall-bar, Raising the right sulcus, Lowering the right sulcus, 3D made easy (4-curve scoliosis)
4	Stretch	3-curve	Pulling toward wall-bar, Resistive pelvis shift, Strap-holding exercise, Lifting the trunk with two bars, Stretching in the sitting position using a bar, Prostration in the kneeling position, Exercise to stretch and strengthen the back in the low sliding position
		4-curve	Pulling toward wall-bar, Strap-holding exercise, Lifting the trunk with two bars, Stretching in the sitting position using a bar, Prostration in the kneeling position, Exercise to stretch and strengthen the back in the low sliding position
5	Education	3-curve	Sitting training (3-curve scoliosis), Standing training with flat back (3-curve scoliosis), Standing training with kyphosis (3-curve scoliosis)
		4-curve	Sitting training (4-curve scoliosis)



Item Type	Pelvic Shift	Trunk Compensation	Curve Apex	Number of Curves	Wedge Sign	Sulcus's Direction
3CH	Left	50/50	Not important	3	×	Left sulcus is higher
3C	Left	Exist	Not important	3	×	Left sulcus is higher
3CTL	Left	Doesn't Exist	T_{12}–L_2	1	×	Left sulcus is higher
3CL	Right	Doesn't exist	L_2–L_2	1	×	Left sulcus is higher
4C	Right	-	Not important	-	√	Right sulcus is higher
4CTL	Right	-	T_{12}–L_2	-	√	Right sulcus is higher
4CL	Right	-	L_2–L_2	-	√	Right sulcus is higher

Figure 1. A Comprehensive Scheme of Decision-making Rules

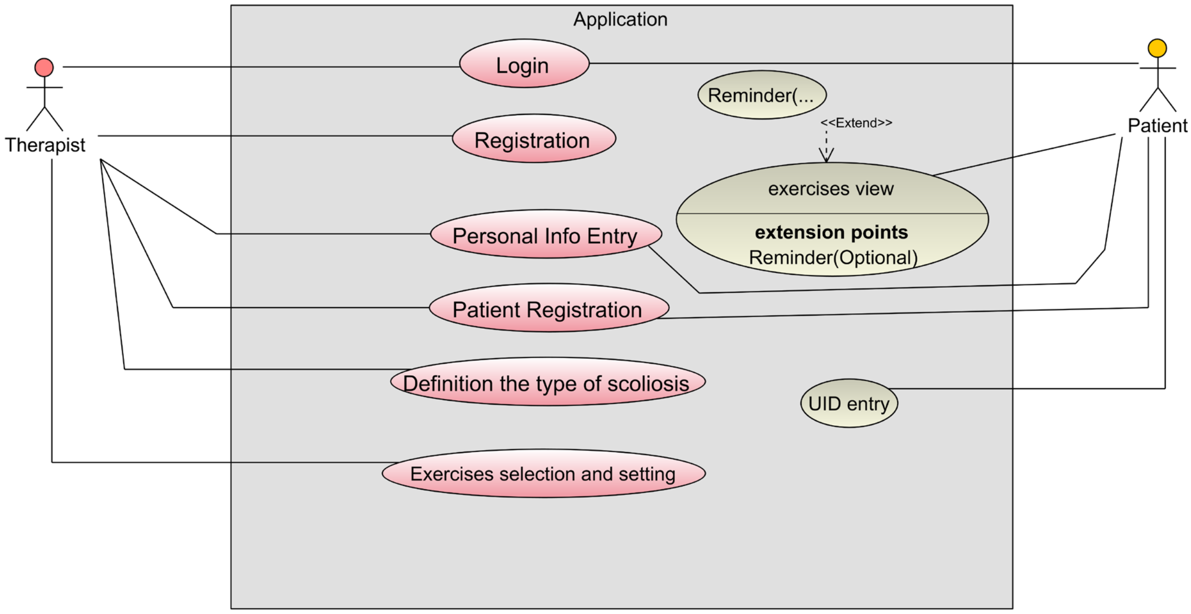


Figure 2. Use Case Diagram of Application

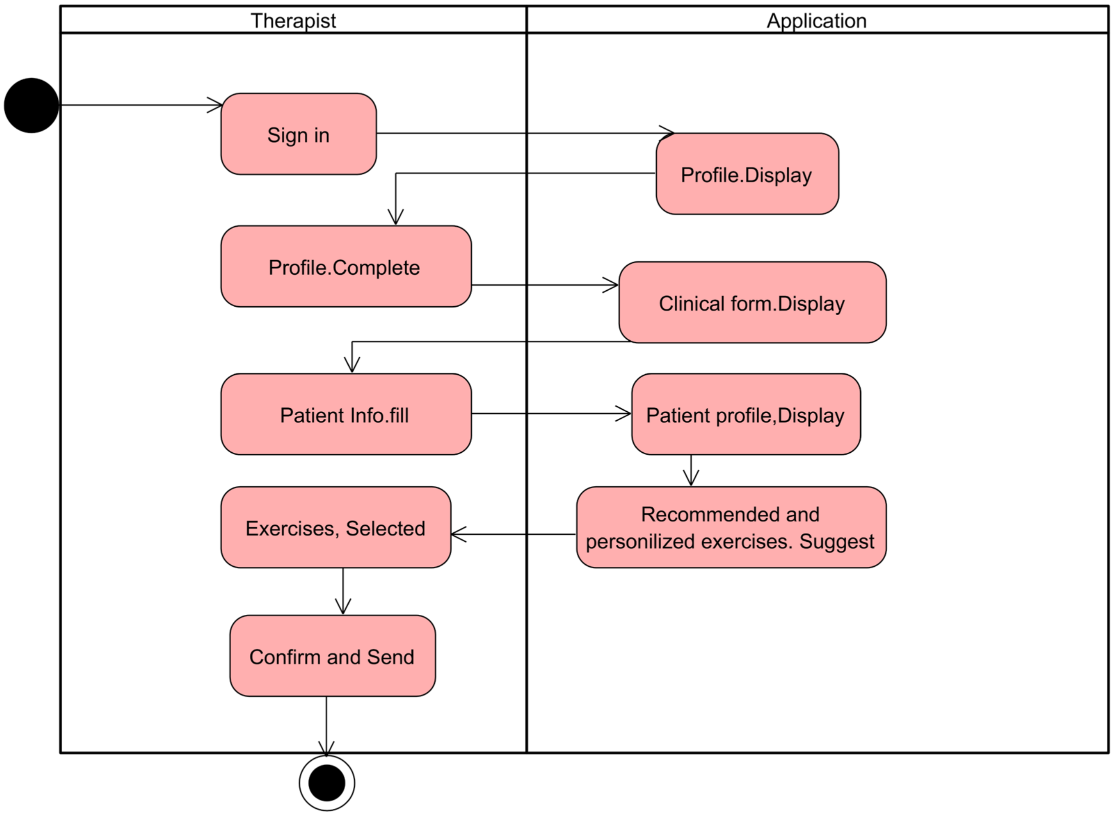


Figure 3. Activity Diagram of Application (Interactions between a therapist and the application)

registration of patient information, scoliosis type determination, selection and customization of corrective exercises, exercise notifications, observation, feedback, and reminders.

The results of the evaluation phase revealed that, in the case group, there was a significant relationship between application use and recovery rate ($P=0.004$). According to the Wilcoxon test, there was a significant difference in the Cobb angle in the case group before and after the intervention, with the improvement being greater in the case group than in the control group. Considering the 95% confidence interval (CI), the application had a positive effect on patients' recovery (Table 3). Overall, 80% of the patients in the case group demonstrated good exercise learning after using the application, compared to only 30% in the control group. Therefore, the use of the application also had a positive effect on the rate of learning corrective exercises. Furthermore, analysis of

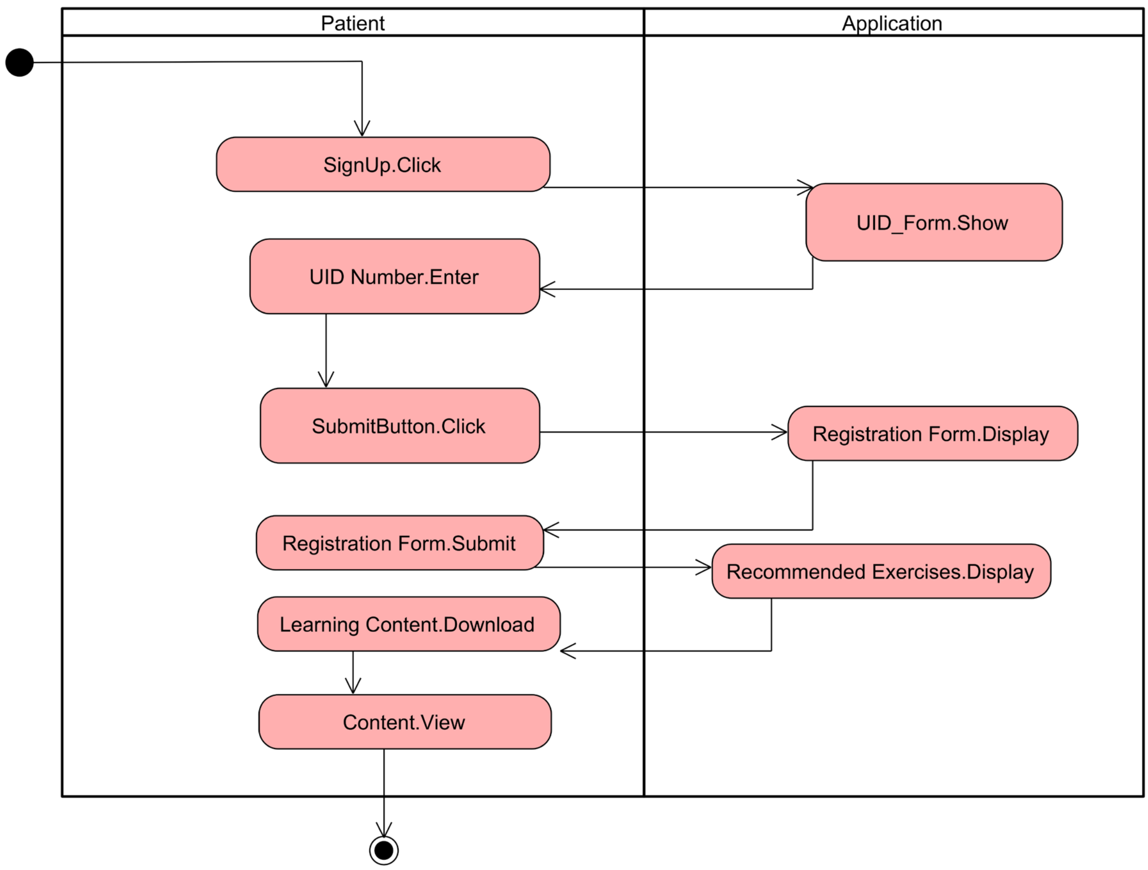


Figure 4. Activity Diagram of Application (interactions between a patient and the application)

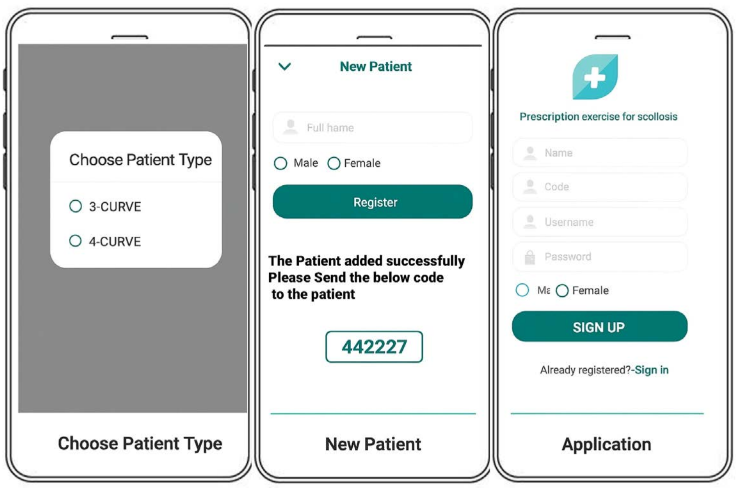


Figure 5. The Screenshot User Interface of the Application

the confusion matrix showed that the system accuracy was100%.

The results of the usability evaluation demonstrated that the highest score was associated with the "perspicuity" dimension, while the lowest was associated with the "stimulation" dimension of the application (Figure 6). The application achieved results within 10% of the best outcomes reported in other studies in terms of attractiveness, perspicuity, efficiency, dependability, and novelty, and was within 75% of the lowest scores in terms of stimulation.

Discussion

The present study developed a smartphone-based application that provided a comprehensive home exercise program through an interactive platform for managing scoliosis. In this study, 51 corrective exercises were identified for scoliosis treatment, and seven rule-based reasoning models were used in comprehensive decision-making rules. Identifying and determining data elements are the main tasks of data collection to achieve the appropriate functionality of applications. A review of existing research showed that there was no standard or

Table 3. Changes in the Cobb Angle Before and After the Intervention in Study Groups

Groups	Before n (mean ± SD)	After n (mean ± SD)	*P* value	Before 95% CI [lower-upper]	After 95% CI [lower-upper]	Before Max (min)	After Max (min)	Before Q1, Q3 (IQR)	After Q1, Q3 (IQR)	Before median	After median
Case	10 (30.10 ± 5.68)	10 (17.60 ± 10.56)	0.004	30.10 ± 3.52 [26.58 – 33.62]	17.60 ± 6.54 [11.06 – 24.14]	40 (20)	30 (0)	26, 35 (9)	16, 25 (9)	30	18
Control	10 (29.80 ± 10.56)	10 (22.30 ± 10.13)	0.008	29.80 ± 6.54 [23.26 – 36.34]	22.30 ± 6.27 [16.03 – 28.57]	40 (20)	35 (0)	25, 35 (10)	18, 27 (9)	28	23

Note. **SD:** Standard deviation; **CI:** Confidence interval; **Max:** Maximum; **Min:** Minimum; **Q1:** First quartile; **Q3:** Third quartile; **IQR:** Interquartile range.

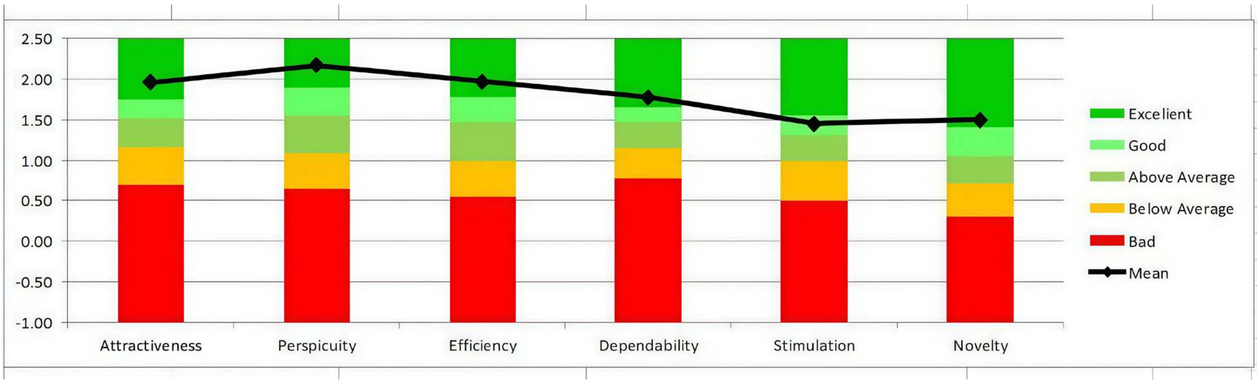


Figure 6. Usability of the Application Based on User Experience Questionnaire

uniform format for data collection in this field. Therefore, it is essential to determine data elements at early stages of mobile-based application development for scoliosis management.[12]

Various methods have been suggested for scoliosis in recent studies. Among them, the Schroth is the most widely used, and it was selected for implementation in the present study. The Schroth Method is a nonsurgical approach to scoliosis treatment. It uses individualized exercises designed to return the curved spine to a more natural position. The goal of Schroth exercises is to de-rotate, elongate, and stabilize the spine in a three-dimensional position. The ultimate aim of the Schroth method is to reduce dysfunction and alleviate pain experienced by patients in daily activities.[13] This method benefits patients by utilizing techniques that inhibit the progression of the spinal curve, restore muscular symmetry within the body, improve respiratory function, and enhance postural awareness. In some cases, the Schroth method has even been reported to reverse the irregular scoliosis curve.[14]

The results of the evaluation phase revealed that the application had a positive effect on the patients' recovery and rate of learning corrective exercises. A smartphone application was also developed for home exercise programs in a study by Lambert et al,[15] and their findings similarly demonstrated the positive effect of a mobile-based application on patients' recovery. The above-mentioned application was compatible with the application designed in the present study in terms of platform, although they differed in terms of their purposes and functionalities.

The smartphone is a complex tool that connects people to a world of information. In recent years, smartphone use has increased significantly. Features such as interactive screens, fast and easy access, data transfer and tracking, and wide availability have made smartphones more commonly used than other devices for internet access and health applications.[15] The positive effect of the mobile-based application on patients' recovery can be attributed to better learning exercises and greater adherence to corrective exercises, which are related to the advantages mentioned above. In addition, the results of the present study are similar to those of Baek et al, in which self-exercise programs were designed for female farmers with musculoskeletal problems.[16,17]

According to the results, the accuracy of the application was 100%. The proposed application used rule-based reasoning methods instead of machine learning algorithms. A rule-based reasoning approach is a well-known method suitable for designing evidence-based systems. The results of some studies indicate that a rule-based reasoning approach achieves high accuracy compared with other machine learning methods. The current study also indicated that domain knowledge should be available to developers in guideline-based medicine, as rule-based reasoning methods are more efficient in design and easier for stakeholders to understand. Some machine learning algorithms, such as artificial neural networks, behave as "black boxes", meaning their inference processes are unclear and difficult for experts to interpret. In contrast, a rule-based reasoning algorithm functions as a "white box", allowing clear analysis of the problem-solving process in many health-related challenges. Given the uncertainty inherent in medicine, rule-based reasoning methods help analyze the relationships between rules and outcomes.[18,19]

Application usability evaluation showed that users were generally satisfied. Consistent with the present study, another study developed a rehabilitation program for elderly individuals with musculoskeletal disorders. The results demonstrated a relatively high level of user satisfaction.[12]

There are various approaches, ranging from video conferencing to complex sensors, gamification, and virtual reality technologies, for supporting rehabilitation and assisting patients with musculoskeletal disorders in performing exercises at home. However, most of these methods are not practical in the real-world settings, and the equipment used in such an approach is expensive. Cost-effectiveness is a crucial factor in the applicability of any system.[20,21] In the current study, although many technological options were available, the design was limited to the resources available to patients and aimed to minimize cost burdens on them; therefore, the design was limited to the present approach.

According to the research findings, it is recommended that the application be redesigned, implemented, and evaluated for other types of spinal curvatures. It is also suggested to use interactive tools, sensors, and business intelligence technologies to increase user satisfaction and adopt a web-based architecture in the design to ensure unrestricted access to the application.

Conclusion

An application based on clinical guidelines and physiotherapists' opinions was designed and evaluated in the present study. The results indicated that the designed application had a positive effect on patients' recovery and learning rate. Therefore, considering that scoliosis is a common musculoskeletal disorder and that modern models of care increasingly emphasize patient involvement and self-management, the designed application could serve as a basis for developing broader, similar systems and programs for treatment management, patient monitoring, emergency response, personalized health tracking, and widespread access to healthcare information in low-income countries.

Clinical Relevance

- Treatment of scoliosis, a common musculoskeletal disease, requires proper corrective exercises.
- In scoliosis management, the mobile-based application improves adherence to corrective exercises and ensures their correct execution.
- The proposed mobile-based application empowers scoliosis patients, enhances the quality of care, and positively impacts recovery rates.

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Competing Interests

None.

Ethical Approval

This study was reviewed and approved by the Ethics Committee of Tabriz University of Medical Sciences (IR.TBZMED.REC.60315). All patients provided written informed consent. All methods were carried out in accordance with relevant guidelines and regulations.

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