ExercisePill: An Exercise Application for Balance Problems in the Elderly

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Abstract—ExercisePill is a Microsoft Kinect®-based exercise application developed for balance problems in the elderly. There were three factors to be considered when developing the application. First, it must be functional, usable, and reliable. To ensure this, each of the 20 participants in the program was observed and evaluated by experienced physicians over the course of the 2 months duration of the program. The 20 participants were equally divided between a control group and an exercise group. Testing of the app and a following satisfaction survey were the primary methods applied for measuring the reliability of the application. The second factor was in-home or unsupervised exercise, necessary for reasons such as the time and cost of transport for patients to attend medical centers. This, and other social and personal problems, tended to have a demotivating effect on the elderly influencing them to undertake beneficial exercise programs privately. Especially this latter aspect of the situation gave rise to the third important factor to be addressed, and that was the ability to monitor the progress of the patient. This gave rise to the development of a database in which the results for each exercise are stored and which can be checked anytime. The results from the program showed that the exercise group, who had used the computer application, had remarkably higher scores in most of the balance tests, indicating the effectiveness of the application.

Keywords—health apps, rehabilitation exercise, elderly adults

1 Introduction

Balance problems in the elderly create the serious risk of falls as well as dizziness and faintness which further create the risk of falls. Falling is dangerous, resulting in often serious, even life-threatening injuries. As people grow older, their muscle mass and strength decline significantly [1]. Balance training programs for the elderly, involving daily routines of appropriate activities best rely on the direct and attentive involvement of a physical therapist. However, such programs that include the presence and close involvement of a physical therapist may not be available to many elderly persons in the community due to the cost, time involvement, and social disruption that often arises from the need to attend a medical or therapy center. Home-based or unsupervised exercise routines therefore are an essential element in making these important programs accessible to many elderly people in the community. However, while such home-based and unsupervised programs are essential and do play an important role in the health and physical well-being of the elderly, ways must be found that overcome the problem of lack of continuous exercise and inefficient use of personal time and ineffective application of appropriate techniques that may occur when undertaken in an unsupervised manner [2]. These were the factors that informed and drove the development of an application for computer-assisted balance training programs that could be practically implementation and applied.

There are many prominent balance tests used in clinical evaluation including the Berg Balance Scale (BBS) [3], the Fall Efficiency Scale (FES), Functional Reach Test (FRT) [4], Timed Up & Go Test (TUGT) [5][6], Five Times Sit to Stand Test (FTSST) [7], Hand Grip Strength Test (HG) [8] and Gait Speed Test (GST) [9][10]. These scoring systems are the most widely used by experienced clinicians and result in the collection of data with high reliability and validity.

Recently, there has been research undertaken and published that focused on the Microsoft KinectV2® as a computer device suitable for this purpose. The KinectV2® has an RGB camera, 3D-motion capture and skeletal tracking, together with virtual reality technology, have become available. Virtual reality technology is now a widely researched topic with its application to many research areas [11]. Chen et al. proposed a system for exercise-based Yoga training called YogaST which included instructions for performing postures correctly [12]. A martial art learning system proposed by Chye et al. uses Kinect sensors in a game-based approach [13]. Rehabilitation is also a favorite area in which real-time and virtual reality technology has been applied by many researchers [14][15][16][17][18]. Real-time visualization feedback has also gained attention in several studies. For example, a dance training framework proposed by Muneesawang et al. exploits a cave automatic virtual environment [19] (better known by the recursive acronym CAVE) which is an immersive virtual reality environment where projectors are directed to between three and six of the walls of a room-sized cube to bring an additional impression. As well, Chan et al. proposed a practical scoring method for feedback and for calculating a score when using clinical data [20].

In the health area, both stroke rehabilitation and Parkinson's disease have been studied by using body movement evaluation [21][22][23]. However, most of this research focused on the accuracy of their methods. There has been no study to investigate the impact of each method and the beneficial outcomes for patients: an application that was proven to be trustworthy, by rating the various balance tests referenced above, was necessary.

This, then, was the objective of this research: to measure the balance assessments of elderly participants who were using, a specific KinectV2 application in a clinical environment and compare their outcomes to elderly participants who were doing the same exercise routines but without using the application. The duration of the research activity was 2 months during which time the progress of each subject was tracked with data collected to allow the evaluation of the various methods and their effectiveness for the purpose of balance training in the elderly.

The set of evaluated balance tests used in this research included BBS, FES, FRT, TUGT, FTSST, HG, and GST. All participants were closely observed by experienced physicians, and the program was accomplished without any injuries.

2 Designing components

The application applies two important methods. The first method is an Incremental Dynamic Time Warping (IDTW) algorithm for comparing the similarity of two gestures seen through the Microsoft Kinect sensor. The second method is color-based and scoring visualization feedback for monitoring the progress of users in real-time via color line on a skeletal body and scoring number on the screen. The overall application has 3 modules (shown in Figure 1).

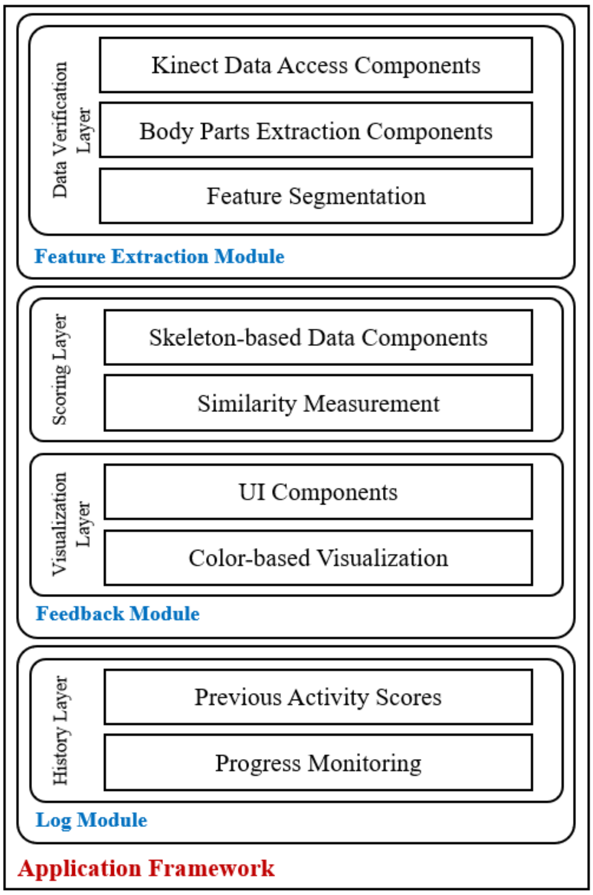

Fig. 1. Structure of conceptual framework

2.1 Feature extraction module

The feature extraction Module uses the 3D coordinates of specific points on the skeleton as data. Let a skeleton data point be indicated by $S = \{X_L\} \mid L = 0, \dots, 25$ where X represents the 3D coordinates of 25 joints on the skeleton. Normalization was used to ensure the comparability of the results by scaling each data into the same ratio. The hip joint of the skeleton is the central, designated parent joint X^0. Then the formula for the normalized joints is $norm\ X_L = X_L - X_L^0 / \|X_L - X_L^0\| \mid L = 0, \dots, 25$. Each joint is grouped into four segments: the upper left, upper right, lower left, and upper left segments of the skeletal structure. The upper left part consists of the left hand, left wrist, left elbow, and left shoulder. The lower left part consists of the right hand, right wrist, right elbow, and right shoulder. The upper right part consists of the left foot, left ankle, left knee, and left hip, and the lower right part consists of the right foot, right ankle, right knee, and the right hip.

2.2 Feedback module

The feedback module was divided into the visualization part and the scoring part (shown in Figure 2). Exercise movements are visualized as temporal sequences and the visualization processing measures the similarity between two sequences by applying incremental dynamic time warping, achieving highly accurate results than a classic DTW algorithm. IDTW is a classic DTW with the two additional features of matching a partial sequence with a complete trainer's sequence and then reusing the calculated sequences [3].

Let a trainer user sequence be represented by $U = \{u_1, u_2, \dots, u_n\}$ where u is a trainer's movement sequence of normalized joints and n is the number of total frames of the sequence. Let a volunteer user sequence be represented by $V = \{v_1, v_2, \dots, v_m\}$ where v is a volunteer's movement sequence of normalized joints and m is the number of frames of the sequence. IDTW is divided into two parts: finding the distance and warping the path. The distance between the sequences is calculated as:

$$d(u_i, v_j) = \|u_L - v_L\|, L = 0, \dots, 25 \quad (1)$$

After calculating every distance for each instance in the sequence, an optimal warping path is determined using a classic DTW. The warping path for IDTW is also calculated by finding a minimum value of the possible frames as:

$$D(U, V) = \frac{1}{T} \sum_{t=1}^{T} d(P_t) \quad (2)$$

$$D_{IDTW}(U, V) = \min_{i=0,\dots,m} D(U_i, V) \quad (3)$$

where T is the number of visited paths P and i is the number of possible frames of the trainer's sequence U_i. As the result of reusing the calculated sequences, IDTW is much less time consuming than DTW.

Color-based visualization indicates how well a user can perform in each movement in a comparison with the trainer image presented on the screen. The colors used in the visualization were blue, green, yellow, red, blue, each representing a level of similarity between the trainer's movements and the participant's movements. Red represents the least similar movement with level of similarity increasing across that set of colors, with blue representing almost equality. While doing the exercises, this color-based visualization provides real-time feedback to give the user the immediate opportunity to adapt their movement based on the color they are seeing.

Scoring visualization is displayed as the overall result of the performance of each movement. The scores vary from 0 to 100 with 0 as the worst and 100 as the best score of similarity. Such scoring motivates the user to achieve a higher score. Adapting from IDTW, the score is calculated as:

$$s = \frac{1}{2}\left(D^{a}_{IDTW} + D^{b}_{IDTW}\right) \tag{4}$$

$$z = e^{-v*s} \tag{5}$$

where a and b are comparing grouped segments. Here, v is a sensitivity parameter. The higher value of v causes the feature less likely tolerant to mistake. In this research, the suitable value of v was set to 20 for an accurate score which is a similar practice in previous research where the value of 20 has been used frequently.

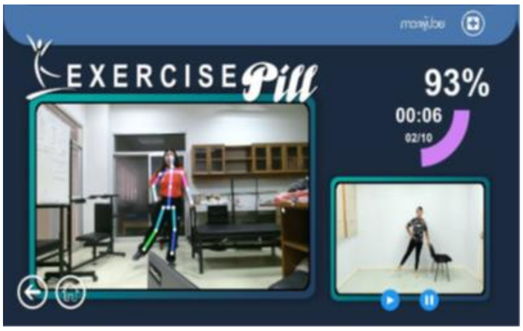

Fig. 2. Skeletal visualization and scoring feedback screen

Fig. 3. An actual environment of application demonstration

2.3 Log module

The log module collects results from every user in a database (shown in Figure 4) for comparing their improvement. Using both percentage score and a graph, a user can check if there are any movements on which they need to improve.

Fig. 4. Score summary screen in log module; (Top) Scoring results of each movement and (Bottom) graph-based progression summary

3 Application description

ExercisePill is a Windows-based application developed with Microsoft KinectV2® using the Unity engine. Figure 5 shows the overview of the application's user interfaces. Starting from the login page, every user is identified by a unique id that is used to track everyone's progress record. After login, the user is asked to take a physical activity readiness questionnaire (PAR-Q) in a questionnaire page to ensure that they are qualified to use the application. In the exercise selection page, the exercise movements can be selected by the qualified user. The demonstration video and description of each movement are shown in advance to prevent any confusion for the user. In the exercise page, while facing KinectV2®, each user matches the exercise movements displayed on the video. The optimal distance between user and KinectV2® is 1.5 meters. Having completed a selected movement program, the overall similarity score of the user's movements to the displayed movements is displayed in the analysis page. The users can choose to either repeat a movement program or select a new movement. The analysis page shows similarity percentages and a progression graph for each movement that has been done so far.

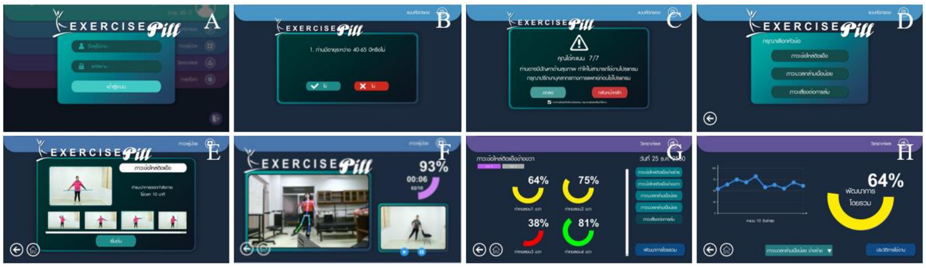

Fig. 5. Application user interface (A) Login page (B)/(C) Questionnaire page (D)/(E) Exercise selection page (F) Exercise page (G)/(H) Analyze page

4 Experiment

This research was a long-term experiment focused on elderly participants who had diagnosed balance problems. The duration of the research was 2 months. The elderly participants were divided equally into 2 groups: a control group and an exercise group. The exercise group used the application while the control group did not. The 7 types of evaluation methods are BBS, Modified Thai FES (MFES), FRT, TUGT, FTSST, HG and GST.

The 20 elderly participants were all aged 60-69 years, and were residents of Tha Poe district, Thatong district, areas nearby Naresuan University which ensured that the participants could attend evaluation sessions conveniently.

All twenty participants were instructed on the exercise routines and had read manuals on fall prevention published by the Foundation of Thai Gerontology Research and Development Institute (TGRI) [24]. They were also shown how to exercise for each 15–20 minute exercise session that would undertake.

For both the control group and the exercise group, 13 standard movements from the Otago Exercise Program [25] were practiced by the participants, with each movement repeated in a set of 10 repetitions, with each movement practiced for both the left-hand side and the right-hand side. The overall process took about 1 hour three times a week for the 8-week duration.

4.1 Control group

The control group included 10 participants. During the two months experimental period, the control group exercised without the application. They were also asked to respond to a health questionnaire once a week. After the 4th week, i.e., the mid-point of the period of the activity, and the last week, the control group were asked to exercise with the application which would provide information on the similarity of their exercise movements compared to the trainer exercises. Apart from these two test sessions, the control group exercised without the application for the whole period.

4.2 Exercise group

The 10 participants in the exercise group used the application to undertake their exercise program continuously during the 8-week period thereby being given constant, real-time feedback on their movements by the color-based visualization feedback process of the application.

4.3 Experiment implementation

The exercise coaching application developed has 13 original movements programmed into it. The participants in the exercise group were required to imitate the training model movements, on the training video, as closely as possible. The level of similarity achieved was continuously notified by an overall percentage score or on the color-based illustrative bone lines on a skeletal model which showed as blue-green-yellow-red, as discussed previously.

4.4 Movement and how to exercise

Movement sets appropriate to elderly adults were chosen from The Otago Exercise Program which focuses on strength and balance exercises [25]. Each movement can be prepared and followed without any support from a physical therapist, and important factor in the home-based unsupervised exercise which was a priority in the research.

In this implementation, the volunteers were asked to exercise in 6 movements (A1 – A6) for the first 4 weeks. After the 4th and 6th weeks, the volunteers were introduced to 3 new movements each time: B1 – B3 after the 4th week, C1 – C3 after the 6th week (shown in Figures 6 – 8). For participant safety, appropriate first aid preparations were made for the possibility of dizziness or faintness, or to treat discomfort arising from rheumatism or other conditions. For the worst-case scenario of injury to a participant or some serious medical issue arising, that participant would be sent to the emergency department at Naresuan University Hospital.

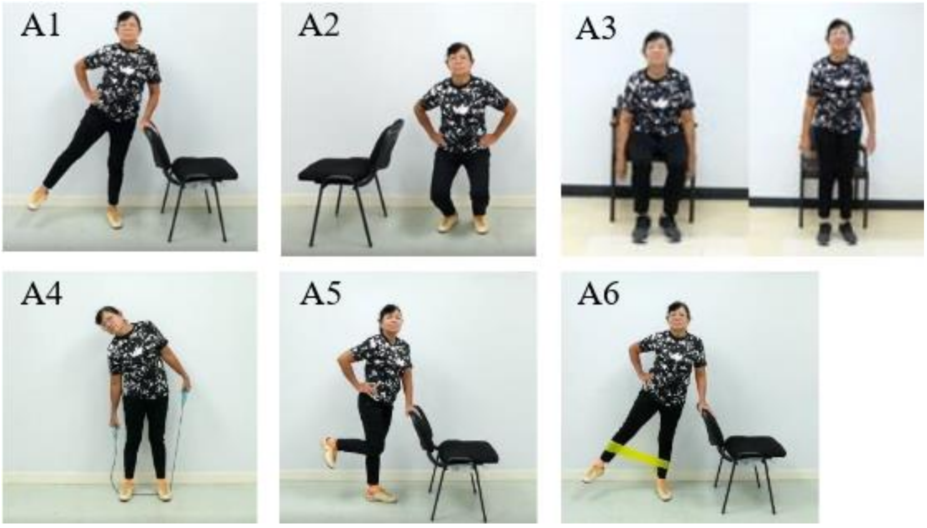

Fig. 6. Movement set (A1) Single leg standing with hip abduction (A2) Both knee flexion (A3) Sit to stand (A4) Lateral trunk flexion (A5) One knee flexion (A6) Single leg standing and hip abduction with elastic band

Fig. 7. Movement set (B1) Single leg standing with hip abduction and knee flexion (B2) Single leg standing with hip flexion and abduction (B3) Sideways walking (B4) Arm abduction and side-ways walking

Fig. 8. Movement set (C1) Single leg standing and hip flexion with elastic band (C2) Single leg standing and hip extension with elastic band (C3) Squat and shoulder flexion with elastic band

4.5 Result

Table 1 shows the users satisfaction survey scores collected at the end of the experiment. The survey consisted of two topics: appearance and usability. The participants indicated a high satisfaction score for both the design and appearance of the user interface $\bar{x} = 4.92, SD = 0.28$ and usability of the application $\bar{x} = 4.75, SD = 0.77$. Some of participants suggested many application improvements such as hand gesturing or voice commands for application control.

Table 1. User satisfaction score

Topic	**User's satisfaction**					$\bar{x} \pm SD$
	5	***4***	***3***	***2***	***1***	
1. Contents and UIs						
Resolution	10	2	0	0	0	4.83±0.39
Beauty	12	0	0	0	0	5.00±0.00
Easy to understand	11	1	0	0	0	4.92±0.29
Average score						4.92±0.28
2. Usability						
Easy to use	10	0	1	1	0	4.58±1.00
Understanding of instruction	12	0	0	0	0	5.00±0.00
Understanding of feedback and score	11	1	0	0	0	4.92±0.29
Practically useful	8	1	2	1	0	4.25±1.29
Overall usability	12	0	0	0	0	5.00±0.00
Average score						4.75±0.77
Summary score						4.81±0.64

Table 2 shows the *p*-value of each balance test for both the control group and the exercise group. The critical *p*-value was less than 0.05. For the balance-focused tests, the control group showed no significant change in outcomes over the two months period, except for BBS, whereas the exercise group showed positive changes in many of the tests, including BBS, MFES, FRT and GST. The balance-focused tests indicate how well the participants can maintain their balance, which means the application was effective in helping the participants in the exercise group to improve their balance. For the strength-focused tests, the exercise group showed an improvement only in FTSST. However, there were no major improvements in the control group at all. Overall, there are not many improvements achieved by the strength-focused tests. This is not considered to be a problem because muscular strength was not a focus in this research, even though it is a bonus effect derived from the exercises

In this implementation, the volunteers were asked to exercise in 6 movements (A1 – A6) for the first 4 weeks. After the 4th and 6th weeks, the volunteers were introduced to 3 new movements each time: B1 – B3 after the 4th week, C1 – C3 after the 6th week (shown in Figures 6 – 8). For participant safety, appropriate first aid preparations were made for the possibility of dizziness or faintness, or to treat discomfort arising from rheumatism or other conditions. For the worst-case scenario of injury to a participant or some serious medical issue arising, that participant would be sent to the emergency department at Naresuan University Hospital.

Table 2. Difference and standard error between pre-test and post-test of each balance tests

Parameters and time		**Control Group**		***p*-value**	**Exercise Group**		***p*-value**
		diff	***SE***		***diff***	***SE***	
Balance	BBS (score)						
	0 week – 4 weeks	1.583	0.626	0.007	3.667	0.626	**0.003**
	0 week – 8 weeks	1.917	0.556	0.002	4.333	0.556	**0.003**
	4 weeks – 8 weeks	0.333	0.376	0.521	0.667	0.376	0.046
	MFES (score)						
	0 week – 4 weeks	-0.250	4.354	0.813	12.750	4.354	**0.013**
	0 week – 8 weeks	-0.500	5.455	0.859	11.250	5.455	0.075
	4 weeks – 8 weeks	-0.250	1.978	0.859	-1.500	1.978	0.344
	FRT (cm)						
	0 week – 4 weeks	-1.229	0.868	0.512	1.490	0.868	0.301
	0 week – 8 weeks	-0.408	1.070	1.000	4.279	1.070	**0.002**
	4 weeks – 8 weeks	0.821	0.688	0.737	2.790	0.688	**0.002**
	TUG (second)						
	0 week – 4 weeks	0.435	0.372	0.764	-0.483	0.372	0.621
	0 week – 8 weeks	-0.055	0.399	1.000	-0.988	0.399	0.065
	4 weeks – 8 weeks	-0.489	0.229	0.132	-0.504	0.229	0.115
	GST (second)						
	0 week – 4 weeks	-0.523	0.409	0.272	-0.365	0.409	0.480
	0 week – 8 weeks	-0.486	0.421	0.433	-1.051	0.421	**0.015**
	4 weeks – 8 weeks	0.037	0.233	1.000	-0.686	0.233	**0.019**
Muscular Strength	FTSST (second)						
	0 week – 4 weeks	-0.167	0.621	1.000	-0.627	0.621	0.971
	0 week – 8 weeks	-0.730	0.596	0.701	-1.850	0.596	**0.016**
	4 weeks – 8 weeks	-0.563	0.255	0.114	-1.223	0.255	**0.000**
	HG (kg)						
	0 week – 4 weeks	-0.027	0.024	0.811	0.030	0.024	0.688
	0 week – 8 weeks	-0.022	0.024	1.000	0.032	0.024	0.587
	4 weeks – 8 weeks	0.005	0.013	1.000	0.003	0.013	1.000

Table 3. Evaluation methods and interpretation

Balance test	**Definition**	**Interpretation [26]**	
		Common	***Uncommon***
Berg balance scale (BBS)	The Berg balance scale is used to objectively determine an elderly ability (or inability) to safely balance during a series of predetermined tasks. It is a 14-item list with each item consisting of a five-point ordinal scale ranging from 0 to 4, with 0 indicating the lowest level of function and 4 the highest level of function.	Score: 56 points or higher	Score: 45 points or lower
Modified Thai fall efficiency scale (MFES)	Fall efficiency scale is a clinical test consisted of 14 items for measuring confidence level of balance. Modified Thai FES is a modified version which is compatible with the elderly Thai population.	Score: more than 80 points	Score: equal or less than 80 points
Functional reach test)FRT)	Functional reach test is a clinical outcome measure and assessment tool for ascertaining dynamic balance in one simple task. Functional reach is defined as "the maximal distance one can reach forward beyond arm's length, while maintaining a fixed base of support in the standing position". This test measures the distance between the length of an outstretched arm in a maximal forward reach from a standing position, while maintaining a fixed base of support.	Distance: 18.5 cm	Distance: less than 15 cm
Timed up and go test (TUG)	Timed up and go test was initially designed for elderly persons to determine fall risk and measure the progress of balance, sit to stand and walking.	Time: less than 10 seconds	Time: more than 20 seconds
Five times sit to stand test (FTSST)	Five times sit to stand test measures one aspect of transfer skill. The test provides a method to quantify functional lower extremity strength and/or identify movement strategies a patient uses to complete transitional movements.	Time: 12.9s for men/ 13.2s for women	Time: longer than common time
Hand grip strength test (HG)	The Hand grip strength test is to measure the maximum isometric strength of the hand and forearm muscles.	Strength: 26kg for men/ 18kg for women	Strength: less than common strength
Gait speed test (GST)	The Gait speed test is a performance measure used to assess walking speed in meters per second over a short distance.	Speed: 1.16 m/s for men 1.08 m/s for women	Speed: less than common speed

5 Conclusion

Our results showed that the balance ability of the exercise group participants had gradually improved over the duration of experiment. Most of the balance tests resulted in significantly improved scores for the exercise group participants. However, the control group participants had only a slight improvement or no improvement at all. The results of the satisfaction survey showed that the participants were impressed with the application and were motivated and willing to use the application in the future, even in their home-based, unsupervised exercise programs.

There are some limitations in this research that must be acknowledged. First, the two-month duration of this program limited the possible outcomes for the participants. This was demonstrated by the situation where, at the end of the two-month period, participants were starting to show better results.

This implies that a longer period would show greater discrimination between the control and the exercise group's results. Second, with only 20 participants the results may be seen as unreliable, and by increasing the scale of the research the effectiveness of the application would be more proven and there would be a reduction in the risk of result bias. Lastly, every chosen movement has a clear frontal display due to a single Microsoft Kinect limitation. The addition of more Kinect cameras with different observational directions would allow a greater number of selectable movements. Finally, we are confident that this application can be developed further and enhanced for any rehabilitation program.

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