Chapter 6

Effectiveness of an individually tailored home-based exercise program for frail older adults, driven by a tablet application and mobility monitoring: a prospective cohort trial

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Submitted
Abstract

**Objectives**

This exploratory study assesses effectiveness of a home-based exercise program for frail older adults with independent use of novel technology.

**Methods**

A prospective cohort trial. Forty transitionally frail older adults joined a six-month home-based exercise program using a tablet PC for exercise administration and feedback, and a necklace-worn motion sensor for daily physical activity registration. Subjects received weekly supervision by telephone during the first three months. Daily physical activity and mobility were assessed at baseline, after three months and after six months of training.

**Results**

Twenty-one subjects completed the program. Overall adherence to exercising five times a week was 60.8 ± 32.5%. Adherence among completers was 69.2 ± 32.2%, which was significantly higher than among dropouts. Overall, objective daily activity as well as mobility improved (non-) significantly. The improvements occurred mainly during the supervised part of the intervention.

**Conclusion**

Especially the supervised part of the program generated a trend toward amelioration on daily physical activity and mobility. Remote supervision seems essential to preserve adherence to and effectiveness of a home-based exercise program. Its effectiveness should be quantified in a randomized controlled trial.

**Practice implications**

Home-based exercising using novel technology seems promising for physical activity and mobility amelioration.

**Acknowledgements**

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Introduction

Our ageing society and its associated higher demand on health care resources has created a growing need for programs to prevent physical decline and preserve the health and independent functioning of older adults [1,2]. A chronic condition especially interesting in ageing research and prevention of physical decline is frailty. Frailty is defined as “the state of vulnerability to stressors that is independent of any specific disease or disability but that is common in older people and predisposes them to various adverse health outcomes” [3]. According to this definition, 14.5% of Dutch men and 20.7% of Dutch women aged 65 years or older are frail [4], as are 7 to 12% of American older adults [5]. Frailty is considered a major predisposition for falls and chronic health conditions that impede independent physical functioning [6].

Regular physical activity has been shown to preserve health and prevent frailty in ageing persons, thus facilitating a longer independent life with higher quality of life [7,8]. Research has shown that a mere 30 minutes a day of moderate physical activity will prevent physical decline [9]. It is therefore of great importance to stimulate exercising and physical activity in frail older adults who generally are inactive [10]. Research indicates that home-based exercise programs are promising for frail older adults to ameliorate their mobility and health. Previous studies found amelioration on leg biceps strength, chair rise time and gait velocity after six weeks of home-based exercises targeting strength, flexibility, balance, gait and cardiovascular fitness in frail older adults [11]. However, uptake and adherence among frail older adults is generally low for home-based exercise programs due to reasons such as fear of falling or injury, or the belief that being physically active is not for older adults [10,12]. Low adherence can be considered a very important factor compromising the effectiveness of home-based programs, therefore efforts need to be made to maximize adherence among frail older persons.

Recent developments in technology such as wearable sensors and tablet use with mobile internet are promising in providing home-based exercise programs while also preserving the benefits and adherence stimulators from supervised exercise training in an exercise facility or even group training [13]. For instance, small body-worn sensors integrating accelerometers and gyroscopes are being developed to unobtrusively measure physical activity in daily life [14-19]. The accurate objective physical activity data collected by these sensors can be used for motivational strategies enhancing daily physical activity behavior [13,20]. A combination of objective data collection from daily life, tablet-based exercise instructions and motivational strategies using these data seems an effective method to improve daily physical activity and mobility [20]. Although one might think that frail older adults would not be the ideal target group for home-based exercise programs using novel technology, recent research shows that tablet, computer and internet use among older adults is rising steeply [21-23]. Older adults could therefore benefit from these technologies in the near future. The effectiveness of using novel technology in home-based exercise programs for frail older adults to enhance daily physical activity requires further study though. Research on the feasibility and effectiveness of such programs is needed before its use can be established.

The aim of this study was therefore to gain initial insight into the effectiveness of a home-based exercise program for older adults with independent use of remote novel technology. Primary research question was: What is the effectiveness of the home-based exercise program using novel
technology for older adults, as indicated by an increase in their daily physical activity? An additional research question was: What is the effectiveness of the home-based exercise program using novel technology for older adults, as indicated by an amelioration in their mobility?

Methods

Study design
The study consisted of a six-month prospective cohort trial. Subjects participated in a home-based exercise program five times a week, with exercise instructions through videos on a tablet PC, and daily physical activity registration through a necklace-worn sensor. During the supervised first three months, subjects were contacted by telephone for weekly coaching and help with the technology when needed. During the unsupervised last three months subjects were not contacted by phone but could call their coach if they encountered problems. When issues could not be solved on the telephone, the coach visited the subject at home. The study protocol was approved by the Medical Ethical Committee of University Medical Center Groningen (METc number 2013/246). A full in-detail description of the study design is provided elsewhere [20].

Subjects
Community-dwelling transitionally frail older adults living in the Dutch province of Groningen were recruited for the study. Informed consent was obtained for all subjects. Inclusion criteria included being over age 70 and the ability to walk at least 10m independently or using a walking aid. Subjects had to be transitionally frail, as indicated by the Groningen Frailty Indicator (GFI) (score of 4 or 5 out of a range of 0-15), which denotes a minor elevated chance of loss of functionality and heightened disability [24]. Exclusion criteria were physical conditions that hamper safe independent execution of a home-based exercise program or working with a tablet, such as Parkinson’s disease stage 4 or 5 or severe visual problems. Subjects were recruited between January and November 2014 by means of advertisements and leaflets among participants of the integrated care program Embrace [25].

Exercise program
The exercise program consisted of lower-body strength and balance exercises based on the Otago Kitchen Table Exercise program [26,27]. Subjects performed these exercises independently at home using the tablet PC for instructions. The exercises were built up in 18 levels. Progression through levels increased the exercise burden by adding more repetitions and longer training time as well as incorporating the use of ankle weights in the later levels. Each level was presented with an instruction video on the tablet. All subjects started at level 1 and could progress through the levels as they desired. Subjects exercised five times a week. In addition to the strength and balance exercises, subjects were encouraged to increase their daily overall physical activity by a visual graph showing their daily physical activity progression.

Technical applications

Sensor
The necklace-worn sensor package included a miniature hybrid sensor containing a 3D-MEMS accelerometer and a barometric pressure sensor. Accelerometry data were sampled at 50 Hz with a range of 8g, barometric data were sampled at 25Hz. A micro-SD card was used for storage and exchange of data. The weight of the sensor was about 30 gr and its measures were 55 by 25 by 10 mm (Research prototype, Philips Research, Eindhoven). Subjects were asked to connect the sensor to the tablet manually using a USB cable for data transfer and battery loading every night.

Tablet PC
Participants received exercise instructions and distant feedback through a tablet PC, a Dell Latitude 10 with Windows 8 operating system. The tablet PC was adjusted to independent older adult use, keeping menus and necessary interaction as simple as possible. Exercise instructions were given by means of a web-based application (providing exercise videos and performance monitoring features; Figure 1) that the subjects could imitate. Subjects were able to choose their own level of exercising in consultation with the coach. Each level had a different video showing the full exercise bout. After completing a video, a tailored motivational message as well as a graph with feedback on the participants’ daily activity level up to the previous day as registered by the sensor was provided. The exercise program was provided by means of an internet-based application running on a remote web server. Internet connection was provided by means of a 3G or 4G mobile internet card inserted into the tablet or by a subject’s own home Wi-Fi.

Evaluation methods

Adherence
Adherence to the exercise program was based upon data logging of the video playing behavior on the tablet, and was calculated as the number of days that a full exercise bout was performed as indicated by ≥90% of an exercise video played on the tablet out of the number of planned exercise

Figure 1: Web Based Video Exercise Application
Statistical analysis
Means and standard deviations were calculated for all variables at baseline, post-test and follow-up tests. All variables were first analyzed for normal distribution using the Kolgomorov-Smirnov test. When data were not normally distributed, non-parametric tests were used for further analyses and comparisons. Data were compared between completers and dropouts as well as between the three measurement points within these two groups. Additionally, results of the supervised part of the intervention were compared to those of the non-supervised part. Bonferroni post hoc tests were used for comparison between the three measurement points. Performance was assessed with the body sensor.

Adherence
The adherence percentages of exercising and sensor-wearing between baseline and post-test, and between post-test and follow-up were compared to one another by means of Repeated Measures ANOVA.

Daily physical activity
The average scores of daily physical activity for sensor and self-reported outcomes at baseline, post-test and follow-up tests were compared to one another by means of Repeated Measures ANOVA.

Mobility
Comparison between the average scores on STS, TUG and CR tests at baseline, post-test and follow-up tests was performed using the non-parametric Friedman test. These tests were performed with the help of sensor data.

Results
Participants
Forty transitonally frail (mean GFI score 4.4 ± 0.5) participants were included, 15 of them male and 25 female. Their mean age was 81.0 ± 4.6. Twenty-one subjects completed the entire program including the three measurements. Nineteen subjects dropped out: eleven due to internet reception problems, five for medical reasons not related to the exercise program, two because of illness of their spouse, one due to financial problems, one deceased. Sixteen of the dropouts stopped during the first three months of the trial and did not complete post-test or follow-up measurements, three stopped during the last three months and did not complete the follow-up measurement. Characteristics of the participants are summarized in Table 1. Dropouts and completers were significantly different at baseline in SQUASH score, smartphone ownership and previous computer experience. Dropouts were less active at baseline in SQUASH and had less previous computer experience than completers.

Table 1. Characteristics of participants

<table>
<thead>
<tr>
<th></th>
<th>Total Group (N = 40)</th>
<th>Completers (N = 21)</th>
<th>Dropouts (N = 19)</th>
<th>P (Mann-Whitney)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender (M/F)</td>
<td>15/25</td>
<td>8/13</td>
<td>7/12</td>
<td>0.90</td>
</tr>
<tr>
<td>Mean Age ± SD (years)</td>
<td>81 ± 4.6</td>
<td>80 ± 4.7</td>
<td>83 ± 4.2</td>
<td>0.06</td>
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<tr>
<td>Mean GFI ± SD (score)</td>
<td>4.4 ± 0.50</td>
<td>4.4 ± 0.50</td>
<td>4.5 ± 0.51</td>
<td>0.66</td>
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<tr>
<td>Mean FES-I ± SD</td>
<td>9.6 ± 2.6</td>
<td>9.1 ± 2.8</td>
<td>10.10 ± 2.5</td>
<td>0.21</td>
</tr>
<tr>
<td>Mean BMI ± SD (Kg/M²)</td>
<td>27.9 ± 4.1</td>
<td>28.1 ± 4.4</td>
<td>27.6 ± 3.7</td>
<td>0.75</td>
</tr>
<tr>
<td>Mean Baseline PA ± SD (%)</td>
<td>66.0 ± 26.2</td>
<td>69.3 ± 25.9</td>
<td>61.8 ± 26.9</td>
<td>0.56</td>
</tr>
<tr>
<td>Mean Baseline Squash ± SD</td>
<td>2137.1 ± 1473.3</td>
<td>2487.0 ± 1428.8</td>
<td>1485.0 ± 742.7</td>
<td>0.02*</td>
</tr>
<tr>
<td>Mean Baseline TUG (s)</td>
<td>13.6 ± 5.8</td>
<td>12.6 ± 4.3</td>
<td>14.5 ± 7.2</td>
<td>0.38</td>
</tr>
</tbody>
</table>

Mobility

Mobility was assessed by means of three tests performed at baseline, post-test and follow-up. Subjects were asked to perform three separate sit-to-stand (STS) actions at their preferred speed and without using chair armrests [17,18]. Next, the Timed-Up-And-Go test (TUG) was performed twice at a self-selected pace [30]. The Five-times-Chair-Rise test (CR) was performed twice without using chair armrests [17,18]. Next, the Timed-Up-And-Go test (TUG) was performed twice at a self-selected pace [30]. Mean and standard deviations were calculated for all variables at baseline, post-test and follow-up tests. All variables were first analyzed for normal distribution using the Kolgomorov-Smirnov test. When data were not normally distributed, non-parametric tests were used for further analyses and comparisons. Data were compared between completers and dropouts as well as between the three measurement points within these two groups. Additionally, results of the supervised part of the intervention were compared to those of the non-supervised part. Bonferroni post hoc tests were performed to assess the groups or periods responsible for significant outcomes.

Performance was assessed with the body sensor.

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Total Group (N = 40)  Completers (N = 21)  Dropouts (N = 19)  P (Mann-Whitney)

Mean Baseline CR (s)  20.0 ± 7.8  20.2 ± 9.2  19.8 ± 6.0  0.90
Computer Experience (Y/N)  25/15  18/3  7/12  0.00*
Smartphone owner (Y/N)  1/39  1/20  0/19  0.04*
Internet Type (3G/4G/Wi-Fi)  17/11/12  4/6/11  13/5/1  0.04*

* Significant difference between dropouts and completers (P ≤ 0.05).

Adherence

Overall adherence to the program was 60.8 ± 32.5%. Completers had a mean overall adherence to the program of 69.2 ± 32.2%, while dropouts had a significantly less overall adherence of 49.9 ± 30.4% (p = 0.05). In addition, mean adherence of completers to the program during the first three months was significantly higher than that of dropouts, at 75.8 ± 29.2% vs. 49.3 ± 30.3% (p = 0.01). Adherence to sensor wearing was on average 40.1 ± 20.9%.

Daily physical activity

Overall there was a non-significant increase in objectively measured daily physical activity during the supervised period, with a drop back to baseline level at follow-up (p = 0.84). Completers had the same pattern (p = 0.62), while dropouts did not alter their daily physical activity. There was a non-significant increase of self-reported physical activity during the trial (p = 0.25), with the highest raise in the supervised period too. Both completers and dropouts experienced this increase. Table 2 summarizes the daily physical activity scores of the subjects at all measurement points.

<table>
<thead>
<tr>
<th>Table 2. Mean scores daily physical activity at all measurement points</th>
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<tr>
<td>Total Group (N = 40)</td>
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<tr>
<td>Physical activity Baseline (%)</td>
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<tr>
<td>Physical activity Post-test (%)</td>
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<td>Physical activity Follow-up (%)</td>
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<tr>
<td>P</td>
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<tr>
<td>SQUASH Baseline</td>
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<tr>
<td>SQUASH Post-test</td>
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<tr>
<td>SQUASH Follow-up</td>
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<tr>
<td>P</td>
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Values are means ± standard deviation.  
* Significant difference (P ≤ 0.05).

Mobility

All subjects except one were able to perform the required repetitions of STS, TUG and CR tests at all three measurement appointments. One subject was unable to perform any physical test at follow-up due to an amputated toe. In addition, all but two subjects were able to perform their CR tests twice at all appointments. Those two subjects only performed one CR test at any given appointment.

Average time needed to perform the STS decreased significantly from baseline to follow-up (p ≤ 0.01), with the largest decrease during the supervised period. Post hoc tests indicated that the difference between baseline and post-test was responsible for the significant decrease of STS measure among completers and thus the whole group (p ≤ 0.01).

Average time needed to perform the TUG showed a trend toward decrease from baseline to follow-up (p = 0.07), with the largest decrease occurring during the supervised period. Post hoc tests indicated that the difference between baseline and post-test was responsible for a significant decrease in TUG measure (p = 0.01). Average time needed to perform the CR decreased non-significantly from baseline to follow-up (p = 0.43), with the decrease occurring mainly during the supervised period. Post hoc tests however did not indicate a significant effect in either the supervised or the non-supervised period.

There were no significant differences between completers and dropouts in STS, TUG and CR scores. Table 3 summarizes the STS, TUG and CR average scores of the subjects at all measurement points.

<table>
<thead>
<tr>
<th>Table 3. Mean scores physical functioning tests at all measurement points</th>
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<tr>
<td>Total Group (N = 40)</td>
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<tr>
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</tr>
<tr>
<td>STS Baseline (s)</td>
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<tr>
<td>STS Post-test (s)</td>
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<td>STS Follow-up (s)</td>
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<tr>
<td>P</td>
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<tr>
<td>TUG Baseline (s)</td>
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<tr>
<td>TUG Post-test (s)</td>
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<td>TUG Follow-up (s)</td>
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<tr>
<td>P</td>
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<tr>
<td>CR Baseline (s)</td>
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<tr>
<td>CR Post-test (s)</td>
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<tr>
<td>CR Follow-up (s)</td>
</tr>
<tr>
<td>P</td>
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</tbody>
</table>

Values are means ± standard deviation.  
* Significant difference (P ≤ 0.05).

Discussion and Conclusion

The program improved daily physical activity and mobility in various degrees of significance. In particular the supervised period achieved significant ameliorations (albeit some borderline), indi-
cating a need for regular supervision to preserve adherence and effectiveness in the home-based exercise program.

**Discussion**

When compared to other similar interventions in the literature, the mean adherence rate among completers in our intervention (mean ± SD; 69.2 ± 32.2%) can be considered moderate to high. For instance, Silveira et al. developed Active Lifestyle, which provides a similar platform to our current tablet application to improve subjects’ balance and health through balance- and strength-training sessions. They reported adherence rates varying between 73% and 89% among their completers during their two-week training [32]. They also reported adherence rates of 71.1 ± 41.5% and 81.9 ± 1.6% among completers in their intervention groups in the 12-week intervention using the technology after the pilot [33]. While our adherence rates among completers for the exercise sessions are slightly lower (mean ± SD; 69.2 ± 32.2%), our intervention has a substantially longer time span, so a lower overall adherence can be expected. The adherence of 75.8% among completers during the supervised part of our intervention is however comparable to the adherence among these shorter studies. The adherence in our intervention would also be rated as high among home-based exercise programs that integrate a coaching strategy but are not supported by technology, in which adherence rates vary between 32.1 and 91% [13]. This suggests an additional value of the technology.

The significant amelioration of daily physical activity among completers in the supervised part of the current study is also in line with the findings of Morey et al., who report a significantly greater change in weekly durations of strength and endurance training after 12 months of training with infrequent telephone coaching [34]. In terms of mobility, our current intervention gained a significant positive effect on STS performance and a trend toward amelioration of TUG performance. These results reflect those obtained by Mailiot et al., who found a significant decrease in TUG time in their intervention group receiving WiiMote and Balance board training at home during 12 weeks, and the results of Jorgensen et al., who found that by administering a WiiBalance training during 10 weeks TUG performance increased significantly more among the intervention group than the placebo control group [35,36]. In terms of mobility, the results of our program are comparable to those summarized in a systematic review by Laufer et al., which report significant and nonsignificant positive but very variable effects of home-based programs integrating Wii technology [37]. In conclusion, the current intervention generally achieved effects for adherence, daily physical activity and mobility amelioration comparable to similar interventions from the literature that use novel technology.

The increase in daily physical activity as well as the amelioration of mobility in our study occurred mainly during the three-month supervised part of the intervention. Significant amelioration in performance was only observed in the supervised period, for the STS and TUG. The weekly coaching might be depicted as an important factor to keep subjects up to par with their training, given that their adherence and performance on the tests during the non-supervised last three months deteriorated, as opposed to the amelioration in adherence and functioning when under regular supervision. While non-supervised home-based exercise programs are generally hampered by low adherence [13], studies that are supported by remote technology and coaching have experienced higher adherence. For instance, the tablet-assisted 12-week home-based strength and balance training pilot program implemented by Silveira et al. yielded low dropout rates and improved preferred and fast gait speed [32,33]. One might conclude that a stand-alone exercise program without supervision and regular coaching by a coach is suboptimal. We would therefore recommend integrating tablet use into a supervised exercise program or as an extra training option in regular rehabilitation supported by a coach or physiotherapist. This finding is in line with previous research that identifies remote coaching as an important factor for keeping up adherence in home-based exercise programs [13,38].

This study has several strengths to its design. First of all, the number of participants is relatively large for an intervention in the field that lasts six months. Second, the three-month supervised period and the three-month non-supervised period provide a time span that should suffice to pinpoint the long-term effects. This indicates the potential for long-term behavioral change. Based upon current results it is advised to incorporate a weekly coach contact into such a long-term program.

There are also some limitations to the design. In the initial phase of the study poor internet connectivity disrupted the trial and this influenced adherence, probably causing an underestimation of the effectiveness of the intervention. Eleven of the dropouts left solely for this reason. This probably caused an underestimation of adherence and effectiveness. Despite adherence not being up to par due to lack of a stable internet connection for much of the study population, mobility increases of various significance degrees were observed in daily activity and TUG and CR tests. To further establish its effectiveness, it is therefore advised to further test the intervention in a trial using a stable internet connection. Another limitation of the study is rooted in its design as a prospective cohort trial. This design can only provide an indication of its effectiveness, but since there is no control group the effectiveness cannot be definitely stated. The use of prospective cohort trials to gather information on the feasibility of a technology before progressing to a larger randomized controlled trial is however common in this field, where large costs are encountered developing and testing new technology. Also, physical activity stimulation is known to be effective in the prevention of health decline [7,8]. It was therefore most essential in the current study to prove the program’s feasibility in the stimulation of physical activity. In order to prove the intervention’s effectiveness, further investigation in the form of a randomized controlled trial is necessary. A further limitation can be found in the inclusion criteria based on frailty and daily activity questionnaires. While all subjects were transitionally frail according to the GFI, their baseline outcome measures on the STS, TUG, CR and physical activity assessments indicated them as being less physically frail than originally expected [19,29,31]. This identifies them as already more physically active and less frail at baseline than the intended target group of the current intervention. An explanation can be found in the nature of the questionnaires used for inclusion. The GFI measures not only physical aspects, but psychological aspects too [25]. Also, questionnaires used for inclusion in a program encourage socially desirable answers about health and performance [39]. When measuring objectively by means of the sensor, this overestimation caused by socially desirable answering is not present.

**Conclusion**

Subjects ameliorated (non-)significantly in physical activity and mobility after three months of training with weekly coaching; this was most apparent among completers of the intervention. Weekly contact with a coach seems to be essential for adherence and effectiveness. Effectiveness needs to be further established in a randomized controlled trial.
Practise Implications

Home-based exercising using novel technology seems promising for physical activity and mobility amelioration. Regular contact with a coach is advised in home-based exercise programs to stimulate adherence and effectiveness.

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References

Chapter 6

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