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New for old

Development and implementation of a home-based exercise intervention using novel remote technology for older adults

Proefschrift

Ter verkrijging van de graad van doctor aan de Rijksuniversiteit Groningen op gezag van de rector magnificus prof. dr. E. Sterken en volgens besluit van het College voor Promoties.

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Hildegard Geraedts
geboren op 14 januari 1983
te Roermond
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Chapter 1
General introduction
Ageing Society

The ageing of our society is becoming a more and more prominent topic in health care, research and politics nowadays. The percentage of older adults aged 65 years and over in The Netherlands was 27% in 2012, by 2040 this percentage will be 51% [1]. While people are reaching a higher age, the added years however often are compromised by chronic health conditions and decreasing fitness, debilitating one’s independence and quality of life [2]. A prevalent condition compromising older adults’ health and fitness is frailty, which affects about ten percent of the general older adult population [3]. A commonly used definition for this condition is proposed by Fried et al (2001); “a clinical syndrome in which three or more of the following criteria are present: unintentional weight loss (10lbs in the past year), self-reported exhaustion, weakness (grip strength), slow walking speed and low physical activity” [4]. As indicated by the definition, frailty has widespread influence on physical functioning. It also severely heightens the risk for falls, disability, hospitalization and mortality [5]. Due to the ageing of society and prevalence of frailty among the ageing population, an important feature in healthcare research is to heighten the fitness, quality of life and eventually independence among (frail) older adults. It was commonly thought that deterioration of fitness is inevitable when ageing. However, research has shown that the downward spiral in ageing that is commonly feared is preventable, and even reversible [6]. Since fitness is one of the premises for health and independence, this creates a need to keep physical functioning up to par in later life.

Prevention of physical decline

An important factor preventing decline in fitness is physical activity [6,7]. Previous research has shown that structured regular exercise can improve fitness in older adults [8], since there are mutual relationships between physical activity, fitness and health as illustrated in Figure 1 [9].

In ageing it is presumed that health deteriorates, due to on the one hand a less active life caused by for instance retirement and on the other hand the growing risk of degenerative diseases and wear-and-tear of body structures [9]. In response fitness, i.e. the ability to perform activities of daily life (ADL), is lowered. This causes a person’s independence and quality of life to decrease. In stimulating physical activity, a person’s fitness can be ameliorated. Enlarged fitness provides persons with a greater capability to perform their ADL and therefore to stay independent in their home life, which heightens quality of life [10]. Fitness comprises many physical aspects such as physical strength, balance, walking speed and cardiovascular functioning. These can be ameliorated by means of sufficient daily physical activity and training in older adults [11-13]. Sufficient daily physical activity in turn has preventive effects regarding health and for instance diabetes type II, coronary heart disease and osteoporosis and is known to reduce fall risk [14]. Training or daily physical activity do not have to concern very vigorous activities: merely thirty minutes per day of low to moderate intensity activities such as walking or household chores can already provide noticeable positive differences in physical functioning. A small effort therefore provides relatively large gains on health.

To prevent physical decline, it is essential for older adults to be sufficiently physically active. However, older adults generally do not engage in sufficient daily physical activity to prevent physical decline [15]. In The Netherlands, merely 49.4-57.7% of older adults engage in the minimal amount of physical activity to stay healthy as described by the World Health Organization [16]. These guidelines recommend to perform at least a minimum of 30 min. five a week of moderate-intensity aerobic physical activity to preserve fitness and health or a minimum of 20 min. three days a week of vigorous-intensity aerobic activity in order to improve fitness and health [16,17].

Motivating older adults to be physically active

Multiple reasons can cause older adults to not be as active as ideally should be to stay fit and healthy, even though staying fit and healthy in older age is depicted as an important goal for most people. Barriers to being physically active that older adults often experience are practical barriers such as the inability to go to an exercise facility due to lack of transportation or physical inability, and psychological barriers such as fear of falling, the belief that exercise is not beneficial or even dangerous for them or the feeling that “exercising is not for older adults” [6]. Design of physical activity interventions for older adults should therefore address the barriers older adults often face in order to motivate them to adhere. A possible solution for multiple of these barriers can be found in the design of home-based exercise programs. Home-based programs can provide exercise opportunities while relieving practical barriers such as lack of transportation or exercise facilities in the older adult’s neighborhood.

Home-based exercise programs

Home-based exercise programs have demonstrated great use in ameliorating daily physical activity and physical performance in past research [18]. However, home-based independent training often suffers from low adherence since there is a lack of an incentive such as exercise group colleagues or a coach [15,19]. Especially in older adults that already do tend to be physically inactive, this lack of adherence is an important point to be addressed in design of home-based exercise programs. A possible solution can be found in remote coaching of participants by means of telephone or internet. Remote coaching allows subjects to train at their own time and place, while still offering the support and stimulation from an exercise trainer. In previous studies, remote coaching in home-based exercise programs has often been performed by telephone and is considered quite effective in raising adherence in home-based exercise programs [20]. Some efforts have been made to use web-based remote coaching, which were quite successful in raising subjects’ motivation compared to control groups that did not use web-based remote coaching [21,22]. However, optimal design of web-based remote coaching strategies has yet to be further determined.
Accurate remote measurement

A premise for effective remote coaching strategies in a home-based exercise program is insight into the subject’s physical activity behavior, to allow the coaching to be tailored to the participant’s needs. When exercising independently at home, a coach is generally not able to monitor adherence and progress unless the behavior is adequately monitored at the site. Body-worn sensors such as for instance pedometers, accelerometers or a combination of sensors can provide this monitoring. Accelerometers have been used in numerous occasions to measure gait and postures, and in many cases are accurate under laboratory circumstances [23]. Currently, efforts are made to transfer accurate laboratory measurement into accurate daily life measurement, which provides more challenges than standardized measurement under laboratory circumstances due to the variance in performance of activities in daily life [24]. By measuring gait and postures, daily physical activity could be estimated. When body-worn sensors can measure gait, postures and daily physical activity accurately and reliably and are unobtrusive and safe to the wearer regarding design and use, these sensors could be the key to supporting remote coaching in home-based exercise programs [25].

Remote instructions

In recent studies remote administration of exercise by means of novel technology such as smartphones and tablet PC’s has also been known to be effective in supporting home-based exercise programs. For instance, Bickmore et al. demonstrated a significantly higher increase in daily step count as measured by a step counter after two months of training using an automatic exercise coach on a tablet compared to a control group receiving training without tablet-based coaching [26]. Silveira et al. recently performed a pilot study with Active Lifestyle, a tablet-based system providing home-based training to enhance balance and strength. The application successfully enabled independent training at home and demonstrated high adherence and enthusiasm with its participants [22].

Home-based exercise programs integrating novel technology

Based upon the abovementioned developments, a combination of body-worn sensors for daily physical activity monitoring, a tablet application for exercise instruction and remote contact with a coach seems like a good opportunity to allow older adults to successfully perform a personally tailored and coached exercise program at home to preserve and ameliorate their fitness and/or health. Nonetheless, providing older adults with novel technology such as tablets, smartphones and sensors is often met with skepticism, as the current generation of older adults often have no experience in working with computers or tablet PCs. Learning new skills at advanced age provides a steep learning curve, which is often discouraging to take up use of a new technology [27]. However, the percentage of persons aged 65 years and over that do own a tablet or smartphone has been rising steeply over the past years [27]. In 2014, 18% of US and 65% of Dutch older adults of 64 years and over owned a tablet, and these percentages are expected to rise further in the coming decades since people of 45-65 years are more and more accustomed to using computers or tablets in their work life [28,29]. It is therefore a very timely effort to start designing tailored, effective home-based exercise programs for older adults using novel technology, an effort that was undertaken in the project providing the platform for this thesis.

Aim and outline of the thesis

The main aim of this thesis is to develop a home-based exercise program for older adults stimulating daily physical activity and physical functioning that integrates remote coaching supported by a necklace-worn gait- and posture sensor and a tablet, and to evaluate its feasibility and effectiveness. The research questions that therefore will be addressed in this thesis concern the optimal design of this home-based exercise program. Specific questions that will be addressed are:

- Is the home-based exercise program suitable for the selected target group?
- Is the home-based exercise program effective in increasing daily physical activity and ameliorating physical functioning?
- Is the set-up of the technology supporting the home-based exercise program suitable for stimulating daily physical activity and physical functioning?
- Is the behavioral strategy driving the intervention effective for stimulation of daily physical activity and physical functioning?

Chapter 2 addresses a review of the literature regarding the different remote coaching strategies for home-based exercise programs for older adults that have been proposed in literature. A coaching strategy should be optimized in mode, content as well as frequency of contact to provide optimal stimulation to adhere for the participant. In chapter 3 a tool to support remote coaching is validated for use in daily life of older adults: a necklace-worn gait- and posture sensor that can objectively assess physical activity. The objective data of the sensor can be used to provide coaches with accurate information of daily physical activity and adherence in participants. In chapter 4 the design of a six-month cohort study integrating a home-based physical activity intervention for frail older adults supported by the necklace-worn sensor and a tablet is described, in which subjects are remotely coached to enhance adherence and effectiveness of the program. The feasibility and practical implications of this home-based exercise program as addressed in the cohort study described in chapter 4 are evaluated in chapter 5. In chapter 6, the effectiveness for increasing daily physical activity and physical functioning of the home-based exercise program is addressed. Chapter 7 will address our target group selection, content of the exercise program, technologic performance and behavioral strategies behind the intervention in a general discussion. In addition, practical implications of the results in this thesis will be addressed as well as a critical reflection upon our results and recommendations for future research will be provided.
References

Chapter 2
Remote feedback in home-based physical activity interventions for older adults: a systematic review

Geraedts H.A.E.
Zijlstra A.
Bulstra S.K.
Stevens M.
Zijlstra W.

Abstract

Objective
To evaluate the literature on effectiveness of remote feedback on physical activity and capacity in home-based physical activity interventions for older adults with or without medical conditions. In addition, the effect of remote feedback on adherence was inventoried.

Methods
A systematic review. Data sources included PubMed, PsycInfo, Cochrane and EMBASE.

Results
3087 articles were identified: 22 studies met the inclusion criteria for systematic effectiveness evaluation and 21 for adherence inventory. Three categories of contact were identified: frequent or non-frequent contact and direct remote contact during exercising. Evidence for positive enhancement of physical activity and capacity was conflicting in studies using frequent contact and strong in studies using non-frequent contact or direct remote contact during exercising. Adherence rates for home-based interventions varied between 32.1 and 91%.

Conclusion
Results imply with varying strength that frequent and non-frequent remote contact in home-based physical activity programs enhance effectiveness of physical activity and capacity measures. In particular, direct remote contact during exercise looks promising for enhancing effectiveness. Adherence in interventions using remote feedback seems acceptable to good.

Practice Implications
Remote feedback is a promising direction in an older population getting increasingly used to new technology.

Introduction

The number of older persons in our society is growing: in the Netherlands, the group of people aged 65 or older comprised 14% of the population in 2010, and by 2040 this percentage will be 23% [1]. In the United States these numbers will reach 72.1 million individuals by 2030, roughly an estimated 20% of the US population [2]. In general, older persons are in need of more chronic monitoring of health and health care than younger individuals. As a result, the burden on the health care system will grow.

There is ample evidence that a physically active lifestyle can improve and maintain general health and quality of life in older adults, leading to a lower use of health care resources and longer independent living [3]. It is therefore important to keep people physically active as they age. Current physical activity recommendations advise older adults to perform moderate-intensity aerobic physical activity for a minimum of 30 min. five days a week or vigorous-intensity aerobic activity for a minimum of 20 min. three days a week [4]. Based on this recommendation, 42-90% of Dutch and 21-40% of American older adults are physically inactive [5,6]. Older adults face multiple barriers to exercising regularly and therefore experience difficulties starting with a physical activity program and adhering to it. These barriers include lack of transportation to an exercise facility, fear of falling, and lack of knowledge about the beneficial effects of physical activity [3].

Home-based physical activity interventions for older adults with or without comorbidities show promising results in enhancing starting and adherence to physical activity interventions [7]. In this review, home-based physical activity interventions are defined as structured physical activity interventions exclusively situated in the participant’s own home, aimed at raising their (daily) physical activity or capacity. Providing physical activity interventions in the home situation has several advantages, considering the barriers to exercise that older adults face. It removes the barrier of transportation, and makes it easier to integrate physical activity into daily life.

However, home-based physical activity interventions also pose challenges. For instance, according to Social Cognitive Theory (SCT) an important factor in adherence is feedback and encouragement [8], yet these are difficult to provide when people exercise on their own [9] and no live supervision is available. Providing remote feedback or counseling in home-based physical activity interventions might be able to replace live supervision. Remote feedback or counseling is defined here as any structural contact between a coach or instructor with a participant that does not concern a physical meeting, and is aimed at enhancing effectiveness or adherence of a physical activity program. A commonly used tool for remote feedback is the telephone, but recently internet and video use have been expanding and might provide more possibilities than telephone contact. For instance, Wu et al. used video conferencing in a home-based physical activity program. All subjects were exercising in their own homes while simultaneously being connected through video to an instructor who could see, instruct and coach the exercising participants, hence allowing direct remote contact between coach and participants [10]. Messaging devices and internet-based strategies have also been reported [11,12]. New technological advances for providing remote feedback in home-based physical activity interventions for older adults might positively influence effectiveness in enhancing target health-related outcome measures or stimulating physical activity.
It should be noted however that the effectiveness of remote feedback in home-based interventions is unknown. The main objective of this systematic review is therefore to evaluate the existing literature on the effectiveness of remote feedback strategies on physical activity and capacity in home-based physical activity interventions for older adults with or without comorbidities. In addition, a non-systematic inventory of the effect of remote feedback strategies on adherence to home-based physical activity interventions was conducted.

**Methods**

**Search strategies**

Potentially relevant articles were retrieved from the databases PubMed, PsycInfo, Cochrane Controlled Trials Register and EMBASE. The literature search was limited to articles published between 1990 and July 2011. The principal search strategy was designed in PubMed using MeSH key terms and free terms. The search strategies used in PsycInfo, Cochrane Controlled Trials Register and EMBASE were tailored versions of this search strategy. Search terms used in PubMed were:

**Key term # 1:** homebased OR home OR home-based

**Key term # 2:** remote OR stimulation OR coaching OR feedback

**Key term #3:** monitoring OR telemonitoring OR telecommunication OR tele-communication OR telephone (NOT “telephone survey” OR “telephone surveys”) OR physiotherapy OR “Physical therapy” OR telerehabilitation OR tele-rehabilitation OR rehabilitation OR tele-exercise OR telecare OR tele-care OR tele-training OR teletraining OR telemedicine OR tele medicine

**Key term #4:** fitness OR balance OR mobility OR exercise OR “physical activity” OR activity OR “Physical Fitness” OR Exercise OR “Motor Activity” OR “Psychomotor Performance” OR “Exercise Movement Techniques” OR “Postural balance”

**Key term #5:** (“Middle age” OR Aged) OR (“older subjects” OR “old subjects” OR “old persons” OR “middle aged” OR elderly OR elders OR “older adults” OR “older people” OR seniors OR middle-aged)

The bold terms are Medical Subjects Headings (MeSH) key terms. Search lines are connected as follows: #1 AND (#2 OR #3) AND #4 AND #5. To identify further studies, a related-articles search was conducted in PubMed and the reference lists of included articles for this review were scanned.

**Selection of studies**

After performing the searches in the databases, all duplicates were removed. The remaining references were scanned on title and abstract by two reviewers (HG & AZ) independently. Subsequently, the remaining articles were checked for relevancy for either the research question on effectiveness or the research question on adherence through full-text reading by the two reviewers independently. Discrepancies between the two reviewers were solved by discussion or a third reviewer (WZ).

The following general inclusion criteria were formulated for study selection:

1. The study assesses a physical activity intervention program.
2. The study includes at least one study group that receives the intervention exclusively in the home situation.
3. The study mentions remote feedback used in the physical activity program, which does not include any structural contact that is not remote except for effect measurements and explanation of or initiation into the exercise program.
4. The study addresses at least one aspect of general physical activity behavior or physical capacity as a primary or secondary outcome measure. Studies that only report disease-specific physical outcome measures were excluded.
5. The study concerns at least one group of participants aged 55 years and older on average.
6. The study is neither a case study nor a review.
7. The article is in the English, Dutch or German language.

Two additional inclusion criteria were defined for the effectiveness research question: 1) The design is a controlled trial with an exercise or non-exercise control group, 2) The study receives a Physiotherapy Evidence Database (PEDro) score of at least 4 out of 10 in PEDro items 2-11 as shown in Table 1 [13]. To be included in the adherence analysis, studies needed to address adherence in addition to the general selection criteria. Adherence in this review was defined as “the degree to which a person correctly follows a prescribed exercise routine”.

**Quality assessment**

The PEDro scale was used to evaluate the quality of the studies. The full list is shown in Table 1. Answer categories of PEDro items are “yes” or “no” (1 or 0 points per item) and quality assessment includes items 2-11 addressing internal and statistical validity. The reliability of the PEDro score is considered fair to good [13]. Quality assessment was performed independently by two researchers (HG & AZ), and any disagreements were solved by a third researcher (WZ). A study was considered to be of high quality when the sum score on the PEDro items 2-11 was 6 out of 10 or higher [14,15].
Table 1. Quality rating of the selected studies.

<table>
<thead>
<tr>
<th>Criteria of the PEDro scale</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>External validity</strong></td>
<td></td>
</tr>
<tr>
<td>1. Eligibility criteria were specified.*</td>
<td></td>
</tr>
<tr>
<td><strong>Internal and statistical validity</strong></td>
<td></td>
</tr>
<tr>
<td>2. Subjects were randomly allocated to groups.</td>
<td></td>
</tr>
<tr>
<td>3. Allocation was concealed</td>
<td></td>
</tr>
<tr>
<td>4. The groups were similar at baseline on the most important prognostic indicators.</td>
<td></td>
</tr>
<tr>
<td><strong>Quality rating only includes items 2-11.</strong></td>
<td></td>
</tr>
</tbody>
</table>

| Internal and statistical validity |   |
| 5. There was blinding of all subjects. |   |
| 6. There was blinding of all therapists who administered the therapy. |   |
| 7. There was blinding of all assessors who measured at least one key outcome. |   |
| 8. Measurements of at least one key outcome were obtained from more than 85% of the subjects initially allocated to groups. |   |
| 9. All subjects for whom outcome measures were available received the treatment or control condition as allocated; where this was not the case, data for at least one key outcome were analyzed by “intention to treat”. |   |
| 10. The results of between-group statistical comparisons are reported for at least one key outcome. |   |
| 11. The study provides both point measurements and measurements of variability for at least one key outcome. |   |

**Best-evidence synthesis**

After an initial screening of the selected articles it was decided that a qualitative rather than quantitative analysis of the results would be more appropriate, since the selected articles were heterogeneous in terms of testing procedures and outcome measures. Statistical pooling was therefore not possible and a best-evidence synthesis was used [14,15]. Quality assessment results of the studies were used to classify level of evidence. The best-evidence synthesis method identifies five levels of evidence:

- **Strong evidence**: generally consistent findings in multiple high-quality studies (≥ 75% of the studies report consistent findings).
- **Moderate evidence**: generally consistent findings in one high-quality study and one or more low-quality studies, or generally consistent findings in multiple low-quality studies (≥75% of the studies report consistent findings).
- **Limited evidence**: only one study (high- or low-quality).
- **Conflicting evidence**: inconsistent findings in multiple studies (<75% of studies report consistent findings).
- **No evidence**: no randomized controlled trials (RCTs) or non-RCTs.

**Results**

The full selection procedure flow chart is shown in Figure 1. The search strategy identified 3087 articles. After duplicate removal, 2251 articles were left. After scanning their titles, 507 articles were included. Abstract reading resulted in 76 articles; after full-text reading of these, 30 articles were left for total inclusion. Three articles were excluded due to a PEDro score below 4 [16,17,18]. Twenty-two articles were finally included in the effectiveness evaluation. The agreement between raters on the 22 studies was 96%. The range of PEDro scores was between 4 and 7 with a median score of 6. Twenty-one articles were finally included in the adherence evaluation, exclusion being in most cases a lack of reporting on adherence.

**Figure 1. Flow diagram, Study selection procedure**

The characteristics of the studies included are shown in detail in Table 2. Remote contact frequencies of included studies varied, therefore these studies were divided into three groups according to frequency of contact: 1) studies using frequent telephone contact (> once a month during most of the intervention), 2) studies using non-frequent telephone contact (≥ once a month during most of the intervention), 3) studies using direct remote contact during exercising.
<table>
<thead>
<tr>
<th>Reference</th>
<th>Design</th>
<th>Study size (mean age; patient group)</th>
<th>Characteristics of exercise program</th>
<th>Feedback technology and frequency</th>
<th>Outcome measures</th>
<th>PEDro</th>
<th>Results</th>
<th>E / A*</th>
</tr>
</thead>
</table>
| Courneya (2003) [19] | RCT    | 102 (61,13/59,92); colorectal cancer survivors | Duration: 16 weeks  
Intervention: Moderate-intensity exercise at home 3-5x pw, 20-30 min  
Control group: Not doing any structured exercise | Weekly phone calls to report level of exercise, for adherence. | Flexibility/ resting heart rate/ adherence | 7 | Flexibility similar, non-sign. increase in both groups. Resting heart rate similar, non-sign. decrease in both groups. Adherence in intervention group 75.8%. | E + A |
| Haines (2009) [20]   | RCT    | 53 (80.9/80.5); family caregivers | Duration: 8 weeks  
Intervention: "Kitchen Table Exercise Program" Lower-limb strength and balance exercises. 6 types with 6 levels  
Control group: No intervention | Weekly phone calls to provide advice, encouraging. Control group nothing. | Physical capacity/ compliance | 7 | After 2 months, no sign. differences in physical capacity between intervention and control group. 15 out of 19 participants attempted program at home at least once during week 1, with 12 completing all 6 exercise types at least twice. Similar in week 2 but compliance dropped fast during weeks 3-8. | E + A |
| Arthur (2002) [21]   | RCT    | 242 (64,262,5); post-CABG surgery | Duration: 6 months  
Intervention: 60 min. aerobic training (walking), 3x pw  
Control group: Hospital-based supervised training | Biweekly telephone calls; 2x/1h exercise consultation. | Peak VO 
/ resting heart rate/peak heart rate/ peak METs | 6 | Patients who exercise during cancer treatment maintain or increase cardiorespiratory fitness. Adherence in intervention group 67.6%, in control group 77.6%. | E + A |
| Griffith (2009) [22] | RCT    | 126 (60.2); cancer patients | Duration: Variable, mean 12.83  
Intervention: Individualized walking 20-35 min., 3x pw  
Control group: Usual care | Biweekly telephone calls. Intervention and control group. | Peak VO/ compliance | 6 | Subjects in the exercise-high compliance (>50%) group showed sign. improvement in free and fast walking speed. Improvements sign. larger than in the exercise-low compliance and control groups. Adherence problematic due to program intensity. | E + A |
| Jan (2004) [23]      | RCT    | 53 (58.8/59.3/57); unilateral hip replacement | Duration: 12 weeks; 50-60 min. daily  
Intervention: Daily; hip flexion ROM exercises, isotonic strengthening exercises, additional strengthening of hip abductors; 30-min. walk at comfortable speed  
Control group: No intervention | Weekly phone call, to solve problems. | Walking speed/ compliance | 6 | Sign. more improvement in tandem gait in intervention group. Adherence 89% of recommended sessions. | E + A |
| Jette (1999) [24]     | RCT    | 215 (75.4/74.6); older adults with disabilities | Duration: 6 months  
Intervention: 3x pw, 35-min. videotaped program using Therabands for individualized resistance  
Control group: Waiting list | Phone support to monitor progress. Calls for questions or problems. | Strength/ balance/ TUG/ Adherence | 6 | | E + A |

Legend: p/w = per week; sign. = significant; ROM = range of motion  
* E: article included in effectiveness evaluation; A: article included in adherence evaluation
<table>
<thead>
<tr>
<th>Reference</th>
<th>Design</th>
<th>Study size (mean age); patient group</th>
<th>Characteristics of exercise program</th>
<th>Feedback technology and frequency</th>
<th>Outcome measures</th>
<th>PEDro</th>
<th>Results</th>
<th>E/A*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regensteiner (1997) [25]</td>
<td>CT</td>
<td>20 (65/64); intermittent claudication</td>
<td>Duration: 3 months Intervention: Hospital-supervised training group Control group: Home-based walking; 3x pw as rapidly as possible 35 min., up to 50 min. later in program</td>
<td>Weekly calls to record # walking sessions and time, and give support and encouragement.</td>
<td>Peak VO₂</td>
<td>6</td>
<td>Peak walking time, sign. increase in all patients. Only supervised group sign. increase in peak VO₂.</td>
<td>E</td>
</tr>
<tr>
<td>Windsor (2004) [26]</td>
<td>RCT</td>
<td>66 (69.3/68.3); cancer</td>
<td>Duration: 4 weeks Intervention: 3x/w 30 min. moderate-intensity walking Control group: Normal advice</td>
<td>Weekly phone contact, wearing heart rate monitor before/during activity.</td>
<td>Shuttle test/ adherence</td>
<td>6</td>
<td>Intervention group sign. increase in shuttle-run test, control group deteriorates. Control group non-sign. decline in adherence, intervention group small non-sign. increase.</td>
<td>E+A</td>
</tr>
<tr>
<td>Oka (2000) [27]</td>
<td>RCT</td>
<td>40 (30-76); heart failure</td>
<td>Duration: 3 months Intervention: Endurance and resistance exercise 3-5 days/week 20-30 min. with rising intensity, resistance and walking Control group: No exercise</td>
<td>Phone weekly.</td>
<td>Peak VO₂/ METs/ adherence</td>
<td>5</td>
<td>Minimal changes in physical fitness levels. No sign. differences in peak VO₂ between the two groups. Average exercise varied between 75 and 110% for the different physical aspects of the program. Adherence decreased over the 12 weeks.</td>
<td>E+A</td>
</tr>
<tr>
<td>Oka (2005) [28]</td>
<td>RCT</td>
<td>24 (30-76); heart failure</td>
<td>Duration: 3 months Intervention: 2x/w resistance 40-60 min.; walking at home Control group: Usual care</td>
<td>Phone weekly</td>
<td>Peak VO₂/ METs/ adherence</td>
<td>5</td>
<td>No sign. differences in exercise capacity measures between the groups. Average exercise varied between 75 and 110% for the different physical aspects of the program.</td>
<td>E+A</td>
</tr>
<tr>
<td>Senzuun (2006) [29]</td>
<td>RCT</td>
<td>60 (54.7); heart failure</td>
<td>Duration: 12 weeks Intervention: 3x pw 45-60 min. session of home-based exercises Control group: No exercise</td>
<td>Phone every 2 weeks to provide self-efficacy enhancing program.</td>
<td>Exercise capacity/ adherence</td>
<td>5</td>
<td>Exercise capacity, sign. improved in intervention group compared to control group. Mean adherence 91% in intervention group.</td>
<td>E+A</td>
</tr>
<tr>
<td>Brosseau (1995) [30]</td>
<td>RCT</td>
<td>80 (58.8/58.5); cardiac surgery</td>
<td>Duration: 8 weeks Intervention: Home program, low-intensity aerobic training; 1.5-4 METs Control group: General guidelines to enhance PA progressively</td>
<td>Phone calls 2x 1st week, once 2nd week, every two weeks on weeks 3-8. 6-minute walking distance (6MWD); compliance, adherence</td>
<td>4</td>
<td>No sign. differences in aerobic capacity or peak rate-pressure product between intervention and control group at 8 weeks. Frequency and duration of exercising relatively compliant, intensity not. Intervention has no more effect than on control group. Low exercise intensity.</td>
<td>E+A</td>
<td></td>
</tr>
</tbody>
</table>

Legend: p/w = per week; sign. = significant; ROM = range of motion
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<tbody>
<tr>
<td>Nocera (2009) [31]</td>
<td>CT</td>
<td>20; Parkinson’s patients</td>
<td>Duration: 10 weeks&lt;br&gt;Intervention: Parkinson's patients performing balance-training exercises&lt;br&gt;Control group: No exercise, healthy older adults</td>
<td>One instruction visit, weekly phone calls.</td>
<td>Postural control</td>
<td>4</td>
<td>At post-test, sign. improvement in PD balance scores and no sign. differences between PD group and healthy control group.</td>
<td>E</td>
</tr>
<tr>
<td>Oh (2003) [32]</td>
<td>RCT</td>
<td>23 (64.8/66.8); lung patients</td>
<td>Duration: 8 weeks&lt;br&gt;Intervention: 5x/day; inspiratory muscle training, upper and lower extremity exercises, relaxation, phone session&lt;br&gt;Control group: Educational advice</td>
<td>2 phone calls/week</td>
<td>6MWD</td>
<td>4</td>
<td>Sign. increase in exercise group and sign. decrease in controls in 6MWD at 8weeks.</td>
<td>E</td>
</tr>
<tr>
<td>Courtney (2011) [33]</td>
<td>RCT</td>
<td>128 (78); acute medical admission</td>
<td>Duration: 24 weeks&lt;br&gt;Intervention: Muscle-stretching, balance training, walking, muscle strengthening&lt;br&gt;Control group: Routine care Feedback on general exercise, progress, adherence and availability/support</td>
<td>Weekly phone calls 4 weeks after discharge, then monthly follow-up for 5 months.</td>
<td>Walking impairment questionnaire (WIQ)/adherence</td>
<td>7</td>
<td>Sign. interactions in time and group for subscale WIQ walking speed, walking distance, climbing stairs; intervention group greater improvement than controls. Greatest effects seen 4 weeks after discharge. Moderate level of adherence to exercise program, 53% (n=531) of the intervention group undertaking their program all the time or nearly every day.</td>
<td>E+A</td>
</tr>
<tr>
<td>Morey (2009) [34]</td>
<td>RCT</td>
<td>641 (65-91); long-term cancer survivors</td>
<td>Duration: 12 months&lt;br&gt;Intervention: Daily 15 min. strength and 30 min. endurance training, including dietary advice&lt;br&gt;Control group: Waiting list</td>
<td>Phone first weekly, then every 2 weeks, then monthly. To overcome barriers, enhance self-efficacy.</td>
<td>PA (duration and frequency of strength and endurance training)</td>
<td>7</td>
<td>PA increased sign. in intervention group. Diet and exercise intervention more effective than waiting-list controls.</td>
<td>E</td>
</tr>
</tbody>
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## Remote feedback in home-based physical activity programs

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</tr>
</thead>
<tbody>
<tr>
<td>King (2002) [35]</td>
<td>RCT</td>
<td>100 (62.2/63.3); older adult family caregivers</td>
<td>Duration: 12 months</td>
<td>Intervention: Home-based, phone-supervised exercise training. Four 30-40 min. sessions/week brisk walking</td>
<td>Regular phone contact</td>
<td>PA self-reported/ adherence</td>
<td>5</td>
<td>Compared with control group, intervention group showed sign. improvements in total energy expenditure. Adherence in intervention group 73.4% mean across 12 months.</td>
</tr>
<tr>
<td>Kodis (2001) [36]</td>
<td>Retr.</td>
<td>713 (61); coronary artery disease</td>
<td>Duration: 6 months</td>
<td>Intervention: Unsupervised at home</td>
<td>Phone occasionally</td>
<td>Peak VO₂</td>
<td>4</td>
<td>Comparable sign. increase in peak VO₂ and peak METs in both groups.</td>
</tr>
<tr>
<td>Savage (2001) [37]</td>
<td>21 (66.3/66.1/66.4); intermittent claudication</td>
<td>Duration: 12 weeks</td>
<td>Intervention: Home 3x p/w, walking to the point of intense pain, resting, then continuing to a total of 15 min. walking. Grad. increase to 40 min.</td>
<td>Phone once a month to discuss the program.</td>
<td>Peak VO₂</td>
<td>4</td>
<td>Non-sign. difference in peak VO₂ in intervention group, comparable to supervised program.</td>
<td>E</td>
</tr>
<tr>
<td>Weinstock (2011) [38]</td>
<td>RCT</td>
<td>1650 (70.9/70.8); diabetes</td>
<td>Duration: Variable</td>
<td>Intervention: Video conference with diabetes educator every 4-6 weeks</td>
<td>Video-conferencing</td>
<td>PA</td>
<td>6</td>
<td>PA declined sign. less over years in telemedicine group compared to control group.</td>
</tr>
<tr>
<td>Wu (2010) [10]</td>
<td>RCT</td>
<td>64 (76.1/74.1/75.9); seniors at risk for falls</td>
<td>Duration: Intervention: 15-week, 24-form Tai-Chi, 3x/week at home</td>
<td>Control group: Home unsupervised group and a group at center; same Tai-Chi routines</td>
<td>Live feedback during exercise (Doc-Box)</td>
<td>TUG/ SLS/ body sway/ compliance</td>
<td>6</td>
<td>Intervention group and center-based control group sign. higher improvement in TUG compared to unsupervised controls. Intervention group sign. improvement in SLS. Intervention and center-based group higher compliance than unsupervised group.</td>
</tr>
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* E: article included in effectiveness evaluation; A: article included in adherence evaluation
### Reference Design Study size (mean age); patient group

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</thead>
<tbody>
<tr>
<td>Ades (2000) [39]</td>
<td>Non-random</td>
<td>133 (56/58); cardiac rehabilitation</td>
<td>Duration: 3 months&lt;br&gt;<strong>Intervention:</strong> Progressive individualized monitored program at home 40-50 min. per session&lt;br&gt;<strong>Control group:</strong> Center-based exercise. Both groups education program</td>
<td>Direct phone contact during exercise sessions.</td>
<td>Peak VO2</td>
<td>4</td>
<td>Peak VO2 similar sign. rise in both groups. Submaximal VO2 not altered in either group.</td>
<td>E</td>
</tr>
</tbody>
</table>

### Characteristics of exercise program
- **Duration:** 3 months
- **Intervention:** Progressive individualized monitored program at home 40-50 min. per session
- **Control group:** Center-based exercise. Both groups education program

### Outcome measures
- Direct phone contact during exercise sessions.

### Feedback technology and frequency
- **Outcome measures:** Peak VO2
- **PEDro:** 4
- **Results:** Peak VO2 similar sign. rise in both groups. Submaximal VO2 not altered in either group.

### Adherence only articles (all contact strategies)

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<th>Results</th>
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</thead>
<tbody>
<tr>
<td>Castro (2002) [40]</td>
<td>RCT</td>
<td>100 (62,73); women caring for relatives with dementia</td>
<td>Duration: 12 months&lt;br&gt;<strong>Intervention:</strong> 4x/wk for 6 weeks gradually increasing exercise, phone calls to monitor for 12 months afterwards. Most persons do brisk walking&lt;br&gt;<strong>Control group:</strong> Nutritional advice through phone calls matched with exercise group</td>
<td>Non-frequent contact. 15 phone calls for 12 months, using counseling strategies from social cognitive theory.</td>
<td>Adherence 74% of prescribed sessions. More contacts directly related to higher adherence.</td>
<td>-</td>
<td>Adherence exercise group 74% of prescribed sessions. More contacts directly related to higher adherence.</td>
<td>A</td>
</tr>
</tbody>
</table>

### Characteristics of exercise program
- **Duration:** 12 months
- **Intervention:** 4x/wk for 6 weeks gradually increasing exercise, phone calls to monitor for 12 months afterwards. Most persons do brisk walking
- **Control group:** Nutritional advice through phone calls matched with exercise group

### Feedback technology and frequency
- **Outcome measures:** Adherence
- **PEDro:** -
- **Results:** Adherence 74% of prescribed sessions. More contacts directly related to higher adherence.

### Legend:
- p/w = per week; sign. = significant; ROM = range of motion
- *E: article included in effectiveness evaluation; A: article included in adherence evaluation*
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<tbody>
<tr>
<td></td>
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<td></td>
<td>Exercise at least 30 minutes each day, reinforced by either Health Buddy (HB) or telephone calls</td>
<td>HB device or phone contact.</td>
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<td></td>
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<td></td>
<td>Control group:</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Telephone calls</td>
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<tr>
<td>Papadourk (2003)</td>
<td>RCT</td>
<td>74 (60 min); osteoporosis</td>
<td>Duration: 12 months</td>
<td>Intervention:</td>
<td>Adherence</td>
<td>A</td>
<td>A</td>
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<td>3x p/w 60min, stretching, strength training and aerobics during the day</td>
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<td>Control group:</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>No exercise</td>
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<tr>
<td>Ruhland (1997) [44]</td>
<td>Intervention-control</td>
<td>28 (56.2); chronic peripheral neuropathy</td>
<td>Duration: 6 weeks</td>
<td>Intervention:</td>
<td>Adherence</td>
<td>A</td>
<td>A</td>
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<td></td>
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<td>10 reps each day, aerobic conditioning incl. walking or cycling 10-20 min.</td>
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<td></td>
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<td>Control group:</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>No exercise</td>
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<tbody>
<tr>
<td>Sashika (1996) [45]</td>
<td>CT</td>
<td>23 (63.4); THA</td>
<td>Duration: 6 weeks; 15-20 min, daily</td>
<td>Intervention: ROM and muscle-strengthening exercise (2 different groups)</td>
<td>Compliance</td>
<td>E</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Control group: No exercise</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wu (2006) [12]</td>
<td>Single group design</td>
<td>17 (81); independently-living seniors</td>
<td>Duration: 15 weeks</td>
<td>Intervention: Aerobic exercise 3x p/w, 30-60 min.</td>
<td>Compliance</td>
<td>E</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Control group: Aerobic exercise training on treadmill, 30-60 minutes</td>
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Effectiveness of remote feedback strategies

Twelve high-quality studies and 10 low-quality studies were included in the systematic effectiveness evaluation [10,19-39]. See Table 2 for quality scores. The frequent-contact group included eight studies rated high-quality (PEDro ≥ 6) [19-26] and six low-quality [27-32]. Findings were inconsistent so results provide conflicting evidence. Results imply that home-based physical activity programs with frequent contact have effects on physical capacity comparable to hospital-based programs and better results on physical capacity than usual care.

The non-frequent telephone contact group included five studies [33-37], two high-quality [33,34] and three low-quality [35-37]. The studies reported generally consistent findings, thus providing strong evidence. Home-based physical activity programs with non-frequent remote contact were equally effective in physical capacity measures as supervised exercise groups and more effective in enhancing physical activity and capacity measures than usual-care or non-exercise control groups.

The direct-remote-contact-during-exercising group consisted of three studies using live feedback during exercising by internet, video or telephone: two high-quality studies [10,38] and one low-quality study [39] that report generally consistent findings and therefore provide strong evidence. Results indicate that direct remote contact during exercising provides positive results on physical capacity measures. Effects are comparable to supervised training on physical activity and capacity measures, and is more effective than unsupervised exercising.

Adherence in remote feedback strategies

Adherence was addressed in 21 studies [10,12,19-24,26-30,33,35-45]. Details on adherence are shown in Table 2. Adherence rates in intervention groups varied between 32.1 and 91%. Castro et al. reported that more contacts are directly related to higher adherence [40]. Wu et al. (2010) reported that their intervention group exercising with the live connection with their instructor had a higher adherence than the group exercising at home without feedback, and adherence was comparable to a group exercising in supervised classes [10]. Harada et al. reported a significantly higher adherence for their home-based exercising group using a text-messaging feedback strategy than for their home-based exercising group using a phone-contact feedback strategy (57.4 vs. 32.1% adherence) [11].

Discussion and Conclusion

Discussion

This systematic review presents an overview of the literature reporting about the effectiveness on physical activity and capacity of remote feedback used in home-based physical activity interventions for older adults with or without medical conditions. In addition, an inventory on adherence to home-based physical activity interventions for older adults using remote feedback was taken. Frequent, non-frequent and direct remote contact was used in 30 included studies. The studies identified in this review primarily use telephone contact strategies. Recent advances in technology provide new possibilities for remote contact such as direct video, cell phone and internet [10,11,12]. Frequent, non-frequent and direct contact all seem beneficial to effectiveness of home-based physical activity programs for older adults, but the strength of evidence varies between these categories. Frequent contact, mostly once a week, is often used for remote contact in home-based physical activity programs for older adults. Results in the 14 studies using frequent contact are conflicting though. Some studies show significant increases in physical capacity measures comparable to that in supervised training [21,25], but others show no significant results on physical capacity measures [27,28] or results comparable to waiting-list controls [19,27,28]. The inconsistency in findings is probably caused by the wide variety of target groups, interventions and goals of the studies included. Overall, it can still be concluded that there is a trend toward a positive influence of frequent contact on effectiveness of physical capacity and activity measures in home-based physical activity programs for older adults. This is in line with literature pointing to the positive influence of encouragement and feedback on physical activity programs [8].

The five non-frequent remote contact interventions show consistent positive results on several physical capacity measures [33,36,37]. In two studies, results are comparable to results of supervised exercising [36,37]. Strong evidence indicates that non-frequent remote feedback can influence effectiveness of physical capacity in home-based physical activity programs for older adults. This is also in line with the literature [8].

Strong evidence based on three studies indicates that direct remote contact during exercising provides positive results on physical activity and capacity measures comparable to supervised training. Direct remote contact with a coach during exercising is identified as a positive influence on effectiveness with respect to physical activity and capacity measures of home-based physical activity interventions [10,38,39]. The results imply that home-based interventions with a direct remote feedback strategy can be as effective as center-based supervised exercising. Additionally, home-based exercises can be comfortably integrated into the lifestyle of older adults, making it easier to keep up for a longer period.

Although the results in this systematic evaluation show a positive trend, there are also some points that need to be critically evaluated. The number of articles included in the non-frequent and direct remote-contact groups is not extensive. Articles included in the evaluation of effectiveness varied widely in design, outcome measures and target groups. And even though similar outcome measures were addressed for the same physical capacity or activity determinant, several different questionnaires or tests were used. For instance, to determine physical activity self-report questionnaires are used as well as the number of exercise bouts completed. Also, only a limited number of studies reports use of an alternative exercise program with a control group. Still, even with this limited number of heterogeneous studies there is a clear trend in results indicating a positive influence of remote feedback on effectiveness of physical activity and capacity in home-based physical activity programs for older adults.

In addition to the systematic evaluation of effectiveness on physical activity and capacity, adherence to home-based physical activity programs using remote feedback was inventoried non-systematically. Adherence to interventions using remote feedback seems mostly acceptable-to-good, with rates in intervention groups varying between 32.1 and 91%. Several interventions using frequent feedback contact report larger adherence than their control groups, or adherence comparable
to supervised exercise interventions. In the literature, supervised on-site physical activity programs have been depicted as being more effective than non-supervised programs [9]. Based on our inventory of adherence, direct remote contact during home-based exercising seems a good alternative to supervised on-site exercising. One study included in this review compared text messaging to a phone strategy in a home-based physical activity program [11]. Text messaging led to a significantly higher adherence than the phone strategy, which seems to be an interesting contact strategy for future use.

Even though use of a remote feedback strategy in studies is often a means to an end instead of a primary goal to be studied, in several included articles the remote contact strategy was explicitly mentioned and grounded in theory. The content of contacts in all 30 included studies was inventoried. In five studies the contacts were reported to be integrated into a counseling or motivational strategy based on theoretical background and findings from the literature [24,29,33,34,41]. Interestingly, goal-setting was used as part of a counseling or motivational strategy in three studies [24,29,33]. Social-cognitive strategies to enhance self-efficacy were used in two studies [28,29,34]. Ten other studies mentioned using individualized feedback, education or encouragement [11,20,21,23,25,26,28,32,35,40]. The three studies using a direct remote contact strategy did not report using specific theory-based motivational or coaching strategies [10,38,39]. The results suggest that frequent or non-frequent remote contact combined with a counseling or motivational strategy could positively influence effectiveness and adherence in home-based physical activity interventions for older adults, but more research is necessary.

Finally, it should be remarked that there are some limitations to this review. First, studies that implicitly used a remote feedback strategy might be missing, since they are not recognized by our search strategy. However, since reference lists of included studies were scanned for relevant studies, the probability of missed studies is small. In this respect, mixed remote contact designs are not included either, since studies with a substantial number of live visits were not allowed. There might be interesting studies using these mixed designs that have a supporting remote feedback strategy in addition to live visits. A point of potential bias is the language selection, as only studies reported in the English, Dutch and German languages were included. This review may also have a potential publication bias, as results of relevant studies might not have been published.

Conclusions
Evidence for effectiveness of remote contact in home-based physical activity programs for older adults on enhancing physical activity varies from conflicting in frequent-contact strategies to strong in non-frequent and direct remote contact strategies. Direct remote contact looks particularly promising for enhancing effectiveness. Adherence to interventions using remote feedback seems acceptable to good. The studies in this review primarily used telephone contact strategies and showed little use of recent communication technology such as direct video contact. The studies seldom included explicit descriptions of the content of motivational or counseling strategies.

Practice implications
Remote feedback in home-based physical activity programs for older adults seems promising for enhancing effectiveness on physical activity and capacity. Modern information and communication technology offers several attractive options for providing remote feedback, and older people’s skills to use such technology seem to be increasing. In 2006, 33% of Dutch 65- to 75-year-olds did not have any computer skills [46] and by 2010 this percentage was down to 25%; the percentage of older adults with computer skills thus grew from 12 to 19% [46]. Cell phone use in older adults is also rising [46]. In 2011, 58% of U.S. older adults over age 65 owned a mobile phone [47]. In addition, use of computers and cell phones is widely spread among middle-aged individuals. Use of computers and mobile phones will therefore probably keep rising among older adults. Direct remote contact during exercising could be a possibility to replace supervised training, if participants know how to work with the technology.

Acknowledgements
This study was financially supported by ZonMw (program “Diseasemanagement chronische ziekten”; project number 40-00812-98-09014). The authors would like to thank R. Rose for her language revisions of the final manuscript. The authors would also like to thank D.G. Van Ittersum for her assistance in designing the search strategy.
References


Chapter 3

Validation and User Evaluation of a Sensor-Based Method for Detecting Mobility-Related Activities in Older Adults

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Zijlstra W.
Van Keeken H.G.
Zhang W.
Stevens M.

Chapter 3

Abstract

Regular physical activity is essential for older adults to stay healthy and independent. However, daily physical activity is generally low among older adults and mainly consists of activities such as standing and shuffling around indoors. Accurate measurement of this low-energy expenditure daily physical activity is crucial for stimulation of activity. The objective of this study was to assess the validity of a necklace-worn sensor-based method for detecting time-on-legs and daily life mobility related postures in older adults. In addition user opinion about the practical use of the sensor was evaluated. Twenty frail and non-frail older adults performed a standardized and free movement protocol in their own home. Results of the sensor-based method were compared to video observation. Sensitivity, specificity and overall agreement of sensor outcomes compared to video observation were calculated. Mobility was assessed based on time-on-legs. Further assessment included the categories standing, sitting, walking and lying. Time-on-legs based sensitivity, specificity and percentage agreement were good to excellent and comparable to laboratory outcomes in other studies. Category-based sensitivity, specificity and overall agreement were moderate to excellent. The necklace-worn sensor is considered an acceptable valid instrument for assessing home-based physical activity based upon time-on-legs in frail and non-frail older adults, but category-based assessment of gait and postures could be further developed.

Introduction

Regular physical activity is crucial in the prevention of health decline in older adults [1]. However, older adults generally do not engage in sufficient daily physical activity [2]. Six to ten percent of older adults aged 70 and over in the United States engage in the required minimum of 30 minutes of moderate activity five days a week [3,4]. In The Netherlands only ten percent of seniors are sufficiently active regarding these guidelines [2]. World wide numbers vary between 2.4 and eighty-three percent for older adults 60 years and over, depending on the definition and measurement method used [5].

Accurate measurement of daily physical activity is crucial for assessment and stimulation of activity. Many daily activity measurements are based upon self-report, such as the Physical Activity Scale for the Elderly (PASE) [6] and the International Physical Activity Questionnaire (IPAQ) [7,8]. However, self-report measures are generally biased due to recall bias and social desirability [9].

Step counters and accelerometers measure daily physical activity objectively and are therefore less prone to bias in measurement [10,11]. Though easy to use, step counters do not provide an accurate measurement of daily physical activity. Current developments in technology enable more accurate measurement of physical activity by means of accelerometers. These small, lightweight body-worn sensors can provide an unobtrusive method to measure subjects’ physical activity for longer periods in non-laboratory environments and daily life [12]. Body-worn sensors have been demonstrated to have an accuracy in detecting gait or postures in healthy and physically impaired older adults varying between 64.4 to 100.0 percent under standardized laboratory circumstances [13–20]. When assessing accuracy under semi-standardized or real life conditions, accuracy is lower [15, 16]. Real life measurement of gait and postures, in order to assess daily physical activity, could still be improved. A recent development in body-worn sensors is a necklace-worn motion sensor which may be used to measure physical activity by detecting and monitoring postures and walking. This sensor is especially suitable for assessment of daily activity due to its necklace-worn design. A sensor that is worn in a well-known fashion, such as as a necklace or around the wrist, is considered least intrusive by wearers and therefore more suitable for daily wearing [21]. This is a major advantage when compared to earlier body-worn sensor methods, that were mainly placed on the hip lower back, or had multiple sensor attachments [13–20].

The necklace-worn sensor is a miniature hybrid sensor which contains a 3D-MEMS accelerometer together with a barometric pressure sensor. The sensor assesses “time-on-legs” (ToL: the time spent actively on the legs, i.e. standing, shuffling around, walking and transitions in between). ToL provides a novel, very suitable measurement of daily activity in older adults, since in (frail) older adults an important part of their daily activity consists of activities such as standing and shuffling around within their own home. In general, only more vigorous activities (such as for instance outdoor walking, cycling) are considered physical activity in objective activity measurement and used for performance tests indicating subject’s progress [22]. However, in order to depict (frail) older adults’ activity and detect changes in their daily activity caused by physical activity interventions, the indoor less vigorous activity should also be included in physical activity assessment. The sensor-based method for activity detection proposed in this paper takes into
account also this indoor light activity and should therefore be appropriate for detection of daily life mobility related postures and activity in (frail) older adults.

Primary objective of this study was to assess the validity of a sensor-based method to detect time-on-legs and daily life mobility related postures in older adults based on a necklace-worn motion sensor. Secondary objective was to evaluate user opinion about the practical use of the sensor.

Materials and Methods

Design
This study consisted of validation of a sensor-based method for activity detection in the home environment and evaluation of user opinion. The study protocol was approved by the Medical Ethical Committee of University Medical Center Groningen (METc 2011/022).

Subjects
Subjects were frail and non-frail older adults. Subjects were community-dwelling or living in an older adult home, aged ≥70 years and able to walk 10 metres without support or with a cane or walker. Frailty was assessed by means of the Groningen Frailty Indicator (GFI). 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” [23]. The GFI is a 15-item screening instrument for the level of frailty, stating questions on physical, cognitive, social, and psychological characteristics [24]. All scores are dichotomized, a score of 1 indicating a problem or dependency. GFI scores range from 0 to 15, 0 indicating no depletions in functioning and 15 indicating major problems in physical, cognitive, social and psychological functioning [24]. Subjects with a total score ≥4 are considered frail.

Exclusion criteria were orthopedic impairments that debilitating the ability to walk unsupported for ten metres, total hip- or knee replacement surgery in the previous six months, having had a stroke within the last six months, Parkinson’s disease stage 4/5 or other neurologic diseases that can impair daily functioning or visual problems to a degree that make it impossible for the subject to accurately read the questionnaires or walk around safely.

Subjects were recruited from an existing list of older adults that participated in earlier studies and using flyers and information gatherings in neighborhoods where many older adults live or at residential homes in the city of Groningen, the Netherlands. Written informed consent was obtained before start of the measurements.

Sensor signal processing and classification
The miniature hybrid sensor contains a 3D-MEMS accelerometer and a barometric pressure sensor, and is worn as a necklace. Accelerometry data were sampled at 50 Hz with a range of 4g, 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 grams and it measured 55 by 25 by 10mm (Philips Research, Eindhoven). An algorithm to classify periods that a person is on his/her legs—time-on-legs (ToL)—was developed. The algorithm aimed to detect periods a person was active on his/her legs. Details of sensor signal processing and feature computation are described in Zhang et al. [25]. We briefly describe the classification of ToL in the rest of this section.

A low-pass filter was applied to the raw 3D-acceleration and the air pressure signal. De-noised and smoothed signals were the input to each of the movement and posture detection modules to detect ToL related activities: 1. active period, 2. sit/stand transfer, 3. walking and 4. lying. The outputs of the aforementioned modules were then fed to a heuristic classifier to detect ToL.—Active period: active and inactive periods were determined by the signal intensity. An experimental threshold, based on representative pilot data (separate from the data reported upon in this manuscript), was applied to categorize signal bouts with sustained intensity above the threshold to active periods.—Sit/stand transfer: features including cross correlation with transfer template signal, time difference between signal peak and valley, sensor orientation, signal intensity before or after a transfer and altitude change during the transfer were computed and fed into Support Vector Machine (SVM). The SVM then determined whether the signal bout represented a sit-to-stand transfer or a stand-to-sit transfer.—Walking: repetitive peaks present in the norm of 3D acceleration signals were selected. Number of peaks in the signal, peak heights and peak intervals in one bout were feature vector to a threshold-based classifier to detect walking steps.—Lying: sensor orientation was first computed to decide the position of z-axis. A sustained period of time showing z-axis of the sensor in (close) perpendicular position to the horizontal plane was classified as lying period.—Heuristic classifier: outputs of the above mentioned movement and posture classification modules were first assembled into one output signal with a label of movement or postures second-by-second. Signals which received multiple labels from different modules were corrected following a descending priority of sit/stand transfers, walking and lying. For example, a signal bout labeled with sit-to-stand transfer and walking was corrected as sit-to-stand transfer since the transfers had higher priority than walking. In addition, active and inactive periods were corrected to the 1). label of standing if the signals succeeding a sit-to-stand transfer or walking and preceding a stand-to-sit transfer or walking; or to the 2). label of sitting if the signals succeeding a stand-to- sit transfer and preceding a sit-to-stand transfer or lying. Finally, signals classified as sit/stand transfers, walking, standing and the un-labeled active periods were categorized to ToL [25].

Training of the algorithm and its thresholds for detection was performed on separate but representative pilot data incorporating healthy adult subjects as well as frail and non-frail older adults. These data included sit-to-stand, lying and walking exercises as well as the protocol as presented in the manuscript. These data were only used for education and testing of the algorithm, and not included in the data reported in this paper.

Video validation
Validation of the sensor-based method included a standardized movement protocol as well as a free movement protocol. The standardized movement protocol included standing up, walking, lying and sitting while wearing the sensor and being filmed. Also, the Timed Up and Go Test (TUG) [26, 27] and the Five Times Chair Rise Test were included. Participants were allowed to take rest in-between exercises or skip exercises that were too difficult. Circumstances were standardized as much as possible by removing possible distractions and subjects were only addressed for instructing or helping them when performing the protocol. The protocol is shown in Table 1.
The free movement protocol consisted of 30 minutes of self-chosen activities such as performing household chores while being filmed. Subjects were instructed to perform household chores or indoor leisure activities at will, and were provided with suggestions when they could not think of any themselves. Common activities chosen were vacuuming, reading, preparing tea or coffee, cleaning dishes and watering plants. The videos from the standardized movement protocol and the free movement protocol were annotated in a video analysis program, Noldus “The Observer” version 10.5 (Noldus Information Technology, The Netherlands). Scoring observations included start and end of each pre-defined activity, namely sitting, standing, walking and lying. The performance of the activities as observed by video was taken as the gold standard. The video camera was kept perpendicular to the actions of the participant whenever possible, which resulted in a side view of all movements. Scoring was performed by three independent extensively trained assistants. All videos were rated by two of the three raters, which were assigned randomly to the videos.

**User evaluation**

User evaluation was based on a week of wearing the sensor in daily life after the initial visit, by means of a user evaluation questionnaire. Participants were instructed to wear the sensor day and night, but if wearing the sensor while sleeping was uncomfortable they were allowed to leave off the sensor during the night. At the end of the week, a researcher administered the user evaluation questionnaire about the sensor. The user evaluation questionnaire consisted of seven statements addressing comfort, weight, size and usability of the sensor which had to be scored between 1 and 5 (1 meaning “Do not agree at all” and 5 meaning “Completely agree”), and an optional additional question regarding suggestions for improvement of the sensor. A high mean score on the questionnaire indicates a positive opinion on wearing the sensor. The additional question regarding improvements for the sensor was assessed separately.

### Table 1. Standardized protocol.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standing still in front of the chair for 5 seconds</td>
<td>1</td>
</tr>
<tr>
<td>Sit down on the chair</td>
<td>2</td>
</tr>
<tr>
<td>Timed Up and Go- slow condition</td>
<td>3</td>
</tr>
<tr>
<td>Timed Up and Go- normal condition (3 repetitions)</td>
<td>4</td>
</tr>
<tr>
<td>Timed Up and Go- fast condition</td>
<td>5</td>
</tr>
<tr>
<td>Five Times Chair Rise</td>
<td>6</td>
</tr>
<tr>
<td>Standing up from the chair (STS)</td>
<td>7</td>
</tr>
<tr>
<td>Bending over to pick up pen from the floor*</td>
<td>8</td>
</tr>
<tr>
<td>Lying down on bed- on back, turn on right side and stand up again</td>
<td>9</td>
</tr>
<tr>
<td>Lie down on the floor and get up again*</td>
<td>10</td>
</tr>
<tr>
<td>Walking 10m using cane or walker**</td>
<td>11</td>
</tr>
</tbody>
</table>

* These activities are optional
** Walking 10m using cane or walker only for subjects that use these in daily life

The free movement protocol consisted of 30 minutes of self-chosen activities such as performing household chores while being filmed. Subjects were instructed to perform household chores or indoor leisure activities at will, and were provided with suggestions when they could not think of any themselves. Common activities chosen were vacuuming, reading, preparing tea or coffee, cleaning dishes and watering plants. The videos from the standardized movement protocol and the free movement protocol were annotated in a video analysis program, Noldus “The Observer” version 10.5 (Noldus Information Technology, The Netherlands). Scoring observations included start and end of each pre-defined activity, namely sitting, standing, walking and lying. The performance of the activities as observed by video was taken as the gold standard. The video camera was kept perpendicular to the actions of the participant whenever possible, which resulted in a side view of all movements. Scoring was performed by three independent extensively trained assistants. All videos were rated by two of the three raters, which were assigned randomly to the videos.

### Data analysis

Percentage of agreement was calculated for assessment of inter-rater reliability on the video annotation. Inter-rater reliability (Intra-class Correlation Coefficient, Two way Random, average measures) was deemed sufficient when the Intra-class Correlation Coefficient (ICC) exceeded 0.8 [28].

Physical activity was assessed based on “time-on-legs” (ToL), which algorithm was described into more detail in section 2.3. In addition, a category-based analysis of gait and postures was performed for more in-depth information on gait and posture detection. The categories were lying, sitting, standing and walking. Lying was defined when the person’s trunk was in a horizontal position with the back, stomach or side touching a horizontal underground without signs of further movement. Sitting was defined when the person’s trunk was in a vertical seated position without movement in the trunk. The angle between the legs and the trunk should be about 90 degrees. Standing was defined when the person was in an upright vertical position with no or only a small displacement, but no distinctive steps, of the feet [28,29]. Walking was defined when the person was moving the feet forward in a walking pattern with the trunk in a forward displacement, from when the heel of the foot cleared the ground for the initial step until the foot of the closing step made complete contact with the floor, with a minimum of 2 steps [29, 30]. For data-analysis purposes, all activities were number-coded representing the corresponding activity category. For validity calculations, the percentage of correspondence of the sensor outcomes and the observational outcomes was calculated over activity data of all separate subjects. Afterward, sensitivity, specificity and overall agreement measures were calculated group-wise based on second-by-second analysis. For example, the definitions used for the calculations for “walking” were as follows [29, 30]:

1. Sensitivity: (total duration that the video observation and the sensor corresponded at the same moment for walking/total duration that walking was observed on video) 100%
2. Specificity: “(total duration that the video observation and the sensor corresponded at the same moment for detected non-walking activities/total duration of non-walking activities as observed on video) 100%”

Afterwards, overall agreement on all categories was calculated as follows [29, 30]:

3. Overall agreement: (total duration that the video observation and the sensor corresponded at the same moment for all categories/total duration that the activities were observed on video) 100%

Sensitivity, specificity and overall agreement were calculated ToL-based as well as category-based. Cut-off values for sensitivity, specificity and overall agreement were defined as: ≤ 40% insufficient, 40%≥ till ≤ 60% moderate, 60% > till ≤ 80% good and > 80% excellent agreement [28, 31], as defined in Fleiss et al [31]. All measures were also calculated for frail and non-frail subjects separately. An independent samples T-test was used to assess whether sensor performance in both physically differently performing groups was comparable. Statistical analyses were performed in Matlab 2012a, Microsoft Office Excel 2010 and SPSS version 16.0.
Results

Twenty subjects were included in the study (4 male, 16 female, mean age ± SD 78.7 ± 5.4). Seven were considered frail, thirteen non-frail. Mean GFI score was 2.7 ± 2.1. Table 2 summarizes the subjects’ characteristics.

Table 2. Subject characteristics.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Total group (n=20)</th>
<th>Frail subjects (n=7)</th>
<th>Non-frail subjects (n=13)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (year)</td>
<td>79.7 ± 5.7</td>
<td>84.1 ± 2.6</td>
<td>77.3 ± 5.5</td>
</tr>
<tr>
<td>Gender (male/female)</td>
<td>5/20</td>
<td>0/7</td>
<td>5/8</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>165.0 ± 0.1</td>
<td>161.1 ± 0.1</td>
<td>166.5 ± 0.1</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>79.6 ± 11.2</td>
<td>79.7 ± 11.3</td>
<td>79.6 ± 11.5</td>
</tr>
<tr>
<td>GFI score</td>
<td>2.7 ± 2.1</td>
<td>6.0 ± 2.6</td>
<td>1.4 ± 1.1</td>
</tr>
<tr>
<td>Living conditions (independent/dependent)</td>
<td>16/4</td>
<td>4/3</td>
<td>13/0</td>
</tr>
<tr>
<td>User of cane or walker (yes/no)</td>
<td>9/11</td>
<td>7/0</td>
<td>2/11</td>
</tr>
</tbody>
</table>

Values are means ± standard deviation

The ICC for inter-rater agreement of the video observation based upon category-wise assessment was 0.97 in the standardized assessment and 0.91 in the free movement protocol. The video observation was therefore deemed sufficient to be used as a reference method [28].

Validity

Standardized protocol

For the video validation of the sensor in the standardized assessment, 11285 seconds of data (3.13 hours) were collected. Mean duration per subject was 564.25 seconds.

Table 3 shows the average correspondence of video observation and sensor data in the standardized assessment. Time-on-leg based, sensitivity, specificity and overall agreement were good to excellent. Category-based sensitivity, specificity and overall agreement measures varied from good to excellent with the exception of lying in which the sensitivity was insufficient. There were no significant differences between frail and non-frail older adults (p ≥ 0.61).

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Overall (n=20)</th>
<th>Non-frail (n=13)</th>
<th>Frail (n=7)</th>
<th>Overall (n=20)</th>
<th>Non-frail (n=13)</th>
<th>Frail (n=7)</th>
<th>Overall (n=20)</th>
<th>Non-frail (n=13)</th>
<th>Frail (n=7)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOL</td>
<td>72.1</td>
<td>70.2</td>
<td>75.7</td>
<td>87.7</td>
<td>85.8</td>
<td>91.1</td>
<td>87.5</td>
<td>79.2</td>
<td>86.0</td>
</tr>
<tr>
<td>Sitting</td>
<td>82.3</td>
<td>79.2</td>
<td>88.1</td>
<td>65.8</td>
<td>67.2</td>
<td>63.2</td>
<td>74.9</td>
<td>72.9</td>
<td>78.8</td>
</tr>
<tr>
<td>Standing</td>
<td>61.5</td>
<td>61.3</td>
<td>61.8</td>
<td>83.1</td>
<td>80.7</td>
<td>87.4</td>
<td>78.4</td>
<td>75.9</td>
<td>83.0</td>
</tr>
<tr>
<td>Walking</td>
<td>61.0</td>
<td>63.6</td>
<td>56.3</td>
<td>97.7</td>
<td>97.5</td>
<td>98.4</td>
<td>93.1</td>
<td>93.3</td>
<td>92.6</td>
</tr>
<tr>
<td>Lying</td>
<td>31.8</td>
<td>35.6</td>
<td>26.2</td>
<td>99.5</td>
<td>99.3</td>
<td>99.7</td>
<td>97.2</td>
<td>96.9</td>
<td>97.5</td>
</tr>
</tbody>
</table>

Free movement protocol

For the video validation in the free movement protocol, in total 35855 seconds of data (9.96 hours) were collected. Mean duration was 1708.95 seconds.

Table 4 shows the average correspondence of video observation and sensor data in the free movement protocol. Time-on-leg based, sensitivity, specificity and overall agreement were excellent. Category-based sensitivity, specificity and overall agreement measures were moderate to excellent with the exception of walking in which the sensitivity was insufficient. There were no significant differences between frail and non-frail older adults (p ≥ 0.07).

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Overall (n=20)</th>
<th>Non-frail (n=13)</th>
<th>Frail (n=7)</th>
<th>Overall (n=20)</th>
<th>Non-frail (n=13)</th>
<th>Frail (n=7)</th>
<th>Overall (n=20)</th>
<th>Non-frail (n=13)</th>
<th>Frail (n=7)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOL</td>
<td>84.3</td>
<td>83.2</td>
<td>86.2</td>
<td>94.2</td>
<td>92.2</td>
<td>97.7</td>
<td>81.6</td>
<td>85.0</td>
<td>91.6</td>
</tr>
<tr>
<td>Sitting</td>
<td>84.2</td>
<td>83.6</td>
<td>85.2</td>
<td>83.0</td>
<td>84.7</td>
<td>79.9</td>
<td>84.4</td>
<td>84.6</td>
<td>85.1</td>
</tr>
<tr>
<td>Standing</td>
<td>77.5</td>
<td>77.7</td>
<td>77.2</td>
<td>68.6</td>
<td>65.3</td>
<td>74.7</td>
<td>73.1</td>
<td>70.7</td>
<td>77.4</td>
</tr>
<tr>
<td>Walking</td>
<td>42.9</td>
<td>48.1</td>
<td>33.5</td>
<td>96.7</td>
<td>95.7</td>
<td>98.6</td>
<td>87.9</td>
<td>86.2</td>
<td>90.9</td>
</tr>
<tr>
<td>Lying</td>
<td>57.6</td>
<td>62.6</td>
<td>32.5</td>
<td>99.9</td>
<td>99.8</td>
<td>99.9</td>
<td>99.7</td>
<td>99.5</td>
<td>99.9</td>
</tr>
</tbody>
</table>

User evaluation

For user evaluation, 142 days of daily life data were collected (mean per subject seven days). All subjects wore the sensor during daytime of all requested days. Sixteen subjects wore the sensor while sleeping. The average score on the user evaluation questionnaire was 4.4 (SD ± 0.6; range 2.4–5.0) on a scale of 1 to 5. Recommendations regarding improvements mainly concerned the sensor’s shape: five subjects indicated that it would be a possible amelioration for the sensor to be thinner.
Discussion

In order to be able to measure and provide feedback on daily activity in real life, it is imperative that activity assessment of a sensor-based method is accurate. Overall, the proposed sensor-based method in this paper provided an excellent estimation of ToL, and a moderate to good estimation of gait and postures in the home situation in standardized as well as free movement conditions. User acceptance is high. The sensor is deemed suitable for daily activity assessment in real life in (frail) older adults.

Accuracy of sensor-based methods to measure physical activity, gait and postures based upon accelerometry have shown a high validity under laboratory circumstances with sensitivity and specificity reaching above 0.95 and overall accuracy ≥ 87% [14–16,30,31]. Sensitivity and specificity are however generally lower in the home environment than under laboratory circumstances [32], due to for instance the lack of standardization of movement instructions. However, the current sensor-based method shows equally excellent accuracy in validation in the home environment based on ToL detection, comparable to outcomes of other sensor-based measures under laboratory circumstances [14–16,32,33].

Accuracy of ToL detection in the free movement protocol was comparable to the standardized protocol, contrary to what one would expect due to the more unpredictable nature of free movement as opposed to standardized circumstances. The standardized assessment involved many transitions within a short time span while in free movement, many older adults chose several longer walking, sitting- or standing periods. With fewer transitions to detect, agreement of ToL detection is higher in free movement. This is promising for accuracy of the sensor-based method in daily life, since the free movement is designed to resemble daily life situations [16].

ToL assesses the daily activity from a macro perspective, which might be a useful and relevant performance indicator for the older population. A further analysis into specific movement and posture categories was conducted to gain additional information of the daily activity from a micro perspective. We analyzed the following four categories: Walking, Sitting, Standing and Lying, which were also studied in other literature. With detection of sitting and standing comparable to or better than earlier results in literature under laboratory circumstances [16,29,30], detection of lying proves to be the most difficult to detect (sensitivity 0.32) even though specificity of detection of lying was excellent (0.99). This difficulty in detection is most probably due to the short lying intervals in the data. Due to the short durations small errors in synchronisation had a large negative impact on the accuracy of detection. A shift of merely one second is a large error in detection in a two-second lying interval and results in low sensitivity. However, when addressing the number of lying intervals accurately detected the sensor detected fifteen out of sixteen intervals in the free movement and 15 out of 26 intervals in the standardized assessment. The missed intervals were mostly very short lying bouts (2–9 seconds), including several seconds of “turning over onto the side” halfway during the interval. Since in real life lying mostly is prominent during long periods of resting and sleeping, the current protocol is most probably not representative for the detection of lying in real life. Detection during the longer periods of lying in daily life is expected to be higher based on these results. Also, a large part of the inaccuracy in lying is caused by the design of the sensor as a necklace. When lying down the sensor often slides to the side, causing additional noise in the detection signal. Especially in the aforementioned short lying bouts of 2–9 seconds, this sliding down comprises a substantial part of the lying bout and therefore causes a large inaccuracy. In addition, lying provided some challenges causing a moderate sensitivity. These challenges were mostly due to low sensitivity to detection of walking periods in frail subjects. Frail older persons generally walk slower, more inconsistent and have more body sway during walking, which may disturb detection of walking [34, 35]. Also, all frail subjects used a cane or walker. Cane use is of large influence on gait pattern, introducing asymmetry and weight shift in the walking pattern compared to walking without cane use [35]. The gait patterns and asymmetry due to cane use can hamper recognition of the walking pattern by the necklace-worn sensor, which may explain the slightly lower sensitivity to walking of the sensor in frail older adults. Overall, regardless of the challenges provided by lying and walking, hampering it’s use for specific gait- and posture detection in the home situation, the sensor excellently detected ToL, and is therefore able to make an accurate distinction between time spent active and time spent inactive, which is crucial for accurate daily activity detection.

Next to the accuracy of detection algorithms, the use of body-worn sensors should be unobtrusive and designed not to hamper wearers during everyday life. If a sensor is not comfortable to wear or difficult to use, subjects will reject it [36] and adherence will be low. Recent studies provide that people prefer body-worn sensors on the wrist, torso, arm or waist [37]. Acceptability is heightened when the sensor is worn around the wrist, or as a necklace. The high adherence in wearing and score in the user evaluation in this study emphasize these findings.

Strengths and limitations

In previous literature, sensor-based methods for measurement of daily physical activity have mostly been tested under laboratory circumstances [15]. However, assessment under laboratory circumstances is not applicable to daily life [35]. In the current study, validation of the movement registration method for older adults is performed in a semi-structured way including standardized assessment, free movement and an indication of daily life behaviour in the home environment of the target group. This set-up is a major advance in home assessment of mobility registration technology, allowing semi-structured validation and evaluation of a device after laboratory circumstances have been tested and following recently published recommendations [37]. The assessment is suitable for non-frail as well as frail older adults, since the standardized assessment is short and the free movement is tailored to a person’s capabilities.

A study limitation is found in the free movement. Subjects are instructed to perform daily tasks at will during thirty minutes. This instruction results in subjects performing several tasks in an often rushed manner, which they would normally be performing over a longer time span. This heightened activity causes accuracy in the free movement to be probably underrated. The moderate results of the detection of lying serve to illustrate this point. Another limitation is found in the nature of the tasks in the standardized assessment and free movement. While being fairly complete regarding postures, gait and indoor activities, bicycling was not included in the protocol. Since bicycling is a common activity among the very healthy older adult population, this could be included in further validation of the sensor.
Conclusions

The necklace-worn sensor-based method is an acceptable valid and feasible instrument for detecting daily physical activity based upon ToL in frail and non-frail older adults. Accuracy for detecting ToL in daily activity is excellent. User acceptance of the sensor is high.

Acknowledgments

The sponsor was not involved in any part of the research, the writing of the manuscript nor in the decision to submit the manuscript for publication.

References

Chapter 3

Detecting mobility-related activities


Chapter 4

Adherence to and effectiveness of an individually tailored home-based exercise program for frail older adults, driven by mobility monitoring: design of a prospective cohort study

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Zijlstra W.
Zhang W.
Bulstra S.
Stevens M.

Abstract

Background
With the number of older adults in society rising, frailty becomes an increasingly prevalent health condition. Regular physical activity can prevent functional decline and reduce frailty symptoms. In particular, home-based exercise programs can be beneficial in reducing frailty of older adults and fall risk, and in improving associated physiological parameters. However, adherence to home-based exercise programs is generally low among older adults. Current developments in technology can assist in enlarging adherence to home-based exercise programs. This paper presents the rationale and design of a study evaluating the adherence to and effectiveness of an individually tailored, home-based physical activity program for frail older adults driven by mobility monitoring through a necklace-worn physical activity sensor and remote feedback using a tablet PC.

Methods/design
Fifty transitionally frail community-dwelling older adults will join a 6-month home-based physical activity program in which exercises are provided in the form of exercise videos on a tablet PC and daily activity is monitored by means of a necklace-worn motion sensor. Participants exercise 5 times a week. Exercises are built up in levels and are individually tailored in consultation with a coach through weekly telephone contact.

Discussion
The physical activity program driven by mobility monitoring through a necklace-worn sensor and remote feedback using a tablet PC is an innovative method for physical activity stimulation in frail older adults. We hypothesize that, if participants are sufficiently adherent, the program will result in higher daily physical activity and higher strength and balance assessed by physical tests compared to baseline.

Conclusion
If adherence to and effectiveness of the program is considered sufficient, the next step would be to evaluate the effectiveness with a randomised controlled trial. The knowledge gained in this study can be used to develop and fine-tune the application of innovative technology in home-based exercise programs.

Background
As the number of older adults in our society rises [1], health professionals, including physiotherapists, are increasingly confronted with frail older adults. Frailty is a multidimensional feature that has been defined and described in many different ways. A widely used definition is that of Fried [2]: “Frailty is 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”. Frailty is an important predisposition for falls and associated adverse health conditions [3]. Previous research indicates that regular physical activity has many beneficial effects on daily functioning, balance and strength, as well as other health-related factors in older adults [4,5]. Exercise programs can potentially be helpful in reducing frailty of older adults and fall risk, and in improving associated physiological parameters, thus facilitating a longer independent life [6]. Specifically, home-based physical activity programs can be considered promising in the promotion of a physically active lifestyle among frail older adults [7]. Daily physical activity and adherence to home-based exercise programs is generally low among this group though [8]. This compromises the effectiveness of home-based exercise programs.

Current developments in technology can assist physiotherapists in enlarging adherence to home-based exercise programs. The use of objective activity monitoring with wearable sensors can potentially be helpful in strategies aimed at increasing daily activity and adherence to home-based physical activity programs [9]. Recent studies have shown the possibility to monitor mobility-related activities based on a thorax-worn motion sensor [10] or motion sensors on the lower trunk [11]. Such sensor-based approaches can be used to measure physical activity by detecting and monitoring different postures (i.e. lying, sitting, standing) and activities such as rising from a chair and walking. Motion sensing-based activity monitoring combined with information and communication technology (ICT) create the possibility to remotely monitor and influence daily physical activity behaviour in real life, instead of solely under laboratory circumstances or in a physiotherapy practice. Hence technology can assist in enlarging adherence by providing home-based exercise programs through gaining participant information and enabling remote contact with participants. The use of computers and tablets is steadily rising among older adults in the Netherlands [12]. How such new technology can be used to optimally support exercise-based interventions tailored for older adults is not yet clear though.

We recently developed an innovative home-based physical activity intervention that is based on the use of a tablet PC in order to present a home-based exercise program and a necklace-worn motion sensor to continuously monitor mobility-related activities. The data monitoring is used for remote coaching of intervention participants. The current paper presents the design of a study that aims to evaluate the adherence to and effectiveness of our approach on independently living, transitionally frail older adults.

The primary research question is: What is the adherence to a home-based exercise program for use by older adults including exercise instructions from a tablet PC and monitoring by means of a necklace-worn motion sensor, as determined by adherence to the exercise program and wearing of the sensor? Secondary research questions are: Does participation in the home-based exercise program (including use of the sensor and tablet) increase the daily amount of physical activity, mea-
Chapter 4

Sured both objectively and self-reportedly? Does participation in a home-based exercise program (including use of the sensor and tablet) improve functional performance?

**Methods**

**Study design**

This will be a prospective cohort study. Participants will join a 6-month home-based exercise program. Training and measurements will take place at participants’ homes. Study design and procedures are approved by the Medical Ethics Committee of the University Medical Center Groningen (UMCG). See the “Flowchart of the study design” subsection for a flowchart of the study design.

**Participants**

Fifty subjects will be included. Inclusion criteria will be:
- Age 70–85 years.
- Transitional frailty as measured by the Groningen Frailty Indicator (GFI). The GFI is a screening instrument for level of frailty. Scores range from zero (not frail) to 15 (very frail). Older adults will be considered transitionally frail if they have a GFI score of 4 or 5. This GFI score indicates persons with only a minor elevated chance of loss of functionality and heightened disability [13].
- Community dwelling or assisted living conditions.
- Ability to walk 10 m without support or using a cane or walker.
- Availability of a telephone.
- Ability to understand instructions regarding the use of the technology and execution of the exercise program.

Persons will be excluded based on conditions that hamper safe execution of the exercise program:
- Total hip or knee replacement in the past 6 months.
- Visual problems to a degree that makes it impossible for the subject to accurately read the questionnaires or walk around safely in his own home.
- Stroke within the last 6 months.
- Parkinson’s disease stage 4 or 5.
- Other neurological conditions that can impair daily functioning (e.g. dementia).

**Recruitment**

Recruitment will be done by several means:
1. At information gatherings and when spreading information folders in neighbourhoods where many older people live.
2. Through healthcare organisations for older adults.
3. Recruitment in the participant pool of SamenOud. SamenOud is an UMCG-initiated project introducing a new healthcare model that combines all aspects of older-adult health care: living, well-being and care. SamenOud is running in the north-eastern part of the Dutch province of Groningen [14].
Intervention
All older adults participate in a home-based exercise program that consists of 3 months of home-based exercising with weekly telephone support from a coach and 3 months follow-up of exercising without coach contact. Participants exercise 5 days a week, starting with exercise bouts of 10 minutes which can progress up to 45 minutes. The program progresses in 18 levels. The first step-in level of the program consists of light and easy exercises, in order to accommodate for sedentary participants. Progression of difficulty and duration of exercises across levels elapses in small steps and in consultation with the coach. Participants are not obliged to finish all levels during the program.

The exercise program is based on the Otago Kitchen Table home-based exercise program, an individually tailored fall prevention program for muscle strengthening and balance-retraining exercises of increasing intensity used worldwide [15] [16]. The exercises are functional and closely related to daily activities (e.g. standing up from a chair).

From a behavioural point of view this program is based on insights from Social Cognitive theory [17]. The program aims to enhance self-efficacy. Self-efficacy is defined as “the belief in one’s capabilities to organize and execute the courses of action required to manage prospective situations.” [18]. It is hypothesised that by enhancing self-efficacy adherence to the program will improve. In order to enhance self-efficacy, motivational feedback is provided to the participant. The layout of the program as well as the provided feedback is based on the four main sources of efficacy information described by Bandura in the Social Learning theory. These sources include performance accomplishments, vicarious experience, social persuasion, and physiological and emotional states [18]. The sources are used in four different strategies:
1. Exercises are presented by a role model in the instructional videos.
2. An encouraging message is provided after completing an exercise bout.
3. Automatic feedback on time spent “active” (standing and walking) is provided on a daily basis.
4. Weekly phone calls with the coach will be applied, addressing progression and motivational issues during the first three months.

Two devices are utilised during the program: a sensor to collect daily activity data and a tablet PC to provide exercise instructions and feedback.

Mobility monitoring
Daily mobility will be monitored by a necklace-worn motion sensor. The sensor is a miniature hybrid sensor that contains a 3D-MEMS accelerometer together with a barometric pressure sensor. Data is sampled at 50Hz with a 4 mg resolution. A Micro-SD card will be used for data storage and exchange. The sensor weighs about 30gr and measures about 55x25x10mm. Measured sensor data is used to identify different activities, like standing, sitting, lying and walking [10] [19] [20]. Daily activity level will be calculated based on these categories. Participants will wear the sensor during the daytime and connect it to the tablet PC at night for data upload and battery reloading.

Tablet PC
A tablet PC is provided as a user device to give exercise instructions and distant feedback. Functionality of the tablet PC is adjusted to independent older adult use, keeping menus and necessary interaction as simple as possible. Completion of the exercise bouts is notified through the tablet PC. Participants are able to choose their level of exercise, after which they are provided with a video showing the entire exercise bout being performed by an older adult, which they are asked to imitate. By means of this procedure they are guided through the entire exercise bout. The videos include a spoken explanation of the exercises while the exercises are being shown. After completing the video, a motivational message based on the rate of completion of the video appears on the screen. The tablet collects data on number of shown videos and the level of the videos shown. Feedback on daily activity level as registered by the sensor is provided by means of a graph that compares daily activity performance to one’s earlier performances as well as to a norm population.

Outcome measures
Demographic characteristics (e.g. age, gender, family status and comorbidity) and information on experience with computers, tablets and smartphones will be collected at baseline. Also, written informed consent will be completed at baseline. In addition to the monitoring data, standardised measurements will be taken at baseline (T0), at 3 months (T1) and at 6 months (T2).

Primary outcome measure
Adherence: Adherence to the intervention will firstly be assessed based on adherence to the exercise program and wearing of the sensor. Adherence to the exercise program will be calculated based on completion of exercise bouts. Adherence to wearing the sensor will be calculated based on the number of days the sensor is worn and the successful collection of data. Adherence will be considered sufficient when adherence to the exercise program and to the wearing of the sensor exceeds 70%. Additional information on factors that may influence adherence will be collected by means of a questionnaire. The user evaluation questionnaire is an adapted version of the SensAction-AAL subject evaluation form [21]. The questionnaire contains questions about the perceived burden of the intervention, wearing of the sensor, and acceptability of the technology. Information will be collected at T1 and T2.

Secondary outcome measures
Objective daily physical activity based on sensor data: Baseline (T0) information on time spent “active” (standing and walking) will be collected while wearing the sensor for a week before starting the exercise program. A week of wearing will also be used as intermediate and follow-up information on daily activity at T1 and T2.

Self-reported daily physical activity: In addition to objective daily physical activity, self-reported daily physical activity will be measured by questionnaire at T0, T1 and T2. The Short Questionnaire to Assess Health-enhancing physical activity (SQUASH) gives an insight into habitual physical activity [22]. The SQUASH consists of four domains: A) commuting activities, B) leisure-time activities, C) household activities, and D) activities at work and school. The questions within the
four domains are prestructured into frequency, duration and intensity of an activity. Reproducibility and relative validity of the SQUASH for assessing physical activity have been evaluated [22] [23]. Functional performance: Functional performance is assessed by means of several clinical tests for physical functioning at T0, T1 and T2. First, subjects are requested to stand up from a chair at a self-selected pace (Sit-To-Stand; STS). STS is commonly used as a test to assess lower-limb strength and balance [24] [25]. Slower test scores are associated with higher fall risk in older adults [26]. Subjects are instructed to sit still for several seconds, stand up from the chair at their preferred pace and then stand still for several seconds. The STS movement has good inter-rater and test-retest reliability in healthy older adults [27]. The test is repeated three times if possible.

Second, the Timed Up-and-Go test (TUG) will be used to measure balance and functional mobility. The TUG is a widely used clinical test and is known to be associated with fall risk in older adults [28] [29]. The test protocol includes standing up from a chair, walking 3 m at a preferred speed, turning 180°, walking back and sitting down again. Intra-rater reliability ICC as well as inter-rater reliability ICC of the TUG are excellent [30]. The test is deemed to be a valid measure of dynamic balance and functional control in older adults [31]. This test will be repeated two times if possible.

Third, the Five-Times-Sit-to-Stand test (FTSS) will be used to indicate postural control and lower extremity strength. The FTSS has been associated with postural control, lower extremity strength and fall risk in older adults [26]. Slower test scores have been related to more functional impairments in daily living among older adults (Judge 1996). Subjects are instructed to stand up from a chair consecutively five times as fast as possible, preferably without using their hands for support. Test-retest reliability of the FTSS in community-dwelling older adults is adequate [32] [33]. The FTSS is deemed to be a valid measure of dynamic balance and functional ability in community-dwelling older adults [31]. Inter-rater reliability is good to excellent [33] [34]. The test will be repeated twice if possible.

In addition, subjects follow a weekly functional performance self-assessment protocol independently while wearing the sensor. The protocol consists of one STS, one TUG and one FTSS test. Subjects are asked to shake their sensor five times before and after performing their self-assessment, to mark the self-assessment in their daily life data.

Data acquisition
Demographics collected by written questionnaire and information on adherence and personal circumstances collected during telephone contacts are manually entered into a database. Information on daily physical activity during the week of wearing and daily life data are collected by the worn sensor. These data are collected during the week before the home visits at T0, T1 and T2. Functional tests are performed during the home visits and by self-assessment; data from the functional tests are collected by using the sensor as well as by registration of duration using a stopwatch. For self-assessment, subjects note the date and time at which they perform the weekly self-assessment and shake the sensor five times before and after to mark the self-assessment in the daily life data. All sensor data are transmitted to a tablet by Bluetooth every night and then stored in a web-based interface. Stopwatch times are entered manually into the database.

Design of an individually tailored home-based exercise program

Data analysis
Descriptive statistics will be used to describe the baseline and demographic characteristics as well as data on adherence. Changes in daily physical activity and performance on the functional performance tests at T0, T1 and T2 will be analysed by means of Repeated measures ANOVA. Subgroup analyses will be conducted taking into account the potential influence of age, gender, marital status, GFI and BMI. All data will be analysed with Matlab (version 2013a) and SPSS (version 20.0). A p-value lower than 0.05 will be considered statistically significant.

Sample size calculation
Sample size calculation is based on the secondary outcome measure of objective physical activity behaviour as measured with the sensor. Based on earlier studies on the effectiveness of physical activity programs for older adults, it should be possible to reach a 15% increase in objective daily activity within six months [35]. To detect this difference with 80% power (significance level 0.05), a group of 40 participants completing the entire program is required. Assuming a dropout rate of 20%, a total of 50 participants should be enough to demonstrate an increase in daily activity.

Discussion
The objective of this study is to investigate adherence to and determine the effectiveness of an intervention using a necklace-worn sensor and a tablet PC for driving an individualised home-based physical activity program for transitionally frail older adults.

The optimal design for home-based physical activity programs for older adults using advanced technology is not yet clear. Adherence to such programs is an important issue. [36]. Although a general cut-off point for sufficient adherence has not yet been defined, in the literature a cut-off value of 70% adherence is often used. Adherence to home-based physical activity programs for older adults can be influenced by several factors. First, the physical activity program should be physically attainable and encouraging for the participant. In contrast to many group-based physical activity programs found in literature, home-based physical activity programs provide an opportunity to tailor the exercise to the participant. Individual tailoring is a means to ensure practical attainability [5]. Such customisation can be quite extensive, giving each participant his or her own specific training conditions. It can also be more structured, by providing levels of exercising and letting subjects progress through these levels at their own pace. In this study, structured individual tailoring is provided in order to keep the exercise program well-defined.

Adherence is also influenced by the means through which a program is provided to participants. Technology should be encouraging to the target group [37]. Applications should be easy to use independently by older adults, who are generally limited in their use of modern technology [12]. A major advantage of tablet PCs is the use of touchscreens. Touchscreens are instinctive in their use and provide opportunities for lay users, like older adults. In addition, the body-worn sensors are small, unobtrusive tools that can be used to easily gain objective insight into the amount of physical activity of older adults [9]. Accurate measurement of physical activity is essential for proper feedback to participants and to get an impression of the effectiveness of the intervention.
In conclusion, the strength of the current study is the personal tailoring of the exercise program as well as the individual feedback based on actual objective performance of the participant. The ultimate goal is to make the innovative technology available in the community for older adults and health professionals like physiotherapists.

Acknowledgements

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Chapter 5

An individually tailored home-based exercise program for frail older adults driven by tablet application and mobility monitoring: feasibility and practical implications

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Prev Chronic Dis. 2017 Feb 2;14:E12
Abstract

Objective
To evaluate feasibility and user opinion of a six-month home-based exercise program supported by a necklace-worn mobility sensor and a tablet application for frail older adults.

Methods
A cohort study. Subjects exercised 3 months with and 3 months without remote coaching. Feasibility was operationalized as adherence to the exercise program and wearing of the sensor, as well as incidents participants reported. Adherence was considered sufficient when it exceeded 70%. User opinion was measured with a questionnaire.

Results
21 subjects completed the trial. Mean adherence to the program was 60.9%. Adherence in completers was almost sufficient and significantly higher than in dropouts (69.2% vs. 49.9%). Adherence was sufficient in completers in the supervised part (75.8%). Mean adherence to wearing of the sensor was 66.7% and significantly higher in completers than in dropouts (75.7 vs. 54.2%). Connectivity-related incidents were most prominent. Incident rates were significantly lower in completers than in dropouts (0.39 vs. 1.19). User opinion of the system was positive.

Conclusion
A home-based exercise program using novel technology seems feasible. The user opinion was positive. With regular coaching and a stable internet connection, this home-based exercise program is promising for daily physical activity stimulation in frail older adults.

Introduction
Due to the ageing of our population, the preservation of health and self-reliance in advancing age is increasingly important [1,2]. Older adults generally are insufficiently physically active to maintain health and physical functioning [3,4]. Stimulation of a physically active lifestyle in advancing age is therefore essential 5.

Older adults often prefer exercising at home [6], but guidance and motivation is necessary and could previously not be provided adequately in home-based exercise programs [7]. However the development of internet and novel technology, which can be used to enable remote administration of and guidance in home-based exercise programs, has been rising exponentially and could fulfill this need [1,7]. Body-worn sensors for measurement of physical activity are developed on a large scale to accurately and objectively measure daily physical activity, providing a support of personally tailored stimulation of physical activity [8-14]. Recent developments in tablet PC’s and smartphones using mobile internet seem especially suitable for remote contact with an exercise coach stimulating adherence. Text messages, exercise instruction through video contact and contact with a coach that follows one’s achievements on the internet have been successfully implemented [15-17]. Especially motivational contact with a coach seems to be important for adherence. Internet-based platforms integrating body-worn sensors and video instructions through a tablet are promising for allowing older adults to exercise independently [18].

However, older adults often are unwilling to and uncomfortable in using innovative technology, though computer, tablet and smartphone use among older adults and middle-aged individuals is rising steeply [19-22]. Exercise programs using novel technology for older adults have already been reported, though research on features of these novel technologies and problems one might run into when implementing technology in this target group is necessary [18,23,24]. The aim of this study was therefore to assess the feasibility and user opinion on independent use of remote novel technology in a home-based exercise program for older adults.

Methods

Study design
A prospective cohort study. Subjects participated in a six-month home-based exercise program, using a tablet for exercise instructions and a necklace-worn sensor for daily activity registration. In the first three supervised months, subjects were contacted by phone to receive weekly coaching. During the unsupervised last three months, subjects were not contacted by the coach but could call themselves when encountering problems. If issues could not be solved by telephone, the coach performed a home-visit. 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 6.
Subjects
Subjects were community-dwelling older adults living in the province of Groningen, the Netherlands. Inclusion criteria included being at least 70 years old and being able to walk at least 10 metres independently or using a walking aid. In addition, subjects had to be transitionally frail as indicated by the Groningen Frailty Indicator (GFI) score of 4 or 5 [26].

Exclusion criteria were physical conditions that hamper safe independent performance of a home-based exercise program or working with a tablet, such as severe visual problems. Subjects were recruited between January and November 2014 by means of advertisement, leaflets and recruitment during Embrace community meetings [27].

Technical components
Necklace worn sensor
The sensor was a miniature hybrid sensor containing a 3D-MEMS accelerometer and a barometric pressure sensor, worn as a necklace. Accelerometer data were sampled at 50 Hz with a range of 8 g, barometric data were sampled at 25 Hz. A micro-SD card was used for storage and exchange of data. The weight of the sensor was about 30 grams and it measures 55 by 25 by 10 mm (Philips Research, Eindhoven). Data transfer and battery recharge was performed automatically every day when connecting the sensor to the tablet with a USB-cable during nighttime.

Tablet PC
A tablet PC (Dell Latitude 10 tablet; Windows 8 operating system) was provided as a user device, giving exercise instructions by means of videos and distant feedback. Functionality of the tablet PC was adjusted to independent older adult use, with menus and necessary interaction designed as simple as possible. Subjects were able to choose their own level of exercising. Exercises were shown in videos which the subject had to imitate. Each level had a different video showing the full exercise bout. After completing a video, a tailored motivational message as well as sensor-registered graphical feedback on daily activity level during the previous days was provided. Internet connection was provided with mobile internet card inserted in the tablet with 3G- or 4G connection or home WiFi-connection when available. The exercise program was provided by means of an internet-based application running on a distant server.

Evaluation methods and statistical analysis
Adherence
Adherence to the exercise program was calculated based upon completion of the planned exercise bouts as indicated by watching the online exercise videos. Adherence to wearing the sensor was calculated based on the number of days the sensor was worn with successful collection of data as registered by the sensor locally. Scheduled holidays were excluded from analysis. Adherence was considered sufficient when adherence to the exercise program and to the wearing of the sensor exceeded 70%.

Technical and operational feasibility
An inventory of problems that users ran into when performing the program was made. All phone calls and home visits other than scheduled weekly contacts and measurements were catalogued including reasons of contact. The problems subjects encountered were divided into three categories: technology-related incidents, connectivity-related incidents and participant-induced incidents. Technology-related incidents were for instance malfunctioning of cables or a defect soundcard of the tablet. Connectivity-related incidents were incidents related to low internet coverage or server downtime. Participant-induced incidents were for instance the opening of other web pages due to the inability of subjects to accurately push the correct buttons on Google Chrome. Incidents were assessed regarding number of contacts during the intervention period as well as density of contacts (mean number of contacts per subject per week).

Determinants influencing participation
By means of a questionnaire determinants that might have influenced older adults’ ability to independently perform a home-based exercise program using novel technology were assessed. Questions included age, gender, marital status, prior and current use of computer and smartphone, fall history, chronic conditions and level of frailty (GFI). Prior and current use of Information and communication technology such as PC, smartphone and associated software was assessed by means of a multiple choice question with answer categories “Never used before”, “Occasionally” or “Daily, now or in the past”. Smartphone use was assessed in a dichotomous question “Own a smartphone” or “Do not own a smartphone”. Fall history was assessed by a question stating how many times a person had fallen in the previous year “Never”, “Once” or “Multiple times”.

User evaluation
User evaluation was performed by means of a written questionnaire filled in by the participants after the supervised period (post-test) and again after the unsupervised period (follow-up). This user evaluation questionnaire is an adapted version of the SensAction-AAL subject evaluation form [28]. The questionnaire addressed ease of use of the tablet and sensor, frequency of contact and help from the coach and trust in the correct functioning of the devices. Answer categories varied from “Not agree at all” (0) to “Fully agree” (5) on a Likert scale. A higher mean score on the questionnaire indicated a more positive opinion on the intervention.

Dropouts were also contacted for a short review of the program after ending their participation. In this review, subjects were asked one question: “Rate the program and technology with a mark between 1 and 5, 1 being very ill-performing and not enjoyable and 5 indicating very well-performing and enjoyable”.
Results

Participants
Forty transitionally frail (mean GFI score 4.4 ± 0.5) and independently living participants were included, of which 15 males and 25 females. Mean age at intake was 80.8 ± 4.6 years. All participants experienced one or more chronic conditions or debilitations, most commonly heart failure, diabetes and leg injuries. Twenty-five subjects had prior experience with tablet or laptop, of which twenty-one used such a device on a daily base. One participant owned a smartphone. Subjects' characteristics are summarized in Table 1.

Table 1. Participant Characteristics

<table>
<thead>
<tr>
<th></th>
<th>Total Group (N = 40)</th>
<th>Completers (N = 21)</th>
<th>Dropouts (N = 19)</th>
<th>P</th>
</tr>
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<tbody>
<tr>
<td>Gender (M/F)</td>
<td>15/25</td>
<td>8/13</td>
<td>7/12</td>
<td>0.90</td>
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<tr>
<td>Age (Year)*</td>
<td>81 ± 4.6</td>
<td>80 ± 4.7</td>
<td>83 ± 4.2</td>
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<tr>
<td>GFI (Score)*</td>
<td>4.4 ± 0.50</td>
<td>4.4 ± 0.50</td>
<td>4.5 ± 0.51</td>
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<tr>
<td>BMI (Kg/M²)*</td>
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<td>28.1 ± 4.4</td>
<td>27.6 ± 3.7</td>
<td>0.75</td>
</tr>
<tr>
<td>Computer Experience (Y/N)</td>
<td>25/15</td>
<td>18/3</td>
<td>7/12</td>
<td>&lt;0.010</td>
</tr>
<tr>
<td>Smartphone owner (Y/N)</td>
<td>1/39</td>
<td>1/20</td>
<td>0/19</td>
<td>0.04b</td>
</tr>
<tr>
<td>Internet Type (3G/4G/WiFi)</td>
<td>17/11/12</td>
<td>4/6/11</td>
<td>13/5/1</td>
<td>0.04b</td>
</tr>
</tbody>
</table>

a. Data are expressed in Means ± SD.
b. Significant difference between Completers and Dropouts at the 0.05 level.

Adherence
Twenty-one subjects completed the half-year program, nineteen subjects dropped out pre-term: eleven due to internet reception problems, five because of medical reasons not related to the exercise program, two because of illness of their spouse and one deceased. Sixteen of the dropouts quit during the first three months of the trial, three during the last three months. Main adherence to the wearing of the sensor among 3G-, 4G-, and WiFi-users was resp. 62.6 ± 31.8, 83.7 ± 23.0 and 60.9 ± 31.8% (p = 0.04). Adherence to the wearing of the sensor, while dropouts had a significantly lower adherence of 54.2 ± 31.2% (p = 0.04). Adherence to the exercises among 3G-, 4G-, and WiFi-users was resp. 62.6 ± 31.8, 83.7 ± 23.0 and 60.9 ± 31.8% (p = 0.21). Table 2 summarizes the details of adherence to the program.

Table 2. Adherence rates

<table>
<thead>
<tr>
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<th>Total Group (N = 40)</th>
<th>Completers (N = 21)</th>
<th>Dropouts (N = 19)</th>
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<tr>
<td>Number of days in intervention*</td>
<td>126.2 ± 86.8</td>
<td>202.6 ± 10.8</td>
<td>45.7 ± 49.6</td>
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<tr>
<td>Adherence Exercises (%)*</td>
<td>60.9 ± 32.5</td>
<td>69.2 ± 32.2</td>
<td>49.9 ± 30.4</td>
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<tr>
<td>Adherence Exercises Supervised (%)*</td>
<td>64.3 ± 32.1</td>
<td>75.8 ± 29.2</td>
<td>49.3 ± 30.3</td>
<td>0.01b</td>
</tr>
<tr>
<td>Adherence Exercises Non-supervised (%)*</td>
<td>60.5 ± 40.6</td>
<td>62.4 ± 41.9</td>
<td>40.5 ± 18.2</td>
<td>0.44</td>
</tr>
<tr>
<td>Adherence Sensor (%)*</td>
<td>66.7 ± 30.7</td>
<td>75.7 ± 27.7</td>
<td>54.2 ± 31.2</td>
<td>0.04b</td>
</tr>
</tbody>
</table>

a. Data are expressed in Means ± SD.
b. Significant difference between Completers and Dropouts at the 0.05 level.

Feasibility of an individually tailored home-based exercise program

Technical and operational feasibility
The total number of incident contacts was 249, which entails a mean density of 0.78 ± 0.8 incident contacts per person per week. The density of contacts was significantly different among completers and dropouts, resp. 0.39 ± 0.5 vs. 1.19 ± 0.8 (p = 0.01). Hundred-and-nine incident contacts were technology-related, with a mean density of 0.20 ± 0.5 contacts per person per week. Hundred-and-ten contacts were connectivity-related, which entails a mean density of 0.36 ± 0.3. Twenty-nine contacts were participant-induced, which was a density of 0.07 ± 0.1 contacts per person per week. All three contact types differed significantly in completers and dropouts, with technology-related, connectivity-related and participant-induced contacts resp. p = 0.04, <0.01 and 0.02.

When stratifying regarding connection type, contact density among 3G-users was significantly higher than contact density in 4G- and WiFi-users (1.30 ± 0.8 vs. 0.45 ± 0.3 vs. 0.43 ± 0.7 contacts per person per week; p = 0.01). In particular, connectivity-related contacts was higher in 3G-users (0.74 ± 0.5 vs. 0.21 ± 0.4 vs. 0.17 ± 0.4 contacts per person per week; p = 0.00). Incident rates and densities are summarized in Table 3.
Table 3. Incidents

<table>
<thead>
<tr>
<th></th>
<th>Total Group (N = 40)</th>
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<th>Dropouts (N = 19)</th>
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<tr>
<td><strong>Technology-related</strong></td>
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<tr>
<td>Amount</td>
<td>109</td>
<td>80</td>
<td>60</td>
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<tr>
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<td>0.16 ± 0.2</td>
<td>0.24 ± 0.4</td>
<td>0.04^p</td>
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<td>Density (mean/subj/week)</td>
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<td>0.39 ± 0.5</td>
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<th>3G-Users (N = 17)</th>
<th>4G-Users (N = 11)</th>
<th>WiFi-Users (N = 12)</th>
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<tr>
<td>Amount</td>
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<td>29</td>
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<td>Density (mean/PP/week)</td>
<td>0.23 ± 0.3</td>
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<td>0.18 ± 0.4</td>
<td>0.01^a</td>
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<td></td>
</tr>
<tr>
<td>Amount</td>
<td>50</td>
<td>25</td>
<td>27</td>
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</tr>
<tr>
<td>Density (mean/PP/week)</td>
<td>0.74 ± 0.5</td>
<td>0.21 ± 0.4</td>
<td>0.17 ± 0.4</td>
<td>&lt;0.01^p</td>
</tr>
<tr>
<td><strong>Participant-induced</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amount</td>
<td>6</td>
<td>7</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Density (mean/PP/week)</td>
<td>0.03 ± 0.1</td>
<td>0.07 ± 0.2</td>
<td>0.05 ± 0.1</td>
<td>0.88</td>
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<tr>
<td><strong>Total</strong></td>
<td>78</td>
<td>61</td>
<td>86</td>
<td></td>
</tr>
<tr>
<td>Density (mean/PP/week)</td>
<td>1.30 ± 0.8</td>
<td>0.45 ± 0.3</td>
<td>0.43 ± 0.7</td>
<td>0.01^a</td>
</tr>
</tbody>
</table>

* Data are expressed in Means ± SD.
* ^a^ Significant difference between Completers and Dropouts at the 0.05 level.

Subjects received feedback on their performance during their scheduled weekly contacts. There were in total 216 weekly scheduled telephone contacts performed, which lasted between one and two minutes each when no additional motivation or technological assistance was needed. Base load of the weekly contacts was therefore between 216 and 432 minutes in the total intervention. During forty of these contacts motivational strategies regarding the performance were used. The motivational part of these contacts took between two and five minutes each, providing a total additional coaching load between 80 and 200 minutes during the coached part of the intervention. All of the additional motivational contacts needed were in the coached part of the intervention. In twenty-three of these contacts, subjects were advised to adjust their training load. In the other seventeen contacts, subjects received feedback upon their adherence to the program when this seemed to be below par.

**User evaluation**

Average score on the user evaluation questionnaire in completers was 4.3 ± 0.4 (range 0-5) at post-test and 4.2 ± 0.2 at follow up assessment. This indicates a positive opinion on the system and application. Subjects indicated to prefer the weekly phone contact with the coach instead of exercising independently (18 out of 21).

Eleven of the dropouts responded to the user evaluation question after their participation. Mean score on this question was 2.00 ± 0.9. Four of these subjects had not dropped out due to the internet reception problems and valued the program significantly more positive than the subjects that had dropped out due to the internet reception problems, resp. 2.8 ± 1.0 vs. 1.6 ± 0.5 (\( p = 0.03 \)).

**Discussion**

The current study provides insight into the feasibility of a home-based exercise program using a body-worn sensor and a tablet application. Mean adherence to the exercises was 60.9 ± 32.5%, which does not reach our goal of 70% for adherence to the exercises to be considered sufficient. However, completers did reach the 70% adherence to the program in the coached part of the adherence, as opposed to a non-sufficient adherence in the non-coached part of the intervention. This indicates that the weekly coaching by telephone is an important feature in keeping subjects exercising sufficiently. This is in line with earlier findings in literature depicting coach contact as an important factor influencing adherence [29]. Data reports on wearing of the sensor almost reached 70% in general, and did reach the 70% level in completers. Our reported adherence rates are however lower than earlier reported studies in the field [18]. This can be explained by the significantly longer intervention time in our study, which invites non-adherence more than short trials [18,30], but adherence was probably mostly influenced by stability of the system which was often compromised by connectivity issues.

The use of mobile internet connections has drawbacks, illustrated by the high connectivity-related incident rate. In more rural areas such as where this study was performed the 4G-coverage was often very low. Internet pages not loading due to minimal reception caused discontentment and a 4G-network instead of 3G. After this switch, the problem with internet reception was solved, as indicated by the higher adherence and lower dropout in the 4G-users as well as their incident rates. Another solution was found in home Wi-Fi connection. Of the twelve subjects using a Wi-Fi connection, none dropped out due to connectivity problems and connectivity-related incidents were significantly less prominent than in 3G-users. A stable and reliable performance of the system can
therefore be depicted as a very major influence on adherence to home-based exercise programs supported by an internet-reliant application.

Subjects who completed the intervention were very enthusiastic about working with the technology. The rating of 4.3 out of 5 at the questionnaire regarding the appreciation of the tablet, sensor, coaching and exercise program can be considered very positive. However, the questionnaire was performed at posttest and follow up measurements and therefore dropouts did not complete the questionnaire, providing a significant positive bias. The eleven dropout subjects able and agreeing to cooperate with the phone review question indicated the program low on average, indicating that these dropouts were not pleased by the performance of the application. Of these eleven subjects, seven dropped out primarily due to the unstable performance of the internet. The four subjects that did not drop out due to the unstable internet had a significantly more positive view on the application than the dropouts related to internet problems. This indicates that the internet instability was very determining in user opinion among dropouts.

The coach load in this intervention was small when technology was stable, with a base load of 1 to 2 minutes per week per person when running smoothly to 2 to 5 minutes per person a week for additional coaching by telephone when subjects need to be motivated to adjust their training load or keep adherent. The additional effort of weekly telephone contact can therefore be seen as a small but necessary investment for the exercise program. It can be expected that, when provided with ideal circumstances by means of a stable internet connection and regular coaching, adherence to the exercises and wearing of the sensor will reach the sufficient level threshold of 70%.

The design of the current study has some major strengths. First, the exercise program lasted six months. This is a fairly long period for an exercise intervention in this field, which can provide an indication of the long-term adherence to the program. Second, forty subjects in an extensive intervention like this is a substantial subject pool in this field. In addition, with a mean age of 80.8 years and a very diverse medical background, subjects can be considered very representative for a general sample of older adults in the community. Also, subjects were diverse regarding background and prior experience with technology, providing information on feasibility for lay users as well as more experienced users.

However, there is a limitation in this study due to the problems regarding connectivity. The unreliable internet connection most probably caused feasibility and adherence of the application to be underrated. An intervention period fully supported by a stable internet connection might provide more reliable insight in the performance of the system itself.

In conclusion, a home-based exercise program using novel technology for older adults seems feasible. Adherence was sufficient among the completers in the coached part of the intervention, indicating regular coaching as a positive influence on adherence. Dropout, adherence and user opinion were strongly influenced by stability of the internet connection and system. Especially switching to a more stable and better internet provider did significantly improve adherence. The coach load regarding weekly coaching when subjects were provided with a stable internet connection and system was low. The older adult subjects completing the program were positive about using the novel technology in performing the exercise program.

References

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22. K. Zickuhr, M. Madden, Older Adults and Internet Use [Internet]. 2012. Available at http://www.pewinternet.org/2012/06/06/older-adults-and-internet-use/ Accessed at 03/09/2015.


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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Zijlstra W.
Zhang W.
Wynia K.
Ibarra F.
Khaghani Far I.
Stevens M.

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 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.

**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
days in the trial for the subject. Adherence to sensor wearing was calculated as the number of days on which the sensor was plugged out of the tablet and registered activity for at least four hours.

Daily physical activity

Daily physical activity was assessed by means of the necklace-worn sensor, which was worn daily throughout the entire intervention. Subjects wore the sensor during the week before starting the exercise program for baseline assessment of daily physical activity. The week before the end of the supervised period was regarded as the posttest measurement of daily physical activity, and the week before the end of the unsupervised period was regarded as the follow-up measurement of daily physical activity. Daily physical activity was expressed by means of time-on-legs. Time-on-legs (TOL) was defined as the percentage of time during the day spent active on one’s legs (i.e. standing, walking, shuffling and adherent activities) [19]. This was compared to a reference group that was assessed in an earlier study to calculate a percentage of activity, where the percentage of daily activity level is a ratio to the mean level of the reference data [19,20]. The assessment weeks at the three measurement points provided seven measurement days each. The average physical activity over these seven days was then calculated for all three measurement points. In case one or more of the seven adjacent measurement days were not available, the physical activity measurement of an adjacent day prior to or after the seven-day measurement period was added to complete a seven-day measurement period. Physical activity as measured by the necklace-worn sensor was compared between the three measurement points. Also, daily physical activity was assessed by means of the self-reported Short Questionnaire to Assess Health-enhancing physical activity (SQUASH) [29], which addresses questions about the habitual physical activity level during a week.

Mobility tests

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 at a self-selected pace too, provided the participant was able to perform this task [31]. The average time over the repetitions of the mobility tests per measurement point was calculated and used for comparison between the three measurement points. Performance was assessed with the body sensor.

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 performed to assess the groups or periods responsible for significant outcomes.

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 transitionally 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>
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<th>Total Group (N = 40)</th>
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<th>P (Mann-Whitney)</th>
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<td>8/13</td>
<td>7/12</td>
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<tr>
<td>Mean Age ± SD (years)</td>
<td>81 ± 4.6</td>
<td>80 ± 4.7</td>
<td>83 ± 4.2</td>
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<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>
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<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>
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<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>
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Chapter 6

Effectiveness of an individually tailored home-based exercise program

Table 2. Mean scores daily physical activity at all measurement points

<table>
<thead>
<tr>
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<th>Total Group (N = 40)</th>
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<th>Dropouts (N = 19)</th>
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</thead>
<tbody>
<tr>
<td>Physical activity Baseline (%)</td>
<td>65.0 ± 24.4</td>
<td>66.3 ± 25.1</td>
<td>61.2 ± 26.9</td>
<td>0.94</td>
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<tr>
<td>Physical activity Post-test (%)</td>
<td>67.6 ± 27.1</td>
<td>69.2 ± 27.8</td>
<td>61.1 ± 21.1</td>
<td>0.28</td>
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<tr>
<td>Physical activity Follow-up (%)</td>
<td>64.5 ± 18.4</td>
<td>64.5 ± 18.5</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>P</td>
<td>0.84</td>
<td>0.62</td>
<td>0.61</td>
<td>-</td>
</tr>
</tbody>
</table>

SQUASH Baseline
2137.1 ± 1473.3
SQUASH Post-test
2985.3 ± 1776.5
SQUASH Follow-up
3070.2 ± 1562.8

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

Table 3. Mean scores physical functioning tests at all measurement points

<table>
<thead>
<tr>
<th></th>
<th>Total Group (N = 40)</th>
<th>Completers (N = 21)</th>
<th>Dropouts (N = 19)</th>
<th>P</th>
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<tr>
<td>STS Baseline (s)</td>
<td>1.8 ± 0.5</td>
<td>1.8 ± 0.5</td>
<td>2.1 ± 0.7</td>
<td>0.20</td>
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<tr>
<td>STS Post-test (s)</td>
<td>1.5 ± 0.4</td>
<td>1.5 ± 0.4</td>
<td>1.3 ± 0.0</td>
<td>0.49</td>
</tr>
<tr>
<td>STS Follow-up (s)</td>
<td>1.4 ± 0.4</td>
<td>1.4 ± 0.4</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>P</td>
<td>&lt;0.01*</td>
<td>&lt;0.01*</td>
<td>0.32</td>
<td>-</td>
</tr>
<tr>
<td>TUG Baseline (s)</td>
<td>14.0 ± 4.6</td>
<td>14.2 ± 5.2</td>
<td>13.6 ± 3.4</td>
<td>0.59</td>
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<tr>
<td>TUG Post-test (s)</td>
<td>12.2 ± 2.2</td>
<td>12.1 ± 2.0</td>
<td>13.6 ± 3.9</td>
<td>0.21</td>
</tr>
<tr>
<td>TUG Follow-up (s)</td>
<td>11.6 ± 2.3</td>
<td>12.0 ± 3.0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>P</td>
<td>0.07</td>
<td>0.29</td>
<td>0.10</td>
<td>-</td>
</tr>
<tr>
<td>CR Baseline (s)</td>
<td>20.4 ± 9.4</td>
<td>20.4 ± 9.4</td>
<td>20.0 ± 5.7</td>
<td>0.90</td>
</tr>
<tr>
<td>CR Post-test (s)</td>
<td>18.2 ± 3.3</td>
<td>18.2 ± 3.3</td>
<td>19.7 ± 5.8</td>
<td>0.79</td>
</tr>
<tr>
<td>CR Follow-up (s)</td>
<td>18.9 ± 5.5</td>
<td>18.9 ± 5.5</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>P</td>
<td>0.43</td>
<td>0.43</td>
<td>0.27</td>
<td>-</td>
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</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 Maillot 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 Lauffer 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 psychosocial 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.
Practice 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 7
General discussion
Main findings

In this thesis, a home-based physical activity program for older adults stimulating daily physical activity and physical functioning supported by a necklace-worn gait- and posture sensor and a tablet was developed and its feasibility and effectiveness were evaluated. Several aspects of such a program were explored. An indication of the most optimal remote coaching strategy was provided by means of a systematic literature review comparing remote contact strategies in home-based physical activity programs. Results of this systematic review imply that frequent as well as non-frequent remote contact enhance adherence to and the effectiveness of home-based physical activity programs. Remote contact during exercising seems particularly beneficial (Chapter 2).

In a video validation study integrating standardized assessment consisting of sitting, standing, lying and walking, as well as free movement in subject’s homes the necklace-worn gait- and posture sensor was evaluated. The sensor-based method was found applicable for daily activity assessment based upon Time-on-Legs (ToL) of frail and non-frail older adults in their home situation (Chapter 3).

Measurement of daily activity by means of the necklace-worn sensor and contact with a coach when following a home-based physical activity program were combined in a six month home-based physical activity program for transitionally frail older adults (Chapter 4, 5 and 6). This intervention study was implemented in forty transitionally frail, community/dwelling older adults. The home-based physical activity program integrated a tablet application for exercise instructions and feedback on performance and daily physical activity (Chapter 4). An important message in the findings of this intervention is that, to be able to let older adults independently work with novel technology in a home-based program, the technology should be one hundred percent reliable for the older person (i.e. adequately providing exercise instructions) as well as for the coach (i.e. adequately providing feedback on exercise adherence and daily physical activity). In addition, weekly contact by telephone was essential to preserve sufficient adherence and effectiveness and was greatly appreciated by participants (Chapter 5). Findings in the intervention therefore do support the conclusion of the systematic review (Chapter 2) that frequent feedback from the coach is essential for the success of home-based physical activity programs. When the technology is reliable and weekly contact is provided, the exercise program showed a (non-)significant beneficial effect on daily physical activity and functional outcomes such as the Timed-Up-and-Go test (TUG), although outcomes were not yet significant. Older adults are also surprisingly appreciative of and able to work with this novel technology and appreciate the technology when made suitable for lay use (Chapter 6).

This general discussion aims to discuss the obtained results in light of the overall aim of this thesis. The main aim was to develop a home-based exercise program for older adults stimulating daily physical activity and physical functioning that integrates remote coaching supported by a necklace-worn gait- and posture sensor and a tablet, and to evaluate its feasibility and effectiveness. The factors of importance when designing such a program will be discussed by addressing the following themes: target group selection; content of the exercise program; technology use; and the motivational strategies driving the intervention. The recommendations henceforth will indicate the most optimal design for a home-based exercise program. In addition, the practical implications of the results in this thesis will be addressed. Finally, the thesis will provide a critical reflection upon our results, recommendations for future research and the conclusions.

Target group

The target group for the intervention in this thesis were transitionally frail older adults: a group of people already experiencing minor deterioration in their daily functioning [1]. The inclusion regarding frailty was based upon the Groningen Frailty Indicator (GFI), a multidisciplinary questionnaire integrating physical as well as psychosocial aspects of frailty [2]. While our subject group indeed was transitionally frail as based upon the results of the GFI (mean score 4.4 ± 0.5), their daily physical activity scores as objectively measured by the sensor as well as self-reported by means of the SQUASH questionnaire and physical test scores on the Sit-to-Stand test (STS), TUG and the Five Times Chair Rise test (CR) indicate them to be less frail than intended [2,3]. A likely explanation is the fact that the GFI is a scale integrating physical and psychosocial aspects of frailty, and probably not completely valid for frailty assessment when only looking into physical frailty [4]. The definition of frailty varies among literature and its characteristics encompass multiple aspects of health, such as physical, social and psychological health [1]. As a result, multiple tools for assessing frailty are available, which all set differing standards [5]. This causes difficulty when using frailty as an inclusion criterion for an exercise-based program. It might be more appropriate to primarily base inclusion on the outcomes of physical tests such as the STS, TUG and the CR tests when assessing frailty as an entrance criterion in exercise programs in future research [4-8].

Our participants in the studies consisted of a diverse group of older adults regarding health, medical conditions and living conditions as well as socio-economic status. The diversity of these participants might raise concerns for the applicability of our results for frail older adults and the generalizability of our results. However, older adults are in general a very diverse group regarding medical and socio-economic status [9]. Thus, the diversity of the subjects included is actually quite representative for the target group of community-dwelling older adults in general. Therefore, while not being specifically applicable to frail older adults, our results do have relevance for are significant for older adults in general. This diversity of characteristics among older adults however does call for individual tailoring of exercise programs.

Exercise program

The exercise program in our intervention was based upon the Otago Kitchen Table Exercise Program. This program has been used in many home-based exercise programs for older adults. Programs were mainly aimed at fall prevention by means of amelioration of physical performance, and less frequently aimed to enlarge daily physical activity [10,11]. It contains basic strength- as well as balance exercises aimed at ameliorating performance on activities of daily living. The exercise program in our intervention comprised training five times a week on a subject’s preferred level out of eighteen exercise levels. The levels started with ten minutes of light exercise and progressed towards forty minutes of moderate exercise using ankle weights if possible for the subject. In that...
way the exercises accommodated the daily guidelines for health preservation and amelioration in older adults [12]. Level fifteen out of eighteen provided an exercise load representative of these guidelines. End levels of completers varied between level three and eighteen, with forty-three percent reaching level 15 or higher. This exercise regime on average gained a significant positive effect on the outcomes of the STS and the TUG test, and a positive trend in amelioration of daily physical activity and CR tests. When comparing the results to earlier results in literature, it can be concluded that the overall effect on physical activity and performance is mediocre [13]. However, as mentioned in paragraph 2, our participants were physically fitter at baseline than intended. This might have had a ceiling effect on the outcomes of the physical tests in our group due to which the intervention was not able to provide a larger amelioration. With a more suitable target group selection on physical frailty at baseline, results of the intervention might be more prominent.

Illiffe et al. for instance compared a community group-based exercise program (FaME) and a control group (group-based exercising) to a home-based exercise program using the Otago program for a general community group of older adults aged 65 years and over, targeted at enlarging physical activity. The experimental program ameliorated the proportion of their subjects reaching a minimal target of 150 minutes per week of moderate to vigorous daily activity [14]. This is comparable to reaching the fifteenth level in our intervention. Twelve months after the cessation of their intervention, results indicated that only the group-based intervention group still showed significant positive differences regarding physical activity from the control group. The positive differences regarding daily physical activity in the Otago program home-based group were non-significant [14]. These outcomes resemble the outcomes of our intervention.

**Optimal technology use in home-based exercise programs for older adults**

Current developments in technology provide multiple opportunities to support remote provision, coaching and data collection in home-based physical activity programs. The intervention proposed in this thesis integrated a tablet application, on which participants could play videos showing the exercise routines that they could imitate to complete their exercise bouts. The tablet application collected the data regarding exercise bouts completed on the tablet and daily physical activity data collected by the necklace-worn sensor, providing subjects with feedback on their progress after each exercise bout. Performance on all these aspects should be up to par to effectively support independent training in home-based exercise programs for older adults.

**The sensor-based method of daily physical activity assessment**

As indicated by the validation studies presented in the current thesis as well as results from studies from adjacent projects [15-18], the sensor-based method used in this project is deemed sufficiently accurate in assessing physical activity in daily life among older adults, and is acceptable to users [19]. When looking into the performance of other sensor-based methods in literature regarding assessment of daily physical activity, mainly step counters and accelerometers have been used with varying performance [13]. On average, mostly the assessment of more vigorous activities such as walking outdoors are recognized well, but the small amounts of light activity such as shuffling around that mainly frail older adults make are recognized poorly [19]. Our sensor algorithm managed to adequately assess physical activity in daily life in frail as well as non-frail older adults, indicating a more suited performance than other sensor-based methods among frail older adults [19]. Besides further tweaking of the sensor-based method regarding assessment of lying, this can therefore be considered a well-suited tool for assessment of daily physical activity among home-based exercise programs for older adults.

**The tablet application**

In the current intervention, a tablet application was chosen due to the practical nature of a tablet: the touchscreen is very intuitive in use, a tablet format is able to provide a screen that is large enough for most older adults to read and operate, the sensor technology can be supported by tablet software and a tablet is portable so subjects can use the application wherever they feel like training. Indeed, the user evaluation and personal opinions of the subjects indicate that these are aspects older adults generally appreciate in the technology. The tablet application allows precise prescription of exercises and objective collection of exercising behavior and daily physical activity through full exercise bouts on videos that the participants can copy. Participants receive feedback upon exercise behavior after ending an exercise bout as well as visual feedback in a graph regarding their daily physical activity behavior.

Other options have however been proposed in previous studies. For instance, Rendon et al. implemented a 6-week virtual reality gaming program for community-dwelling older adult veterans to reduce fall risk. In this randomized controlled trial, subjects trained 3 times a week using a Wii Fit for balance games. Results indicated a significant positive effect on the TUG test, indicating a significant positive effect on dynamic balance and thus fall risk [22]. This program was more effective on ameliorating TUG performance than our intervention. One of the factors that might be of influence, is the higher adherence reported. An aspect contributing to the higher adherence and effectiveness, can be the gaming aspect that was included opposed to our intervention. Integrating a game element looks beneficial to keep participants motivated [20,21]. Also, the baseline physical performance level of their participants was lower, which provides a larger possibility for improvement [22]. In another study, applying a biofeedback-based Nintendo Wii training to a general group of older adults for 10 weeks, Jorgensen et al. concluded that the group using the Nintendo Wii training had significantly higher amelioration regarding muscle strength, TUG and chair rise tests than the control group only wearing insoles [23]. There was a high degree of compliance to the Nintendo Wii program [23]. The amelioration regarding TUG and CR was comparable with the amelioration shown in our intervention [23]. In a study by Esculier et al., a small group of Parkinson’s patients were provided with a WiiFit and balance board training using visual feedback on stance and movement during balance exercise games. In this 6-week pilot study, significant ameliorations on STS and TUG performance were observed [24]. These short-term results surpass the results of our intervention. The visual feedback system implemented does seem to have a positive influence in the program, and this type of direct feedback upon performance or quality of exercising might be beneficial in our current application as well. In the iStoppFalls project, an Information and Communication Technology-based system to deliver an unsupervised exercise program in older people’s
Counseling and motivational strategies

Adherence to and effectiveness on amelioration of health parameters of an exercise program is in general highly influenced by the motivational strategy and design of the coaching involved [27]. Motivating older adults to be physically active has been attempted based on different behavioral (change) theories. The current exercise program and coaching was based on the Social Cognitive Theory (SCT) [28]. Self-efficacy is a key component in the SCT. SCT states that persons learn behaviors through observation, modeling, and motivation such as positive reinforcement. Self-efficacy is defined as “people’s beliefs about their capabilities to produce designated levels of performance that exercise influence over events that affect their lives” [28]. SCT describes factors such as social support, setting achievable goals and tangible rewards to raise one’s self-efficacy and in that way enhance the motivation to adhere [28,29]. These aspects can be implemented quite well in technology-assisted home-based physical activity programs by means of peer interaction, setting reachable targets through personalized tailoring and procuring rewards by means of positive feedback or personal benefits within the program [28,29]. In the current intervention, providing a personally tailored exercise regime with direct feedback as well as daily feedback on exercise behavior and daily activity, social support by the coach and a suitable role model in the form of an older adult performing the exercises in the videos addresses core principles of the SCT [28,30].

Other options that might be beneficial to add to heighten adherence is feedback on objective quality of performance of the exercises. While this was not incorporated in the current application yet, other solutions have successfully provided feedback based upon filming one’s exercising or sensor-based feedback [24,26,31-33]. Another aspect from SCT that could be integrated is peer interaction, which has been used successfully in other exercise programs in literature as well [34-36].

To further refine the exercise program and coaching the SCT could be combined with insights from the Stages of Change theory [30]. The stages of change define the steps through which people progress as they make changes and the processes of change people use to make changes [30]. The five stages defined in this theory vary from precontemplating taking up a new behavior, to maintaining a new behavior. Each stage requires a different mode and content of feedback to start up and consolidate the progress. Structured, tailored feedback regarding one’s stage of change could be beneficial to enlarge adherence to the exercises. In the current intervention, this feedback was integrated non-structurally during the telephone contacts. To enhance adherence and effectiveness, structured motivational feedback tailored to a participant’s stage of change could be integrated in the feedback provided by application.

However, evidence-based integration of motivational strategies in home-based physical activity programs and serious games using novel technology is not yet common practice [20]. Many applications do not use a theoretically based motivational strategy [20]. As stated in the systematic review (Chapter 2) in this thesis as well, efforts should be made to further explore optimal use of motivational strategies in these programs to enlarge adherence and effectiveness [13].

Opportunities for society and health care

As people in our society on average become older and the number of older adults in society grows, so called dual aging, the issue of age-related morbidity also grows [37,38]. Mainly the burden of chronic diseases such as cardiovascular diseases, diabetes, osteoarthritis and obesity grows, burdening patients in their physical functioning and quality of life as well as health care resources [37,38]. With the still growing shortage of resources in health care due to the dual ageing of our society, a need for tools that can make health care more efficient arises [37,38]. Especially technology that enables patients to become more self-supporting in their health behavior is growing in popularity and possibilities [39]. Within this thesis, the tools that have been developed can assist in health care in multiple domains. The development of a sensor-based method for accurate objective assessment of daily physical activity among older adults is relevant for health care providers that need objective assessment of daily physical activity in this target group in order to be able to accurately stimulate these people to become more active and in that way stimulate their health and prevent further decline in physical functioning [13,19]. This sensor-based method is, in contrast to many other assessment tools, sensitive to the small amount of low-activity movements older adults generally make.

Integration of this sensor-based method in the tablet application providing an individually tailored exercise program can be of use in many target groups. On the one hand general community-based prevention programs could make use of this application to stimulate a healthy lifestyle and prevent physical decline and disease. Such strategies integrating technology for remote assessment of vital markers such as for instance blood pressure or glucose levels have been successfully implemented in diabetes and cardiovascular disease programs [40-43]. On the other hand health care providers can use this application as a tool to support rehabilitation at home. This has for instance already been started in the implementation of an upgraded version of the application in a rehabilitation program for Total Hip Arthroplasty (THA) patients at UMCG. With the implementation of fast track surgeries and the minimization of coverage of expenses for postoperative physiotherapy, using such a tablet application could be an effective way to heighten post-operative physical functioning and quality of life in THA patients by providing a platform for physiotherapy instructions during rehabilitation at home. This intervention integrates a slightly different set-up than the intervention presented in this thesis. In addition to the coaching strategy, rehabilitated patients are provided the...
opportunity to use a Social Gym environment on their tablet with scheduled training appointments in which they can view if their fellow patients are present at the training. This program already combines several aspects that were introduced in the previous section regarding motivational strategies. A possible addition to further add to the social aspect for motivating participants to adhere is the opportunity to send fellow participants messages and communicate with the coach through a message board and email service. These features are already possible with regards to the technology, but the options are not yet in use in that intervention. In future research using this technology, these options should be implemented in the motivational strategy. The technology platform used in this intervention could in future be implemented amongst a broad spectrum of other target groups in rehabilitation as well, such as for instance cardiac- or transplantation surgery. Also, chronic health monitoring and guidance could be provided among instance community-dwelling older adults that require health monitoring but are not limited in their functioning enough yet to move to an older adults’ home. The remote health monitoring and interaction opportunities this platform provides could stall the necessity to move into an older adults’ home further. Many health professionals might benefit from this platform, such as for instance physiotherapists prescribing daily exercise routines at home or general practitioners or visiting nurses caring for diabetes patients. Opportunities for integration of this kind of interventions into the health care system should be further investigated.

Critical afterthoughts

The application presented in this thesis was well-received by the participants that were provided with a reliable internet connection, as indicated by the high scores on the user evaluation questionnaire regarding the exercise program and the technology among the completers. Also, the application managed to collect exercise behavior and daily physical activity data well, providing feedback to the participants itself and objective information for the remote coach to monitor the progress. This provides a valuable tool to assist in interventions heightening health care efficiency. However, there are still some critical issues to be addressed. In all the considerations for type, mode and frequency of contact and design of technology that are presented in this thesis, we might consider anew whether it would be wise to use technology for contact and support for the specific persons that are training in future programs. In discussion with the participants of the studies in this thesis, it turned out that most people value the interpersonal contact through telephone or live visits in interventions most. Especially the people that were living further away from their families or were more hampered in their ability to go outdoors could really appreciate the social contact that the researchers provided. The telephone contact was greatly appreciated, as illustrated by the significantly higher adherence in the supervised training period than the non-supervised period among the completers in the intervention trial. This is in line with earlier research, in which regular telephone contact was indicated as an important factor for enlarging adherence [13]. Live visits in our intervention were appreciated as well, even when that meant the training was not running smoothly regarding for instance technology. In these visits, further encouragement could be delivered by ad-

dressing goals, drawbacks and fears regarding the training. In other words: never underestimate the motivational value of a shared cup of coffee!

Following this conclusion, the question arises: Just because we can develop and use novel technology for older adults, does that automatically mean we should? One could imagine that with the development of technology providing assistance in training, the abovementioned personal contact with a coach disappears. It could be more affordable for health care to provide patients with an app instead of providing an exercise coach or physiotherapist for an hour a week. In light of the economic health care challenge caused by the graying of our society [37,38], this is an interesting course for health care organizations in for instance rehabilitation or preventive strategies. Efforts have already been undertaken to minimalize necessary contact in for instance revalidation processes and fast track surgery [44,45]. However, with the loneliness and loss of social contacts that often are reported among older adults [46], this might cause older persons to lose a substantial part of their social contact. In a group of people already prone to loss of social interaction and often dependent of caregivers for social interaction [47], enlarging the use of technology as a total replacement for live social interaction would not be wise. Loneliness is one of the factors undermining functioning, wellbeing and quality of life among older adults [48-50]. Further minimalizing social contact therefore also might bring on unexpected health care costs due to higher loneliness, raising the question whether minimalizing social contact would actually be beneficial for health care. An opportunity to contribute to lowering loneliness can however also be provided by remote technology: in a technology platform a social component can be added, such as is provided in currently popular internet platforms such as Facebook. In recent research, solutions have been proposed providing participants with the possibility to for instance send other participants messages, keep track of other’s progress, or even join a virtual training group with other fellow participants present [34-36]. Integrating a social component to home-based independent training, these exercise programs can not only stimulate physical health but also psychological health.

Recommendations for future research

The studies in this thesis accentuate the promise of home-based physical activity programs supported by sensor technology and tablet applications and provided insight into the design of those programs regarding for instance contact intensity. However, the work is not finished at this moment. The current prospective cohort study provides a valuable first insight into adherence and effectiveness of the program, but to provide more solid evidence for effectiveness of the program in enlarging daily physical activity and functional performance a Randomized Controlled Trial is indispensable. In addition, cost-effectiveness of the program should be explored. For that, a comparison of the costs engaged in the program and costs of usual care is of interest. Furthermore several set-ups for future research regarding this home-based physical activity program would be interesting: one could compare the effectiveness of the intervention when using the technology to the same intervention not supported by technology to specifically investigate the additional benefits or downsides of the use of the necklace-worn sensor and the tablet application. Several set-ups regarding the elements of the coaching strategy and –frequency should also be considered, to determine the most
optimal coaching. An interesting aspect to further quantify raised here is the amount of coaching contact and set-up: is it better to let people train fully on their own or would the addition of a virtual group training be beneficial? In that respect, what would be more stimulating: working with coaching through a virtual or actual coach, or by integrating a social component by means of peer contact, or a combination of both? Last, a more thorough, structured integration of behavioral strategies in home-based exercise programs using remote technology should be further explored.

Conclusions

The main aim of this thesis was to develop a home-based exercise program for older adults stimulating daily physical activity and physical functioning that integrates remote coaching supported by a necklace-worn gait- and posture sensor and a tablet, and to evaluate its feasibility and effectiveness. It can be concluded that the home-based exercise program was found feasible and promising regarding amelioration of daily physical activity and physical functioning. Most important factors influencing effectiveness of such programs are accurate selection of the target group, remote contact and the motivational strategy. In order to further enlarge adherence and effectiveness, a strategy integrating regular remote contact with a coach throughout the total duration of the program should be adopted and a social interaction or game strategy would be beneficiary to stimulate social interaction. These programs are not fully independent from human interaction: regular contact with a coach seems to be necessary to preserve adherence and effectiveness. The technology is a promising tool to support independent home-based exercising, but one should keep in mind that technology cannot fully compensate for actual human interaction. A valuable addition to these programs would be a social component by means of for instance allowing peer contact. Optimal design and effectiveness of home-based physical activity programs for older adults using novel technology and integration of theoretically based motivational strategies should still be further investigated, but this thesis provides evidence for the relevance of such efforts.

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Appendices
Summary

In chapter 1 an introduction into the ageing problem in the Netherlands is provided, introducing the need for preventive programs that provide older adults with tools to keep themselves healthy and independent. In this, regular physical activity is one of the keys. Preventive programs promoting regular physical activity can benefit from recent developments in novel technology such as sensors and tablet PC’s using mobile Internet. However the optimal design and their feasibility and effectiveness in older adult target groups are not yet known. Consequently, the aim of this thesis is to develop a home-based physical activity program for older adults stimulating daily physical activity and physical functioning supported by a necklace-worn gait- and posture sensor and a tablet, and to evaluate its feasibility and effectiveness.

First, several aspects that contribute to the development of a successful home-based physical activity program were investigated. In that regard, the systematic review addressed in chapter 2 provides an insight into the status quo of remote feedback strategies in home-based physical activity programs. Remote feedback might be an interesting tool to use in home-based physical activity programs for older adults, for instance by means of adherence monitoring with a body-worn sensor and feedback on a computer or tablet. Twenty-two papers met the inclusion criteria for the effectiveness evaluation, and twenty-one papers met the criteria for inventory of adherence. This systematic review organized results into three categories of contact: frequent contact (≥ once a week), non-frequent contact (< once a week) and direct remote contact during exercising. Results imply with varying strength that frequent and non-frequent remote contact in home-based physical activity programs enhance effectiveness of physical activity and capacity measures. Direct remote contact during exercise looks particularly promising for enhancing effectiveness. Adherence in interventions using remote feedback seems acceptable to good. Remote feedback therefore seems a promising direction in an older population getting more and more used to new technology.

Chapter 3 addresses the validation of a tool to support remote coaching for use in daily life of older adults, namely the Mobility Monitor: a necklace-worn gait- and posture sensor that objectively can measure daily physical activity by means of gait- and postures assessment, which is translated into ‘Time-on-legs (ToL). The sensor is validated in older adults’ homes in a standardized protocol incorporating sitting, standing, walking and lying as well as more elaborate actions and in free movement incorporating common household tasks. In addition the subjects wore the sensor day and night during a week, to gain insight in their daily physical activity behavior. In both standardized protocol as well as free movement the activities were filmed, and the results of the sensor were compared to the film as gold standard for validation. Overall, the proposed sensor provided an excellent estimation of ToL, and a moderate to good estimation of gait and postures in the home situation in standardized as well as free movement conditions. User acceptance of the sensor was high. It was concluded that the objective data of the sensor can be used to provide coaches accurate information of daily physical activity and adherence in older adult participants.

Next, a cohort of older adults were asked to join a six-month intervention using the Mobility Monitor in a home-based physical activity intervention for transitionally frail older adults, using the Mobility Monitor for daily activity assessment and a tablet PC for exercise instructions and feedback on daily activity and exercise adherence. Chapter 4 introduces a detailed description of the design of this study. Subjects were instructed to exercise five times a week using the tablet, with exercises tailored to their own personal level. During the first three months of the intervention, subjects received weekly coaching by telephone and during the last three months subjects were independent in their training. Feasibility of the intervention as well as an indication of its effectiveness was evaluated.

In chapter 5, feasibility and user evaluation of the intervention introduced in chapter 4 is presented. Forty-one older adults participated in a six-month home-based physical activity program in which they exercised five times a week using a tablet application, and wore a gait- and posture sensor daily. Adherence to the program and wearing of the sensor was assessed to indicate feasibility. In addition, incidents participants reported while training with the system were evaluated. Mainly due to internet reception problems, adherence to the program was relatively low. Most important factor was the reliability and stability of the 3G-mobile internet connection. In future, it is therefore advisable to use a stable 4G-mobile internet or WiFi connection. Older adults were however very enthusiastic about using the system, as indicated by the user evaluation.

Chapter 6 provides the analysis of the effectiveness of the six-month home-based physical activity intervention introduced in chapter 4. Due to the unstable 3G-mobile internet connection during the first part of the intervention and the low adherence caused by that, the effectiveness was lower than expected. However, when looking at the enhancement in adherence caused by the introduction of a more stable 4G internet connection, one can expect that effectiveness was underestimated. It would be interesting to test a future intervention in a RCT-design with the help of a 4G-mobile internet and WiFi connection to gain more accurate information regarding effectiveness.

Chapter 7 discusses the major findings presented in this thesis. Most important factors influencing effectiveness of a home based physical activity program is an accurate selection of the target group, remote contact and the motivational strategy. The execution of home based programs is not fully independent from human interaction: regular contact with a coach seems to be necessary to preserve adherence and effectiveness. Remote technology cannot fully compensate human interaction. A valuable addition to home based programs could therefore be a social component by means of for instance allowing peer contact. Optimal design and effectiveness of home-based physical activity programs for older adults using novel technology and integration of theoretically based motivational strategies should be further investigated, but this thesis provides evidence for the relevance of such efforts.
Samenvatting

In hoofdstuk 1 wordt de vergrijzing van de Nederlandse samenleving en de gevolgen daarvan voor de kwaliteit van leven van ouderen beschreven. Daaruit volgt de behoefte voor preventieve interenties die het ouderen mogelijk maakt om zo lang mogelijk gezond en zelfstandig te kunnen blijven functioneren. Hierbij is regelmatige lichamelijke activiteit de sleutel: wie blijft bewegen vermindert de kans op chronische ziekten en gebreken die met veroudering geassocieerd zijn. Recentelijk geeft daarbij de technologische ontwikkeling van sensoren, tablets en draagbaar internet interessante mogelijkheden: deze technologie kan mogelijk ingezet worden bij het aanbieden en monitoren van oefenprogramma’s voor ouderen in hun thuissituatie. Echter het optimale design, de gebruiksvriendelijkheid van dergelijke technologie bij deze doelgroep en de effectiviteit zijn vooral nog onduidelijk. In dit proefschrift wordt dan ook een thuis-oefenprogramma voor ouderen ontwikkeld, welke dagelijkse lichamelijke activiteit en het lichamelijk functioneren stimuleert door middel van een om de hals gedragen beweegsensor en een tablet. De beweegsensor monteert de lichamelijke activiteit, en met behulp van de tablet worden oefeningen aangeboden en feedback gegeven.

Allereerst is er in dit proefschrift aandacht besteed aan verschillende aspecten van het ontwikkelen van een effectief thuis-oefenprogramma waarin gebruik gemaakt wordt van instructie door middel van een tablet applicatie en feedback door middel van sensor registratie. In hoofdstuk 2 wordt met behulp van een systematisch review de huidige stand van zaken op het gebied van feedback op afstand in thuis-oefenprogramma’s in kaart gebracht. Feedback op afstand kan in de toekomst toegepast worden door middel van een combinatie van computer- of tablet applicaties en sensoren, waarbij de therapietrouw en dagelijkse lichamelijke activiteit gemonitord worden en feedback wordt gegeven via de computer of tablet. In deze systematische review zijn drie categorieën van feedback: frequent contact (≥ wekelijks), non-frequent contact (< wekelijks), en direct contact onderscheiden gedurende het uitvoeren van de voorgeschreven oefeningen. Deze worden beoordeeld op effectiviteit en therapietrouw. Tweeëntwintig artikelen voldeden aan de criteria voor inventarisatie van de therapietrouw. De resultaten laten zien dat frequent en non-frequent contact in thuis-oefenprogramma’s de effectiviteit verhogen. Therapietrouw in interenties die gebruik maken van feedback op afstand is acceptabel tot goed. Feedback op afstand lijkt daarom een veelbelovende toepassing voor thuis-oefenprogramma’s met gebruikmaking van nieuwe technologie voor ouderen.

In hoofdstuk 3 wordt de validatie van de Mobility Monitor, een om de hals gedragen sensor die gebruikt kan worden voor dagelijkse monitoring van lichamelijke activiteit van ouderen in hun thuisomgeving beschreven. De sensor meet houdingen en bewegingen, wat vervolgens vertaald wordt in Time-on-legs (ToL). ToL kan gebruikt worden als een indicatie voor de dagelijkse hoeveelheid lichamelijke activiteit. De sensor is gevalideerd bij ouderen thuis in een gestandaardiseerd protocol dat staat, zitten, lopen en liggen alsmede enkele complexere taken bevat. Daarnaast is de sensor gevalideerd met behulp van een half uur vrij bewegen in huis, waarbij de deelnemer naar eigen inzicht veelvoorkomende huishoudelijke taken uitvoerde. Zowel bij het gestandaardiseerde protocol als het vrij bewegen is de activiteit gefilmd, en zijn de resultaten van de sensor vergeleken met de film als gouden standaard. Als laatste droegen de deelnemers de sensor gedurende een week dag en nacht, wat informatie gaf over hun lichamelijke activiteit en de gebruiksvriendelijkheid van de sensor. Over het algemeen voorzag de sensor in een excellente schatting van ToL en in een gemiddelde meerderheid tot goede schatting van beweging en houdingen in zowel het gestandaardiseerde protocol als het vrij bewegen. De gebruiksvriendelijkheid is goed. Geconcludeerd kan worden dat de objectieve data van de sensor gebruikt kan worden om coaches bij oefenprogramma’s voor ouderen accurate informatie over dagelijkse lichamelijke activiteit en therapietrouw te verscheffen.

De volgende stap was het testen van de beweegsensor in combinatie met een tablet applicatie in een 6 maanden durende interentie, waarin semi- kwetsbare ouderen een tablet PC gebruikten voor oefen-instructies en de Mobility Monitor droegen ter registratie van hun dagelijkse lichamelijke activiteit en feedback op hun dagelijkse lichamelijke activiteit en therapietrouw. Hoofdstuk 4 voorziet in een gedetailleerde uiteenzetting van het design van deze interentie. Deelnemers werd gevraagd om vijf maal in de week zelfstandig te oefenen waarbij gebruik gemaakt werd van filmpjes op de tablet, de oefeningen konden op het individuele niveau van de deelnemer aangepast worden. Gedurende de eerste drie maanden werden de deelnemers wekelijks telefonisch gecoached en gedurende de laatste twee maanden van de interentie oefende men volledig zelfstandig. Naast deze coaching was er een motivatiesl散布atie in automatische feedback gegeven op de dagelijkse lichamelijke activiteit en therapietrouw in de interentie van het gebruik van de tablet. Hoofdobjectieve van deze interentie waren het bepalen van de haalbaarheid en het verkrijgen van een indicatie van de effectiviteit. Ook werd een gebruikersevaluatie en een inventarisatie van de problemen waar deelnemers tegenaan liepen uitgevoerd.

Hoofdstuk 5 rapporteert vervolgens de resultaten van de interentie met betrekking tot haalbaarheid en gebruiksvriendelijkheid. Eeneenveertig ouderen namen deel aan een van zes maanden durende interentie waarin zij vijf maal per week bezocht werden het oefenprogramma uit te voeren met behulp van een tablet en een om de hals gedragen beweegsensor. Therapietrouw betreffende het uitvoeren van de oefeningen en het dragen van de sensor gaf een indicatie van de haalbaarheid van de interentie. Ook werden incidenten die deelnemers rapporteerden gedurende deelname geëvalueerd. Met name de stabiliteit van 3G-mobiel internet bleek een belangrijke factor die de therapietrouw negatief beïnvloedde. Deelnemers waren vaak niet in staat de applicatie te gebruiken voor hun oefeningen, en de technologie was dikwijls niet in staat om gegevens zoals verzameld door de sensor te verwerken door gebrek aan een stabiel internetverbinding. Daardoor was de therapietrouw relatief laag. Het slagen van een dergelijk thuis-oefenprogramma staat of valt dan ook met een stabiel systeem, waar deelnemers van op aan kunnen. Aangeraden wordt daarom gebruik te maken van 4G-mobiel internet of bij voorkeur WiFi. De oudere deelnemers waren desondanks erg enthousiast over de interentie getuige de uitkomsten van de gebruikersevaluatie.

In hoofdstuk 6 wordt de effectiviteit van het thuisoefenprogramma verder belicht. Door de minder stabiele 3G internetverbinding in het eerste deel van de interentie en het gebrek aan therapietrouw die daaruit voortvloeide, was de effectiviteit lager dan verwacht. Echter, gezien de verbetering in therapietrouw na inzet van een stabiele 4G-verbinding, is te verwachten dat deze effectiviteit een
onderschatting is van de werkelijkheid. Het is een interessante vervolgstap om de interventie te gaan testen in een randomized controlled trial design, om meer accurate informatie aangaande de effectiviteit van deze interventie.

In hoofdstuk 7 worden de belangrijkste bevindingen in dit proefschrift bediscussieerd. Uit de bevindingen blijkt dat de voornaamste voorwaarden voor een succesvol thuis-oefenprogramma voor ouderen een adequate keuze van de doelgroep, regelmatig contact op afstand met een coach, en een gedegen motivatiestrategie zijn. Ondanks het individueel uitvoeren van een thuis-oefenprogramma is menselijke interactie toch essentieel: regelmatig contact met een coach blijkt essentieel voor succesvolle deelname en effectiviteit. De technologie kan daarom nooit volledig compenseren voor menselijke interactie. Daardoor zou de toevoeging van een sociaal aspect binnen het programma een waardevolle aanvulling kunnen zijn. De optimale opzet van een thuis-oefenprogramma voor ouderen waarin gebruik wordt gemaakt van moderne technologie dient nog verder uitgediept te worden, echter dit proefschrift onderstreept wel de relevantie daarvan.
Dankwoord


Groningen, 2017. It’s been a bumpy ride….but a good one! Inmiddels heeft Groningen voor mij alles waarmaken wat ik er hoopte te vinden: zelfstandigheid, fijne mensen, veel nieuwe inzichten. En last but not least: eindelijk de vervulling van mijn promotiekriebels.

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Ik had me geen betere co-promovendus op dit project kunnen wensen!

Dr. Ruben Regterschot, mijn gewaardeerde collega-PhD op dit project en paranorm. Waar zouden we zijn geweest zonder jouw stille kracht en positiviteit? Ik vind jouw gave om altijd overal het positieve van in te zien enorm inspirerend. Dank je wel voor alle steun en hulp rondom onze onderzoeken in het algemeen, en voor je bijdrage met betrekking tot sensoren en Matlab in het bijzonder.

Jan van der Scheer, de derde van de drie kamer-211-musketiers. Dank je wel voor je steun en lustrerend oor, en je enorme enthousiasme en betrokkenheid bij alle grote momenten in een van onze projecten. Ook het filosoferen over meer of minder belangrijke kwesties tussen de werkzaamheden door heb ik erg gewaardeerd!

Daarnaast wil ik graag Dr. Sophie Spoorenberg en Dr. Klaske Wynia bedanken voor het mogelijk maken van aansluiten bij SamenOud, wat het vinden van deelnemers enorm geholpen heeft. Ook jullie bijdragen als mede-auteurs van de artikelen in hoofdstuk 5 en 6 heb ik erg gewaardeerd.

Bij deze wil ik ook graag de (student)-assistenten Marjanne, Jildou, Miranca en Holger bedanken voor hun goede, gedegen en gezellige!-hulp bij het verzamelen en verwerken van de data. Daarnaast is een dank jullie wel voor alle collega’s van het Centrum voor Bewegingswetenschappen (BW) in Groningen op zijn plaats. BW werd toen ik net aankwam in Groningen beschreven als een “warm bad”, wat in de jaren daarna zeker bevestigd werd. Of het nu hulp bij Matlab-perikelen tijdens de kerstvakantie, ideeën voor proefschriftomslagen, of het spontaan maken van professionele foto’s voor in presentaties betrof: geen moeite was teveel!

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Appendices

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...en na jullie bijdragen als mede-auteurs van de artikelen in hoofdstuk 5 en 6 heb ik erg gewaardeerd...
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Hilde Geraedts, 13 Februari 2017
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