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Short Paper

Interchangeability of the Wii Balance Board for Bipedal Balance Assessment

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Abstract

Background: Since 2010, an increasing interest in more portable and flexible hardware for balance and posture assessment led to previously published studies determining whether or not the Wii Balance Board could be used to assess balance and posture, both scientifically and clinically. However, no previous studies aimed at comparing results from different Wii Balance Boards for clinical balance evaluation exist.

Objective: The objective of this crossover study is to assess the interchangeability of the Wii Balance Board.

Methods: A total of 6 subjects participated in the study and their balance was assessed using 4 different Wii Balance Boards. Trials were recorded simultaneously with Wii Balance Boards and with a laboratory force plate. Nine relevant clinical parameters were derived from center of pressure displacement data obtained from Wii Balance Board and force plate systems. Intraclass correlation coefficients (ICC), *F* tests, and Friedman tests were computed to assess the agreement between trials and to compare the Wii Balance Board and force plate results.

Results: Excellent correlations were found between the Wii Balance Board and force plate (mean ρ =.83). With the exception of 2 parameters, strong to excellent agreements were found for the 7 remaining parameters (ICC=.96). No significant differences were found between trials recorded with different Wii Balance Boards.

Conclusions: Our results indicate that for most of the parameters analyzed, balance and posture assessed with one Wii Balance Board were statistically similar to results obtained from another. Furthermore, the good correlation between the Wii Balance Board and force plate results shows that Wii Balance Boards can be reliably used for scientific assessment using most of the parameters analyzed in this study. These results also suggest that the Wii Balance Board could be used in multicenter studies and therefore, would allow for the creation of larger populations for clinical studies.

Trial Registration: Ethical Committee of the Erasme Hospital (CCB B406201215142).

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KEYWORDS

force plate; balance board; balance performance; validity; repeatability

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Introduction

The potential use of the Nintendo Wii Balance Board for assessing balance and posture has already been previously investigated [1]. A recent paper presented a comparison between a laboratory force plate and a Wii Balance Board to measure postural control [2]. The strength of this study was that by simultaneously recording with the force plate and the Wii Balance Board, subject variability was removed. Despite some doubts on the methodology and conclusions of the latter paper [3], it appears that the Wii Balance Board can be used to assess posture [4].

Most previously published papers on this particular topic reported a high correlation between a force plate and a Wii Balance Board for evaluating center of pressure trajectories. Such conclusions have therefore encouraged the use of Wii Balance Board hardware in daily clinical practice to assess balance in various pathological conditions such as Parkinson disease, orthopedics, and elderly assessment (eg, [5]). Many accuracy studies can be found in the literature (ie, comparing Wii Balance Board to some laboratory gold standard such as force plate hardware). Surprisingly, only one study can be found in the literature that assesses the repeatability of the measurements performed using different Wii Balance Board systems [6]. These authors compared force and localization of the center of pressure recorded with different Wii Balance Boards using different weight placed in various places on the Wii Balance Board. The authors found an uncertainty of 4.1 mm across the different Wii Balance Boards in static measurement; no information can be found in the literature about the reproducibility of measurement of center of pressure trajectories obtained with different Wii Balance Boards. However, this information is important to ensure repeatability and comparison of measurements between several clinical centers (eg, within multicenter studies organized to analyze a large amount of patients). This is an important question since this hardware was developed solely for gaming purposes and no scientific validation is available from the manufacturer.

The present study presents the repeatability of balance measurements using 4 different Wii Balance Boards systems.

Methods

Participants

Healthy adults (N=6) with a mean age of 36 years (SD 13), height of 176 cm (SD 11), and weight of 81 kg (SD 22), including 2 women participated in the study. This study was approved by the Ethical Committee of the Erasme Hospital (CCB B406201215142) and all participants provided informed consent.

Measurement Setup

In order to assess the repeatability of Wii Balance Boards, the protocol of Huurnik et al was used [2]. A Wii Balance Board was placed on top of a force plate (AMTI model OR6-6, Watertown, MA, USA, size 50 cm × 46 cm) that was embedded within the laboratory floor. The sample rate for the force plate was 1000 Hz. Four different Wii Balance Boards were used (serial numbers BEH428405719, BEH428409281, BEH428408987, and BEH428409175). The Wii Balance Boards were connected to a laptop (Intel Core I5, Windows 7, 6 GB RAM) via Bluetooth connection, and data were retrieved using a custom-written software based on the Wiimotelib software [7]. The force plate was calibrated before the measurement was taken using the manufacturers' recommendations. Although some methods have been proposed [1,2], no calibration procedure was used for the Wii Balance Board. Such calibration-free methodology was adopted because the purpose of this study was to evaluate the repeatability of measurements of the Wii Balance Board without the practical constraint of such systematic calibration procedures.

Procedure

The participants performed 3 repetitions of double limb standing on each available Wii Balance Board in a single session; the 4 Wii Balance Boards were tested in this one session (12 trials per subject). Subjects were asked to stand in the middle of the Wii Balance Board for 30 seconds, as motionless as possible, eyes open, arms aligned along the body, and eyes fixed on a target on the wall in front of them. The same methodology was repeated for the 4 different Wii Balance Boards. The order of the tested Wii Balance Board system was randomly determined.

Data Processing

Linear interpolation of the raw signals of the Wii Balance Board sensors was applied to get a regular sample rate of 1000 Hz (same as the force plate) [8]. Both data from the Wii Balance Board and force plate were then filtered using a second order Butterworth low-pass filter with a cutoff frequency of 12 Hz [2]. The displacements of the center of pressure along anterior-posterior (CP AP) and medio-lateral (CP ML) directions were obtained. Supplementary parameters were computed from the available center of pressure data using equations (Figure 1) based on previously published methodology [9]. The calculated parameters are defined in Textbox 1.

Since the data recorded during posture measurement was highly variable between trials (eg, various foot positions on the force plate and concentration of the subject) the mean difference between force plate and Wii Balance Board values was computed for each studied parameter, for each 30 second trial in order to tackle this variability. All statistics were performed on the mean of the 3 trials for each Wii Balance Board (6 subjects and 4 Wii Balance Boards each).

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Figure 1. Equations.

$$DOT = \sum_{i=1}^{N} \sqrt{CP_{AP}(i)^2 + CP_{ML}(i)^2} \quad \text{(a)}$$

$$Area = \pi \times prod\left(2.4478 \times \sqrt{svd\left(eig\left(cov(CP_{AP}, CP_{ML})\right)\right)}\right) \quad \text{(b)}$$

$$RMS_{AP} = \frac{1}{N}\sqrt{\sum_{i=1}^{N} CP_{AP}(i)^2} \quad \text{(c)}$$

$$RMS_{ML} = \frac{1}{N}\sqrt{\sum_{i=1}^{N} CP_{ML}(i)^2} \quad \text{(d)}$$

$$AdCP_{AP} = \max(CP_{AP}) - \min(CP_{AP}) \quad \text{(e)}$$

$$AdCP_{ML} = \max(CP_{ML}) - \min(CP_{ML}) \quad \text{(f)}$$

$$MV_{AP} = \frac{f}{N}\sum_{i=1}^{N-1} |CP_{AP}(i+1) - CP_{AP}(i)| \quad \text{(g)}$$

$$MV_{ML} = \frac{f}{N}\sum_{i=1}^{N-1} |CP_{ML}(i+1) - CP_{ML}(i)| \quad \text{(h)}$$

$$TMV = \frac{f}{N}\sum_{i=1}^{N-1} \sqrt{\left(CP_{AP}(i+1) - CP_{AP}(i)\right)^2 + \left(CP_{ML}(i+1) - CP_{ML}(i)\right)^2} \quad \text{(i)}$$

Textbox 1. Calculated parameters.

Parameter

- DOT: total displacement of sway
- Area: the area of the 95% prediction ellipse (often referred to as the 95% confidence ellipse)
- SD AP and ML: the dispersion of center of pressure displacement from the mean position
- $AdCP_{AP}$ and $AdCP_{ML}$: the distance between the maximum and minimum center of pressure displacement
- MV_{AP} and MV_{ML}: the mean velocity of center of pressure displacement
- TMV: the AP and ML displacements of the total center of pressure sway divided by the total duration of the trial

Statistics

Intraclass correlation coefficients (ICC) (two-way random average measures; Model 2, single measurement) were computed to assess the reliability of the differences between devices and trials. Friedman tests (repeated measures) were also computed to compare the 4 different Wii Balance Boards. Differences between the force plate and Wii Balance Board for each trial (3 repetitions for each of the 4 Wii Balance Boards for each subject (N=6) totals 72 trials) with mean difference and confidence intervals plotted. The amount of observations that were outside the confidence intervals for each variable and each Wii Balance Board were summarized in a contingency table. Chi-square tests were computed to detect interactions between the Wii Balance Board and studied variables. Spearman correlation coefficients were computed between variables obtained from the force place and Wii Balance Board.

Results

ICC results for agreement between Wii Balance Boards and results of the *F* and Friedman tests are presented in Table 1. Low agreements were found for variables derived from ML displacements (ICC values of .334 and .345 for RMS_{ML} and $AdCP_{ML}$, respectively). Strong agreements were found for DOT (.704) and $AdCP_{AP}$ (.786). Almost perfect agreements were found for the other variables (mean ICC=.962).

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Table 1. Intraclass correlation coefficient (ICC) of the studied parameters for the 4 different devices.

Variable	ICC agreement	Bounds of the confidence interval		Friedman, *P* value
		Lower	Upper	
DOT	.704	-0.110	0.955	.93
Area	.959	0.858	0.994	.91
RMS_{AP}	.906	0.686	0.985	.42
RMS_{ML}	.334	-1.761	0.901	.87
$AdCP_{AP}$	.786	0.336	0.965	.25
$AdCP_{ML}$	.345	-1.911	0.904	.72
MV_{AP}	.985	0.950	0.998	.95
MV_{ML}	.980	0.931	0.997	.86
TMV	.984	0.945	0.997	.94

The differences between each trial and the mean difference with confidence intervals are presented in Figure 2. The contingency table of values that are outside the confidence intervals is presented in Table 2. The *P* value of the chi-square test is .59 (df=43); there is thus no association between the number of observations outside the confidence interval and the device.

The correlations between the data collected with the force plate and Wii Balance Boards are shown in Table 3. No statistical significant difference (Friedman test) was found for the correlations between the 4 different Wii Balance Boards.

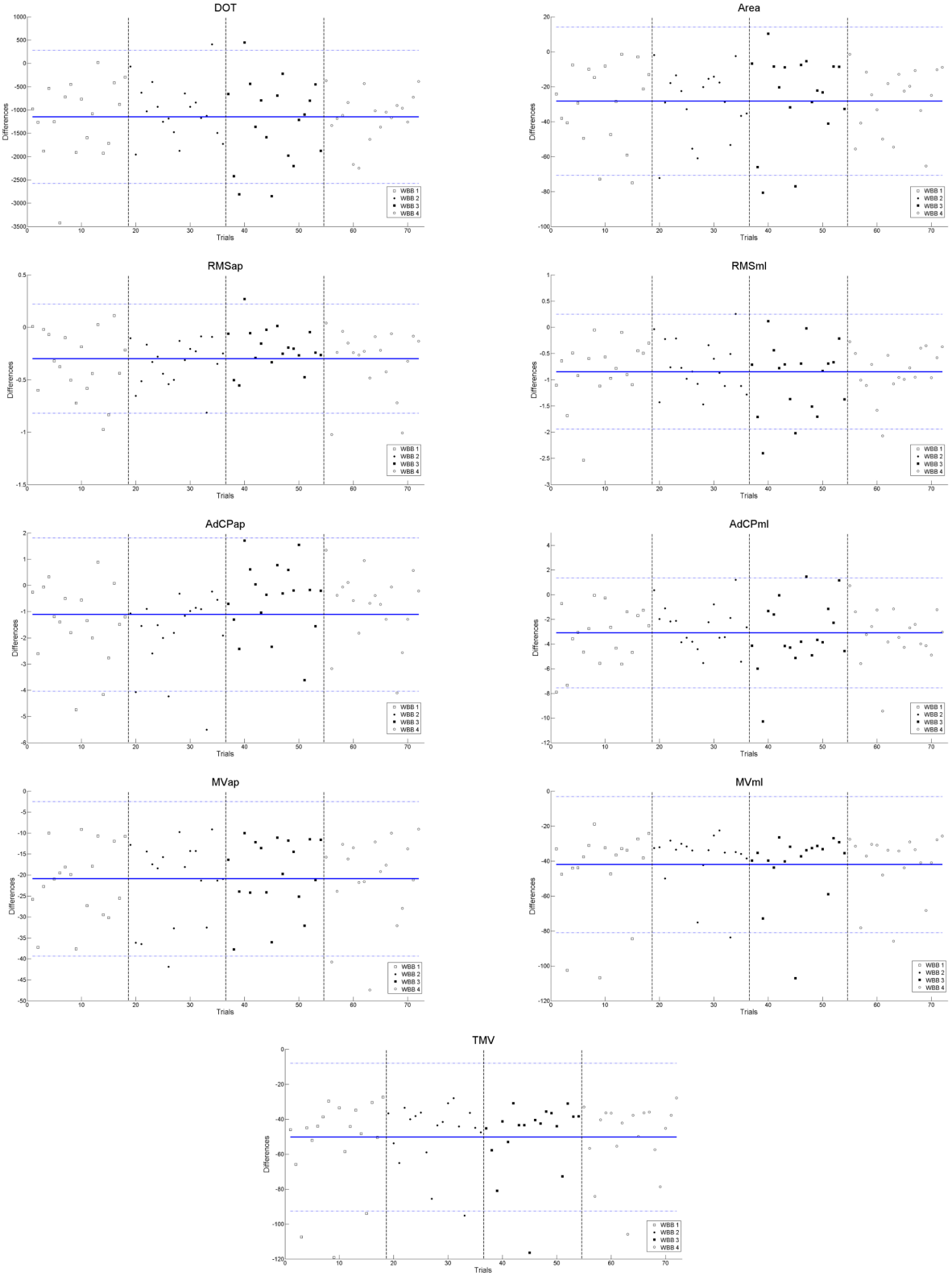
Table 2. Contingency table of the number of observations outside of the confidence interval.

Variable	Wii Balance Board device number				
	1, n[a]	2, n[a]	3, n[a]	4, n[a]	Total, per variable
DOT	1 (0.05)	1 (0.05)	3 (0.16)	0 (0)	5 (0.07)
Area	2 (0.11)	1 (0.05)	2 (0.11)	0 (0)	5 (0.07)
RMS_{AP}	2 (0.11)	0 (0)	1 (0.05)	2 (0.11)	5 (0.07)
RMS_{ML}	1 (0.05)	0 (0)	2 (0.11)	1 (0.05)	4 (0.06)
$AdCP_{AP}$	2 (0.11)	3 (0.16)	0 (0)	1 (0.05)	6 (0.08)
$AdCP_{ML}$	1 (0.05)	0 (0)	2 (0.11)	1 (0.05)	4 (0.06)
MV_{AP}	0 (0)	1 (0.05)	0 (0)	2 (0.11)	3 (0.04)
MV_{ML}	3 (0.16)	1 (0.05)	1 (0.05)	1 (0.05)	6 (0.08)
TMV	3 (0.16)	1 (0.05)	1 (0.05)	1 (0.05)	6 (0.08)
Total, per device	15 (0.09)	8 (0.05)	12 (0.07)	9 (0.05)	44

[a]Values inside brackets represent the ratio between outside values and number of observations.

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Figure 2. Differences between force plate and Wii Balance Boards for the 72 trials. Solid horizontal lines represent the mean difference. Dotted horizontal lines represent upper and lower confidence intervals (95%). Vertical lines indicate separation between the 4 different devices (18 trials per Wii Balance Board).



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Table 3. Spearman correlation coefficients between the force plate and the 4 different Wii Balance Board devices.

Variables	Wii Balance Board device number				
	1, ρ	2, ρ	3, ρ	4, ρ	Mean, ρ
DOT	.79	.73	.73	.87	.78
Area	.85	.89	.82	.90	.86
RMS_{AP}	.79	.92	.85	.78	.83
RMS_{ML}	.85	.72	.72	.80	.76
$AdCP_{AP}$	.76	.89	.74	.79	.80
$AdCP_{ML}$	.89	.79	.76	.73	.79
MV_{AP}	.94	.89	.88	.90	.91
MV_{ML}	.96	.84	.85	.91	.89
TMV	.82	.80	.77	.86	.81
Mean, ρ (SD)	.85 (0.02)	.83 (0.02)	.79 (0.02)	.84 (0.02)	.83 (0.05)

Discussion

Principal Findings

To the best of our knowledge, this is the only study assessing the repeatability of measurements performed with different Wii Balance Boards. Our results confirm the findings of previous studies [1,2] where good correlations were found between Wii Balance Boards and force plates for center of pressure displacement. For other studied parameters derived from center of pressure displacement, good correlations were found.

With respect to the 4 different Wii Balance Boards, no differences were found between the boards (repeated measure Friedman test), but surprisingly, the ICC values showed low agreement for the ML parameters (RMS_{ML} and $AdCP_{ML}$) although correlations with the force plate were high (.80 and.89 for RMS_{ML} and $AdCP_{ML}$, respectively). The contingency table of the number of observations outside of the confidence intervals did not show particular errors for those measurements (Table 2). The other parameters had strong to almost perfect agreements. The fact that no differences were found between the different Wii Balance Boards (repeated measure Friedman test), and they all had good correlations to the force plate results indicates that different Wii Balance Boards can be used interchangeably. However, our results suggest that parameters derived from the ML displacement of center of pressure should be interpreted carefully.

This study presents results on several different parameters derived from center of pressure displacement. Most other studies have focused on investigating differences between Wii Balance Boards and a force plate for a single parameter (eg, center of pressure displacement) [1,2]. In addition to making a direct comparison over multiple boards with the same subjects and tasks, this study also compares multiple parameters.

Limitations

The repeatability of some balance assessment protocols can be rather low. In our setup, we ran the risk of suffering from the same problem: in order to compare all the Wii Balance Boards and the force plate in a single trial, we would have had to place all the boards together on top of the force plate. As this is unfeasible, we processed our data by computing the difference between the Wii Balance Board and the force plate (for all the parameters) for each of the 4 trials. Over 3 trials and 6 subjects, we obtained 4 groups of 18 differences. ICCs were computed between those 4 groups. As the ICCs were high, the differences between the Wii Balance Board and force plate were considered consistent.

Conclusions

This study indicates that balance and posture results recorded with one Wii Balance Board can be compared to the results recorded with another Wii Balance Board. This is particularly interesting for multicenter studies and supports the creation of larger populations for clinical studies. This study also allows us, in part, to address several criticisms that have recently been expressed. Some researchers [3,10] have doubts about the results of previous studies (past 3 years) on the validity of the Wii Balance Board. In addition to showing excellent correlation between the Wii Balance Board and force plate, this study shows that these high correlations are independent of the Wii Balance Board used.

Acknowledgments

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Conflicts of Interest

None declared.

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Abbreviations

AP: anterior-posterior
DOT: Total displacement of sway
ICC: Intraclass correlation coefficient
ML: medio-lateral
MV: Mean velocity
TMV: Total mean velocity

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Original Paper

Are Virtual Rehabilitation Technologies Feasible Models to Scale an Evidence-Based Fall Prevention Program? A Pilot Study Using the Kinect Camera

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Abstract

Background: Falls in older adults are a significant public health issue. Interventions have been developed and proven effective to reduce falls in older adults, but these programs typically last several months and can be resource intensive. Virtual rehabilitation technologies may offer a solution to bring these programs to scale. Off-the-shelf and custom exergames have demonstrated to be a feasible adjunct to rehabilitation with older adults. However, it is not known if older adults will be able or willing to use a virtual rehabilitation technology to participate in an evidence-based fall prevention program. To have the greatest impact, virtual rehabilitation technologies need to be acceptable to older adults from different backgrounds and level of fall risk. If these technologies prove to be a feasible option, they offer a new distribution channel to disseminate fall prevention programs.

Objective: Stand Tall (ST) is a virtual translation of the Otago Exercise Program (OEP), an evidence-based fall prevention program. Stand Tall was developed using the Virtual Exercise Rehabilitation Assistant (VERA) software, which uses a Kinect camera and a laptop to deliver physical therapy exercise programs. Our purpose in this pilot study was to explore if ST could be a feasible platform to deliver the OEP to older adults from a variety of fall risk levels, education backgrounds, and self-described level of computer expertise.

Methods: Adults age 60 and over were recruited to participate in a one-time usability study. The study included orientation to the program, navigation to exercises, and completion of a series of strength and balance exercises. Quantitative analysis described participants and the user experience.

Results: A diverse group of individuals participated in the study. Twenty-one potential participants (14 women, 7 men) met the inclusion criteria. The mean age was 69.2 (± 5.8) years, 38% had a high school education, 24% had a graduate degree, and 66% classified as “at risk for falls”. Eighteen participants agreed they would like to use ST to help improve their balance, and 17 agreed or strongly agreed they would feel confident using the system in either the senior center or the home. Thirteen participants felt confident they could actually set up the system in their home. The mean System Usability Scale (SUS) score was 65.5 ± 21.2 with a range of 32.5 to 97.5. Ten participants scored ST as an above average usability experience compared to other technologies and 5 participants scored a less than optimal experience. Exploratory analysis revealed no significant relationships between user experience, education background, self-described computer experience, and fall risk.

Conclusions: Results support the virtual delivery of the OEP by a Kinect camera and an avatar may be acceptable to older adults from a variety of backgrounds. Virtual technologies, like Stand Tall, could offer an efficient and effective approach to bring evidence-based fall prevention programs to scale to address the problem of falls and fall-related injuries. Next steps include determining if similar or better outcomes are achieved by older adults using the virtual OEP, Stand Tall, compared to the standard of care.

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KEYWORDS

aging, fall prevention, technology, evidence-based, Kinect, falls

Introduction

Falls are a tremendous problem facing older adults. It is estimated that 1 in 3 adults age 65 and over fall annually, costing the health care system over US $30 billion dollars in direct medical costs [1]. Older adults fall due to a complex interaction of risk factors [2]. Many factors for falling (ie, age, vision impairment, balance impairment, hearing impairment) increase in risk with increasing age. Therefore older adults, regardless of functional status, are always at some level of risk.

Clinical practice guidelines recommend all older adults be screened annually for fall risk [3]. Older adults who screen positive should have a comprehensive fall risk assessment to determine contributing risk factors. Evidence-based interventions should be prescribed to address all identified factors [4].

One of the most effective interventions to prevent a fall for community-dwelling individuals at low or moderate risk is structured and progressive strength and balance exercises [5,6]. The recommended minimum dose of strength and balance exercise to achieve a protective effect against a fall is 2 hours/week, and the exercise must be ongoing to maintain this protective effect [7-9]. Current fall risk management models must innovate to deliver this dose of exercise without continued medical or physical therapy oversight, which is time and resource-intensive.

The Otago Exercise Program (OEP) is an evidence-based fall prevention program developed in the late 1990s at the University of Otago, New Zealand [10,11]. The OEP has consistently demonstrated a 35% reduction in falls in at risk, community dwelling older adults [12]. The program is designed to be delivered by a physical therapist (PT) in 5 visits over 8 weeks with monthly follow up phone calls, and visits at 6 and 12 months. During the visits, the PT evaluates and prescribes the appropriate strength and balance exercises from the OEP. When the older adult has improved their strength and mobility, they are also prescribed a walking program to complete three times a week. After the initial 8 weeks, the older adult continues to independently complete the prescribed exercises 3 times a week and their walking program 3 times a week for the 12 months of the program [13].

Though highly effective, this program requires either a high level of compliance from the older adult or significant time and resources from the PT. Given the demographics of the world's aging population and the limited number of PTs, alternative methods to broadly disseminate the OEP must be investigated to have the greatest impact on the problem of falls.

Innovative digital rehabilitation solutions may provide a feasible model to address these challenges. Three-dimensional motion tracking cameras, like the Microsoft Kinect, can guide an older adult through a series of exercises to improve their strength and balance. The technologies have the capability to track the total amount of time spent exercising, the number of repetitions and sets of each exercise, and the quality of the movements performed [14].

Gaming systems for rehabilitation are gaining popularity and acceptance with clinicians and researchers [15]. Several research studies support that exergames, as an adjunct to or in place of traditional rehabilitation for older adults, show promise as an intervention to positively impact functional outcomes [15-17], and can improve balance. [18-20].

Though in early stages, the results from these studies support that exergames may offer a viable option to engage older adults in physical and exercise activity. These results support further exploration of using these systems to deliver proven programs like the OEP to older adults with balance impairments. An important step in this process is to explore the feasibility of using the Kinect to deliver the OEP with a diverse group of older adults. It is unclear from previous studies if older adults from a variety of education and computer experience backgrounds would want to use a virtual system to improve their balance. It is also unknown if older adults with balance impairments or lower levels of functional mobility will be able to or want to independently use these technologies specifically as a fall risk management strategy. Answering these questions will provide insights to the viability of virtual health solutions to bring fall prevention programs to scale.

The purpose of this study was to explore if older adults from a variety of educational backgrounds, self-described computer experience, and level of fall risk could successfully navigate and interact with "Stand Tall" (ST), a virtual translation of the OEP. Stand Tall is the fall prevention exercise program developed using the Virtual Exercise Rehabilitation Assistant (VERA) software. The VERA software uses a Kinect camera and a laptop to deliver therapeutic exercise programs for use independently in the home, rehabilitation or senior center settings.

Methods

Participants

All recruitment took place at a senior center in San Diego, California. Participants were recruited via informational flyer. The flyer described the study as a 90-minute session to interact with a virtual technology designed to improve balance. Participantss were compensated US $50 upon completion of the study. Interested participants were connected to the study personnel by the senior center's site coordinator. All participants were contacted and screened by study personnel. Individuals were included if they: (1) were at least 60 years of age or older, (2) were able to walk independently with or without an assistive device, (3) were able to independently rise from a chair, (4) lived in a noninstitutional setting, (5) self-reported they had at least one chronic disease (arthritis, diabetes, hypertension, etc.),

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(6) were able to speak, hear, and understand English, and (7) had 20/20 vision from 10 feet with or without glasses.

Participants were excluded if they self-reported that they had been hospitalized in the past 6 months or had a diagnosed cognitive impairment or diagnosed neurodegenerative disease (eg, Parkinson's disease). The study received IRB approval from Western Institutional Review Board. Twenty-one adults volunteered for the study. All 21 volunteers met the inclusion criteria, signed informed consent prior to the testing session, and completed the 90-minute testing session.

Data Collection

All data collection took place at the senior center by trained study staff, and included an in-person survey-demographics including highest education obtained, self-reported function, and self-reported computer use. Education is often predictive of adoption of new technologies for older adults [21,22]. Therefore, participants were asked if they had less than 12 years of education (high school or less), an associate's degree, bachelors, or graduate degree. We developed the following question to gauge how older adults perceived their computer abilities: (1) I don't use computers, (2) Novice-I know how to turn it on and can use it with help, (3) Average-I can turn it on, launch programs, and email with minimal to no help, and (4) Expert-I use computers without any assistance and can solve most challenges.

According to the Centers for Disease Control and Prevention (CDC), all older adults are at some level of risk for falling. Quantifying risk is based upon a combination of self-reported risk factors, impairments in strength and balance, history of falls, and additional factors [23]. To standardize fall risk screening, the CDC created the Stopping Elderly Accidents, Deaths & Injuries Fall Risk Algorithm (STEADI) (see Figure 1). The STEADI tool recommends either using the Stay Independent Fall Risk Self-Assessment Tool (Stay Independent) [24] or administering 3 questions to screen for self-reported risk factors. Three physical performance measures, the Timed Up and Go (TUG), the 30-second chair stand (CS), and the four-stage balance test (FS) are the recommended screening tools for impairments in strength and balance.

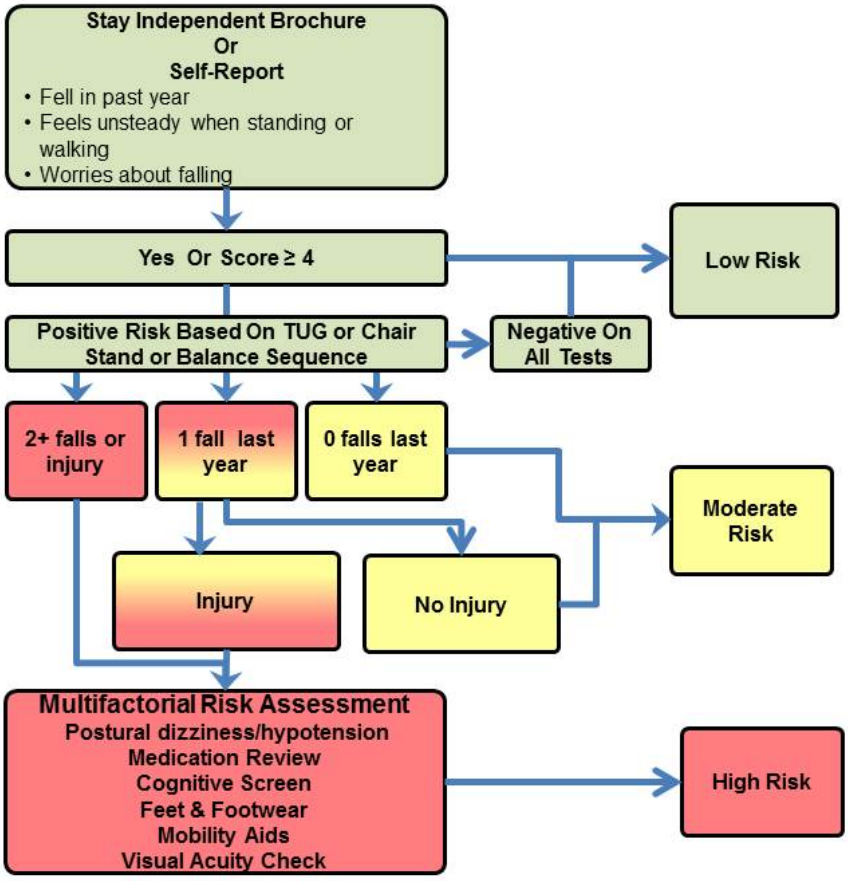
The Stay Independent was used to screen for self-reported risk factors in this study. The Stay Independent is a 12-item validated tool provides a comprehensive picture of fall risk. Participants who score 4 or more are considered at risk for a fall [24]. Participants completed the TUG, CS, and the FS to assess for impairments in strength or balance [5]. Scoring below established cutoffs for any one of the 3 tests is considered a risk factor for falls. The TUG consists of rising from a chair, walking at the Participant's usual speed for 3 meters, turning, walking back, and sitting down. Timing starts when the participant rises from the chair and stops when they sit. The cutoff score is 12 or more seconds [25]. The CS consists of the number of times the older adult can rise from a chair in 30 seconds without using their arms. Cutoff scores are based on age and gender-based normative values [26]. The FS is a standing balance sequence which consists of holding a series of progressively more narrow positions for at least 10 seconds. Those who cannot hold the "tandem stance" (heel-toe) position for at least 10 seconds or the single leg stance (standing on one leg) for at least 10 seconds, are considered at risk [27].

Upon completion of baseline data collection, the usability session was started. All usability sessions were videotaped using Morae Usability Software (Techsmith). The video captured both the Stand Tall screen and the individual's interaction with the technology using a picture-in-picture (PiP) template. Video was started when the participant was introduced to the system and stopped when the participant had exited the room.

Upon completion of the usability study, participants completed a 4-item debrief survey, developed by the study personnel. The survey items were on a 4-point Likert Scale developed specifically to assess participant's confidence setting up and using the Stand Tall product in the senior center or in the home. Participants completed the standardized and validated System Usability Scale (SUS). The 10-item SUS is a 5-point Likert scale which seeks the subjective opinion about the user experience. Considered "technology agnostic" the SUS has been used in over 3500 studies to determine usability of mobile phones, websites, and software. Scores of > 68 are considered to be an "above average" experience for the user [28,29].

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Figure 1. Classification of fall risk based on the Centers for Disease Control's STEADI fall risk assessment tool.



Testing Procedure

Participants completed baseline questionnaires and functional performance tests. Upon completion of baseline assessments, the video was started and participants were oriented to ST.

Study personnel turned on the system. They explained the participant would see 2 images on the screen, one was an animated avatar named VERA that would demonstrate the exercises, and the other was the participant's image as a silhouette. Participants were told to listen to VERA's instructions, observe VERA doing the exercise, and then try the exercise. Study personnel demonstrated calibration, navigation of the application including the "hand swipe" gesture, accessing and completing the exercises, and noted errors, tips and warning messages.

Participants were asked if they were ready to try the system. The participants were first instructed to "think aloud" as they navigated the protocol. Participants stood in front of the camera and identified their silhouette. They were told to extend their hand and identify their hand on the screen. Once the participants identified their hand they were instructed how to navigate to the next screen. Study personnel coached the participants in navigation until they demonstrated they could navigate independently. Participants were instructed to ask for help with navigation and exercise explanation only if they could not successfully complete the tasks after at least one attempt.

Participants independently navigated the program and completed 10 repetitions of 8 of the strength and balance exercises from the OEP: sitting knee extension, standing hip abduction, standing knee flexion, sit to stand from a chair, shallow squats, toe raises, standing on one leg, and tandem stance. Participants were told if they experienced any pain or fatigue they could stop an exercise at any point in time. Study personnel noted if a participant was unable to do a single repetition of an exercise due to either not understanding the exercise, experiencing pain, or a software issue. Participants were supervised the entire session in case of a loss of balance.

Upon completion of the final exercise, participants received notification from VERA that the exercise session was complete. Study personnel began the debrief session. Participants completed the debrief survey, the SUS and answered a series of open-ended questions about the user experience. Participants then received a US $50 gift card and the video was stopped.

Analyses

All data were analyzed using IBM SPSS Statistics for Windows, Version 22.0. Frequencies and distributions were run for all variables. A Chi Square analysis was performed and nonparametric correlations using a two-tailed Spearman's Rho test to identify any trends between computer ability, fall risk, and SUS scores. SUS scores were a continuous variable, and ability and fall risk were categorical. Education was recoded to high school or less (0) and college (1). The 4 variables to

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quantify fall risk were recoded for analysis as follows: Stay Independent was transformed to a categorical variable (0-3 = no risk, 4-12 = risk); the 3 physical performance tests were transformed to categorical variables based on risk (TUG > 12 seconds, CR if < age and gender values, FS if only able to achieve stage 2 or less). The physical performance variables were then collapsed into 1 variable that represented all participants who scored below the cutoff for at least one physical performance test.

For the purposes of this paper, fall risk was operationalized as follows: no risk–score of no risk for the Stay Independent and no risk based on balance and strength tests; low risk–score at risk for the Stay Independent and no risk based on balance and strength tests; Moderate risk–score at risk for Stay Independent and at risk for strength and balance or score at risk for strength and balance; High risk–score at risk for Stay Independent, at risk for strength and balance, and 2 or more falls or 1 fall with injury in the past 12 months.

Results

Participants

Descriptive statistics show that a diverse group of older adults participated in this pilot study (Table 1). They ranged in age from 61 to 85, with a mean age of 69.2 (SD 5.8). Of note, there were similar representations of older adults with a high school education or less and those who had completed college. The sample was relatively healthy, with no participant scoring his/her general health as poor. Almost half of the sample (9/21) described themselves as either “very rarely” or “not a user” of technology.

Table 1. Characteristics of volunteers (n=21).

General characteristics		Number of participants
Gender		
	Female	14
	Male	7
Race		
	Black	8
	White (non-Hispanic)	7
	Asian/Pacific Islander	5
	White (Hispanic)	1
Education		
	High School/GED	8
	Community college	4
	Bachelor’s degree	4
	Graduate degree	5
Computer ability		
	Don’t use	4
	Novice	5
	Average	7
	Expert	5
Living status		
	Alone	16
	With spouse	3
	Other	2
Health status		
	Excellent/Very Good	12
	Good	6
	Fair/Poor	3
Fallen in past 12 months		
	Yes	6
	No	15

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All participants were able to complete the 3 physical performance measures to determine if they were at risk. For the TUG, 3 participants took ≥12 seconds, for the CS, 6 participants did fewer repetitions than age and gender-based normative values, and for the FS, 6 participants could only achieve Stage 1 or Stage 2 for at least 10 seconds (Tables 2 and 3).

Table 2. Physical performance measures: timed up and go and 30-second chair stand (n=21).

Performance measures	Mean (SD) and range
Timed up and go (measured in seconds)	10.4 (2.5) 6.3–18.5
30-second chair stand (number in 30 seconds)	11.8 (3.8) 6-23

Table 3. Physical performance measures –four-stage balance test (n=21).

Stage held for 10 seconds	Highest stage achieved by each participant
Stage 1 (feet side-by-side)	1
Stage 2: semitandem (one foot slightly in front of other)	5
Stage 3: heel-toe position	3
Stage 4: standing on one foot	13

The results of the Stay Independent were summed to identify any participants at risk based on a score of ≥ 4. Per the operational definition, this information was combined with the physical performance measures to identify any participant at low, moderate or high risk of a fall. A total of 11 participants screened positive for fall risk based on self-report. Of those 11, 6 screened negative for strength or balance impairment and were placed in the low risk category and 5 screened positive for a strength or balance impairment and were placed in the moderate risk category. Additionally, 3 participants scored below cut-points for the balance and strength assessment but screened negative for fall risk based on self-report. Finally, 3 of the 8 participants scored below the cutoffs for 2 of the balance and strength measures. Per our definition, participants who scored below cutoffs were placed in the moderate risk category. None of the 21 participants had a combination of history of falls, self-report, and physical performance testing to meet the criteria for “high risk” for a fall (Table 4).

Table 4. Fall risk based on self-report and/or physical performance measures (n=21).

No risk	Low risk based on self-report (score of ≥ 4 on Stay Independent Fall Risk Self-Report Tool)[a]	Moderate risk based on balance or strength impairment
7	6	8

[a] None of the participants had experienced more than 1 fall in past 12 months or a fall with injury.

Usability Testing

Two participants did not have time to complete the usability questions, and 1 participant’s questionnaire data were not completely captured due to a software malfunction. As a result, for 2 questions we report data on 19 participants and for 2 questions we report data on 18 participants.

The majority of participants (18) either agreed or strongly agreed they would like to use ST to help improve their balance, and 17 agreed or strongly agreed they would feel confident using the system in either the senior center or the home. Over half of participants (13) felt confident they could set up the system in their home.

The SUS scores demonstrated a wide range of user experience. There were 4 participants with missing SUS data. Of the 17 scores, the mean score was 65.5 (SD 21.2) with a range of 32.5 to 97.5. ST was rated as an above average usability experience compared to other technologies by 10 participants. This means they believed the entire experience of using the system, logging on, navigating, pausing, and exercising was at least an acceptable experience. Of these 10 participants, 5 rated the experience at an 80 or above, considered the top 10% of usability experience [30]. However, 5 participants scored a 50 or less, which is a less than optimal experience. Of these participants, 2 interacted with the system when the software crashed multiple times, while the other 3 felt the system had “a ways to go” before they would use it. There were no common characteristics among these 5 participants, they came from a variety of educational and computer experience backgrounds and represented a range of fall risk (Table 5).

Preliminary results from nonparametric correlations suggest that no trends existed between low risk per self-assessment and moderate risk based on physical performance and user experience, education and user experience, or level of computer use and user experience (Table 6).

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Table 5. Feasibility and interest in using the Virtual Exercise Rehabilitation Assistant.

	Level of Agreement	N
I would want to use a virtual program to improve my balance (N=19)		
	Strongly Agree	13
	Agree	5
	Disagree	1
	Strongly Disagree	0
I feel confident I can set up a virtual program to exercise at home (N=19)		
	Strongly Agree	6
	Agree	7
	Disagree	3
	Strongly Disagree	3
I feel confident I can use a virtual program to exercise in my home (N=18)		
	Strongly Agree	12
	Agree	5
	Disagree	1
	Strongly Disagree	0
I feel confident I can use a virtual program to exercise at the senior center (N=18)		
	Strongly Agree	12
	Agree	5
	Disagree	1
	Strongly Disagree	0

Discussion

Overview

The purpose of this study was to explore the experience of older adults from a variety of educational backgrounds, computer experience, and level of fall risk navigating and interacting with "Stand Tall", a virtual translation of the Otago Exercise Program.

Falls in the United States are a universal problem, affecting older adults from all socioeconomic backgrounds. To effectively address the challenges of fall risk management and prevention, it is important to develop a technology that can be adopted by older adults from a wide range of backgrounds and experiences. Given the sample size of 21, we are not able to make definitive statements regarding the relationship between education, level of computer expertise or fall risk and the usability of the system. However, our preliminary analysis for this small group supports that none of these factors had a significant impact on the quality of the experience.

Studies support older adults can and will use exergame-based virtual systems for exercise or rehabilitation [18,31,32]. Researchers have demonstrated healthy older adults can use these systems over extended periods of time and demonstrate significant improvements in function. A group of highly functioning older adults in a retirement community demonstrated they could independently use the Wii Fit for a 6-week balance training intervention and achieved significant improvements in physical performance measures [18]. Similar findings were reported by researchers who developed a series of exergames specifically for older adults. These participants used the system with supervision 2-3 times a week for up to 8 weeks. In addition to significant improvements in function, they demonstrated an adherence rate of 81%, completing their exercise sessions at least four times of five each week [20].

Less is known about older adults' interest in using a virtual system that is not gamified, but that simply leads the user through a series of balance exercises, much like one would do with a PT. By replicating the experience with a PT we hope to achieve the same outcomes as the OEP when delivered in a traditional model. To our knowledge, this is the first study to explore the feasibility of using a virtual system to deliver a previously validated evidence-based fall prevention program.

The preliminary results support the ST program may be a feasible option to deliver an evidence-based fall prevention exercise intervention to older adults. As a first step to determine if the concept of using technology to bring these programs to scale was feasible, we recruited participants from a broad range of educational, racial, and socioeconomic backgrounds, levels of fall risk, and self-reported experience with technology. To have a representative sample, we developed broad inclusion criteria in which participants self-reported their health status and chronic disease status. The actual chronic diseases for each participant were not documented for this pilot study, unless the participant had a vision or hearing impairment, which would then exclude them from the study. Future work will document

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the number and types of chronic diseases represented by the study sample, and determine if type of chronic disease has an impact on long-term adherence and compliance with the system.

Table 6. Nonparametric correlations for fall risk, computer ability, SUS and education. All Spearman's Rho correlation coefficients and two-tailed significance levels reported.

		Stay independent	Physical performance	Computer expertise	SUS	Education
Stay independent						
	ρ	1.00	.16	.16	.18	.36
	P		.49	.50	.49	.11
	N	21	21	21	17	21
Risk based on TUG or CS or FS						
	ρ	.16	1.00	.07	.27	-.21
	P	.49		.77	.30	.35
	N	21		21	17	21
Computer expertise						
	ρ	-.16	.07	1.00	-.10	.28
	P	.50	.07		.69	.21
	N	21	21		17	21
SUS						
	ρ	-.18	.26	-.10	1.00	-.31
	P	.49	.30	.70		.23
	N	17	17	17		17
Education						
	ρ	-.36	-.21	.28	-.31	1.00
	P	.11	.35	.21	.23	
	N	21	21	21	17	

We did not formally screen any participants for cognitive impairment, but simply asked participants if they had been given a diagnosis of cognitive impairment from their health care provider. Cognitive impairment is a known risk factor for falls, and any fall risk management product needs to take this into account. The goal for this pilot was to have a representative sample from the community interact with the product. The prevalence of mild cognitive impairment (MCI) is approximately 10% for community-dwelling older adults [33]. Individuals with MCI often have slowed reaction times and difficulty inhibiting irrelevant information. It is possible that some of our participants had some degree of MCI which could impact their user experience. Future studies with larger sample sizes will incorporate validated screening tools for MCI to identify participants with cognitive impairment. The goal would be to assess their usability experience and identify key design elements that would create a positive user experience for those with MCI.

There was concern that older adults at either low or moderate risk for falls would either not be interested in using the system, or have a significantly different user experience. The preliminary analysis did not identify any obvious trends to support this assumption. The number of participants for this study is quite small and we anticipate further exploring these trends in future studies.

In the original OEP studies, the average age was 81 and 41% of participants had experienced a fall [11]. The average age of our participants was 10 years younger and 29% (6/21) had experienced a fall. The participants in our study appear to be at a higher level of function compared to the original OEP research. We may find that if we test the system with older adults at a lower level of function that we may see different results. However, 67% of the participants (14/21) were at some level of fall risk or impaired function. This risk level represents older adults who would greatly benefit from a structured strength and balance exercise to prevent a fall; which supports continued exploration of this technology to determine if it would be acceptable for the majority of users.

Our participants represented a range of education levels, socio-economic backgrounds, and functional ability. This diversity of participants has not necessarily been seen in many of the other research reports which have studied a more homogenous population of well educated, highly functioning older adults [18,31,34]. Though preliminary, the finding that 18 participants either agreed or strongly agreed they would like to use a virtual program to improve their balance supports the

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possibility that ST may be a feasible solution. Previous studies have reported higher levels of technology (internet, text messaging) adoption amongst older adults who were white and with a higher education level [35]. We did not see similar patterns with our users, which may be due to the ease of navigation and using the technology to exercise, as opposed to learning keyboard strokes to seek information. One user with a high school education had never interacted with a computer, nor had she ever participated in a formal exercise class. This participant mastered the technology, was able to complete the 10 exercises, and kept stating, “this is fun, and I need one of these!”

The SUS scores reported for the system demonstrated a wide range of usability experiences. The mean raw score was below that reported in another study that assessed older adult’s usability experience of an exergame [20]. However, the ST program was still in the alpha phase, and the other study assessed a fully functioning system. Given the diversity of usability scores, more testing will be needed on the final product and over a period of time to fully quantify the usability of the system.

Consistent with other studies [15], many participants experienced a feeling of mastery while interacting with the system and statements included, “This is great, when is it coming to the Senior Center?”, “I can do this, it is fun!”, and “I would love to use this in my home, and I see how it would benefit other seniors.” Conversely, when the system did not accurately represent the participant’s efforts, either by over-counting or under-counting repetitions, participants would become frustrated. “What am I doing wrong?” or “Why isn’t she counting me?” were common statements, supporting that a final product must be easy to use but must also be accurate and responsive to provide the optimal user experience.

Limitations

This was a pilot study and the findings have limited application to the general population. However, our sample represented a broad range of socioeconomic backgrounds, computer experience, and level of fall risk. The lack of any significant relationships between these factors and SUS scores warrants further exploration with larger studies. A second limitation was the results were based on our participant’s interacting with the system one time. We may find that after multiple interactions, participants may gain even more mastery and confidence using the system, and see different trends over time with different participants. A final limitation is, like the OEP, ST is, at this time, an exercise-only intervention. It may be that education and behavior changes, in addition to exercise may be necessary to achieve the best results.

Conclusion

The results from this study support that virtual delivery of the OEP, by a Kinect camera and an avatar may be a feasible way to scale and disseminate evidence-based fall prevention programs. Older adults enjoy using the technology and value the feedback provided by the avatar on both their form and progress. One of the most effective ways to prevent a fall is to engage in a minimum of 2 hours of strength and balance exercises each week. Virtual technologies like ST could assist older adults in achieving this goal, at a fraction of the resources. Ideally, these technologies would be available in senior centers, YMCAs, and in the home, and would only require a brief orientation to the system and minimal supervision, allowing the older adult to independently engage in an evidence-based program traditionally delivered by a PT. These technologies provide an opportunity for prevention with embedded alert systems that are triggered with changes in performance - either a decrease in weekly adherence or an increase in frequency of errors. Future studies will include determining if older adults can use the program independently over a period of time and determining if older adults who use the ST achieve similar or better outcomes than those participating in a more traditional setting.

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Authors' Contributions

Dr. Tiffany Shubert developed the study design and contributed to data collection. She conducted and completed all data analysis, and was the primary contributor to the manuscript. Jeanna Basnett contributed to study design, data collection, manuscript content and review. Anang Chokshi contributed to product design, study design, data review and manuscript review. Mark Barrett is the lead product engineer and contributed to software design, product design and manuscript review. Ravi Komatireddy contributed to study design, product design, and manuscript review.

Conflicts of Interest

Dr. Tiffany Shubert is a strategic advisor to Reflexion Health and owns an equity stake in the company. Jeanna Basnett is a founding employee of Reflexion Health and owns an equity stake in the company. Anang Chokshi PT, DPT, is a founding employee of Reflexion Health and owns an equity stake in the company. Mark Barrett, MET, is an employee of Reflexion Health

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and owns an equity stake in the company. Dr. Ravi Komatireddy MD, MCTI is the founding partner and Chief Medical Officer of Reflexion Health and owns an equity stake in the company.

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Abbreviations

CDC: Centers for Disease Control and Prevention
CS: 30-second chair stand
FS: four-stage balance test
MCI: mild cognitive impairment
OEP: Otago Exercise Program
PiP: picture-in-picture
PT: physical therapist
ST: Stand Tall
STEADI: Stopping Elderly Accidents, Deaths, and Injury Fall Risk Algorithm
SUS: System Usability Scale
TUG: Timed Up and Go
VERA: Virtual Exercise Rehabilitation Assistant

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Original Paper

Automated Management of Exercise Intervention at the Point of Care: Application of a Web-Based Leg Training System

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Abstract

Background: Recent advances in information and communication technology have prompted development of Web-based health tools to promote physical activity, the key component of cardiac rehabilitation and chronic disease management. Mobile apps can facilitate behavioral changes and help in exercise monitoring, although actual training usually takes place away from the point of care in specialized gyms or outdoors. Daily participation in conventional physical activities is expensive, time consuming, and mostly relies on self-management abilities of patients who are typically aged, overweight, and unfit. Facilitation of sustained exercise training at the point of care might improve patient engagement in cardiac rehabilitation.

Objective: In this study we aimed to test the feasibility of execution and automatic monitoring of several exercise regimens on-site using a Web-enabled leg training system.

Methods: The MedExercise leg rehabilitation machine was equipped with wireless temperature sensors in order to monitor its usage by the rise of temperature in the resistance unit ($\Delta t°$). Personal electronic devices such as laptop computers were fitted with wireless gateways and relevant software was installed to monitor the usage of training machines. Cloud-based software allowed monitoring of participant training over the Internet. Seven healthy participants applied the system at various locations with training protocols typically used in cardiac rehabilitation. The heart rates were measured by fingertip pulse oximeters.

Results: Exercising in home chairs, in bed, and under an office desk was made feasible and resulted in an intensity-dependent increase of participants' heart rates and $\Delta t°$ in training machine temperatures. Participants self-controlled their activities on smart devices, while a supervisor monitored them over the Internet. Individual $\Delta t°$ reached during 30 minutes of moderate-intensity continuous training averaged 7.8°C (SD 1.6). These $\Delta t°$ were used as personalized daily doses of exercise with automatic email alerts sent upon achieving them. During 1-week training at home, automatic notifications were received on 4.4 days (SD 1.8). Although the high intensity interval training regimen was feasible on-site, it was difficult for self- and remote management. Opportunistic leg exercise under the desk, while working with a computer, and training in bed while viewing television were less intensive than dosed exercise bouts, but allowed prolonged leg mobilization of 73.7 minutes/day (SD 29.7).

Conclusions: This study demonstrated the feasibility of self-control exercise training on-site, which was accompanied by online monitoring, electronic recording, personalization of exercise doses, and automatic reporting of adherence. The results suggest that this technology and its applications are useful for the delivery of Web-based exercise rehabilitation and cardiac training programs at the point of care.

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KEYWORDS

digital intervention; exercise intervention; cardiac rehabilitation; training equipment; online monitoring; exercise dose; telerehabilitation; leg mobilization; Web-based apps; eHealth recordings

Introduction

Substantial evidence has established the value of physical activity and strongly supports the routine prescription of exercise training to all patients, including those with cardiovascular disease and other chronic diseases [1]. However, the current framework of cardiac rehabilitation (CR) is not sustainable due to significant barriers such as high costs [2]. Modern technology facilitates the development of digital interventions for health care, which can provide effective and potentially cost-effective models for improving patient engagement and health outcomes [3]. However, despite a large number of physical activity apps on the market, there is a shortage of evidence-based apps that can be used clinically [4,5].

The overall contribution of technology in improving CR delivery [6] can be conceptualized in relation to four essential components of CR: patient management, motivation, actual training and monitoring (Figure 1). The process of rehabilitation is normally guided by relevant health care providers such as physiotherapists, who perform patient assessments, prescribe training programs, assist in training, and control patient compliance. Figure 1 shows that modern telehealth technology allows remote patient management (arrow 1), including telecare of chronic diseases at home environment [7]. Provision of CR using telehealth approaches was found not significantly inferior to the center-based programs in patients with cardiovascular diseases [8].

Arrow 2 demonstrates that behavioral interventions such as physical activity promotion can be efficiently delivered to the patients using electronic means. The major advantage of digital interventions is the capacity for patient-centered approaches [9] such as age-appropriate apps for older adults [10]. Web-based programs have been suggested as an alternative method of CR [11] and mobile technology is considered a valuable approach to improving access to CR [12]. Nevertheless, access to health information by itself may have insufficient impact on the health-related behavior in patients with cardiovascular diseases [13].

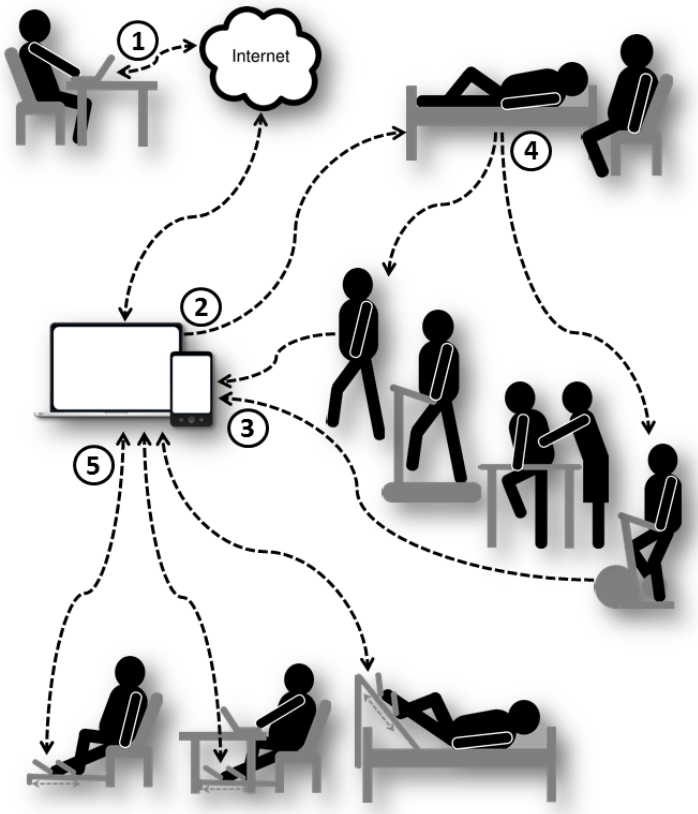
Arrow 3 indicates that modern technology also allows telemonitoring of exercise training by measuring physiological parameters and exercise volumes. For example, the feasibility of home-based telemonitoring in patients with heart failure has been demonstrated in several studies [14]. Wireless multibiosensor systems were found valid for real-time tracking of physical activity among cardiac patients [15] and there are a large number of inexpensive physical activity counters for use in clinical and public health settings [16]. However, accelerometers and pedometers have significant limitations [17] so that subjective self-reporting still remains the main method of physical activity surveillance [18].

Arrow 4 exemplifies typical methods of patient training, where CR can be delivered in self-control, face-to-face or group-based settings. This model has not changed over the past two decades [19] and methods of endurance training such as running and cycling are the same as used by the healthy fit people [6,20]. Because diseases, obesity, and aging reduce patients' endurance and mobility [21,22], their low exercise capacity can be considered as a barrier to sustained CR. Other barriers include lack of transport, financial cost, and embarrassment about participation [23]. Many patients have to organize and support their daily training by themselves, including travel to the gym and expensive professional assistance. The higher costs and resource intensity make them disadvantaged in their access to exercise training compared with the healthy population [19].

Figure 1 shows that the phase of actual training has been influenced by technology to a lesser extent than other components of CR. It could be suggested that taking patients away from the point of care for training and use of conventional exercise methods may hold back implementing the full potential of technology in CR. Therefore, we have developed a Web-enabled system for training on-site, which consisted of an innovative leg rehabilitation system integrated with mobile devices (arrows 5). This study demonstrated that typical exercise regimens used in CR were feasible at home with remote monitoring and automated reporting of compliance. Application of this technology might be useful for the integration of exercise training with digital interventions at the point of care to improve sustainability of CR.

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Figure 1. CR delivery framework using modern technology, where arrows indicate: (1) remote management by healthcare providers; (2) digital intervention delivery to target populations; (3) physical activity monitoring; (4) conventional exercise and cardiac rehabilitation; and (5) on-site training with the MedExercise system in different settings.



Methods

Equipment and Data Collection

MedExercise ST01 leg training system (MDXD Pty Ltd) was used in this work. This portable system has been developed for exercise rehabilitation on-site and consists of a variable resistance unit with two pedals, means for attachment to furniture, and a measurement module as detailed elsewhere [24,25]. In addition, the resistance units were equipped with wireless temperature sensors (Monnit) so that temperature was measured in 1-minute intervals, transmitted to electronic devices using MonnitLink USB gateways and processed using iMonnit stand-alone or cloud-based software. Before each training session, the temperature values were set to zero. Exercise-induced rise of temperature in the resistance unit ($\Delta t°$) was used to monitor training activities of participants and calculate leg work output during exercise bouts. Participants' heart rates (HRs), expressed as beat per minute (BPM), and blood oxygen saturation were monitored using fingertip pulse-oximeter CMS-50E and respective software (Contec). Blood pressure was measured using the Omron blood pressure monitor HEM7200 (Omron Healthcare). Data were analyzed using Excel spreadsheet software (Microsoft).

Study Design

Arrows 5 (Figure 1) illustrate the experimental setups tested in this study, which represent the possible on-site locations of CR including standard upright chairs, recumbent armchairs, beds, and office desks. The participants trained with MedExercise devices attached to the pieces of furniture they normally used at home. Standard electronics such as laptop were equipped with wireless USB gateways and used by participants for monitoring of self-control training. When devices were connected to the Internet, the supervisor could remotely monitor training of participants in real time and access $\Delta t°$ data, which were continuously recorded for retrospective analysis.

The following 5 CR protocols were tested: (1) moderate-intensity continuous training (MICT), where the participants exercised at a steady-state intensity for specified durations, which ranged from 10 to 120 minutes; (2) dosed MICT protocol, where participants were training at the HR of 100 ± 10 BPM for 30 minutes to match the recommended daily exercise volume for healthy adults [20]; (3) high-intensity intermittent training, using a modified Wingate protocol [26], which included 10 cycles of alternate exercise at high (30 seconds) and moderate (2 minutes) intensities; (4) concurrent training at the office desk while participants were working with computers; and (5) training in the bed, where recumbent participants were exercising ad libitum, while viewing TV or entertaining themselves with their electronic devices.

Participants

The inclusion criteria were (1) absence of known medical contraindications to regular exercise training; (2) capacity for installation of training equipment and its regular use at home; and (3) connection to the Internet and ability to manage

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electronic data. The reasons for exclusion included (1) inability to provide informed consent; (2) not adhering to the prescribed training regimen; and (3) failure to use technology reliably. Because this study was focused on the validation of new technology, recruitment was limited to the needs for testing of various training programs in different settings. Overall 7 eligible volunteers (25-52 years old) participated from 2013 to 2015.

Results

Various Training Regimens Feasible On-Site

In this work, we first tested the feasibility of CR regimens on-site and then validated a new method for automated monitoring of compliance (Figures 2 and 3, respectively). Arrows 1-3 in Figure 2 illustrate the data flow from the training equipment to electronic devices and then over the Internet to a remote supervisor. A mobile device at hand allowed participants to monitor and adjust their own training activities in real time, while multiuser cloud-based software enabled the supervisor to access the data from multiple participants regardless of their location. Previously, we demonstrated that remote analysis of recorded data from the preceding week was useful in advising the participants on adjusting their training activities [25].

Arrows 4 and 5 point to the actual recordings of HR and $\Delta t°$ during exercise bouts, where $\Delta t°$ reflects the leg work output [24] and HR is the standard characteristic of exercise intensity [27]. It demonstrates a direct correlation between the intensity of training and participant's leg work output because vigorous exercising at 120 ± 10 BPM resulted at a higher work output per minute indicated by the sharper rise of $\Delta t°$ (curve 1). However, a moderate intensity of training at 100 ± 10 BPM allowed longer durations of exercise sessions such as a 60-minute bout illustrated by Curves 2. MICT bouts of up to 120 minutes were recorded during this study (data not shown). Arrow 6 marks data input from blood pressure monitor, indicating the expected rise of systolic blood pressure during MICT [28]. The oxygen saturation of the blood remained a steady state (Curve 3).

Arrow 7 exemplifies input of HR and $\Delta t°$ data during high-intensity interval training. It shows the association between HR and leg work output, where the busts of intensive training caused sharp rising of HR and $\Delta t°$ followed by recovery periods. The feasibility of high-intensity interval training has been tested because it was shown to increase cardiorespiratory fitness by almost double that of MICT in the patients with lifestyle-induced chronic diseases [29]. However, participants found this regimen more difficult to adhere than MICT so it was not used routinely. The MICT and high-intensity interval training protocols can be described as dedicated training regimens because they have controlled exercise intensity and limited bout durations.

Nevertheless, there are real-life situations when dedicated training bouts are not feasible on a regular basis due to poor participant health or other circumstances. Consequently, we have tested an alternative exercise protocol where leg training was secondary to the sedentary activity of participant such as viewing TV. This exercise regimen can be described as opportunistic as it does not have a specified training intensity and duration. Arrows 8 and 9 indicate the leg work output of participants working with computer at the desk or lying in bed while watching TV. These recordings show that opportunistic exercise sessions had variable leg work output and overall lower training intensity than in dedicated exercise bouts. Typically, they also included breaks, but allowed prolonged leg mobilization averaging at 73.7 minutes (SD 29.7) without committing extra time to dedicated training activities. According to the participants, concurrent training reduced boredom of otherwise monotonous exercising.

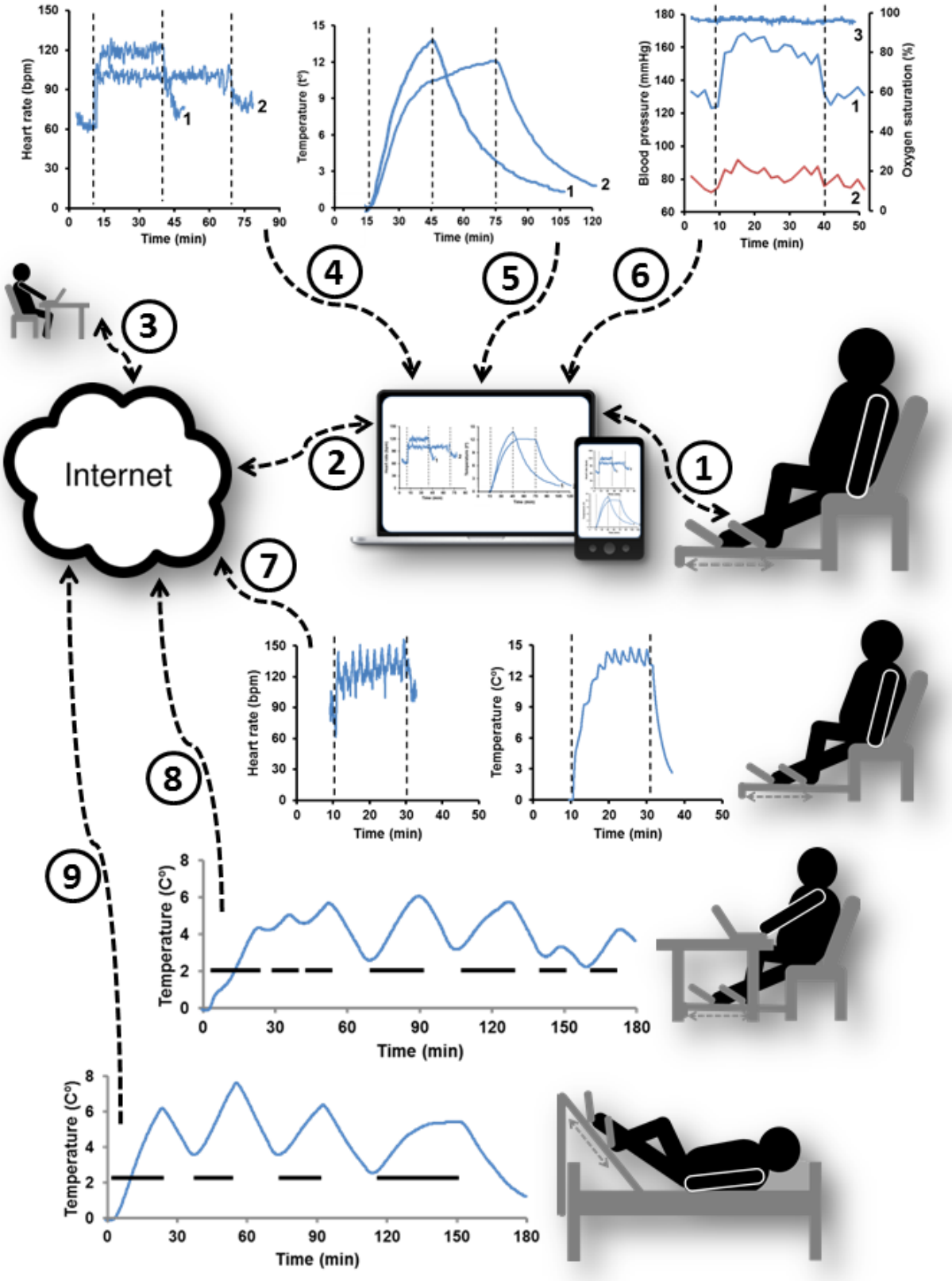
Personalization and Automation of Exercise Doses

Figure 3 explains the method of personalizing MICT doses and automated notification of compliance. The dose of daily exercise was based on the current guideline of *moderate-intensity aerobic (endurance) physical activity for a minimum of 30 minutes on 5 days each week* [6,20]. It was proposed that $\Delta t°$ achieved by MICT in 30 minutes would indicate a participant's personalized dose of exercise to be taken on a daily basis. The curves at a top row demonstrate that $\Delta t°$ values produced by participants in 30-minute MICT bouts ranged from 4.5 to 10.5°C averaging 7.8°C (SD 1.6). These values were used as the numerical expression of personalized exercise doses as exemplified by digital interface. For example, horizontal dashed lines define a half (arrow) and the full dose of 10.5°C at the top curve so that a number 5.25°C indicates 50% of the dose. Reaching a target of 10.5°C signified taking a full personalized dose of MICT.

The participant was instructed to reach the MICT dose of 10.5°C on a daily basis. A middle curve at Figure 3 exemplifies weekly $\Delta t°$ recording, where each peak represents one training bout such as at the top row, but on the scale of 1 week. Once the dose of 10.5°C was achieved (dashed line), an automatic notification will be sent by email. Each message was counted as ticks on the digital interface, which demonstrates that during this week MICT doses were taken on Days 1, 3, 4, 5, and 7. Because the doses were taken on 5 days during the week, the participant was considered to have matched the recommended volume of weekly exercise [20]. A bottom row at Figure 3 shows the overall data flow allowing assessment of compliance using cloud-based software. The digital interface exemplifies that 2 participants took daily exercise doses on 5 days and one on 6 days during the week. Therefore, all 3 participants met the recommended weekly exercise doses [20].

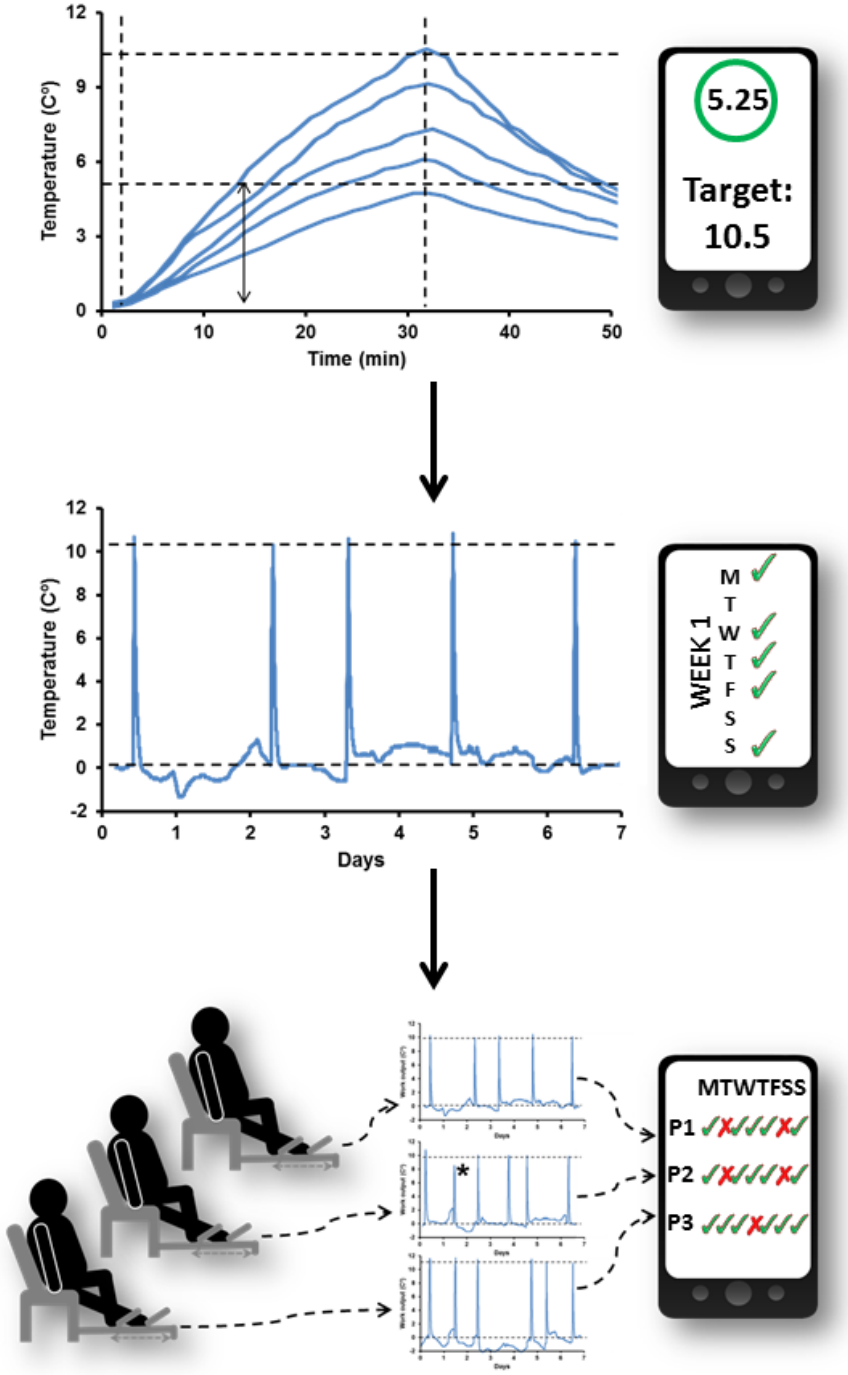
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Figure 2. Typical settings and data recorded during this study, where arrows indicate: (1) wireless data transfer between the participant and electronic device; (2) connection to the Internet; (3) remote access by supervisor; parallel (4) HR and (5) Δt° recordings during exercise at vigorous and moderate intensities indicated by curves 1 and 2, respectively; (6) changes in systolic and diastolic blood pressure, and blood oxygen saturation during MICT, curves 1-3 respectively; (7) changes in HR and Δt° during high intensity interval training; changes of Δt° during (8) under-desk and (9) in-bed training. Dashes show periods of active training.



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Figure 3. Personalization and automation of MICT doses, showing: (top row) variability of Δ*t*° produced at the same HR of 100±10 bpm and numeric expression of the MICT dose; (middle row) continuous Δ*t*° recording for 1 week and a corresponding digital interface, marking compliant days by ticks; (bottom row) data flow during this study from the home-based training systems to supervisor's interface, reflecting daily adherence to the personalized MICT doses of multiple participant as ticks and crosses.



The individual Δ*t*° averaged 7.8°C (SD 1.6) was prescribed to all participants as daily MICT doses and set as the threshold for email alerts. Exercise devices integrated with personal electronic devices were provided for training at home for 1 week. Every time Δ*t*° reached the individual threshold, automatic notifications were sent to the participants and supervisor to notify about taking the MICT dose. Overall, the automatic notifications were received on 4.4 days per week (SD 1.8). Retrospective analysis of Δ*t*° recordings allowed detection of uncompleted MICT bouts, as marked by the asterisk at the middle curve of the bottom row. Previously, we demonstrated that weekly training patterns could vary and poor adherence prompted intervention by supervisor over the phone [25].

Discussion

Principal Findings

In this work, we demonstrated the feasibility of delivering several exercise regimens on-site using an innovative training setup that provided the participants with integrated digital and

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physical interfaces. A standard mobile device such as a laptop was used as the user interface for monitoring of self-control training, whereas a portable leg rehabilitation system served as the physical interface providing means of resistance training [24]. Because data from the exercise device were inputted in real time, it operated in the capacity of a peripheral appliance to the mobile device at hand. Connection to the Internet and application of cloud-based software enabled online networking and remote monitoring of participants' training. Future development of this system might include its integration with patient portals and activity-centered gamified apps [30].

MICT regimens such as bouts of running or cycling are commonly used in CR [6]. An advantage of the MICT mode is measurability of exercise volumes using metabolic equivalents of various physical activities as a function of time [31]. In this work, we proposed a new method for exercise quantification by measuring $\Delta t°$ in the training device. Because $\Delta t°$ correlated with exercise intensity and duration, it was proportional to the energy expenditure of the user. Therefore, $\Delta t°$ produced by MICT in 30 minutes could reflect the recommended amount of daily energy expenditure [6,20]. The numerical nature of $\Delta t°$ allowed expression of daily exercise volumes as single numbers, making it similar to the doses of drugs to be taken daily. The terminology of exercise "dose" and "dose taking" used in this study was analogous to previously proposed expressions such as exercise "pill" and "pill taking" [2,6].

Implications for CR

The feasibility of different training regimens suggests self-sufficiency of compact and inexpensive MedExercise systems, which might allow exercise intervention without taking the patient away from the point of care (Figure 1). By contrast, the current model of CR is limited to specialized gyms because fitness machines such as treadmills and cycle ergometers are too heavy, bulky, and costly for use on-site. For example, a Motomed cycling machine, which is modified for use at the point of care, was found useable [32], but sophisticated mechanics makes it too expensive for widespread applications in CR. Motomed also lacks the networkability for remote management. Facilitating on-site training might be useful to mitigate barriers to sustained delivery of CR such as the need for daily transportation and face-to-face training of weak sedentary patients [2].

The variability of feasible exercise regimens demonstrated in this study allows customization of on-site exercise programs to provide patient-centered intervention. Depending on the level of fitness and other circumstances, patients could be offered training regimens ranging from intensive exercise bouts for relatively fit participants to extensive opportunistic training in bedridden patients. There might be many categories of patients to benefit from on-site CR, including critically ill patients, in which early leg mobilization can improve outcomes [33]. Nonclinical uses of on-site exercising include contemporary workplaces, where there is a high potential for increasing energy expenditure in sedentary workers [34]. Reduced boredom of concurrent exercise may help to improve sustainability of CR.

A single-number exercise dose introduced in this study allowed automation of compliance reporting using the digital threshold settings. This approach can simplify the long-term compliance monitoring, because a "good" adherence could be easily quantified as taking 5 or more daily MICT doses per week. Noncompliance became obvious as less than 5 alerts received in a week [6,20]. Cloud-based software can serve as a Web-based platform for health care providers, useful for controlling CR in the participant network, including remote patients at the point of care. Web-based management is likely to reduce the financial cost of services by eliminating geographical barriers and reducing labor intensity of CR per patient [8].

Limitations

The limitations of this study include participation of only a small number of healthy volunteers and relatively short duration of intervention, which was due to the innovative nature of the technology and focus on testing new training protocols before offering them for the clinical trials. Therefore, this work should be considered as a pilot study, validating the technical feasibility of innovative technology. The encouraging results of this study warrant further research to establish the efficacy, effectiveness, and feasibility of this approach in patients with chronic diseases and other medical conditions preventable and treatable by regular exercise training.

Acknowledgments

A part of this work has been presented at the "Be Active" Conference of Sports Medicine Australia, October 15-18, 2014, Canberra, Australia.

Conflicts of Interest

Dr Vadim Dedov has a stake in MDXD Pty Ltd, which designed and produced training equipment used in this study.

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Abbreviations

BPM: beats per minute
CR: cardiac rehabilitation
HR: heart rate
MICT: moderate-intensity continuous training

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Original Paper

Mobile Jump Assessment (mJump): A Descriptive and Inferential Study

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Abstract

Background: Vertical jump tests are used in athletics and rehabilitation to measure physical performance in people of different age ranges and fitness. Jumping ability can be analyzed through different variables, and the most commonly used are fly time and jump height. They can be obtained by a variety of measuring devices, but most are limited to laboratory use only. The current generation of smartphones contains inertial sensors that are able to record kinematic variables for human motion analysis, since they are tools for easy access and portability for clinical use.

Objective: The aim of this study was to describe and analyze the kinematics characteristics using the inertial sensor incorporated in the iPhone 4S, the lower limbs strength through a manual dynamometer, and the jump variables obtained with a contact mat in the squat jump and countermovement jump tests (fly time and jump height) from a cohort of healthy people.

Methods: A cross sectional study was conducted on a population of healthy young adults. Twenty-seven participants performed three trials (n=81 jumps) of squat jump and countermovement jump tests. Acceleration variables were measured through a smartphone's inertial sensor. Additionally, jump variables from a contact mat and lower limbs dynamometry were collected.

Results: In the present study, the kinematic variables derived from acceleration through the inertial sensor of a smartphone iPhone 4S, dynamometry of lower limbs with a handheld dynamometer, and the height and flight time with a contact mat have been described in vertical jump tests from a cohort of young healthy subjects. The development of the execution has been described, examined and identified in a squat jump test and countermovement jump test under acceleration variables that were obtained with the smartphone.

Conclusions: The built-in iPhone 4S inertial sensor is able to measure acceleration variables while performing vertical jump tests for the squat jump and countermovement jump in healthy young adults. The acceleration kinematics variables derived from the smartphone's inertial sensor are higher in the countermovement jump test than the squat jump test.

(JMIR Rehabil Assist Technol 2015;2(2):e7) doi:10.2196/rehab.4120

KEYWORDS

squat jump; countermovement jump; inertial sensor; smartphone

Introduction

In athletics and rehabilitation, functional capacity can be evaluated through different methods; one of them is the vertical jump test. In addition, the vertical jump serves as a predictor of anaerobic capacity, motor development and athletic ability in sports [1-7]. Other studies report that the vertical jump test seems to be an indicator for assessing functional capacity in the elderly [8] and children [9]. Vertical jump capacity can be measured by different variables such as vertical take-off speed, flight time, mechanical power or the displacement of the center of body mass [10-13].

Some of the classic measurement tools to calculate these variables are the force platform, video-analysis systems, photoelectric cells and contact mats [10-13]. These methods for vertical jumping measurement have excellent validity for

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laboratory studies. However, these tools are expensive and difficult to transport, creating difficult transferability to other environments or professional applications. Furthermore, in recent years new technologies have begun to be used for human motion studies, such as inertial sensors, which are small and portable, and provide solutions to the drawbacks of other commonly used instruments for human motion analysis [14]. In some studies, accelerometric systems have been used to estimate vertical jump capacity [15-19]; these are based on the use of acceleration peak values recorded in the performance of vertical jumps.

Currently, the latest mobile phone generation usually includes inertial sensors with subunits such as accelerometers and gyroscopes that can detect acceleration and the inclination of devices. Numerous apps that display, store and transfer inertial sensor data have been developed for the operation of different mobile phones. These apps have great potential for tracking human motion parameters for research and clinical practice. Apps are being developed for use in different situations related to human movement, such as the pedometer [20], or the development of an assessment tool and quantification of kinematic variables related to the fragility of the elderly [21]. The wide availability of mobile phones, due to the variety of use in the daily lives of most people in developed countries, as well as their small size and portability, make them very useful tools for field study development and subsequent use in professional practice [14].

Because of the advantages offered by mobile phones as tools for the study and analysis of human movement, it is of interest to check their ability to assess and analysis vertical jump tests. The aim of this study was to describe and analyze kinematics characteristics using the inertial sensor incorporated in the iPhone 4S, lower limb strength through a manual dynamometer, and the jump variables obtained with a contact mat in the squat jump (SJ) and countermovement jump (CMJ) tests from a cohort of healthy people. The squat jump (SJ) is defined as a jump that is performed from a squatting position. A counter movement jump (CMJ), which is higher, is a jump where the jumper starts from an upright standing position, makes a preliminary downward movement by flexing at the knees and hips, then immediately jumps up from that position.

Methods

Design and Participants

This was a cross-sectional study, involving 81 jumps from 27 participants. The participants were young Health Sciences students from the University of Málaga (Spain). Participants had to meet the inclusion criteria of being healthy adults aged 18 to 35 years, without musculoskeletal or neurological dysfunction. Subjects with any of the following criteria were excluded: a history of heart disease, surgical interventions in the last year, any disability that would make the correct achievement of the tests difficult, any pain that prevented the completion of tests or neuromuscular pathology that could be aggravated by participating in the study. A physical therapist evaluated the volunteers for the presence of exclusion criteria. Table 1 shows the characteristics of the sample.

The study complied with the principles laid out in the Declaration of Helsinki. The ethics committee of the Faculty of Health Sciences at the University of Malaga, Spain, approved the study.

Table 1. Characteristics of sample (N=81 jumps).

Characteristic	Mean (SD)
Age (years)	24.30 (3.90)
Height (cm)	173.59 (9.74)
Weight (kg)	72.58 (13.01)
Body mass index (kg/m^2)	23.95 (2.96)

Data Collection and Procedures

Overview

Study subjects performed three trials of the jump tests described by Bosco [22]: SJ and CMJ (with arm swing modality). The SJ is a maximum vertical jump starting from the position of leg flexion 90°, with no rebound or counter movement and with hands on hips from the beginning to the end of the jump. The CMJ is performed starting from a standing position, then a quick movement of flexion and extension of the knees, and an immediate maximum vertical jump [22]. Before the start of the vertical jump tests, participants performed a warm-up on a cycle ergometer for 10 minutes. After the warm-up period, each subject was instructed in the proper way to perform each test. Before starting the test, a trial test was performed to verify that the participant had understood the instructions. Between every jump a rest period of 1 minute was set.

Anthropometry

Anthropometric data were obtained following the guidelines of The International Society for the Advancement of Kinanthropometry (ISAK) [23]. The weight was recorded with the subject barefoot and in underwear. The height is the distance from the vertex to the soles of the feet. It is measured with the subject standing in anatomical position and the occipital region, back, gluteal region and heels in contact with the height rod. The subject takes a deep breath at the time of measurement. The body mass index (BMI) was calculated by dividing weight in kilograms (kg) by height in meters squared (m^2).

Kinematics Variables

Linear acceleration was measured along three orthogonal axes using the iPhone 4S inertial sensor, which incorporates a three-axis gyroscope, accelerometer and magnetometer. The mobile phone was attached to a belt and fixed at L5-S1 level.

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Data were obtained for analysis through SensorLog, available as an Apple iPhone app. The recording rate was set at 30 milliseconds. The recordings were stored in the internal memory of the mobile phone and were then sent via email for off-line processing. A previous study [24] showed that the mobile phone (iPhone) accelerometer was accurate and precise compared to a gold standard, with an intra-class correlation coefficient (r^2>0.98). The mobile phone accelerometer showed excellent sequential increases with increased walking velocity and energy expenditure (r^2>0.9). An accelerometer embedded into a mobile phone was accurate and reliable in measuring and quantifying physical activity in the laboratory setting [24].

Jump Measuring

The height and flight time were evaluated through the contact mat Globus Ergojump Thesys in CMJ with arm swing and SJ tests. The Globus Ergojump contact mat was validated in a prior study [12].

The CMJ test is performed with the subject starting from a standing position on the contact mat. A quick flexion and extension of the knee joint with minimal stops between eccentric and concentric phases is performed. The participant can swing his arms to propel himself. The legs should be kept in extension from take-off to landing. In a specific study to determine the reliability of different countermovement tests, an intraclass correlation coefficient (ICC) of 0.88 for the CMJ was determined [25].

For the SJ test, the participant is placed from the vertical position with hands on hips and with knees in flexion position of 90 degrees. Following the indication of the examiner, the subject performs a boost without any countermovement trying to achieve the maximum height in a vertical jump keeping the lower limbs in extension after take-off to landing [12].

The contact mat records flight time in seconds and the height reached in centimeters. Three repetitions of each test were conducted with more than one-minute rest between each.

Maximum Isotonic Strength of the Knee Extensors

Isotonic muscle strength of the knee extensors was evaluated by bilateral dynamometry through the digital manual dynamometer POWERTRACK (JtechMedical). This tool incorporates a load cell affixed to the distal end of the leg of the subject. The dynamometer has a digital display that shows the force applied to the load cell in Newtons and records the peak in each attempt. The validity of this dynamometer has been demonstrated, with an ICCs ranging from 0.72 to 0.85 [26].

The participant is placed in a sitting position on a stretcher, his hands resting on his legs and feet hanging off the ground. The examiner places one hand to stabilize the subject's leg and the other hand to support the load cell on the subject's distal third tibia. Starting from 90° knee flexion, the subject performs a knee extension resisted by the examiner with the load cell. A full extension must be avoided, with the knee flexion reaching 5°. The maximum peak force is recorded in the digital dynamometer. The test was performed three times for each subject, with a 2-minute break between tests; the highest value was taken.

Data Processing

An off-line analysis was guided to obtain kinematic information from the accelerometer for each subject, in each trial, in the SJ and CMJ test. In this study, the mean and standard deviation was obtained from the maximum peak and minimum peak of accelerations in the three axes of movements (x, y and z). Furthermore, the mean and standard deviation from maximum peak and minimum peak from the resultant vector (RV) accelerations [$RV = \sqrt{(x^2 + y^2 + z^2)}$] was obtained.

Statistical Analysis

To analyze the results, a database was created from the information gathered from the participants, the inertial sensor variables, the jump test variables and maximum isotonic strength of the knee extensors variables. The Kolmogorov-Smirnov test was used as determined by the variables normality of distribution. Descriptive statistics were performed with measures of central tendency and dispersion of the variables studied. Analysis was performed with SPSS Version 20.0 (SPSS Inc, Chicago, IL, USA).

Results

The Kolmogorov-Smirnov demonstrated that the distribution of the sample by gender was non-normal. Table 2 summarizes the acceleration-based measures, the jump test measures and maximum isotonic strength of the knee extensors measures in the SJ and CMJ jump test.

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Table 2. Acceleration-based, jump test values and maximum isotonic strength in the SJ and CMJ (N=81 jumps).

		Mean(SD)
Accelerometer SJ		
	Max acc X (m/s^2)	0.585 (.449)
	Min acc X (m/s^2)	-0.549 (.436)
	Max acc Y (m/s^2)	1.851 (.629)
	Min acc Y (m/s^2)	-0.087 (.239)
	Max acc Z (m/s^2)	0.844 (.493)
	Min acc Z (m/s^2)	-1.211 (.567)
	Max acc RV (m/s^2)	2.202 (.679)
	Min acc RV (m/s^2)	0.005 (.003)
Accelerometer CMJ		
	Max acc X (m/s^2)	0.819 (.5385)
	Min acc X (m/s^2)	-0.792 (.501)
	Max acc Y (m/s^2)	2.036 (.645)
	Min acc Y (m/s^2)	-1.158 (.076)
	Max acc Z (m/s^2)	1.046 (.549)
	Min acc Z (m/s^2)	-1.489 (.446)
	Max acc RV (m/s^2)	2.472 (.631)
	Min acc RV (m/s^2)	0.004 (.002)
Jump Test Mat		
	Jump height SJ (m)	0.223 (.076)
	Jump time SJ (s)	0.419 (.077)
	Jump height CMJ (m)	0.329 (.099)
	Jump time CMJ (s)	0.511 (.088)
Dynamometry		
	Right dynamometry (N)	251.92 (53.029)
	Left dynamometry (N)	234.96 (45.846)

Discussion

Principal Results

In the present study the kinematic variables derived from acceleration through the inertial sensor of an iPhone 4S, dynamometry of lower limbs with a handheld dynamometer, and the height and flight time with a contact mat were described in vertical jump tests from a cohort of young healthy subjects, aged between 18 and 35 years. The development of the execution in SJ and CMJ vertical jump tests is described, examined and identified under acceleration variables obtained with the mobile phone.

Comparison With Prior Work

To the best of our knowledge, and according to the literature reviewed so far, the present study is the first to describe and analyze the kinematic variables in vertical jump tests with the use of a mobile phone as the main instrument.

Previous studies have been found in literature that may be relevant to the present study, in which vertical jump tests were evaluated through inertial sensors [15-19,27,28]. However, none of them has instrumentalized jump tests with a mobile phone's inertial sensor. Furthermore, most of these studies have focused on searching algorithms to identify jump height [15], and developing validations of accelerometers as vertical jump evaluators [16-19,27], rather than on the kinematic description of the jump tests through accelerometry variables. Only one of these studies [28] describes the accelerometic characteristics and analyses the acceleration curves during an SJ. However, acceleration features of SJ were not compared with any other type of jump test. On the other hand, the instrumentalization used was a uniaxial accelerometer and not a mobile phone's

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triaxial accelerometer. The mobile phone's triaxial accelerometer offers the advantage of getting variables of the three axes of motion (*x*, *y* and *z*), while the uniaxial accelerometer gives us variables of only one axis of movement. In addition, today, most mobile phones contain triaxial accelerometers, which are very accessible to most people, and the acquisition of another tool to analyze human motion through acceleration values would not be necessary using a mobile phone.

From accelerometry data obtained through the mobile phone, differences in values of minimum and maximum acceleration were identified between the two types of jump tests SJ and CMJ (see Table 2). Higher values of acceleration in the different axes of movement (*x*, *y* and *z*) in CMJ with respect to the SJ, may be explained by the countermovement produced in CMJ test causes greater movement synergies involving higher acceleration [29]. It can also be observed in the jump variables measured by the contact mat; higher mean values of jump height and jump time in the CMJ regarding SJ are shown (see Table 2).

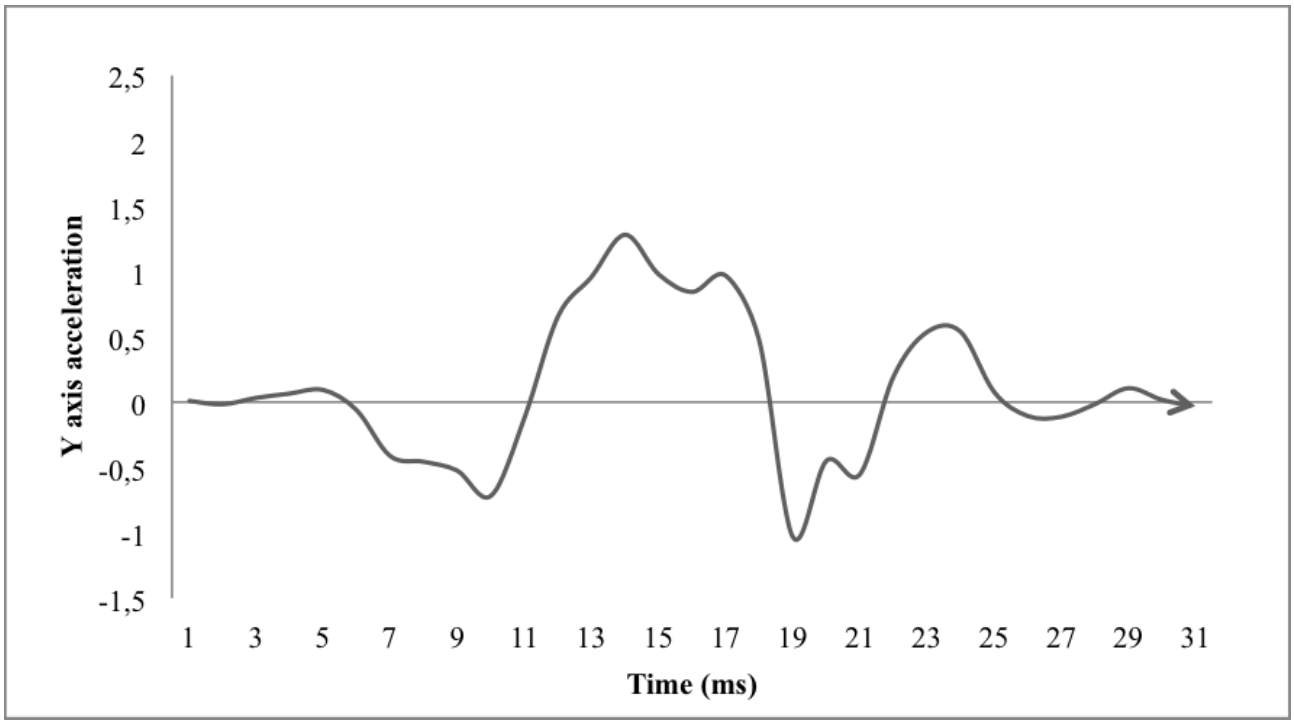
Specifically, the higher maximum acceleration values in the y-axis found in the CMJ are explained by the jump modality, as the countermovement allowed in it facilitates greater vertical impulse [29]. Furthermore, the fact that greater height is reached more easily at CMJ causes greater deceleration after the transition between the maximum peak height and landing; this results in higher minimum acceleration values along the y-axis with a remarkable difference between CMJ and SJ tests—the acceleration difference is the greatest between the two jumps. These perceived differences are consistent with the higher heights and flight times recorded by the contact mat from CMJ test and the known differences between CMJ and SJ tests [29]. Moreover, when analyzing the graphs of acceleration of SJ performed in this study, it has been observed that in the development of this type of jump, a negative acceleration on the y-axis (see Figure 1 and 2) is a common occurrence prior to the start of the upward positive acceleration curve that corresponds to the beginning of the upward thrust. Because the SJ technique must be performed without any countermovement, this could be explained by the possibility that the mobile phone's accelerometer detects small accelerations produced by short, quick countermovements made by the subject, and examiners who determine whether the execution of the jump has been correct, would not be able to detect them with their own eyes.

For acceleration in the z-axis, the differences found may also be explained by the influence of the transition between the eccentric and concentric phases occurring before take-off for CMJ because trunk flexo-extension movements occur, involving higher acceleration values in the z-axis [29].

Regarding the differences in the x-axis acceleration, it is conceivable that lateral displacements by the subject in the execution of both tests can be greater for the CMJ test, also because movement synergies in this jumping technique are implied, and higher flight times are achieved [29].

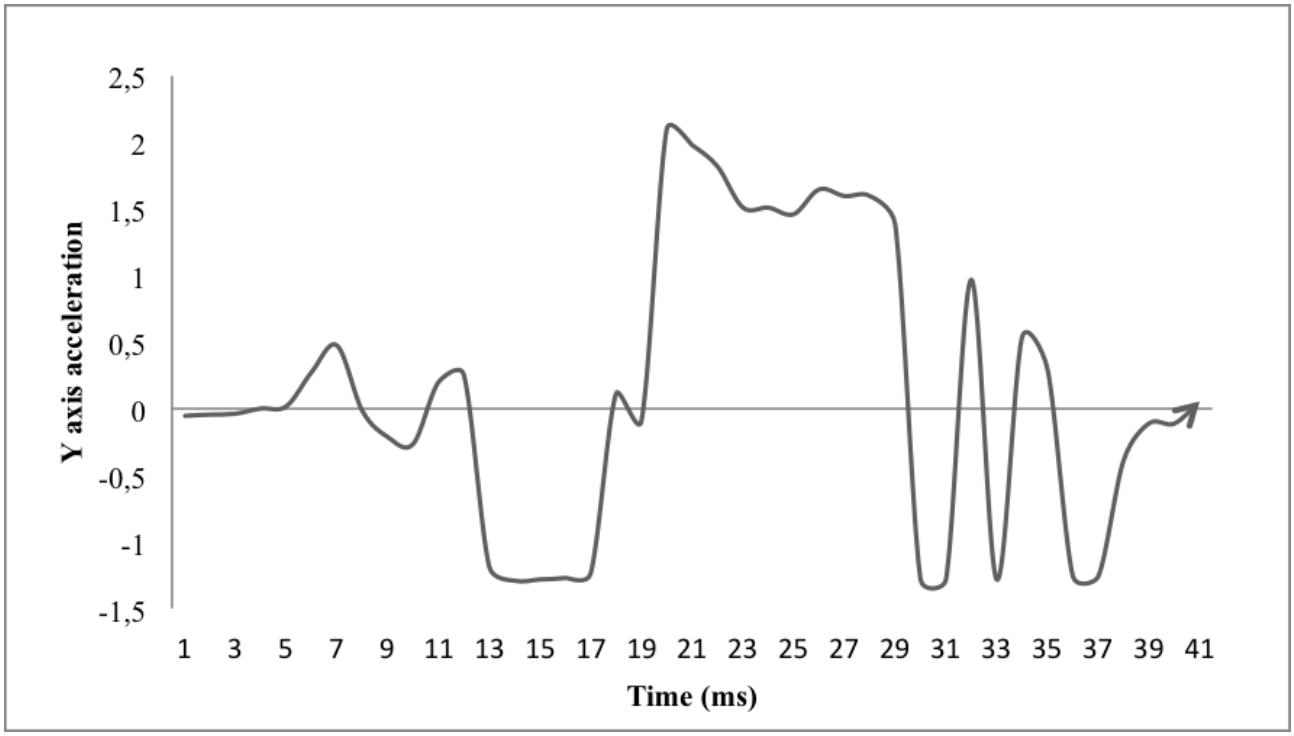
The differences between tests are also maintained for the resultant vector acceleration values, although less so. This can be justified by the integration of the acceleration signals in the different axes of motion to calculate the resulting vector.

Figure 1. SJ Y axis acceleration graphic example.



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Figure 2. CMJ Y axis acceleration graphic example.



Limitations and Future Work

As a limitation in this study, we can mention the fact that there is no separation by gender analysis that would show differences between men and women in performing the jumps [30]. Therefore, future studies with a larger sample to allow a normal distribution of variables, adjusted by gender analysis, could be performed.

As a fortuitous finding, upon visual inspection of the y-axis acceleration graphic in the SJ tests, we observed a previous negative acceleration at the start of the upward curve of positive acceleration. This would be interesting research for future studies to analyze curves and globally analyze the mobile phone discriminating power between correct executions of vertical jump tests without countermovement based on trunk accelerometry.

Conclusions

According to the results obtained in this study, we can conclude that the built-in iPhone 4S inertial sensor is able to measure acceleration variables for vertical jump tests SJ and CMJ in healthy young adults. The acceleration kinematics variables derivate from the mobile phone's inertial sensor are higher in the CMJ test than the SJ test.

Conflicts of Interest

None declared.

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Abbreviations

BMI: body mass index
CMJ: countermovement jump
ICC: intraclass correlation coefficient
ISAK: The International Society for the Advancement of Kinanthropometry
RV: resultant vector
SJ: squat jump

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Original Paper

Disease Profiling for Computerized Peer Support of Ménière's Disease

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Abstract

Background: Peer support is an emerging form of person-driven active health care. Chronic conditions such as Ménière's disease (a disorder of the inner ear) need continuing rehabilitation and support that is beyond the scope of routine clinical medical practice. Hence, peer-support programs can be helpful in supplementing some of the rehabilitation aspects.

Objective: The aim of this study was to design a computerized data collection system for the peer support of Menière's disease that is capable in profiling the subject for diagnosis and in assisting with problem solving.

Methods: The expert program comprises several data entries focusing on symptoms, activity limitations, participation restrictions, quality of life, attitude and personality trait, and an evaluation of disease-specific impact. Data was collected from 740 members of the Finnish Ménière's Federation and utilized in the construction and evaluation of the program.

Results: The program verifies the diagnosis of a person by using an expert system, and the inference engine selects 50 cases with matched symptom severity by using a nearest neighbor algorithm. These cases are then used as a reference group to compare with the person's attitude, sense of coherence, and anxiety. The program provides feedback for the person and uses this information to guide the person through the problem-solving process.

Conclusions: This computer-based peer-support program is the first example of an advanced computer-oriented approach using artificial intelligence, both in the profiling of the disease and in profiling the person's complaints for hearing loss, tinnitus, and vertigo.

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KEYWORDS

Ménière's disease; diagnosis; disease profiling; peer-support; participation restriction; activity limitation; enablement; machine learning

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Introduction

Ménière's disease is a disorder of the inner ear that causes spontaneous episodes of vertigo, fluctuating hearing loss, tinnitus, and fullness of the ear [1]. The impact of this complex chronic condition varies greatly from person to person and from time to time, depending on the vertigo attacks experienced [2]. However, generally this condition can result in physical, mental, and social consequences to both the person affected and their significant others [3], causing a poorer health-related quality of life [4]. Even though people with Ménière's disease are subjected to extensive clinical examination (eg, medical, audiological, and psychosocial evaluations), the diagnosis of this condition is often symptom-based.

There are medical therapies available for this condition (eg, medication, surgery). However, there is no permanent cure from medical therapy, and often there is a requirement for lifestyle changes. Hence, there is a great need for an appropriate rehabilitation program for people with the Ménière's disease and their significant others to help them learn various coping strategies to live well with this condition.

Increasing the knowledge of the impact of the disease (eg, life consequences in terms of activity limitations and participation restrictions) may be an important first step in rehabilitation. This may assist in attitude change, the acceptance of the condition, and lifestyle modification. Moreover, when dealing with chronic conditions, it has been recognized that "social participation," in addition to clinical and medical management, may bring many advantages in terms of improving the adherence and compliance to therapy, as well as improving coping with the condition, thereby resulting in better health outcomes. For example, a recent study in multiple sclerosis suggested that social participation was significantly associated with health-related quality of life [5]. Hence, we suggest that social participation should be an important intervention component of chronic conditions such as Ménière's disease.

Peer support is a salient concept in health care, which considers the patient's social relationship and social participation as important components. Peer support is defined as the "system of giving and receiving help founded on key principles of respect, shared responsibility, and mutual agreement of what is helpful" [6]. Moreover, "peer support has been defined by the fact that people who have like experiences can better relate and can consequently offer more authentic empathy and validation" [7]. Various forms of peer support exist in health care (ie, person-to-person support, telephone calls, and Internet-based support), and these have become more important in recent years as medical developments and medical technology have provided the increasing challenges of disease with alternative treatment possibilities [8-10]. Furthermore, the outcome of modern health care is increasingly focused on the improvement of the quality of life, and people's expectations have subsequently increased [11]. Therefore, the expectations of treatment have been that the therapy will lead to a complete healing of the conditions and will provide a normal state of health [12]. However, complete healing of the condition seldom occurs in chronic diseases like Ménière's disease. The modern approach to improvement emphasizes that in the life of all human beings, social participation is vital. This goal-directed behavior is one of the core constructs. Needless to say, medical therapy seldom achieves these goals whereas peer support commonly focuses on such items. Thus, in peer support the regaining of function is an active process, in that the person should work toward solving their problems.

Peer-support programs give patients an opportunity to actively participate in their own rehabilitation. However, it is important to recognize that peer support is important in all levels of health care delivery, not just in rehabilitation [13]. Person-to-person peer support is based on voluntary activity and is usually constrained by the limited numbers of volunteers. Recently, computerized peer-support programs have been introduced, especially in behavioral disorders [14]. So far, for inner-ear diseases there are a limited number of Internet-based peer-support systems available. One such example is a system developed in Sweden that is aimed at the alleviation of tinnitus and comprises 6 sessions [15]. Most of these sessions entail teaching relaxation techniques and how to avoid the adverse effects of tinnitus with sound therapy. The computer has several advantages: it is anonymous for the supported person, is indefatigable, and can serve hundreds—and even thousands—of people at the same time. Guidance can be tailored to the level of best expertise. And the program can be repeated, restarted, and continued as needed. However, these programs are usually Internet-based implementations, and the interface lacks the capability to profile the person's complaints and personal needs. Nevertheless, the tinnitus program and programs developed for behavioral disorders demonstrate that a computer-based peer-support system is both realistic and acceptable and provides results as good as a form of person-to-person peer-support [14,15].

Methods

Overview

Disease profiling is the first important step in dealing with any chronic condition. Disease profiling should not only consist of medical diagnosis, but should also focus on understanding the impact of the condition on wider life activities. This information is important in planning the management of the disease, especially in tailoring the rehabilitation to meet the needs of the specific individuals. In conditions such as Ménière's disease where it is a common practice to diagnose based on symptoms, an advanced computer-based system can be applied in disease profiling. Such an approach can be extremely beneficial in self-directed Internet-based and/or computer-based peer-support programs.

The aim of the present study is to develop an intelligent computer-based peer-support system that is capable of assessing Ménière's disease and profiling the impact of the condition. By applying artificial intelligence and knowledge-based systems, computerized peer-support can be tailored to meet individual needs. The program collects data on the participant's Ménière's disease symptoms, activity limitations, participation restrictions, personality traits, moods, and attitudes. It then classifies these in terms of the problems experienced from the disease on a

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personal level using the International Classification of Functioning, Disability, and Health (ICF) [16]. The program runs interactively and the patient's profile ultimately controls the program flow so that the computerized peer-support is tailored for individual needs.

Data Collection

Permission was obtained from the Finnish Ménière's Federation (FMF; Suomen Meniere-Liitto Ry) to contact their members, asking them to complete an extensive questionnaire on symptoms related to Ménière's disease. Under Finnish law, this kind of survey study conducted within a patient support organization does not need ethical approval. The sample comprised 1200 individuals. They were sent a 26-page questionnaire by mail, together with a stamped addressed envelope for the return of their responses. These questionnaires have previously been used in our studies on Ménière's disease [17-19]. A total of 781 candidates returned the questionnaire (65% response rate). Of these, 571 were female and 210 were male, and 740 of the questionnaires were adequately completed. The mean age of respondents was 62.3 years (SD 11.5 years), and their Ménière's disease-specific symptoms had lasted an average of 16.2 years (SD 11.2 years).

All of the questionnaires were administered in Finnish. The questionnaires comprised both disease-specific and impact-related questions. An otoneurology questionnaire [20] with 86 questions was used to evaluate the characteristics of the otologic disease. A EuroQol EQ-5D tool was used to study the general health-related quality of life [21]. The EuroQol EQ-5D tool has a test-retest reliability of 0.66 and has validity in relation to other generic health-related quality of life measures such as the 36-item Short Form Health Survey (SF-36) [22]. A short version of the sense of coherence (SOC) questionnaire [23] was used to evaluate personality traits. The short SOC scale internal consistency ranges from 0.74 to 0.91, and has a test-retest reliability of 0.54 [23]. A short form of the post-traumatic growth inventory (PTGI-SF) [24] was used to assess improvements caused by the program. The PTGI-SF has a reliability of 0.90 and is very close to the reliability of the full version of the PTGI [24]. Activity limitations were evaluated using the international tinnitus inventory (ITI) [25] with 8 questions, and the hearing disability and handicap scale (HDHS) [26] with 10 questions. The internal consistency of the ITI ranged from 0.87 to 0.91 [25] and HDHS ranged from 0.81 to 0.89 [27]. Sound localization was evaluated using 4 questions based on the hearing measurement scale (HMS) [28,29]. Dizziness and vertigo were evaluated using the 8 questions about vertigo and dizziness [30,31], with an internal consistency ranging from 0.75 to 0.82. Participation restrictions were evaluated using the Participation Restriction Scale [32], which consisted of 30 questions. Disease-specific impact assessment was done using a mixture of open-ended and closed questions. The questionnaire based on the ICF was used to classify the impact of the disease at the individual level [18]. Anxiety or nervousness was evaluated using a 15D questionnaire, which measures general health-related quality of life, by asking the subject: "Does vertigo, hearing loss, or tinnitus cause you anxiety or nervousness?" [33]. A specific question on vitality was also based on a question presented in the 15D [33]. The 15D scale has been found to have appropriate content and construct validity. The repeatability coefficients of the scale are 92%-100% depending on the dimension, and a high sensitivity is achieved as demonstrated by its discriminatory power [34].

Zaphiris et al have estimated the ideal amount of information to be included in Web pages targeted toward older people [35]. We have followed these guidelines in our program.

Disease Profiling

The complaint history was inputted into the inference engine to assess the diagnosis. In this process, the program uses 2 classes of information: (1) necessary and (2) supportive data. The class of signs depends on the disease so that one sign can be necessary and other supportive. A necessary sign is indicative for Ménière's disease. Supportive signs suggest the condition, but their presence is not obligatory. The program uses a pattern recognition algorithm in classifying the diseases causing vertigo, which has been described in detail elsewhere [36,37]. Based on the outcome of the inference engine, different probability scores are provided. One probability score indicates the outcome when all necessary questions have been answered, and the other when there are missing data resulting in uncertainty. In calculation of the probability values, the person data is compared with the optimal data.

The knowledge base contains extensive descriptors of 14 diseases causing vertigo. In the program, a descriptor defines the mapping between a disease and answers to the questionnaire's symptoms and to medical history questions. For a disease d there are $n(d)$ questions, and a score $S(d)$ for the disease as defined below (Figure 1).

Figure 1. Disease scoring formula.

$$S(d) = \sum_{i=1}^{n(d)} X_i\,(d) P_i(d)$$

In the formula above, the binary variable $X_i(d)$ has the value of 1 if a user has provided an answer i concerning the disease d and otherwise zero. Variable $P_i(d)$ is the significance of the question i for disease d. By this reasoning, we select the diagnosis of disease d where the score $S(d)$ is the highest. A detailed description of disease scoring as well as handling missing data and dealing with the uncertainty of reasoning has been presented in a previous report [38].

System Architecture

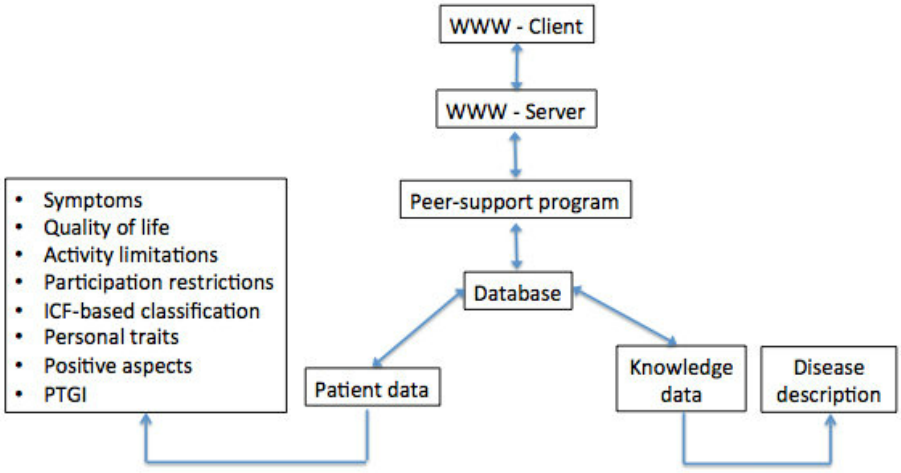
The program's user interface was designed to be simple due to the age group of the potential users. The program presents questions and statements to the user in a thematic series. The user generally sorts text items on the screen with the mouse by dragging and dropping. The program automatically saves the input when the screen changes. Feedback from the computer takes the form of either pure text or graphical presentations.

The peer-support program has been written in PHP-language. It uses a MySQL-database that stores the person data and knowledge data required for verifying the person's diagnosis.

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The program generates interactive www-pages with the help of the Apache www-server. Finally, the server sends the pages to the person's www-client program. The input from the individual is directed to the peer-support program using xhtml forms. The high-level system architecture is presented in the middle of Figure 2.

Figure 2. System architecture and data description of the peer-support program. (Note: Questionnaire data is stored in the person-data database and disease descriptors are stored in the knowledge database. The table in the left shows the questionnaires used. The disease descriptors on the right side include the inference engine.).



Entry Criteria

Entry Criteria Based On the American Academy of Otolaryngology-Head and Neck Surgery (AAO-HNS) Criteria

Candidates belonging to the FMF were classified based on the AAO-HNS criteria for Ménière's disease. The criteria show either definite or probable Ménière's disease (Table 1). Thus, if the criteria were probable of Ménière's disease, 35 people with possible Ménière's disease would be excluded.

Table 1. Exclusion and inclusion criteria and their relationship between AAO-HNS-based symptom classifications.

Criteria	Limit	Accepted	Rejected	Missing data
AAO-HNS criteria	Probable or definite	694	35	11
ONE-program	Diagnostic criteria	706	19	15
EQ-5D	VAS score <95%	709	26	5
Disease-specific impact	Impact >0	692	28	20

Entry Criteria Based On the ONE-Program Criteria

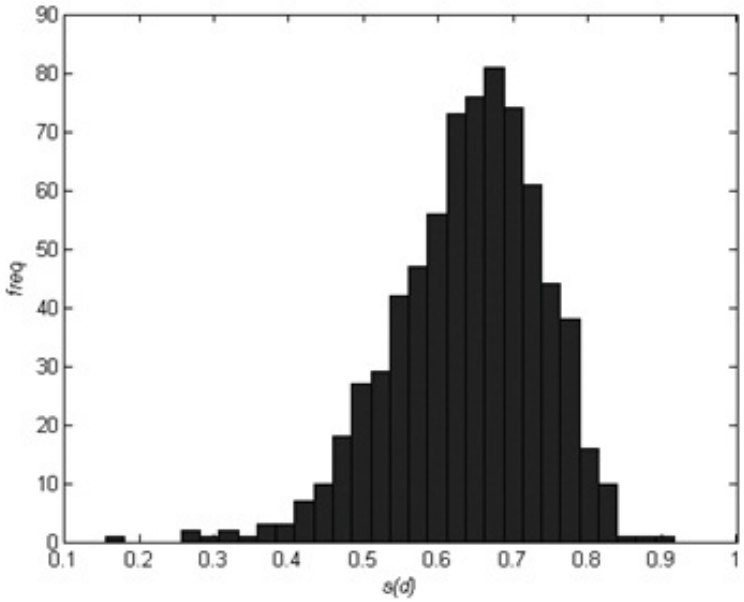
The algorithm of the inference engine compares the diagnostic criteria and symptoms between 14 different conditions and provides fitness scores for each condition. The program suggests the condition with the highest score as the principal diagnosis and provides as diagnostic alternatives the second and third possibilities if their scores exceed a probability of 0.5. Out of the 740 cases, the program accepted 706 as Ménière's disease and 19 cases were rejected. In all cases, however, Ménière's disease was the most likely diagnosis. The rejection was done on the basis of the score *S(d)* mentioned above. If the score *S(d)* was more than 0.43, the person was allowed to attend the program. In Table 2, variables are presented where the differences in mean values were statistically significant in variance analysis at a risk level of $P<.001$ between the groups, where *S(d)* was either less than or over 0.43. A histogram of *S(d)* scores is presented in Figure 3.

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Table 2. Statistically different variables in candidates excluded and included in the computerized peer-support program. (Note: The values belong to the interval [0 x], where 0 means no problem and x means significant problems. Depending on the question, x can have values from 3 to 5.)

Variable	Mean *S(d)*<0.43, excluded	Mean *S(d)*>0.43, included
Age, y	72	62
Frequency of vertigo	0.57	1.96
Duration of vertigo attacks	0.90	2.85
Severity of vertigo	1.0	3.46
Vomiting	0.43	2.22
Balance	2.22	1.31
Severity of unsteadiness	1.67	1.04
Moving ability	1.10	0.48
Raising up from a chair	0.90	0.46

Figure 3. Histogram of program criteria values S(d).



Entry Criteria Based On Quality of Life and Impact of the Disease

In order to enter the peer-support program, the condition should have an impact on the person. In the quality of life measurement, if the visual analogue scale (VAS) score is 95% or less, the person can access the peer-support program. With VAS scores greater than 95%, the person would not benefit from the intervention but will still be able to access the information package. With the data from the pilot group, all candidates had Ménière's disease but their *S(d)* scores varied between 0.15 and 0.92 while the maximum value was 1. The higher the score, the better the match to Ménière's disease. However, low *S(d)* values might indicate that the person can benefit more from another form of rehabilitation. For instance, a personally tailored and conducted physical training regime could be an appropriate choice. Candidates with an *S(d)* value that's less than 0.43 are older and their vertigo characteristics are less severe than those with an *S(d)* that's more than 0.43. The reasoning for a certain threshold is difficult, but in this work we determined the threshold value statistically. By using two standard deviations we cut the left "tail" of the low-end distribution (Figure 3). This excludes 2.6% of candidates from the peer-support program. On the basis of Table 2, these candidates are also seen to have less severe symptoms than the others.

Results

Overview

Based on these criteria, 26 of the 740 cases were excluded from the program. The impact of Ménière's disease was evaluated by the question: "How much does your Ménière's disease affect your life?" With 28 participants, there was no impact and they were thus rejected from the program.

On the basis of AAO-HNS and ONE-program criterion, 12 candidates were the same. However, when comparing the rejected cases based on ONE-program and EQ-5D, only 1 person was same in both rejection criteria. ONE-program and

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disease-specific impact shared 18 candidates with matching rejection criteria.

All of the rejected candidates were provided with access to person-to-person peer support and given a provider's name and contact details. Table 1 summarizes the entry criteria and number of subjects. When a person is accepted into the program, the human gatekeeper provides access codes by email and the person can start the intervention. The age, vertigo, and balance problem variables of the candidates not accepted to the program and of those who were are shown in Table 2.

Computer Interface in the Questionnaires

In the program, the person is asked to select the severity of his or her activity limitations and participation restrictions. Subsequently they are asked to rate these in such a way that the most severe comes first. The peer-support program then deals with this individual rating of their most problematic limitations and restrictions.

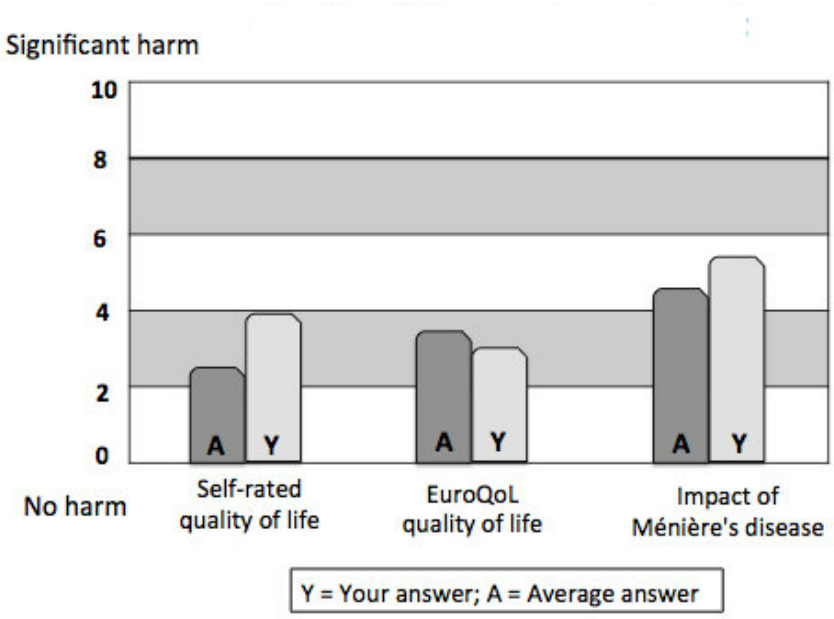
Positive Aspects

An important aspect of the program is to introduce a positive attitude toward disablement. Positive aspects will improve the participant's quality of life [17] and may help the person to move their attention to coping strategies [39]. The peer-support program contains 26 examples of possible positive aspects of the disease, which are based on data collected from 560 people belonging to the FMF who were asked to score each positive aspect on a 4-point scale and then rate them in such way that the most important positive aspect came first.

Feedback on Symptoms When Compared to Average Ménière's Disease

To demonstrate the severity of the person's symptoms compared to other cases, the program provides information on the individual's severity of the symptoms in comparison to the average of replies from all participants. These are presented in a similar manner as the quality of life aspects depicted in Figure 4.

Figure 4. The general health-related quality of life and the disease-specific impact of Ménière's disease compared with 50 matched cases.



Profiling the Person Based on Their Symptoms

The individual profiling based on symptoms was carried out with algorithms using the nearest neighbor classification. This looks for the 50 most similar cases based on symptoms and complaints. The similarity measure is the Euclidean distance between the person profile vectors. In this algorithm, the distance between identical symptom profiles is zero. In order to prevent any component of the profile vector from dominating the distance calculation, all components are divided by their respective maximum values. In order to determine the role of personal trait and attitude, further profiling was used. Both of these individual profiles were related to the General Health Related Quality of Life generic health measure criteria EQ-5D.

In order to have a reasonable number of profiles, participants were profiled on the basis of cardinal symptoms. A person profile is presented in a vector $x=[x_1,\ldots,x_{10}]^T$ where the individual components from the beginning to the end were age, severity of vertigo, intensity of vertigo, frequency of vertigo, severity of walking difficulties, difficulty to attend a conversation, severity of hearing loss, severity of tinnitus, severity of hyperacusis, and severity of the feeling of pressure.

The person profile informs the impact of the condition when related with their personal performance. This information provides feedback on the personal reaction toward the disorder. It informs how personal attitudes, moods, and personality traits modify the suffering from the disorder, and how the person relates him/herself to the context of the illness. Any difference observed will aid the person to realize the difference between problems with their complaints and their consequences in life. In Figure 4, the symptom profile of a patient and the reference group is similar, but the quality of life varies.

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The attitude toward the disease is evaluated by displaying the anxiety and SOC scores, and by comparing the scores from 50 reference cases in a converted Likert scale. According to Stephens et al [40], anxiety was an important factor in explaining a reduced quality of life. This data can be used in the program to analyze the need of attitude change and to instruct the person to develop a positive attitude.

Discussion

Principal Findings

The current paper presents information about the development of an intelligent computer-based peer-support system that is capable of assessing Ménière's disease and profiling the impact of the condition. Disease profiling is an important step in management planning and this information is useful in tailoring rehabilitation to meet the needs of a specific individual. Apart from 1 tinnitus program [15], to our knowledge there are no other peer-support programs that deal with inner-ear functions and related difficulties. The novelty of a computerized peer-support program for Ménière's disease is that it uses artificial intelligence to assess the person's complaints, profile the disease, and define the individual impact of the condition. The program is constructed to allow the person to focus on the individual impairments and compares these with 50 cases with similar complaint profiles. In the further development of the program, the participants will work interactively with their restrictions and empower themselves to adjust to the restrictions. The program is based on real data retrieved from people with Ménière's disease. During development of the program, several disease-specific aspects have been documented [39,41-44]. The validation of the program will be presented in our upcoming publications.

Comparison With Prior and Other Work

Focus on Anxiety and Personal Trait

Several investigations have evaluated the psychological aspects of Ménière's disease [40,45-48]. In general, the authors have focused on mood, anxiety, and personality traits. Söderman et al have indicated that personality traits measured with sense of coherence scale correlated with disability in Ménière's disease [45]. Hägnebo et al evaluated the psychological correlates of vertigo attacks and studied 514 subjects diagnosed with the condition [47]. Principal component analyses showed that the somatic sensation scale could be divided into 2 subscales: (1) dizziness, vertigo, and anxiety, and (2) sensations in the ear. The psychological state scale showed an energy/awareness factor and a negative emotional state factor. The situation characteristics scale showed 2 factors: (1) environmental disturbances and (2) stressful conditions. Thus they considered fatigue as a psychological component of the disability, whereas anxiety was seen as a somatic component. Vitality is a key component in several indices measuring quality of life (eg, 15D, SF-36), as well as in the perception of "wellness" [49].

Levo et al reported that among subjects with Meniere's disease, about 70% of the subjects felt fatigued and in 30% this fatigue was moderate to strong [50]. Fatigue was associated with a reduction in general health-related quality of life and also associated with vertigo attacks, balance problems, and hearing loss. The authors concluded that among consequential factors, mobility and anxiety were the strongest consequences of reduced vitality. Among predisposing factors, a sense of coherence and attitude were significant predictors. Further analysis based on participation restrictions indicated that isolation is a severe consequence of a reduction of vitality. Based on the observations of Levo et al, we made an effort in this peer-support program to bring both fatigue and anxiety into the participants' awareness and by working with the computer program to interactively guide participants to more positively change their attitude to regain social activity [50]. In chronic persistent diseases such as Ménière's disease, it has been suggested that the evaluation and appraisal of stressors and their subsequent management will improve coping with the disease [51]. In chronic Ménière's disease, reduced vitality is a common complaint and, especially in its severe form, it should be recognized and included in any therapeutic procedures that are undertaken.

Ménière's disease is a chronic, progressive disorder that is defined and diagnosed based on the patient's clinical symptoms. However, previous studies have shown no consistent temporal pattern between the perceived levels of stress and any of the core symptoms of the disease [52]. In Ménière's disease, patients without significant vertigo spells or incidents of psychological signs such as depression and anxiety associated with the dizziness handicap are comparable to that of a control group. In addition, individual differences emerge and the time resolution for analyzing the association of stress and the psychological aspects associated with the Ménière's disease may require relatively long-term observation. However, the reciprocal connection between psychological factors and complaint behavior in Ménière's disease is difficult to resolve [46,53], as among people with Ménière's disease, personality trait and anxiety were interrelated [50]. Van Cruissen et al indicated that the psychological profile of Ménière's disease patients seems comparable to patients with other chronic conditions [53]. In their study, Kirby and Yardley indicated that their Ménière's disease group reported more depression and "health anxiety" than the healthy control group, and that "health anxiety" was associated with anxiety and depression [46]. After controlling for the severity of the symptoms, anxiety was associated with several illness perception subscales, including emotional representations, consequences, psychological causes, and the tolerance of uncertainty. Contrary to this, however, Brantberg and Baloh considered fatigue to be a trigger for Ménière's disease [54]. In line with Kirby and Yardley [46] and Levo et al [50], in the computerized peer-support program we consider that the reduction in vitality is a consequence of the condition (in this case vestibular dysfunction) rather than a causative factor. Personality trait has been also been regarded as a modifying factor for the condition [50]. Moreover, the relatively minor role of personality trait in quality of life and disease-specific impact has been previously documented [40,45,46].

An optimistic view of the future results in better adjustment outcomes, since optimists tend to continue with their adaptive coping efforts when confronted by adversity [55]. In Ménière's disease, we observed that a positive attitude improves coping

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with the condition and improves quality of life [17,19]. It is of note that the subjects did not identify any wishful thinking (ie, a miracle improvement) or escape-avoidance coping (ie, trying to forget the disease) that have been otherwise regarded as strong predictors for mal-adjustments in neurological disease [51]. A positive attitude has been associated with lower depression, less anxiety [56], and better physical and social adjustment [57,58]. By bringing up positive aspects in the peer-support program, we aim to improve coping. However, before launching the program to a wider market, the validity and user satisfaction of the program must be certified. For validation we are using changes in the quality of life instrument [21] and in the post-traumatic growth inventory [24].

Computer-Based Peer-Support Programs

Several computerized peer-support programs have been recently launched on the Internet. For instance, programs on diabetes care [59], coping with bulimia [60], bipolar mood disorders, anxiety (eg, Beat the Blues, Cope) [61], phobias and panic (eg, FearFighter) [62], obsessive-compulsive disorder (eg, BT Steps) [61], and tinnitus [15] are now present.

All of these programs use questionnaires and provide instructions to stimulate behavioral changes in order to cope better with the featured condition. The effectiveness of Beat the Blues, Cope, FearFighter, and BT Steps have been considered from a cost/benefit point of view [61]. Computerized treatment can yield savings and provide benefits for patients that are comparable to the therapy provided by physicians [15,61]. The effect of the tinnitus peer-support program for the person was found to be as effective as that of a personal support program [62].

By definition, the expert system is a set of programs that manipulates encoded best knowledge to solve a problem in a specialized domain that normally requires human expertise [35,63]. The program is adaptive and learns during use (ie, a new person's data updates the database). The solutions to problems will converge to the best possible solutions available during the course of the program. If information is not appropriate for the condition, it will not be included in the alternative diagnostic choice.

A symptom-based classification method is recommended by AAO-HNS [64] to make the diagnosis, and this has been used in the present study. Indeed, in a taxonomic investigation of patients with vertigo, after the exclusion of neurological and middle-ear conditions, head trauma, and ototoxicity, Hinchcliffe has found that those with "classical" Ménière's disease (ie, those meeting the "probable" definition based on the AAO-HNS definition) fell into a single nosological entity with all other cases of vertigo [65]. He later argued that Ménière's disease included "formes frustes," where the triad of symptoms is not complete [65]. The AAO-HNS has proposed the currently used classification. It defines "possible Ménière's disease," "probable Ménière's disease," and "definite Ménière's disease." "Certain Ménière's disease" is diagnosed by the symptom entity and histological verification of endolymphatic hydrops in the inner ear. To define the condition clinically, however, the existing AAO-HNS classification is unhelpful [65]. In a recent study, Pyykkö et al used MRI to diagnose endolymphatic hydrops and found that all patients with definite Ménière's disease had endolymphatic hydrops [66]. Patients with probable Ménière's disease had endolymphatic hydrops in 95% of cases. Thus, the current criteria for inclusion of people with definite and probable Ménière's disease into the program seems to be quite accurate, although some cases may be erroneously classified. In a previous study we compared the accuracy of the inference engine and different vertiginous disease diagnoses made by human experts [67]. With the same set of data, the current inference engine correctly diagnosed 65% of the cases, while younger physicians succeeded in 54% and the experienced physician in 65% of the cases [67].

Program Design

User Interface

The selected user interface solutions follow the ideas presented in the work of Hawthorn [68]. Hawthorn stated that most difficulties in the use of a computer originate from a degradation of vision, cognitive ability, and motor control. In our program, the automatic data saving removes the burden from short-term memory, and stationary screens are easy to follow and minimize the need for scrolling, which helps users who may have problems with their motor control.

One major problem is how to construct simple and clear sentences for the questions. In addition, a certain amount of guidance is needed in problematic situations. The program contains help topics and best practices drawn from other participants. If a mouse remains stationary on the questionnaires, a short tooltip shows additional help. This help is available either as a short text or as an example form that shows what the user should do next. The help information docks on the particular page and does not branch the program flow. This prevents the user getting lost in the program. The task in question is always visible on the screen.

Individual Learning

The questionnaires in the program also contain open-ended questions and fields for the person's replies. These replies are stored in the database. The open-ended questions are ultimately used in providing useful self-help items and coping strategies [39,42]. After completing each questionnaire, the person is informed how he/she compares with other persons. The purpose of feedback is 3-fold: (1) it tells the user where he/she stands with their problems when compared to other participants [18]; (2) it enables the progress of the program [35]; and (3) it reinforces learning and motivation [69]. In some self-help programs [15,62], the commitment of users appears to present a problem.

A usual method to reinforce learning is to use forced-choice tasks. By focusing on 3 major problems and ranking them, the program helps the person to focus and identify the major impacts of the disease on his/her life [41,44]. In this decision-making process, the person ranks the impacts and tries to maximize the beneficial outcomes. In the program, these actions are continuously revised by the application of strategies leading to improvement [70]. This type of reinforcement learning leads parsimoniously to improvement as indicated by behavioral and neurophysiological studies in humans [69]. In addition to

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problems classified based on ICF, the program also uses positive experiences to reinforce attitude and personal trait [17,71]. Neurophysiological theories indicate that by reinforcing positive experiences, new synapses are established and the synaptic efficacy is improved. This has a stabilizing effect on the organism, either via improved neural transmission or via targeted synaptic triads [72]. Thus, the use of positive aspects will break down negative reinforcement and allow the nervous system to recover and learn new rules. In this manner, positive aspects work as rewards and allow internal evaluations of covert motor actions without defining them as behaviors [73].

Most often, expert teams build these programs without establishing any solid data collection from individuals. Our computerized peer-support program for Ménière's disease offers a difference, in that it uses an inference engine based on pattern recognition to reveal the accuracy of the diagnosis. It also profiles individual cases with a nearest neighbor classification algorithm and provides peer-support based on real-person oriented data.

Conclusions

We have developed a computerized peer-support program that can verify and assess the diagnosis of Ménière's disease by using a pattern recognition method. The program can function even with partial data. The database is continuously utilized and updated by the program, and uses a knowledge engine to offer solutions to a person's problems. Such a system can be very helpful when assessing and diagnosing chronic conditions that are diagnosed based on symptoms, rather than detailed clinical investigations.

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Conflicts of Interest

None declared.

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Abbreviations

FMF: Finnish Ménière's Federation
HDHS: hearing disability and handicap scale
HMS: hearing measurement scale
ICF: International Classification of Functioning, Disability, and Health
ITI: international tinnitus inventory
PTGI-SF: short form of the post-traumatic growth inventory
SF-36: Short Form Health Survey
SOC: sense of coherence
VAS: visual analogue scale

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