

Usability and Effects of an Exergame-Based Balance Training Program

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Abstract

Background: Post-stroke recovery benefits from structured, intense, challenging, and repetitive therapy. Exergames have emerged as promising to achieve sustained therapy practice and patient motivation. This study assessed the usability and effects of exergames on balance and gait.

Subjects and Methods: Sixteen elderly participants were provided with the study intervention based on five newly developed exergames. The participants were required to attend 36 training sessions; lasting for 20 minutes each. Adherence, attrition and acceptance were assessed together with (1) Berg Balance Scale, (2) 7-m Timed Up and Go, (3) Short Physical Performance Battery, (4) force platform stance tests, and (5) gait analysis.

Results: Thirteen participants completed the study (18.8 percent attrition), without missing a single training session (100 percent adherence). Participants showed high acceptance of the intervention. Only minor adaptations in the program were needed based on the users' feedback. No changes in center of pressure area during quiet stance on both stable and unstable surfaces and no changes of walking parameters were detected. Scores for the Berg Balance Scale ($P=0.007$; $r=0.51$), the 7-m Timed Up and Go ($P=0.002$; $r=0.56$), and the Short Physical Performance Battery ($P=0.013$; $r=0.48$) increased significantly with moderate to large effect sizes.

Conclusion: Participants evaluated the usability of the virtual reality training intervention positively. Results indicate that the intervention improves gait- and balance-related physical performance measures in untrained elderly. The present results warrant a clinical explorative study investigating the usability and effectiveness of the exergame-based program in stroke patients.

Introduction

ACUTE STROKE REHABILITATION SERVICES are limited—primarily because of cost constraints¹—and many individuals return home with residual gait impairment.² The decision to discharge patients from further therapy is often justified with a “plateau” in motor recovery.³ However, further functional gains after acute rehabilitation are possible, even in the chronic stage.^{1,4}

Following a stroke, approximately 80 percent of patients experience hemiparesis accompanied by considerable walking deficits.⁵ The typical “hemiplegic gait” post-stroke is associated with several negative consequences (e.g., gait asymmetry, reduced walking velocity, cadence, and stride length).^{5–9} Six months post-stroke, one-third of elderly stroke survivors are not able to walk independently.¹⁰

An intense, structured therapy program offering numerous repetitions of various, challenging tasks improves motor skills.¹¹ For best recovery results, a rehabilitation program

should be conducted regularly over an extended period of time. When patients find a treatment program enjoyable, their willingness to keep at it is increased. A high level of motivation should lead to high adherence and low attrition and hence positively affect treatment outcomes.¹²

Virtual reality applications in health care have recently received considerable attention. Virtual reality can be used to provide engaging scenarios and improve adherence to therapy.^{13–17} Videogames are most practical and effective in rehabilitation when they have been specifically designed for therapy purposes.^{18–20} Given the importance of gait recovery post-stroke, games should be aimed towards walking recovery. An additional advantage of videogame-based programs is that they can be performed independently at home with minimal equipment.¹⁶

The research project “Rehabilitative Wayout In Responsive home Environments” (REWIRE),²¹ funded by FP7, created such a rehabilitation program based on exergames. Exergames are defined as “any number of types of

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video games/multimedia interactions that require the game player to physically move in order to play.”²² Five exergames have been developed in the context of the REWIRE project—by game developers in collaboration with human movement scientists and rehabilitation specialists. The process for game development within a theoretical framework has been described elsewhere.²³ The underlying exercises—specifically targeting balance and walking recovery—were designed to be performed independently at home and remotely monitored by healthcare professionals. Moreover, the rehabilitation program explicitly considered variable practice and individually tailored progression, hence keeping participants engaged and appropriately challenged.^{18,23,24}

In accordance with the phased iterative approach suggested by Campbell et al.,²⁵ this article aims to evaluate (1) the usability of the rehabilitation program in terms of acceptance, adherence, and attrition and (2) the effect of the program on measures of balance and gait in untrained healthy elderly.

Subjects and Methods

Study design

We assessed usability by means of a user-centered interaction design. The ETH Zurich Ethics Committee granted ethical approval (protocol number EK 2013-N-12). All participants were fully informed prior to participation and signed a consent form.

Participants

Usability and effects were assessed in an untrained elderly convenience sample, in which some balance and gait impairments can be assumed.^{26–30} Sixteen participants were recruited in the city of Zurich, Switzerland, through contact persons of different institutions. Participants were included if they lived independently, were older than 64 years of age, were able to walk independently for 20 m, and had a Mini-Mental State Examination score of at least 22. Excluded were individuals with (1) acute or unstable chronic diseases, (2) rapidly progressing or terminal illnesses, (3) Alzheimer’s disease or dementia, (4) other severe health problems, and/or (5) a recent head injury.

Intervention

The intervention program consisted of exergame-based balance training performed while standing directly on a force

platform (Tymo plate by Tyromotion, Graz, Austria)³¹ or on a compliant foam mat placed on top of this platform. The intervention was performed three times per week for a period of 12 weeks for a total of 36 sessions. Each one-on-one session was partitioned in three parts: 10 minutes training, 10 minutes break, and 10 minutes training. All participants were expected to complete all 36 sessions while being monitored by an instructor, who systematically observed them throughout the intervention. Participants were encouraged to “think aloud” while operating the software and playing the exergames. Accordingly, any expressed comments from the participants related to their demands were documented by the instructor in writing to identify both problem areas and what people like. The aim of this procedure was to assess strengths and weaknesses of the exergame-based training program online in a realistic setting. Consequently, based on participants’ feedback, desired exergame adaptations could be carried out.

Exergames

A set of five exergames—four of them with different levels of difficulty (Fig. 1 gives details)—was used for the intervention. In each exergame, a therapist avatar provided real-time feedback. The exergames aimed to train quiet stance (“Scarecrow” [Fig. 2]), mediolateral weight shifting (“Tractor Driver” [Fig. 3] and “Fruit Catcher” [Fig. 4]), mediolateral weight shifting combined with single leg stance (“Worm Hurdler” [Fig. 5]), and mediolateral weight shifting combined with anteroposterior weight shifting (“Mix Soup” [Fig. 6]). A detailed description of the games can be found elsewhere.^{18,23,24}

Primary outcomes

Acceptance of the training technology. An abridged version³² of the technology acceptance model (TAM) questionnaire evaluated participants’ perceived acceptance of the intervention post-training^{33–35} (Fig. 7).

Responses were recorded using a 7-point Likert scale ranging from “strongly disagree” (rated as 1) to “strongly agree” (rated as 7).

Attrition and adherence. For attrition, the number of participants lost during the intervention was recorded. For adherence, participants’ engagement with the intervention

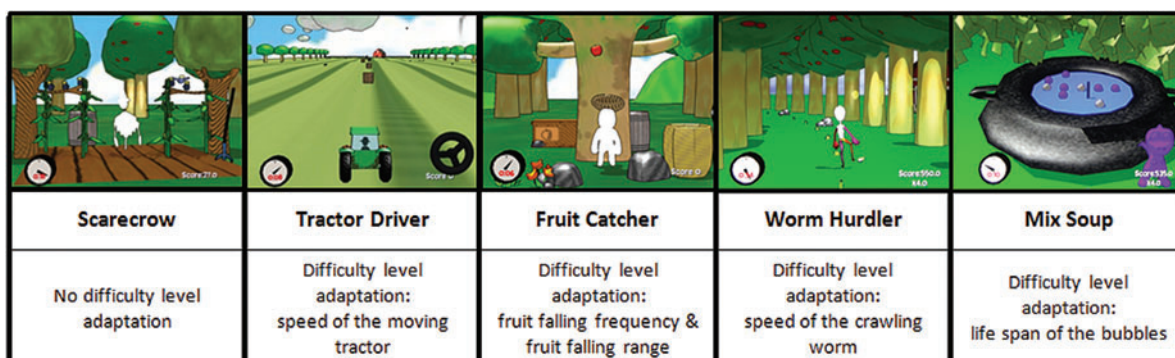


FIG. 1. Exergame difficulty levels. Color images available online at www.liebertonline.com/g4h

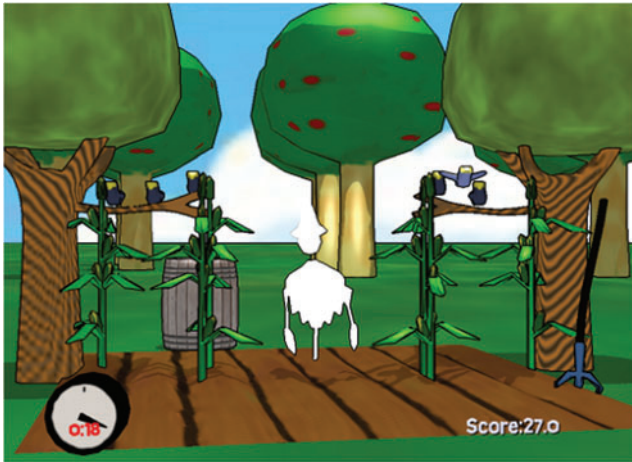


FIG. 2. Screenshot of the exergame “Scarecrow”. Color images available online at www.liebertonline.com/g4h

was assessed. Adherence was calculated as the number of completed training sessions as a percentage of the maximal possible training sessions (i.e., 36).

Secondary outcomes

Berg Balance Scale. Balance ability while performing functional tasks was assessed with the Berg Balance Scale. This test consists of 14 mobility tasks that simulate common daily life activities and is reliable and valid in geriatrics.³⁶ By using a 5-point scale, ranging from 0 (most impaired balance) to 4 (normal balance), a person’s functional capability can be defined for each test. The possible cumulative score ranges from 0 to 56 points.

Timed Up and Go. The Timed Up and Go^{37,38} requires participants to stand up from a sitting position, walk for 3 m, turn 180°, walk back 3 m, and turn to sit down again. We used an extended test version with a 7-m walking distance.³⁹ The test was repeated three times with 30-second breaks in



FIG. 4. Screenshot of the exergame “Fruit Catcher”. Color images available online at www.liebertonline.com/g4h

between, and the total time to complete each trial was measured. The average time was used for further analysis.

Force platform. To measure postural balance control, participants stood quietly on a Kistler (Winterthur, Switzerland) force plate (type 9286B) under two different test conditions: (1) on a stable surface and (2) on an unstable surface (foam mat). Vertical ground reaction forces were collected at a frequency of 1000 Hz. In both conditions, participants were instructed to focus on a red cross displayed at eye level on a white wall at a distance of 30 cm. In each condition, three 20-second trials were performed with a 30-second break in between. For each trial, center of pressure (COP) area was quantified as the area of the smallest ellipse containing 95% of COP data points. Mean COP area was computed for each condition and used for statistical analysis.

Short Physical Performance Battery. The Short Physical Performance Battery, composed of a balance test, a 3-m walking test, and a five-chair-rises test, resulted in scores between 0 (not able to complete the task) and 4 (good



FIG. 3. Screenshot of the exergame “Tractor Driver”. Color images available online at www.liebertonline.com/g4h



FIG. 5. Screenshot of the exergame “Worm Hurdler”. Color images available online at www.liebertonline.com/g4h



FIG. 6. Screenshot of the exergame “Mix Soup”. Color images available online at www.liebertonline.com/g4h

function) points per test. The sum of these scores represents the total Short Physical Performance Battery score. A higher score indicates better lower extremity function.^{40–42}

Gait analysis. Spatiotemporal gait parameters were assessed with the GAITRite[®] system (CIR Systems, Havertown, PA) consisting of an electronic walkway with gait analysis software. The active area of the walkway (i.e., the area equipped with pressure sensors) measures 7.3 m. To eliminate acceleration and deceleration effects on calculated gait parameters, the walkway contains an additional 2.5 m at the beginning and end of the active area. Participants were to walk over the electronic walkway at a self-selected comfortable walking speed. Three successful trials were collected, and the mean values of velocity (cm/second), cadence (steps/minute), step time (seconds), step length (cm), and swing time symmetry (ratio) were calculated. Gait symmetry was calculated from the following ratio⁴³:

$$\text{Symmetry ratio} = \frac{\text{swing time}_{\text{right side}}}{\text{swing time}_{\text{left side}}}$$

Statistical analysis

All statistical analyses were performed using SPSS version 21.0 software (SPSS Inc., Chicago, IL). Secondary outcomes were only calculated and analyzed for participants who completed the intervention as per protocol. A Wilcoxon signed-rank test was used to compare pre- and post-test results. Results were deemed statistically significant at a P value of ≤ 0.05 . Effect size (r) was calculated as $r = (Z/\sqrt{N})$,

where Z represents the approximation of the observed difference in terms of the standard normal distribution and N is the total number of observations. Regarding effect size magnitude, $r=0.1$ is considered a small, $r=0.3$ a medium, and $r=0.5$ a large effect.⁴⁴

Results

Primary outcomes

Sixteen participants were enrolled in the study, 13 of whom received the full allocated training program (Fig. 8). Two participants dropped out because of injuries sustained outside the training, and one discontinued because of self-reported lack of time. All reasons were unrelated to the content of the training. Table 1 presents completers' demographics and clinical characteristics. Adherence was 100 percent. None of the 13 participants suffered any adverse events during the intervention. The exergames were seen as easy to use and useful. The participants expressed a positive attitude toward using the exergames as well as an intention to continue using the games (Table 2).

Table 2 presents the TAM items that were evaluated post-intervention.

During the intervention, participants reported some minor problems with using the games and progressing through the exercises. In response, the exergames were adapted online (Fig. 9 gives details) and subsequently re-assessed for usability.

Secondary outcomes

The results of the pre–post comparisons are presented in Table 3. Significant improvements in Berg Balance Scale, Timed Up and Go, and Short Physical Performance Battery scores were observed. Separate analyses of each of the three Short Physical Performance Battery components (standing balance, repeated chair rises, and gait speed) revealed that only standing balance changed. No significant changes were detected in (1) COP area during quiet stance and (2) any of the gait parameters (all P values > 0.1).

Discussion

This study assessed—in untrained elderly—(1) the usability of the program in terms of acceptance, adherence, and attrition and (2) the effect of the program on balance and gait. The findings revealed a high level of acceptance with concomitant high adherence rates. High scores for each of the four TAM items were found. On average, participants found the exergames easy to use, clear, and understandable without

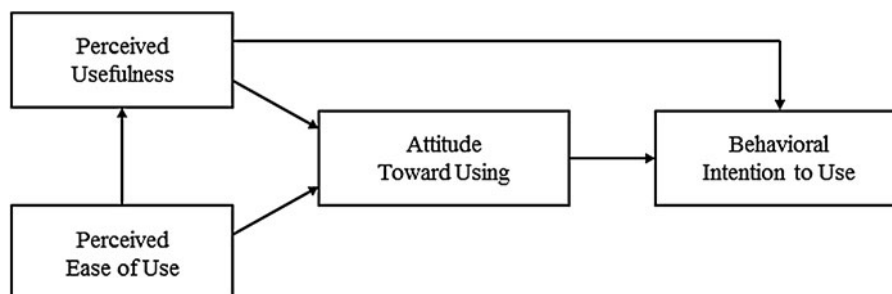


FIG. 7. Research model by Masrom.³²

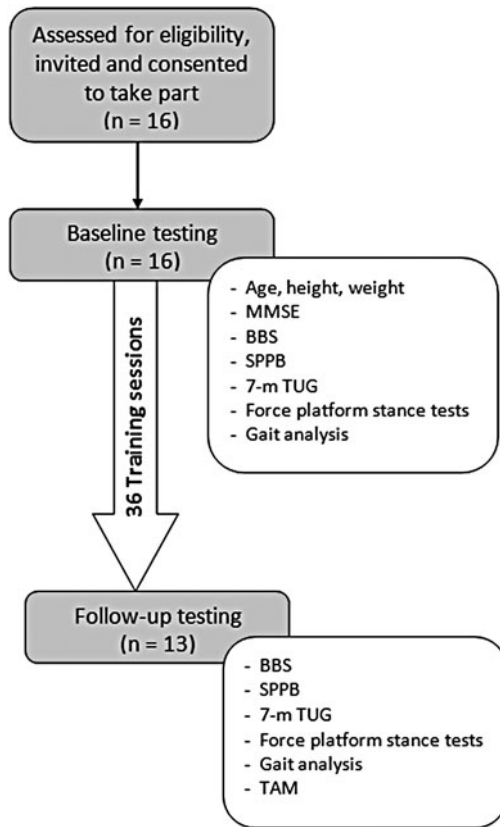


FIG. 8. Study flowchart. BBS, Berg Balance Scale; MMSE, Mini-Mental State Examination; n, sample size; SPPB, Short Physical Performance Battery; TAM, technology acceptance model; TUG, Timed Up and Go.

requiring much mental effort to operate. Perceived Usefulness results showed that the exergames were perceived as a useful means to increase training effectiveness, productivity, and performance. Moreover, there was a broad consensus in terms of Attitude Toward Using: All participants expressed a positive attitude towards the program. In addition, Behavioral Intention to Use results showed that participants liked the idea of continuing their use of exergames on a regular basis. The high acceptance rate obtained in the current study seems at odds with a previous study by Laver et al.⁴⁵ that revealed skepticism about the use of commercially available videogames in geriatric rehabilitation. A likely explanation may be found in game design: Where Laver et al.⁴⁵ used an off-the-shelf system without patient-specific adaptations, the exergames used in this study were specifically designed and developed for rehabilitation and were adapted to the cognitive and physical limitations of functionally impaired persons or elderly. This explanation is in line with Cameirão et al.,⁴⁶ who found high acceptance of a gaming system specifically designed to treat post-stroke motor deficits, and with Lewis et al.,⁴ who demonstrated positive results for newly developed exergames aimed to improve stroke patients' arm function. Our findings also corroborate the high acceptance rates of specifically designed exergames found by Backlund et al.⁴⁷

Thirteen of the 16 participants (81 percent) completed the full allocated training program and attended the retesting assessments. Considering the median rate for attrition in falls

TABLE 1. COMPLETERS' BASELINE CHARACTERISTICS

Characteristic	Value
Number of participants	13
Age (years)	76.5 ± 5.4 (65–85)
Sex (female/male)	10/3
Height (cm)	163.6 ± 8.5 (152–177)
Weight (kg)	71.6 ± 9.7 (57.4–90.5)
MMSE (points) ^a	28.9 ± 1.6 (25–30)
Education	
College educated or higher	2
In a sitting position past profession	5
Health status	
≥ 2 self-reported chronic diseases	8
Feel pain daily	4
Estimated excellent/good health status	10
Estimated excellent/good balance ability	7

Data are number of subjects or mean ± standard deviation (range) values as indicated.

^aThe minimum score was 0, and the maximum score was 30 (a higher score indicates better cognitive functioning).

MMSE, Mini-Mental State Examination.

prevention interventions in community settings for clinical trials,⁴⁸ a 10 percent attrition rate can be deemed acceptable. In our study, we achieved a slightly higher rate. It should be noted, however, that the reasons for discontinuation of the intervention were unrelated to the intervention. In contrast to the somewhat low attrition rate, adherence was 100 percent across the 36 training sessions. This perfect adherence is in line with the high acceptance revealed by the TAM survey. The high adherence and acceptance rates in the present study may be related to the online adaptations of the training intervention: The exergames were subjected to several online adaptations based on participants' feedback during the training period, which might have positively impacted both usability and effectiveness.

We expected the exergames to improve participants' balance and gait. The intervention had a positive effect on clinical measures of balance. This is in line with a study by Lai et al.⁴⁹ that reported similar results through a 6-week interactive videogame-based intervention. Although body sway during quiet stance did not change significantly, both standing on a stable and unstable surface yielded *larger* average COP areas in the post-test compared with the pre-test. Given that better balance is usually associated with *smaller* COP areas, this trend is surprising. Although speculative, it might nonetheless

TABLE 2. EVALUATED TECHNOLOGY ACCEPTANCE MODEL QUESTIONNAIRE ITEMS

Item	Score
Perceived Ease of Use	5.9 ± 1.7 (1–7)
Perceived Usefulness	6.4 ± 1.0 (4–7)
Attitude Toward Using	6.5 ± 1.1 (2–7)
Behavioral Intention to Use	6.0 ± 1.3 (3–7)

Data are mean ± standard deviation (range) values.

Scarecrow	Tractor Driver	Fruit Catcher	Worm Hurdler	Mix Soup
Added two difficulty levels to original three	Added two difficulty levels to original three	Added two difficulty levels to original three	Added two difficulty levels to original three	Added two difficulty levels to original three
Improved consistency of statements and scores provided by virtual therapist	Improved consistency of statements and scores provided by virtual therapist	Improved consistency of statements and scores provided by virtual therapist	Improved consistency of statements and scores provided by virtual therapist	Improved consistency of statements and scores provided by virtual therapist
	Added previously absent obstacles		Increased worm size and hence visibility	

FIG. 9. Description of the online exergame adaptations performed. Color images available online at www.liebertonline.com/g4h

constitute a positive intervention effect: Note that four of the five exergames trained effective control rather than minimization of COP movement. Given that—to be precise—postural stability likewise requires effective control of COP (in order to minimize center of mass movement) rather than its minimization, COP might not be the best indicator of postural stability, particularly in the present study.⁵⁰ Measurements of center of mass movements (e.g., during walking) would have given a better insight into the actual participants' dynamic postural balance control.

The absence of gait-related effects in this study constitutes a confirmation of results by Szturm et al.,⁵¹ who also examined an exergame-based intervention with goal-directed

weight-shifting tasks and found no significant improvement in spatiotemporal gait parameters. Hence, exercises with a stationary base of support do not seem to present the most effective way to improve walking in untrained elderly.

However, the absence of significant effects on gait might also be related to the low power of testing together with the rather high level of walking function in our sample. Effect sizes were medium or close to medium and—with a preferred gait speed between 1.0 and 1.4 m/second—our participants should be classified as normal walkers.⁵² A logical next step would therefore be to apply the present intervention to community-dwelling chronic stroke populations that exhibit mildly abnormal (0.6–1.0 m/second) or seriously

TABLE 3. PARTICIPANTS' BASELINE AND POST-INTERVENTION PHYSICAL OUTCOME MEASURES

	<i>Mean ± standard deviation</i>		<i>P</i> _{within}	<i>r</i>	<i>Z</i>
	<i>Baseline</i>	<i>Post-intervention</i>			
BBS (points)	51.7 ± 3.3	54.8 ± 1.4	0.007 ^a	0.51 ^b	2.590
7-m TUG (seconds)	19.8 ± 2.8	17.5 ± 2.4	0.002 ^a	0.56 ^b	2.830
COP area (mm ²)					
Stable surface	2.47 ± 1.64	4.43 ± 4.17	0.191	0.27	1.363
Unstable surface	10.42 ± 7.73	17.69 ± 18.54	0.414	0.17	0.874
SPPB (points)					
Total	9.9 ± 1.0	11.2 ± 0.8	0.013 ^a	0.48 ^c	2.436
Balance	3.1 ± 0.9	4.0 ± 0.0	0.008 ^a	0.51 ^b	2.585
Chair rises	3.2 ± 0.8	3.4 ± 0.7	0.375	0.26	1.342
Gait speed	3.7 ± 0.5	3.8 ± 0.6	1.000	0.07	0.378
Gait analysis					
Velocity (cm/second)	122.4 ± 17.3	128.4 ± 21.4	0.497	0.14	0.734
Cadence (steps/minute)	115.2 ± 8.7	119.1 ± 9.3	0.244	0.24	1.223
Step time (seconds)	0.52 ± 0.04	0.51 ± 0.04	0.273	0.23	1.153
Step length (cm)	63.6 ± 6.0	64.4 ± 6.9	0.542	0.13	0.664
Swing time symmetry (ratio)	0.99 ± 0.03	1.00 ± 0.04	0.127	0.31 ^c	1.572

^aSignificant within-group differences pre–post ($P_{\text{within}} \leq 0.05$) calculated with Wilcoxon signed-rank test.

For effect size r , $r=0.1$ indicates a small effect, $r=0.3$ indicates a medium effect, and $r=0.5$ indicates a large effect.

BBS, Berg Balance Scale; COP, center of pressure; P_{within} , P value for within-group comparisons; SPPB, Short Physical Performance Battery; TUG, Timed Up and Go; Z , approximation of the observed difference in terms of the standard normal distribution.

abnormal gait speed (below 0.6 m/second) and re-assess intervention effects on gait in this actual target population.⁵² Given that gait speed is an important factor related to community walking in stroke patients, which in turn is strongly determined by balance,⁵³ it seems likely that our exergames—which explicitly target this skill—will improve walking in chronic patients.

Future work

We performed an “a priori power analysis” to determine the minimum sample size for such a future trial.⁵⁴ Specifically, we assessed the requirements for a randomized controlled study with an experimental group (receiving exergame-based therapy and usual stroke rehabilitation) and a control group (receiving usual stroke rehabilitation only). Assuming an effect size of $r=0.30$ (based on our observed value for gait symmetry), acceptable type I and II error probabilities (0.05 and 0.20, respectively) may be obtained with a minimum sample of 12 participants per group for a two-group pre-/post-test design. To account for attrition, initial sample size should be increased to 15 participants per group.

Limitations

Some limitations of this study should be discussed. First, this study featured a rather small sample of healthy untrained elderly, which resulted in limited statistical power for gait analysis. The validity of using elderly persons to test the usability may be questioned. However, (1) the primary focus of this study was on usability, where a sample of five participants is sufficient for detecting 80 percent of the usability problems,⁵⁵ and (2) untrained elderly normally show both balance and gait impairments, which should render them an adequate population for assessing effectiveness as well. Second, the study may suffer from volunteer bias: It can be hypothesized that our volunteer participants were more interested in technology than the average elderly, which might explain in part their positive attitude toward the intervention. Both these limitations would not apply in a controlled trial with stroke patients, which—in combination with the promising results of the present study—highlights the need for such a trial. A third limitation concerns the gender distribution in our sample, with women outnumbering men. However, sex disparity in stroke prevalence persists, with women being more affected than men.⁵⁶ This makes it important to especially test acceptance and feasibility in women.

Conclusion

Small-scale interventions focusing on usability represent an important stage when developing complex theory-based interventions to improve health.²⁵ Usability studies provide invaluable results for information technology developers and rehabilitation specialists using innovative systems and might be highly relevant for furthering the development of new emerging virtual reality-based rehabilitation. Our results corroborate previous findings in showing that virtual training approaches for performing balance training have great potential. Specifically, this study demonstrates that the exergame-based intervention was perceived as usable

and had a positive effect on both standing balance and daily life tasks.

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Author Disclosure Statement

No competing financial interests exist.

S.W. contributed to the conception of the work, the acquisition, analysis and interpretation of data, and writing the manuscript. N.A.B., M.P., and R.M. contributed to the development of the software and exergames. R.v.d.L. assisted in the acquisition of data and contributed to the analysis and interpretation of data and to writing the manuscript. E.D.d.B. initiated the study, assisted in the acquisition of data, and contributed to writing the manuscript. All authors read and approved the final manuscript.

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