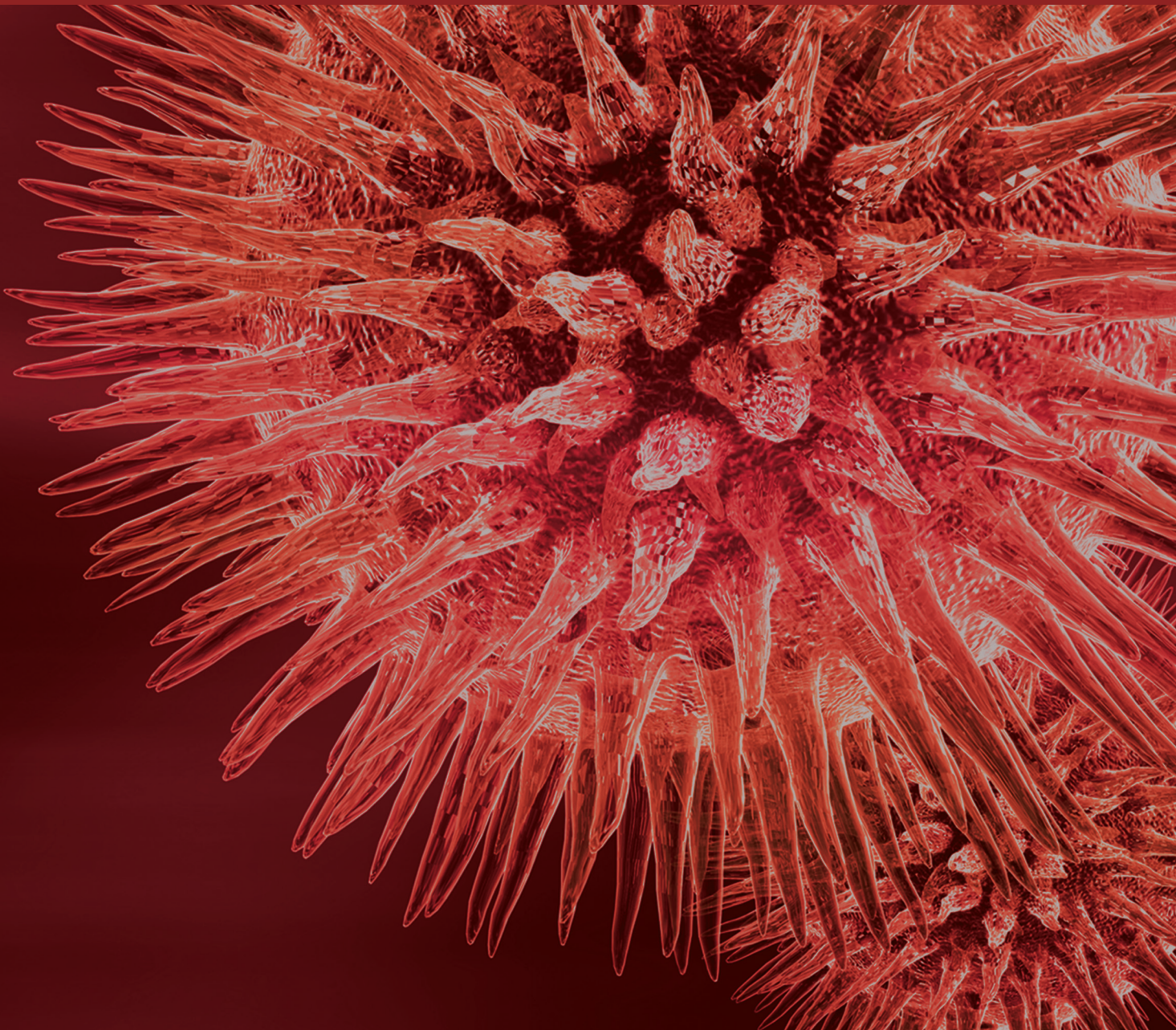


New Technologies for the Management and Rehabilitation of Chronic Diseases and Conditions

Guest Editors: Gianluca Castelnuovo, Giancarlo Mauri, Susan Simpson, Angela Colantonio, and Stephen Goss





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BioMed Research International

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Editorial

New Technologies for the Management and Rehabilitation of Chronic Diseases and Conditions

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Received 10 May 2015; Accepted 10 May 2015

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The economic burden of chronic diseases and conditions (such as cardiovascular pathologies, diabetes, obesity, chronic obstructive pulmonary disease, chronic pain, and traumatic brain injuries) requires new solutions not only in traditional clinical settings (in-patient treatments), but also in innovative healthcare scenarios (out-patient long-term monitoring).

New technologies can provide clinicians and patients with many solutions at different levels: diagnostic and monitoring, early risk detection, treatment and rehabilitation, provision of feedback and alerts, and motivational strategies that facilitate changes in dysfunctional behaviors or maintenance of healthy lifestyles. A health technology assessment approach is necessary in order to collect evidence to evaluate the clinical and cost effectiveness of new tools and to strengthen the political choice to use health technologies in clinical fields.

Telemedicine, e-health, and m-health scenarios can improve health outcomes, quality of life, and well-being and facilitate functional patient empowerment and engagement. Mobile technologies in particular can offer advantageous solutions: m-health could be considered an evolution of e-health and defined as the practice of medicine and public health as supported by mobile communication devices. Indeed, the m-health approach has the potential to overcome

many of the limitations associated with the traditional, restricted, and highly expensive in-patient treatment of many chronic pathologies.

A range of electronic health systems have been implemented in chronic disease management using stationary and mobile computers, smartphones, and other mobile platforms with differing access to data technology. New innovations in technology are required to meet the challenges associated with overcoming various barriers such as organizational and technological difficulties, lack of technology acceptance, costs of system implementation and maintenance, lack of system interoperability with other informatic tools, reduced communication between clinicians and patients, and difficulties in data processing due to the limitations of devices used in patient monitoring.

There is potential for the development of a new and innovative model of healthcare as represented by such technologies as telemedicine, e-health applications, biomedical sensors and devices, integrated platforms and technologies for remote monitoring and management, web and Internet based clinical protocols, and m-health solutions. This model has the potential to offer healthcare that is tailored to the specific needs of the individual, whilst providing the benefits

of a mobile, noninvasive, balanced, integrated, and lifestyle friendly framework that is useful from both a preventative and intervention-focused perspective.

The major aim of this special issue is to bring to light new international developments in the management and rehabilitation of a range of chronic diseases and clinical conditions, such as stroke, dementia, cardiovascular diseases, dialysis patients, or those with facial paresis. A range of technological developments, lifestyle, and environmental factors have been described in relation to these diseases, including a rehabilitation system for stroke patients using vibrotactile feedback, a new system of facial movement analysis for facial paresis, an exploration of the effects of exercise for dialysis and cancer patients, and the influence of environment on those with dementia and coronary artery disease.

In conclusion, as demand for the management of a range of chronic conditions increases in the imminent future, there is likely to be considerable scope for the integration of clinical psychology and medicine. A key future challenge for those working in both traditional and m-health/e-health settings will be to further develop the evidence base for chronic care management in order to enhance technological standards and fine-tune both clinical protocols and organisational models.

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Review Article

Effects of Supervised Multimodal Exercise Interventions on Cancer-Related Fatigue: Systematic Review and Meta-Analysis of Randomized Controlled Trials

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Received 7 July 2014; Revised 10 November 2014; Accepted 18 November 2014

Academic Editor: Gianluca Castelnuovo

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Objective. Cancer-related fatigue (CRF) is the most common and devastating problem in cancer patients even after successful treatment. This study aimed to determine the effects of supervised multimodal exercise interventions on cancer-related fatigue through a systematic review and meta-analysis. **Design.** A systematic review was conducted to determine the effectiveness of multimodal exercise interventions on CRF. Databases of PubMed, CENTRAL, EMBASE, and OVID were searched between January and March 2014 to retrieve randomized controlled trials. Risk of bias was evaluated using the PEDro scale. **Results.** Nine studies ($n = 772$) were included in both systematic review and meta-analysis. Multimodal interventions including aerobic exercise, resistance training, and stretching improved CRF symptoms (SMD = -0.23 ; 95% CI: -0.37 to -0.09 ; $P = 0.001$). These effects were also significant in patients undergoing chemotherapy ($P < 0.0001$). Nonsignificant differences were found for resistance training interventions ($P = 0.30$). Slight evidence of publication bias was observed ($P = 0.04$). The studies had a low risk of bias (PEDro scale mean score of 6.4 (standard deviation (SD) ± 1.0)). **Conclusion.** Supervised multimodal exercise interventions including aerobic, resistance, and stretching exercises are effective in controlling CRF. These findings suggest that these exercise protocols should be included as a crucial part of the rehabilitation programs for cancer survivors and patients during anticancer treatments.

1. Introduction

The number of people diagnosed with cancer worldwide has been estimated to be as high as 10 million [1]. The respective numbers with regard to cancer survivors may reach approximately 25 million [1]. In Colombia, the National Cancer Institute (NCI) declared that malignant tumors present the third cause of mortality, increasing the mortality burden during the last sixty decades from 6% to 15% in 2002 [2, 3]. Cancer-related fatigue (CRF) is a common problem in cancer patients. Approximately, 80% to 100% of cancer patients report suffering from CRF [4]. Furthermore, it has been shown that patients continue to experience fatigue symptoms for months or years after successful treatment [4]. Several concepts of CRF have been published in the

biomedical literature. The National Comprehensive Cancer Network (NCCN) [5] defined CRF as “a distressing, persistent, subjective sense of physical, emotional and/or cognitive tiredness or exhaustion related to cancer or cancer treatment that is not proportional to recent activity and interferes with usual functioning.” Besides, CRF has a severe impact on daily activities, social relationships, reintegration, and overall quality of life [6]. Some evidence has postulated that CRF may be considered as a predictor of survival for these patients [7].

Recent systematic reviews have shown that supervised exercise has the power to combat many of the side effects of cancer treatment and, thus, can be of significant benefit to patients in the short and long term [8–11]. A recent Cochrane systematic review on supervised multimodal exercise and CRF [11] concluded that exercise can be considered

as a beneficial intervention for individuals with CRF and encouraged further research in this field. Benefits include improved muscle strength and body composition in patients with cancer [8, 12, 13]. The effects of multimodal exercise have been attributed to improvements in adherence and intensity [14], perhaps because of greater encouragement or confidence to work when health professional help is at hand. Therefore, it has been suggested that exercise must be individualized to specific conditions of cancer survivors to achieve the numerous benefits of exercise for the treatment of cancer, such as prevention and symptoms management [14, 15]; other authors reported that breast [16] and colon [17] cancer survivors prefer supervised exercise training over unsupervised exercise. In light of this, Lin et al. [18] compared the effects of a supervised exercise intervention with those of usual care for 12 weeks in colorectal cancer patients during chemotherapy and found significant improvements in the supervised exercise group on fatigue, physical activity level, and physical functioning, social functioning, hand-grip strength, cardiorespiratory fitness, and pain subscales of quality of life (QoL). The authors concluded that supervised exercise interventions result in larger benefits for cancer patients on these outcomes when compared with usual care. Likewise, Schneider et al. [15] reported that moderate intensity individualized exercise improves cardiopulmonary function and fatigue during and after treatment in a sample of 113 breast cancer patients. In a past review, Velthuis et al. [14] addressed a subgroup analysis of supervised exercise only, but they integrated this analysis within diagnosis groups, thus limiting the power of their conclusions. The current systematic review aims to update this growing evidence adding specific analyses regarding the effects of supervised multimodal exercise on CRF in cancer survivors.

2. Methods

2.1. Design. This systematic review is reported according to the PRISMA Statement [19]. We also followed the recommendations described in the Cochrane Handbook for Systematic Reviews of Interventions version 5.1.0 [20].

2.2. Literature Search. PubMed, CENTRAL, EMBASE, and OVID databases were searched between January and March 2014 independently by two blinded authors (JFM-E and RR-V). Search strategy incorporated the recommendations for a highly sensitive search strategy for the retrieval of clinical trials on PubMed [21]. The title and abstract were examined and full text was obtained if there was ambiguity regarding eligibility. The final search strategy was as follows: (randomized controlled trial) OR controlled clinical trial) OR randomized) OR trial) OR “clinical trials as topic”) AND cancer) OR neoplasm*) OR tumour*) OR tumor*) OR carcino*) OR leukaemi*) OR leukemi*) AND physical activity) OR exercise) OR resistance) OR strength) OR stretching) AND fatigue). In addition, the authors checked the reference lists of the identified studies and the meeting abstracts of the American Society of Clinical Oncology (ASCO) Annual Meeting on its website from 2004 to 2013, as well as certain journals (i.e., The Lancet Oncology, Journal of

Clinical Oncology, Journal of the National Cancer Institute, Journal of Breast Cancer, The Breast Journal, and The Breast). No language restrictions were applied. Attempts were made to contact authors of trial reports if clarification was necessary. See the Appendix for further details of the search strategy procedures.

3. Selection Criteria

Selection criteria were built based on the PICO acronym as follows.

3.1. Participants. This systematic review included studies with patients (age > 18 years) diagnosed with any type of cancer regardless of the stage of diagnosis or treatment. There were no restrictions for sex, ethnicity, or race.

3.2. Intervention. The experimental intervention was multimodal exercise including aerobic, resistance, and stretching exercise, whilst the control intervention was conventional care, where patients did not participate in any exercise intervention program. In this sense, resistance training (RT) interventions were considered as any form of physical activity that is designed to improve muscular fitness by exercising a muscle or a muscle group against external resistance, performed in a systematic manner in terms of frequency, intensity, and duration, and is designed to maintain or enhance health-related outcomes [22]. All interventions had to be supervised by health professionals; therefore, home-based programs, telephone monitoring interventions, and cognitive approaches were excluded. Yoga and tai-chi interventions were not included because, although these interventions can be supervised by healthcare providers, they do not exert a large physiological impact (energy expenditure).

3.3. Outcome Measures. Primary outcome measure was CRF symptoms measured using the Functional Assessment of Cancer Therapy- (FACT-) Fatigue Scale, European Organization for Research and Treatment of Cancer Quality of Life Questionnaire (EORTC QLQ-C30), Piper Fatigue Scale (PFS), Schwartz Cancer Fatigue Scale (SCFS), and the Multidimensional Fatigue Inventory (MFI).

Selection criteria were verified independently by two blinded authors (JFM-E and RR-V) and disagreements were solved through consensus and active participation of a third author (EG-J).

3.4. Assessment of the Risk of Bias and Methodological Quality. The methodological quality and risk of bias of the studies were assessed using the Physiotherapy Evidence Database (PEDro) scale [23]. The PEDro scale scores the methodological quality of randomized controlled studies out of 10. Scores were based on all information available both from the published version and from communication with the authors. A score of 5 of 10 was set as the minimum score for inclusion in the current meta-analysis. Publication bias was evaluated through visual appraisal of the funnel plot built for CRF and by Egger’s test ($P < 0.05$). Risk of bias was evaluated by two

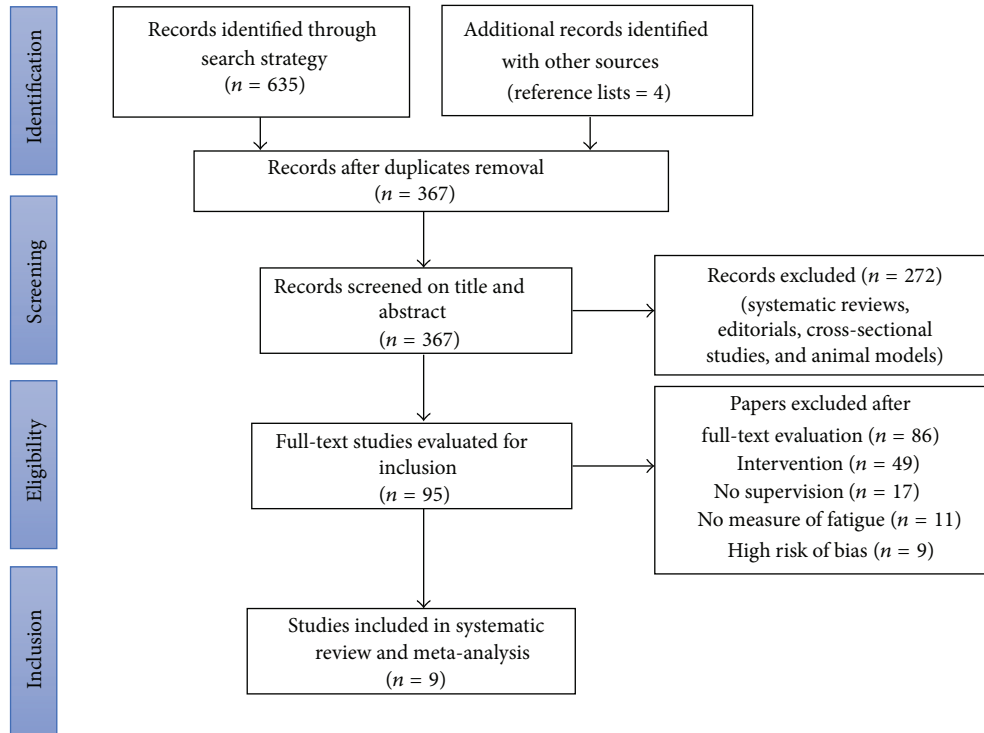


FIGURE 1

independent authors (JFM-E and EGJ) and a third author mediated for consensus (RR-V). Interrater reliability between authors was determined by calculating Cohen’s kappa.

3.5. Data Extraction and Analysis. Key characteristics of the identified studies were also extracted including authors’ information, publication year, study design, cancer treatment, time since diagnosis, and characteristics of the multimodal exercise interventions (mode of training, length, duration, and frequency) and effect estimates. Data extraction was conducted independently by two authors (JFM-E and RR-V) using a standard form; a third author (EG-J) arbitrated in cases of disagreement if necessary. Comprehensive Meta-Analysis Version 2.0 was used for the analyses. Continuous outcomes were pooled calculating standardized mean differences (SMD) with 95% confidence intervals (CI). Statistical heterogeneity was evaluated through visual appraisal of the forest plots and using the I^2 statistic, which was defined using the following cut-off parameters: not important heterogeneity, 0% to 40%; moderate heterogeneity, 30% to 60%; substantial heterogeneity, 50% to 90%; and considerable heterogeneity, 75% to 100% [20]. In the presence of high heterogeneity ($I^2 > 50\%$), the pooled effects were calculated by a random effects model reported in accordance with the DerSimonian and Laird method, which considers both within-study and between-study differences [20]. On the contrary, when substantial heterogeneity was not detected, we conducted a fixed-effects model reported by using the inverse variance method [20]. We performed a metaregression analysis to explore the predictor effects of the supervised multimodal exercise characteristics, such as length (weeks),

frequency (sessions per week), and duration (minutes per session), on the effect estimates. Subgroup analysis was undertaken according to the stage of anticancer treatment (active or not where reported) and by the mode of exercise training. Publication bias was evaluated with Egger’s test and a funnel plot [20]. All P values were two-sided and were considered significant at the 0.05 level.

4. Results

4.1. Characteristics of the Included Studies. A total of nine randomized controlled trials ($n = 772$) were included [24–32] (Figure 1). The assessment of risk of bias showed a mean score of 6.4 (SD ± 1), indicating a low risk of bias and a consistent methodological quality in the studies included (Table 1). Interrater reliability between the two authors was high (mean kappa = 0.81).

CRF levels were measured using the Functional Assessment of Cancer Therapy- (FACT-) Fatigue Scale (FS) in 54.5% of the studies included, the European Organization for Research and Treatment of Cancer Quality of Life Questionnaire (EORTC QLQ-C30; 30 items) in 36.3% of the studies, the Piper Fatigue Scale (PFS) in 9.0% of the studies, and the Schwartz Cancer Fatigue Scale (SCFS) in 9.0% of the studies included.

4.2. Characteristics of Cancer Survivors. The mean age of the cancer survivors ranged from 46 to 60 years with a mean of 55.5 (SD ± 7.2) years. Most cancer survivors were female ($n = 419$; 54.2%). Regarding cancer treatment stage, most studies were performed during current treatment [24,

TABLE 1: Assessment of the risk of bias and methodological quality of the studies included using the PEDro scale.

Study	Random allocation	Concealed allocation	Groups similar at baseline	Participant blinding	Therapist blinding	Assessor blinding	<15% dropouts	Intention to treat analysis	Between-group difference reported	Point estimate and variability reported	Total (0 to 10)
Adamsen et al. 2009 [24]	Y	Y	Y	N	N	N	Y	Y	Y	Y	7
Campbell et al. 2005 [25]	Y	N	Y	N	N	N	Y	N	Y	Y	5
Cantarero-Villanueva et al. 2013 [26]	Y	Y	Y	N	N	Y	Y	N	Y	Y	7
Ergun et al. 2013 [27]	Y	N	Y	N	N	Y	Y	N	Y	Y	6
Galvão et al. 2010 [28]	Y	Y	Y	N	N	N	Y	Y	Y	Y	7
Milne et al. 2008 [29]	Y	Y	Y	N	N	N	Y	Y	Y	Y	7
Mutrie et al. 2007 [30]	Y	Y	Y	N	N	Y	Y	Y	Y	Y	8
Segal et al. 2009 [31]	Y	Y	Y	N	N	N	Y	Y	Y	Y	7
Winters-Stone et al. 2012 [32]	Y	Y	Y	N	N	Y	N	Y	Y	Y	7

N: no, Y: yes, and PEDro: Physiotherapy Evidence Database.

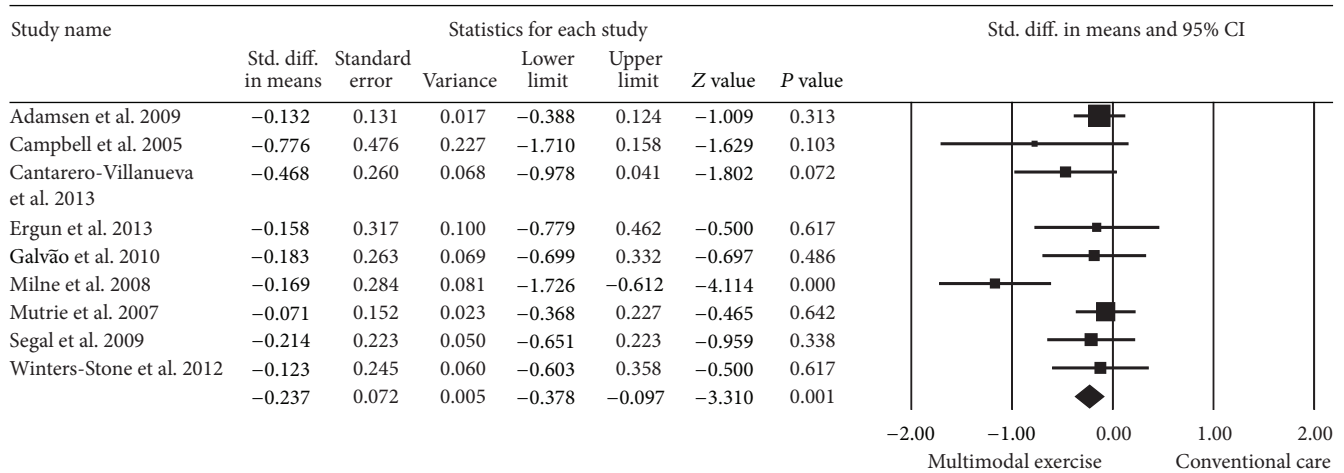


FIGURE 2: Effect estimate of supervised multimodal exercise on CRF. Standardized mean difference (SMD) was calculated for the random effects model of meta-analysis. IV, inverse of variance; CI, confidence interval.

25, 28–31]; the most common treatment was chemotherapy ($n = 522$). The average number of months since cancer diagnosis was 8.2 (SD \pm 10.7), although this report was not consistent across the studies included. Breast cancer was the most investigated cancer type ($n = 6$) [25–30, 32], followed by prostate cancer ($n = 2$) [28, 31], and one trial included diverse types of cancer [24]. Time since diagnosis was not consistently reported by authors, although most of the studies recruited women who were beyond five years since primary cancer diagnosis. Table 2 summarizes the characteristics of the studies included.

4.3. Characteristics of Supervised Multimodal Exercise Interventions. Multimodal exercise interventions had a mean duration of 16.5 (SD \pm 12.3) weeks with an average of 3 (SD \pm 1.2) sessions per week. The mean session duration was 45 minutes (SD \pm 29.1 min). These interventions usually started with aerobic training using stationary bicycle/cycle ergometer, walking periods followed by strengthening exercises of the upper limbs, and a final set of cooldown stretching exercises. Training intensity varied considerably among studies, ranging from 50% to 90% maximum heart rate. All studies reported preexercise screening before exercise (Table 2).

4.4. Follow-Up in the Studies Included. Two studies communicated follow-up for their outcome measures. Milne et al. [29] obtained data for follow-up from 97% of the participants with an adherence rate of 61.3%; the authors reported a significant increase in QoL, fatigue, anxiety, and physical fitness at 12 and 24 weeks of their follow-up period. Mutrie et al. [30] stated that the benefits in CRF observed from the exercise group continued until 6 months of follow-up.

4.5. Adverse Events among Studies. Two studies [26, 31] reported adverse events related to multimodal exercise interventions. Cantarero-Villanueva et al. [26] reported discomfort or low-intensity pain/stiffness in 3 patients; however, these patients completed the multimodal exercise program.

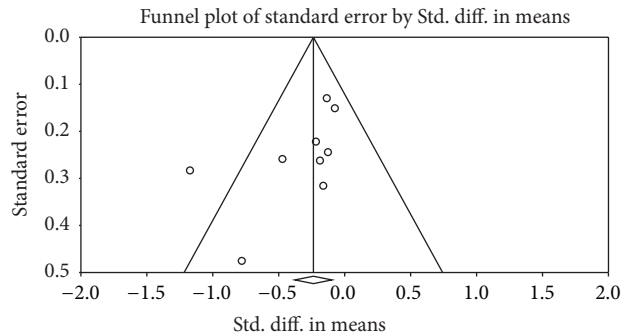


FIGURE 3: Funnel plot for the assessment of publication bias.

Fong et al. [33] reported three adverse events where one case resulted in hospitalization or disability, one participant referred to chest pain related to exercise with negative cardiologic results, and in the aerobic group there was a case of syncope without complications.

4.6. Pooled Analysis. Nine studies reported appropriate statistical measures for the meta-analysis [24–32]. Supervised multimodal exercise interventions resulted in an overall reduction in fatigue in cancer survivors (SMD = -0.23 ; 95% CI -0.37 to -0.09), $P = 0.001$ with low statistical heterogeneity ($I^2 = 46.7%$) (Figure 2).

4.7. Publication Bias. Visual appraisal of the funnel plot showed slight evidence of publication bias, although the reduced number of studies included could limit this analysis (Figure 3) confirmed by Egger’s test ($P = 0.04$).

4.8. Subgroup Analyses: Stage of Treatment and Mode of Exercise. Six randomized controlled trials involved cancer patients undergoing active treatment; chemotherapy was the most common regimen [24, 25, 28–31]. The pooled effects showed overall significant improvements in CRF among

TABLE 2: Characteristics of the included studies in systematic review ($n = 9$).

Study	Design	Type of cancer	Participants*	Intervention**	Outcome measures
Adamsen et al. 2009 [24]	RCT	Mixed types of cancer	<p>Characteristics of cancer treatment = chemotherapy</p> <p>$N = 235$</p> <p>Female = 171</p> <p>Male = 64</p> <p>Exp ($n = 118$)</p> <p>Age (yr) = 47.2 (10.7)</p> <p>Con ($n = 117$)</p> <p>Age (yr) = 47.2 (10.6)</p>	<p>Exp = aerobic exercise, resistance training, and stretching</p> <p>Length = 6 weeks</p> <p>Duration = 120 min/session</p> <p>Frequency = 5 sessions/week</p> <p>Intensity = 85%–95%</p> <p>Con = conventional care</p>	<p>EORTC QLQ-C30,</p> <p>MOS SF-36, Leisure Time Physical Activity Questionnaire, muscular strength (IRM)</p>
Campbell et al. 2005 [25]	RCT	Early stage (I-II) breast cancer	<p>Characteristics of cancer treatment = chemotherapy, radiotherapy, and combination</p> <p>$N = 22$</p> <p>Female = 22</p> <p>Exp ($n = 12$)</p> <p>Age (yr) = 48 (10)</p> <p>Con ($n = 10$)</p> <p>Age (yr) = 47 (5)</p>	<p>Exp = aerobic exercise and resistance training</p> <p>Length = 12 weeks</p> <p>Duration = 20 min/session</p> <p>Frequency = 2 sessions/week</p> <p>Intensity = 60%–75%</p> <p>Con = conventional care</p>	<p>FACT-G, FACT-B, SWLS, PFS, SPAQ, 12-minute walk test</p>
Cantarero-Villanueva et al. 2013 [26]	RCT	Breast cancer (stages I–IIIA)	<p>Characteristics of cancer treatment = chemotherapy, radiotherapy, and combination</p> <p>$N = 61$</p> <p>Female = 61</p> <p>Exp ($n = 32$)</p> <p>Age (yr) = 49 (7)</p> <p>Con ($n = 29$)</p> <p>Age (yr) = 47 (8)</p>	<p>Exp = aerobic exercise and resistance training</p> <p>Length = 8 weeks</p> <p>Duration = 60 min/session</p> <p>Frequency = 3 sessions/week</p> <p>Intensity = 60%–75%</p> <p>Con = conventional care</p>	<p>PFS, the Spanish version of the Profile of Mood States, the “multiple sit-to-stand test,” the trunk curl static endurance test</p>
Ergun et al. 2013 [27]	RCT	Breast cancer (stages I–IIIA)	<p>Characteristics of cancer treatment = chemotherapy, radiotherapy, mastectomy, axillary dissection, and sentinel lymph node biopsy</p> <p>$N = 60$</p> <p>Female = 60</p> <p>Exp ($n = 20$)</p> <p>Age (yr) = 49.65 (8.25)</p> <p>Home-based exercise ($n = 20$)</p> <p>Age (yr) = 55.05 (6.85)</p> <p>Education group ($n = 20$)</p> <p>Age (yr) = 55.30 (10.37)</p>	<p>Exp = aerobic exercise and resistance training</p> <p>Length = 12 weeks</p> <p>Duration = 45 min/session</p> <p>Frequency = 3 sessions/week</p> <p>Intensity = 60%–80%</p> <p>Con = home-based exercise (brisk walking for 30 min/day for 3 days/week) + education programme</p> <p>Education group = patient information booklet that also included lymphedema-specific exercises</p>	<p>EORTC QLQ-C30, BFI, BDI, ELISA kit, RayBio Human Cytokine Antibody Array 3</p>

TABLE 2: Continued.

Study	Design	Type of cancer	Participants*	Intervention**	Outcome measures
Galvão et al. 2010 [28]	RCT	Prostate localized (93.1%) Nodal metastases (6.9%)	Characteristics of cancer treatment = chemotherapy—radiotherapy N = 57 Male = 57 Exp (n = 29) Age (yr) = 53.5 (8.7) Con (n = 28) Age (yr) = 52.1 (11.8)	Exp = aerobic exercise, resistance training, and stretching Length = 12 weeks Duration = 20 min/session Frequency = 2 sessions/week Intensity = 65%–80% Con = conventional care	EORTC QLQ-C30, MOS SF-36, DXA, 1RM
Milne et al. 2008 [29]	RCT	Early stage breast cancer	Characteristics of cancer treatment = chemotherapy—radiotherapy N = 58 Female = 58 Exp (n = 29) Age (yr) = 55.2 (8.4) Con (n = 29) Age (yr) = 55.1 (8.0)	Exp = aerobic exercise, resistance training, and stretching Length = 12 weeks Duration = 30 min/session Frequency = 3 sessions/week Intensity = about 75% Con = delayed exercise group (DEG) completed the exercise program from 13 to 24 weeks	FACT-B, SCFS, rPARQ, Aerobic Power Index
Mutrie et al. 2007 [30]	RCT	Early stage breast cancer	Characteristics of cancer treatment = chemotherapy—radiotherapy and combination N = 174 Female = 174 Exp (n = 82) Age (yr) = 51.3 (10.3) Con (n = 92) Age (yr) = 51.8 (8.7)	Exp = aerobic exercise and resistance training Length = 12 weeks Duration = 45 min/session Frequency = 2 sessions/week Intensity = 50%–75% Con = conventional care	FACT-G, FACT-B, FACT-E, BDI, PANAS, SPAQ leisure time, BMI, 12-minute walk test
Segal et al. 2009 [31]	RCT	Stages I–IV prostate cancer	Characteristics of cancer treatment = radiotherapy N = 121 Male = 121 Exp (n = 40) Age (yr) = 66.2 (6.8) Resistance (n = 40) Age (yr) = 66.4 (7.6) Con (n = 41) Age (yr) = 65.3 (7.6)	Exp = aerobic exercise, resistance training, and stretching Length = 24 weeks Duration = 45 min/session Frequency = 3 sessions/week Intensity = 70%–75% Resistance = supervised resistance training of 3 times/week for 24 weeks and 2 times 8 to 12 reps of 10 exercises at 60% to 70% estimated 1 RM Con = conventional care	FACT-G, FACT-P, FACT-E, VO(2)max, 1RM, DEXA scan (percent body fat)

TABLE 2: Continued.

Study	Design	Type of cancer	Participants*	Intervention**	Outcome measures
Winters-Stone et al. 2012 [32]	RCT	Breast cancer (stages I–IIIA)	Characteristics of cancer treatment = Chemotherapy—radiotherapy N = 106 Female = 106 Exp (n = 52) Age (yr) = 62.3 (6.7) Con (n = 54) Age (yr) = 62.6 (6.7)	Exp = resistance training Length = 1 year Duration = 60 min/session Frequency = 2 sessions/week Intensity = 60%–80% Con = stretching placebo program	SCFS, 1-RM, PPB, hand-grip dynamometry

BDI, Beck Depression Inventory; DXA, dual-energy X-ray absorptiometry; EORTC QLQ-C30, European Organization for Research and Treatment of Cancer Quality of Life Questionnaire; RBDI, Finnish modified version of Beck's 13-item depression scale; FACT-B, FACT-F, FACT-G, and FACT-P, Functional Assessment of Cancer Therapy- (FACT-) Breast, Fatigue, General, and Prostate; FACIT-F, Functional Assessment of Chronic Illness Therapy (FACIT) questionnaire for fatigue; MOS SF-36, Medical Outcomes Study Short Form; MFSI-SF, Multidimensional Fatigue Inventory; PARQ, Physical Activity Readiness Questionnaire; PFS, Piper Fatigue Scale; PANAS, Positive and Negative Affect Scale; SPAQ, Scottish Physical Activity Questionnaire; SCFS, Schwartz Cancer Fatigue Scale; SWLS, Satisfaction with Life Scale; WHQ, Women's Health Questionnaire.

* Age presented with mean and SD or range where reported.

** Supervised multimodal exercise interventions involved a warm-up period, aerobic training (walking, cycling ergometers, and circuits), muscle strength training, and stretching exercises followed by cooldown and relaxation periods.

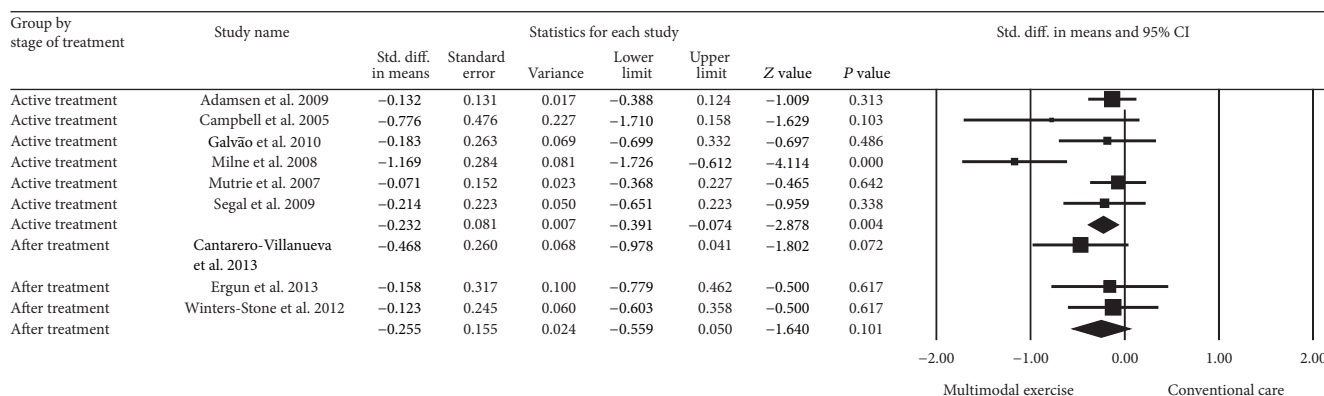


FIGURE 4: Effect estimate of supervised multimodal exercise on CRF according to anticancer treatment stage. Standardized mean difference (SMD) was calculated for the random effects model of meta-analysis. IV, inverse of variance; CI, confidence interval.

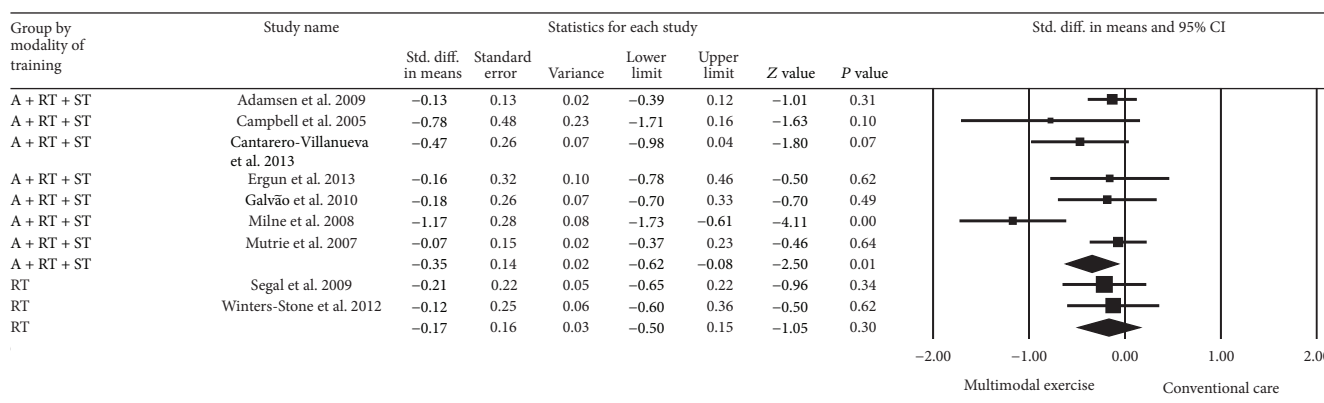


FIGURE 5: Effect estimate of supervised multimodal exercise on CRF according to the mode of exercise. A + RT + ST, aerobic exercise + resistance training + stretching; RT, resistance training. Standardized mean difference (SMD) was calculated for the random effects model of meta-analysis. IV, inverse of variance; CI, confidence interval.

cancer patients receiving anticancer treatment (SMD = -0.23, 95% CI -0.39 to -0.07), $P < 0.0001$ with moderate statistical heterogeneity ($I^2 = 64\%$). Nonsignificant differences were found after anticancer treatment ($P = 0.10$) (Figure 4).

With regard to mode of exercise, multimodal exercise interventions including aerobic exercise + resistance training + stretching were implemented by seven studies [24–30]; the pooled effect estimate for this subgroup showed significant reductions in CRF symptoms (SMD = -0.35, 95% CI -0.62 to -0.08), $P = 0.01$. Two studies evaluated the effects of resistance training on CRF [31, 32]. The pooled effects were not statistically significant (SMD = -0.17, 95% CI -0.50 to 0.15), $P = 0.30$ (Figure 5).

4.9. Metaregression: Heterogeneity and Dose-Response Relationships. Our metaregression model showed that length (weeks of training), frequency (sessions/week), and duration (minutes/session) of the supervised multimodal exercise interventions were linearly associated with overall improvements in CRF levels (Tau-squared = 0.04, $P = 0.04$) (Figure 6). No significant dose-response interactions were observed for publication year and training intensity ($P > 0.05$).

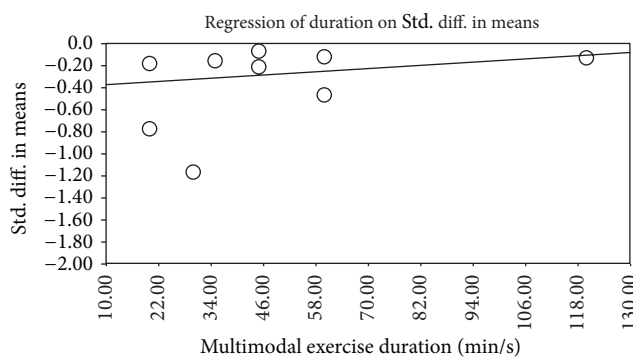


FIGURE 6: Bubble plot for the dose-response relationship between the intervention duration (minutes/session) and effect estimates changes for CRF from the nine randomized controlled trials included in the metaregression analysis ($P = 0.04$).

5. Discussion

Our pooled analysis demonstrated that supervised multimodal exercise improves CRF when compared with conventional care. Similar results have been presented in prior

meta-analyses on fatigue symptoms [8, 14], depression [34], and QoL [35] in cancer survivors. Further, our results are in line with those published by Fong et al. [33], where physical activity including strengthening exercises, with or without supervision, was positively associated with body composition, physical functioning, and psychological outcomes including fatigue. Nevertheless, there is insufficient information available to elucidate the physiological mechanisms for the effects of supervised multimodal exercise in reducing fatigue during cancer therapy and further research is warranted in this field [36–40].

Different from other systematic reviews, a novel finding of this review is that most interventions included in this meta-analysis were performed during an active treatment stage, especially chemotherapy. In this sense, recent findings published by Oechsle et al. [41] in a prospective randomized pilot trial found that structured exercise improved CRF in 48 patients receiving myeloablative chemotherapy who received supervised exercise five times a week with ergometer training and strength exercises for 20 min each during the hospitalization period. Our results and the current body of evidence demonstrate that RT and exercise interventions can provide significant effects on fatigue during cancer treatment, especially in patients receiving chemotherapy; however, further trials are needed to reinforce this evidence and encourage structured exercise interventions for cancer survivors undergoing anticancer treatment.

In this sense, the present meta-analysis revealed that supervised multimodal exercise leads to a significant reduction in fatigue scores in cancer survivors during and after cancer treatment. The effects of RT were not addressed by the American Cancer Society [3] that recommended RT but have been recently examined in patients undergoing cancer treatment [42]. Nevertheless, further studies are needed before RT can be recommended for cancer patients undergoing cancer therapy. Specifically, more information is required regarding the effects of initial chemotherapy and radiation therapy on muscle satellite (progenitor) cells that proliferate in response to supervised multimodal exercise [8, 42]. Clinically, this may allow the maintenance or an increase in functional performance, as well as a reduction of the risk of developing CRF, and improve perceived energy, mental capacity, and psychological status. It is not clear whether previously sedentary patients can or will adhere to an exercise program as proposed by ACSM and, if they cannot, whether the amount of exercise they do engage in will still be of benefit in terms of symptom relief (i.e., anxiety, depression, lack of sleep, and mood change) and reduction of the risk of adverse events [43].

In light of this evidence and considering that supervised exercise is broadly accepted as a beneficial intervention for cancer survivors, it is necessary to carefully conduct pre-screening procedures for cancer survivors in order to achieve an adequate prescription of exercise programs, adjusting patient's specific variables, such as physiological responses and physical disturbances underlying carcinogenic process and its treatment [38]. Thus, healthcare providers who have knowledge of exercise prescription in cancer patients are ideally placed to pursue further research in this area and

to prescribe physical exercise among cancer survivors [43–46]. Our findings indicate that health professionals must recognize the important benefits of adjuvant interventions in cancer survivors, such as exercise, that counteract the negative side effects of cancer treatments.

Naturally, our study has some limitations that need to be addressed. First, the average score of the quality of the studies included in this is greater than the average score for trials in physiotherapy. The risk of bias was evaluated by one author and this could be a limitation for this process, although this limitation could be counteracted considering that PEDro scale is a broadly validated tool. A second limitation is that considerable statistical heterogeneity was present in all effect estimates. Possible explanations for this heterogeneity are the diversity of sample sizes, the characteristics of strengthening programs (i.e., length, duration, and intensity) evaluated in the studies included, and the wide variety in outcome measurement tools used among studies. This heterogeneity can be observed in the forest plots (Figures 2–4).

6. Conclusion

In summary, the findings of this systematic review can be used to promote professional supervision in cancer rehabilitation settings and, eventually, to reinforce the conception that supervised exercise is safe and beneficial for cancer survivors through a major recommendation of strengthening programs by health professionals. A broader recommendation of exercise will lead to achievement of consistent weekly volumes of exercise if possible, including exercise twice weekly, and stretching exercises on days of nonexercise. Likewise, these results supported the implementation of personalized supervision in research, since it can optimize patient's adherence to and compliance with interventions.

Appendix

Full Search Strategy

PubMed Search Strategy

- (1) randomized controlled trialPublication Type
- (2) controlled clinical trialPublication Type
- (3) randomi*edTitle/Abstract
- (4) trialTitle
- (5) "clinical trials as topic" MeSH Major Topic
- (6) #1 OR #2 OR #3 OR #4 OR #5
- (7) cancerTitle/Abstract
- (8) neoplasm*Title/Abstract
- (9) (tumour* or tumor*)Title/Abstract
- (10) carcino*Title/Abstract
- (11) (leukaemi* or leukemi*)Title/Abstract
- (12) #7 OR #8 OR #9 OR #10 OR #11
- (13) Physical activityTitle/Abstract

- (14) ExerciseTitle/Abstract
- (15) AerobicTitle/Abstract
- (16) ResistanceTitle/Abstract
- (17) StrengthTitle/Abstract
- (18) StretchingTitle/Abstract
- (19) #13 OR #14 OR #15 OR #16 OR #17 OR #18 OR #19
- (20) fatigueTitle/Abstract
- (21) #6 AND #12 AND #20 AND #21.

CENTRAL Search Strategy. (randomized controlled trial) OR controlled clinical trial) OR randomised) OR trial) OR “clinical trials as topic”) AND cancer) OR neoplasm*) OR tumour*) OR tumor*) OR carcino*) OR leukaemi*) OR leukemi*) AND physical activity) OR exercise) OR resistance) OR strength) OR stretching) AND fatigue.

EMBASE Search Strategy. (randomized AND controlled AND trial) OR controlled) AND clinical AND trial) OR randomised OR trial OR “clinical trials as topic”/exp OR “clinical trials as topic”) AND (cancer/exp OR cancer)) OR neoplasm* OR tumour* OR tumor* OR carcino* OR leukaemi* OR leukemi*) AND physical AND activity) OR exercise/exp OR exercise OR resistance OR strength/exp OR strength OR) AND (fatigue/exp OR fatigue).

OID Search Strategy. (randomized and controlled and trial) OR controlled) AND clinical and trial) OR randomised or trial).mp. OR “clinical trials as topic”/exp OR “clinical trials as topic”.mp.) AND (cancer/exp or cancer.mp.)) OR neoplasm*.mp. OR tumour*.mp. OR tumor*.mp. OR carcino*.mp. OR leukaemi*.mp. OR leukemi*.mp.) AND physical.mp. AND activity.mp.) OR exercise/exp OR exercise.mp. OR aerobic.mp. OR resistance.mp. OR strength/exp OR strength.mp) AND (fatigue/exp OR fatigue.mp.) mp = title, abstract, full text, caption text.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

Authors' Contribution

Jose F. Meneses-Echavez designed the study, applied the search strategy, extracted the data, conducted the pooled analysis, and redacted the major part of the paper. Robinson Ramírez-Vélez applied the search strategy, extracted data, and contributed to preparation of the paper. Finally, Emilio González Jiménez contributed to design of the study, provided support in the search strategy and selection criteria, wrote the discussion, and made major revisions.

Acknowledgment

This paper and own authors data described in this paper were supported by the grant from Vicerrectoría de Investigaciones, Universidad de Santo Tomás (Contract no. 617-3-2013).

References

- [1] R. Siegel, D. Naishadham, and A. Jemal, “Cancer statistics,” *Cancer Journal for Clinicians*, vol. 63, no. 1, pp. 11–30, 2013.
- [2] R. Murillo, M. Piñeros, and G. Hernández, *Atlas de mortalidad por cáncer en Colombia*, Instituto Nacional de Cancerología, Instituto Geográfico Agustín Codazzi, Bogotá, Colombia, 2004.
- [3] American Cancer Society, *Cancer Facts & Figures*, American Cancer Society, Atlanta, Ga, USA, 2012.
- [4] P. Stone, A. Richardson, E. Ream, A. G. Smith, D. J. Kerr, and N. Kearney, “Cancer-related fatigue: inevitable, unimportant and untreatable? Results of a multi-centre patient survey,” *Annals of Oncology*, vol. 11, no. 8, pp. 971–975, 2000.
- [5] National Comprehensive Cancer Network, “Clinical Practice Guidelines in Oncology,” 2013, https://www.nccn.org/professionals/physician_gls/pdf/fatigue.pdf.
- [6] P. Hartvig, J. Aulin, M. Hugerth, S. Wallenberg, and G. Wage-nius, “Fatigue in cancer patients treated with cytotoxic drugs,” *Journal of Oncology Pharmacy Practice*, vol. 12, no. 3, pp. 155–164, 2006.
- [7] M. Groenvold, M. A. Petersen, E. Idler, J. B. Bjorner, P. M. Fayers, and H. T. Mouridsen, “Psychological distress and fatigue predicted recurrence and survival in primary breast cancer patients,” *Breast Cancer Research and Treatment*, vol. 105, no. 2, pp. 209–219, 2007.
- [8] B. Strasser, K. Steindorf, J. Wiskemann, and C. M. Ulrich, “Impact of resistance training in cancer survivors: a meta-analysis,” *Medicine and Science in Sports and Exercise*, vol. 45, no. 11, pp. 2080–2090, 2013.
- [9] V. Cavalheri, F. Tahirah, M. Nonoyama, S. Jenkins, and K. Hill, “Exercise training for people following lung resection for non-small cell lung cancer—a cochrane systematic review,” *Cancer Treatment Reviews*, vol. 40, no. 4, pp. 585–594, 2014.
- [10] C. Payne, P. J. Larkin, S. McIlfatrick, L. Dunwoody, and J. H. Gracey, “Exercise and nutrition interventions in advanced lung cancer: a systematic review,” *Current Oncology*, vol. 20, no. 4, pp. e321–e337, 2013.
- [11] F. Cramp and J. Byron, “Exercise for the management of cancer-related fatigue in adults,” *Cochrane Database of Systematic Reviews*, vol. 11, Article ID CD006145, 2012.
- [12] J. Choi, Y. Fukuoka, and J. H. Lee, “The effects of physical activity and physical activity plus diet interventions on body weight in overweight or obese women who are pregnant or in postpartum: a systematic review and meta-analysis of randomized controlled trials,” *Preventive Medicine*, vol. 56, no. 6, pp. 351–364, 2013.
- [13] E. Carmeli, S. Sheklow, and R. Coleman, “A comparative study of organized class-based exercise programs versus individual home-based exercise programs for elderly patients following hip surgery,” *Disability and Rehabilitation*, vol. 28, no. 16, pp. 997–1005, 2006.
- [14] M. J. Velthuis, S. C. Agasi-Idenburg, G. Aufdemkampe, and H. M. Wittink, “The effect of physical exercise on cancer-related fatigue during cancer treatment: a meta-analysis of randomised controlled trials,” *Clinical Oncology*, vol. 22, no. 3, pp. 208–221, 2010.
- [15] C. M. Schneider, C. C. Hsieh, L. K. Sprod, S. D. Carter, and R. Hayward, “Effects of supervised exercise training on cardiopulmonary function and fatigue in breast cancer survivors during and after treatment,” *Cancer*, vol. 110, no. 4, pp. 918–925, 2007.

- [16] S. Whitehead and K. Lavelle, "Older breast cancer survivors' views and preferences for physical activity," *Qualitative Health Research*, vol. 19, no. 7, pp. 894–906, 2009.
- [17] R. R. Spence, K. C. Heesch, and W. J. Brown, "Colorectal cancer survivors' exercise experiences and preferences: qualitative findings from an exercise rehabilitation programme immediately after chemotherapy," *European Journal of Cancer Care*, vol. 20, no. 2, pp. 257–266, 2011.
- [18] K. Y. Lin, S. C. Shun, Y. H. Lai, J. T. Liang, and J. Y. Tsauo, "Comparison of the effects of a supervised exercise program and usual care in patients with colorectal cancer undergoing chemotherapy," *Cancer Nursing*, vol. 37, no. 2, pp. E21–E29, 2014.
- [19] A. Liberati, D. G. Altman, J. Tetzlaff et al., "The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration," *Journal of Clinical Epidemiology*, vol. 62, pp. 1–34, 2009.
- [20] J. P. T. Higgins and S. Green, *Cochrane Handbook for Systematic Reviews of Interventions. Version 5.1.0.*, The Cochrane Collaboration, 2011, <http://handbook.cochrane.org/>.
- [21] K. A. Robinson and K. Dickersin, "Development of a highly sensitive search strategy for the retrieval of reports of controlled trials using PubMed," *International Journal of Epidemiology*, vol. 31, no. 1, pp. 150–153, 2002.
- [22] American College of Sports Medicine (ACSM), "American College of Sports Medicine position stand. Progression models in resistance training for healthy adults," *Medicine & Science in Sports & Exercise*, vol. 41, no. 3, pp. 687–708, 2009.
- [23] N. A. de Morton, "The PEDro scale is a valid measure of the methodological quality of clinical trials: a demographic study," *Australian Journal of Physiotherapy*, vol. 55, no. 2, pp. 129–133, 2009.
- [24] L. Adamsen, M. Quist, C. Andersen et al., "Effect of a multimodal high intensity exercise intervention in cancer patients undergoing chemotherapy, randomised controlled trial," *BMJ*, vol. 339, p. b3410, 2009.
- [25] A. Campbell, N. Mutrie, F. White, F. McGuire, and N. Kearney, "A pilot study of a supervised group exercise programme as a rehabilitation treatment for women with breast cancer receiving adjuvant treatment," *European Journal of Oncology Nursing*, vol. 9, no. 1, pp. 56–63, 2005.
- [26] I. Cantarero-Villanueva, C. Fernández-Lao, A. I. Cuesta-Vargas, R. del Moral-Avila, C. Fernández-de-Las-Peñas, and M. Arroyo-Morales, "The effectiveness of a deep water aquatic exercise program in cancer-related fatigue in breast cancer survivors: a randomized controlled trial," *Archives of Physical Medicine and Rehabilitation*, vol. 94, no. 2, pp. 221–230, 2013.
- [27] M. Ergun, S. Eyigor, B. Karaca, A. Kisim, and R. Uslu, "Effects of exercise on angiogenesis and apoptosis-related molecules, quality of life, fatigue and depression in breast cancer patients," *European Journal of Cancer Care*, vol. 22, no. 5, pp. 626–637, 2013.
- [28] D. A. Galvão, D. R. Taaffe, N. Spry, D. Joseph, and R. U. Newton, "Combined resistance and aerobic exercise program reverses muscle loss in men undergoing androgen suppression therapy for prostate cancer without bone metastases: a randomized controlled trial," *Journal of Clinical Oncology*, vol. 28, no. 2, pp. 340–347, 2010.
- [29] H. M. Milne, K. E. Wallman, S. Gordon, and K. S. Courneya, "Effects of a combined aerobic and resistance exercise program in breast cancer survivors: a randomized controlled trial," *Breast Cancer Research and Treatment*, vol. 108, no. 2, pp. 279–288, 2008.
- [30] N. Mutrie, A. M. Campbell, F. Whyte et al., "Benefits of supervised group exercise programme for women being treated for early stage breast cancer: pragmatic randomised controlled trial," *British Medical Journal*, vol. 334, no. 7592, pp. 517–520, 2007.
- [31] R. J. Segal, R. D. Reid, K. S. Courneya et al., "Randomized controlled trial of resistance or aerobic exercise in men receiving radiation therapy for prostate cancer," *Journal of Clinical Oncology*, vol. 27, pp. 344–351, 2009.
- [32] K. M. Winters-Stone, J. Dobek, J. A. Bennett, L. M. Nail, M. C. Leo, and A. Schwartz, "The effect of resistance training on muscle strength and physical function in older, postmenopausal breast cancer survivors: a randomized controlled trial," *Journal of Cancer Survivorship*, vol. 6, no. 2, pp. 189–199, 2012.
- [33] D. Y. T. Fong, J. W. C. Ho, B. P. H. Hui et al., "Physical activity for cancer survivors: meta-analysis of randomised controlled trials," *British Medical Journal*, vol. 344, article e70, 2012.
- [34] A. L. Brosse, E. S. Sheets, H. S. Lett, and J. A. Blumenthal, "Exercise and the treatment of clinical depression in adults: recent findings and future directions," *Sports Medicine*, vol. 32, no. 12, pp. 741–760, 2002.
- [35] R. A. Ferrer, T. B. Huedo-Medina, B. T. Johnson, S. Ryan, and L. S. Pescatello, "Exercise interventions for cancer survivors: a meta-analysis of quality of life outcomes," *Annals of Behavioral Medicine*, vol. 41, no. 1, pp. 32–47, 2011.
- [36] L. W. Jones and K. S. Courneya, "Exercise counseling and programming preferences of cancer survivors," *Cancer Practice*, vol. 10, no. 4, pp. 208–215, 2002.
- [37] J. L. Labourey, "Physical activity in the management of cancer-related fatigue induced by oncological treatments," *Annales de Readaptation et de Médecine Physique*, vol. 50, no. 6, pp. 450–454, 2007.
- [38] K. H. Schmitz, K. S. Courneya, C. Matthews et al., "American college of sports medicine roundtable on exercise guidelines for cancer survivors," *Medicine and Science in Sports and Exercise*, vol. 42, no. 7, pp. 1409–1426, 2010.
- [39] W. L. Haskell, I.-M. Lee, R. R. Pate et al., "Physical activity and public health: updated recommendation for adults from the American College of Sports Medicine and the American Heart Association," *Medicine & Science in Sports & Exercise*, vol. 39, no. 8, pp. 1423–1434, 2007.
- [40] S. A. Mitchell, "Cancer-related fatigue: state of the science," *PM & R*, vol. 2, no. 5, pp. 364–383, 2010.
- [41] K. Oechsle, Z. Aslan, Y. Suesse, W. Jensen, C. Bokemeyer, and M. De Wit, "Multimodal exercise training during myeloablative chemotherapy: a prospective randomized pilot trial," *Supportive Care in Cancer*, vol. 22, no. 1, pp. 63–69, 2014.
- [42] P. M. Clarkson and S. A. Kaufman, "Should resistance exercise be recommended during breast cancer treatment?" *Medical Hypotheses*, vol. 75, no. 2, pp. 192–195, 2010.
- [43] O. Minton, A. Berger, A. Barsevick et al., "Cancer-related fatigue and its impact on functioning," *Cancer*, vol. 119, no. 11, pp. 2124–2130, 2013.
- [44] P. Allavena, G. Germano, F. Marchesi, and A. Mantovani, "Chemokines in cancer related inflammation," *Experimental Cell Research*, vol. 317, no. 5, pp. 664–673, 2011.

- [45] L. N. Saligan and H. S. Kim, "A systematic review of the association between immunogenomic markers and cancer-related fatigue," *Brain, Behavior, and Immunity*, vol. 26, no. 6, pp. 830–848, 2012.
- [46] M. Löf, K. Bergström, and E. Weiderpass, "Physical activity and biomarkers in breast cancer survivors: a systematic review," *Maturitas*, vol. 73, no. 2, pp. 134–142, 2012.

Research Article

A Portable Gait Asymmetry Rehabilitation System for Individuals with Stroke Using a Vibrotactile Feedback

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Received 30 January 2015; Revised 21 April 2015; Accepted 28 April 2015

Academic Editor: Stephen Goss

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Gait asymmetry caused by hemiparesis results in reduced gait efficiency and reduced activity levels. In this paper, a portable rehabilitation device is proposed that can serve as a tool in diagnosing gait abnormalities in individuals with stroke and has the capability of providing vibration feedback to help compensate for the asymmetric gait. Force-sensitive resistor (FSR) based insoles are used to detect ground contact and estimate stance time. A controller (Arduino) provides different vibration feedback based on the gait phase measurement. It also allows wireless interaction with a personal computer (PC) workstation using the XBee transceiver module, featuring data logging capabilities for subsequent analysis. Walking trials conducted with healthy young subjects allowed us to observe that the system can influence abnormality in the gait. The results of trials showed that a vibration cue based on temporal information was more effective than intensity information. With clinical experiments conducted for individuals with stroke, significant improvement in gait symmetry was observed with minimal disturbance caused to the balance and gait speed as an effect of the biofeedback. Future studies of the long-term rehabilitation effects of the proposed system and further improvements to the system will result in an inexpensive, easy-to-use, and effective rehabilitation device.

1. Introduction

Gait disturbance results in functional disability after stroke, and improving walking functionality is the most often stated goal of such subjects among all stroke-related impairments [1–5]. One-sided weakness, also known as hemiparesis, is the most common impairment pattern among the subjects suffering stroke, which can result in gait asymmetry. As gait symmetry and energy expenditure are related, the most efficient pattern is a symmetrical gait [6, 7]. Individuals with stroke have higher energy expenditures during gait and extremely low ambulatory activity levels compared with healthy controls [8, 9]. The poststroke asymmetric gait pattern appears to be an important factor in the increased energy expenditure observed. The musculoskeletal health of the nonparetic limb is also negatively affected by an asymmetric poststroke gait.

High forces repeatedly applied to a limb can lead to pain and joint degeneration [10, 11]. In a poststroke gait, increased vertical ground reaction forces through the nonparetic lower limb are positively correlated with temporal asymmetry [12]. Thus, over time, the asymmetric gait of such subjects exposes the nonparetic limb to increased loading.

Several methods can be used to evaluate and diagnose gait problems, with different classifications according to the severity of the disorder, based on the level of functionality, compared with a healthy gait [13]. Clinical therapists apply specialized rehabilitative techniques to correct the abnormalities [13, 14]. The objective of gait rehabilitation is to increase the functional walking ability of the patient to an acceptable level for performing normal tasks, thus reducing risks for subsequent health defects. Due to variation in the causes and symptoms of gait disorders, rehabilitative methods are often

focused on the individual patient [15]. Adequate gait rehabilitation demands committed time with a therapist, expensive instrumentation and training devices, and the use of a gait laboratory [15–17]. In stationary settings, force plates and force mats are used for their accuracy, but size, cost, and usability limit their implementation outside the clinic [18, 19]. Instrumented treadmills are able to gather large amounts of step data, but are limited by the controlled environment and prescribed walking pattern necessary [20]. Portable systems are also available to measure gait parameters [21–23]. Different implementations of these mobile systems have been evaluated and shown to provide accurate gait data, but they are expensive and complex equipment and the training required has limited their use [24–27].

Gait rehabilitation research has recently focused on the development of measurement and biofeedback devices. Novel air bladder sensors have been developed for gait analysis and have been used to provide visual feedback for correction of applied pressure under the foot [28, 29]. Visual-auditory feedback had been suggested for amputees, based on force sensors requiring a desktop computer for monitoring and feedback; the device is used in conjunction with a treadmill [30]. Recently, a force sensor insole and motion sensors were combined to record running data, demonstrating that the system is wearable with sensors for long periods of time and the data recorded by these sensors can be used for analysis of gait and movement [31]. The visual biofeedback devices implemented for individuals with stroke are either limited to use in providing assistance for improvement of quiet standing, such as restoration of weight-shifting capacity and reduction in body sway [32, 33], or used with treadmill for gait assistance [34, 35]. Similarly the audio-biofeedback devices introduced to individuals suffering stroke can be used for assistance in quiet standing and walking. Enhancement of weight-bearing has been reported to improve in poststroke using an audio-biofeedback device “SmartStep” [36]. Vibrotactile systems have been used recently in postural sway reduction and gait rehabilitation applications. Vibrotactile-based biofeedback systems were found to be an effective method in improving postural stability of healthy young subjects in complex standing tasks like quiet stance on wobble board and tandem-Romberg stance [37, 38]. In community-dwelling elderly subjects, vibrotactile biofeedback delivered control of mediolateral sway during gait and reduction of fall risk [39]. Vibrotactile biofeedback reduced trunk sway during quiet standing and locomotor activities in patients with vestibular loss [40–44]. Balance training in Parkinson’s disease patients using a biofeedback system showed beneficial effects on trunk stability [45]. These studies demonstrate the effectiveness of vibrotactile biofeedback in providing instructional cueing. Vibrotactors can provide effective cues with the least interference to the subject’s activities of daily life in portable biofeedback devices.

The purpose of this paper is to describe the design, manufacture, and verification of an inexpensive and portable gait rehabilitation biofeedback device for use by individuals with stroke. A major goal of this paper is to develop a system that can ultimately be available at low cost for use in gait symmetry rehabilitation outside of the traditional clinical environment

and to demonstrate its effectiveness in enhancing gait symmetry using the proposed system. To our knowledge, this is the first reported system to apply vibration feedback to individuals with stroke for gait symmetry training. The current system is capable of determining common gait parameters through force-sensitive resistors (FSRs) embedded in a custom insole that can be easily implemented in patient’s existing shoes. A waist-mounted microcontroller provides sensor sampling and vibrotactile biofeedback, as well as the ability to transmit real-time gait data wirelessly to a PC via an XBee module. By accurately measuring gait data and providing biofeedback to the user, the system provides an inexpensive and valuable tool for use in clinical rehabilitation. Using the proposed system, clinical trials were carried out in subjects suffering from poststroke gait asymmetry to evaluate and improve the effects of the device in reducing gait asymmetry. The effects of biofeedback were evaluated to provide efficient training with adequate feedback. Here, we describe our system, provide details of our subjects and protocols, and describe the parameters measured and our results. A discussion follows.

2. Materials and Methods

2.1. System Design. Individuals with stroke suffering from hemiparesis are highly motivated to recover a symmetrical gait cycle during normal walking. Temporal asymmetry measurement can be used to design a biofeedback system to assist patients in gait rehabilitation. To detect the temporal gait parameters, such as stance time and swing time, contact-based footswitches can be used. Change in pressure applied to a point can be detected using force-sensitive resistors (FSRs). A FSR-based footswitch system can work in the detection of foot contact with the ground, identifying the heel and toe contacts. This ground contact information for the right and left lower limbs is the basis of two important gait parameters: the time between first heel strike to toe off (stance time) and toe off to next heel strike (swing time). Manipulating these times can provide useful insight in determining gait abnormalities. The idea of our system is to match stance time for both legs and hence adopt temporal symmetry in the gait cycle, targeting subjects suffering from stroke. The wearable system is centered on an Arduino Due microcontroller board; the elements of the system are shown in Figure 1.

Our system collects heel and toe contact data with two insoles containing four FSRs on each insole, positioned at the heel, toe, fifth metatarsal, and first metatarsal. FSRs placed at the metatarsals allow validation in detecting ground contact. To ensure that male and female participants with diverse foot morphology could use this system, insole pairs of various sizes (Korean shoe sizes: 230, 240, 260, and 280) were built. A pair of insoles are connected physically to the Arduino board with wires; FSR signals are sampled at 1kHz. The analog inputs of the Arduino board continuously read the FSR signals. The Arduino board calculates the stance time on each side by reading the FSR sensors and identifying ground contact. FSRs (A401 by Tekscan) utilized in insoles are capable of measuring forces up to 30 kN with a response time of less than

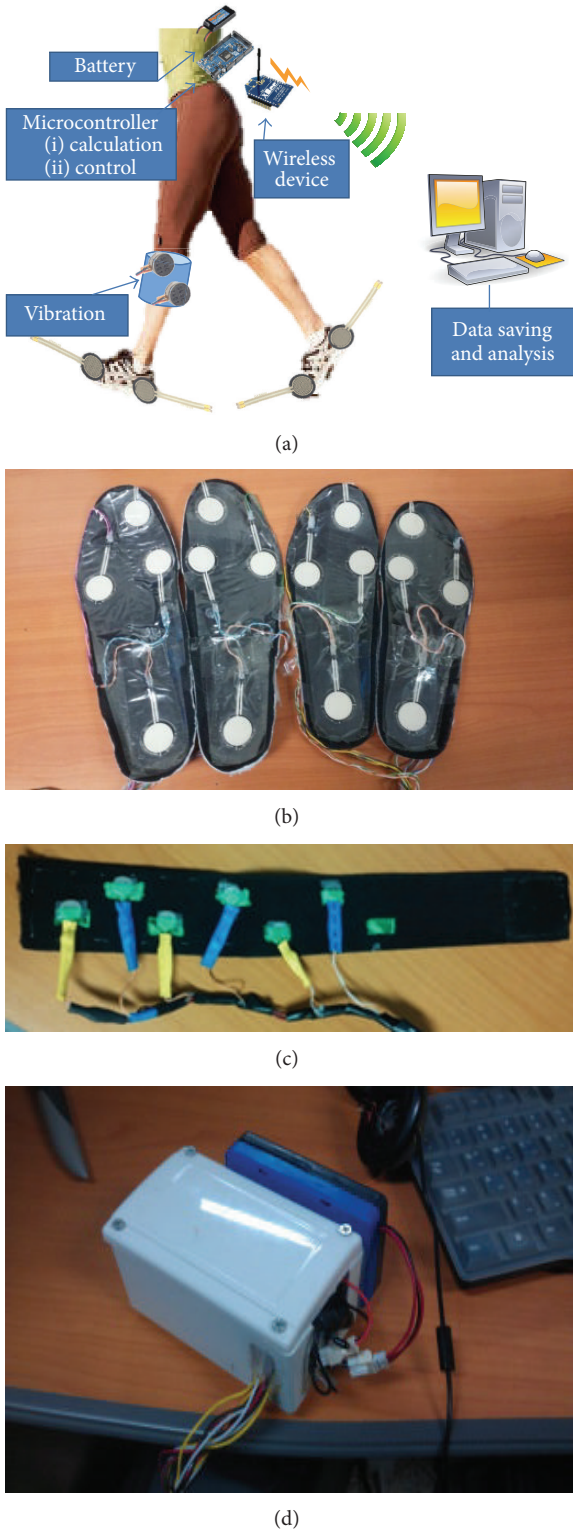


FIGURE 1: The device setup: (a) system diagram, (b) FSR-based insoles, (c) vibrotactors used for feedback, (d) controller with XBee transceiver and battery packed inside project case.

5 microseconds, linearity within $\pm 3\%$, repeatability within $\pm 2.5\%$ of full scale, and hysteresis of less than 4% of full scale [46].

The Arduino board is connected to the XBee [47] transceiver module (Series 1 PRO) through the serial communication port, and the XBee can wirelessly send data to a personal computer (PC) or wirelessly receive a command signal (paretic/handicapped side, vibration mode, and target symmetry ratio) from the PC. The wireless transceiver module also allows monitoring of FSR sensor data for calibration purposes. The portable system is connected with a 2100 mAh polymer lithium-ion battery, allowing an ample continuous operation time of 8 h. A small project case is used to enclose all the circuitry; the case size is $9 \times 12 \times 5$ cm and the whole system, including the battery, weighs about 450 g. An elastic belt, containing an array of six vibrotactors securely attached to the inside of the belt, is used for the vibrotactile biofeedback application on the subject. The vibrotactors used in our system are coin style, with a diameter of 10 mm and body length of 2.7 mm. Each vibrotactor operates at 3.3 V and 66 mA, producing an amplitude of 1.4 G [48]. The belt is worn by the subjects on the lower leg (between the knee and calf) instead of an in-shoe vibrotactor, so it should not interfere with proprioceptor information from the ground, as reduced feedback due to proprioceptive loss is likely to impair balance [49]. Also, direct muscle stimulation could contribute in enhancing the gait modification through afferent signal of vibration [50, 51]. The six vibrotactors cover the whole shank, from front to back. The vibrotactor array is interfaced with Arduino board's output to provide vibrotactile biofeedback. Control signals are proportionally generated on the Arduino board to drive vibrotactors. The modulation of intensity and duration is performed inside the Arduino, which generates the control signal proportionally depending on the mode of operation. An interface circuit provides capability of utilizing six vibrotactors simultaneously at 200 Hz and 3.3 V. The on/off status of the vibration signal can be visualized using the LED light connected to the array of vibrotactors. The whole system can be worn easily using elastic Velcro belts.

2.2. Vibration Modes. To achieve symmetry, subjects using this device get vibrational cues provided through the vibrotactors. Characteristics of the vibrational cue can differ to identify parameters of information being supplied. Currently, the system features three vibration modes: stance time matching constant vibration (StMCV) mode, symmetry ratio matching proportional vibration (SrMPV) mode, and swing phase constant vibration (SpCV) mode (Figure 2). StMCV and SrMPV modes provide cues targeting gait modification with information supplied in terms of vibration time and intensity, respectively. SpCV mode provides information on the swing phase to modify gait parameters.

In StMCV mode, vibration with constant intensity is provided on the handicapped/paretic side; vibration starts at heel strike and stays for time equal to the measured stance time of healthy side. In this mode, amplitude of vibration is 1.4 G and frequency of vibration is 200 Hz. In SrMPV mode, continuous vibration during the whole gait is provided on the handicapped/paretic side with varied vibration intensity. The vibration intensity is varied proportionally with difference between measured and target symmetry ratio. The target

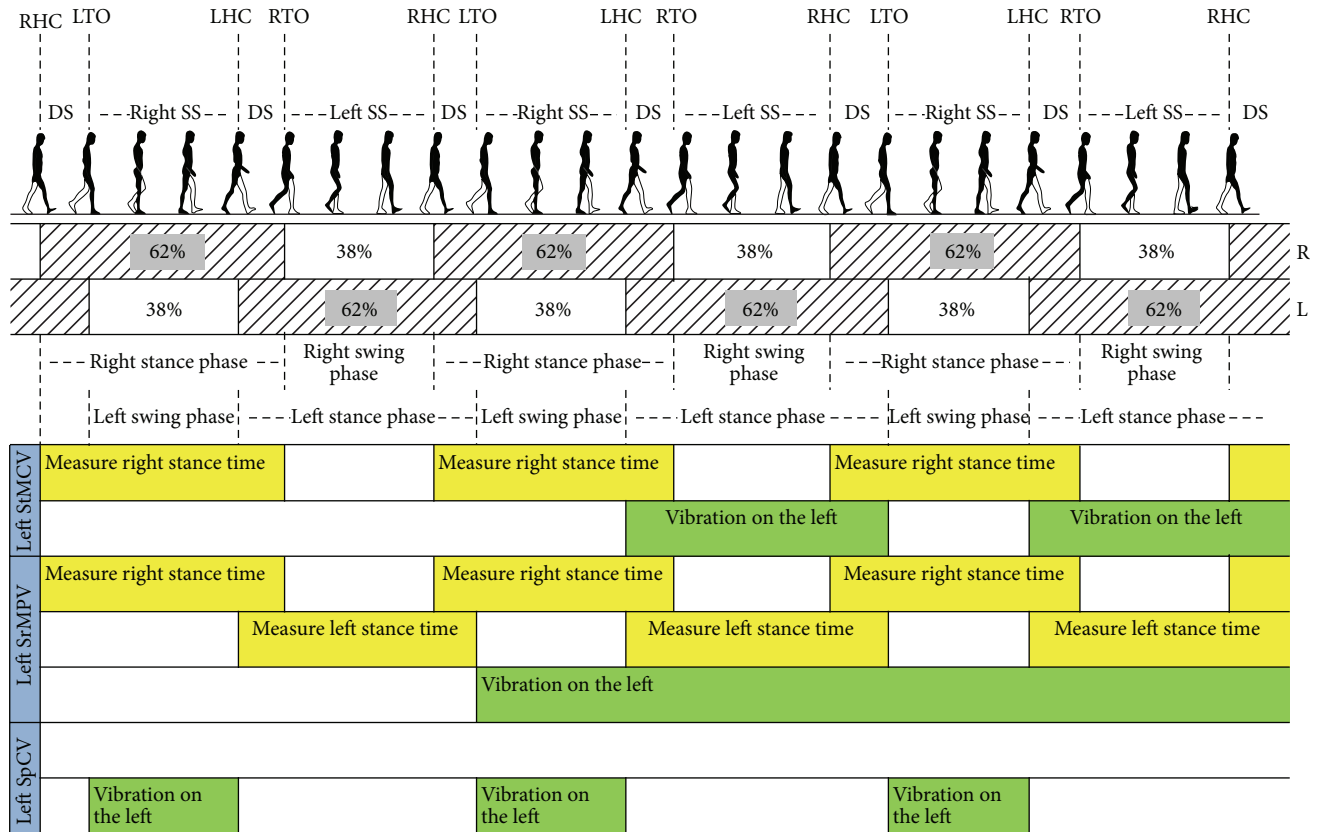


FIGURE 2: Modes of vibration explained with left-side supposed to be paretic/handicapped. (RHC: right heel contact, DS: double support, LTO: left toe off, Right SS: right single support, LHC: left heel contact, RTO: right toe off, and Left SS: left single support).

TABLE 1: Details of individuals with stroke.

Patient	Gender	Age	Height	Weight	Side of hemiplegia	Cause of stroke
1	Male	65	163 cm	57 kg	Left	Infarction
2	Male	67	165 cm	70 kg	Right	Infarction
3	Female	75	165 cm	65 kg	Left	Infarction
4	Male	52	166 cm	62 kg	Right	Infarction

symmetry ratio is matched with the measured symmetry ratio of the previous cycle. If the measured symmetry ratio is close to the target symmetry ratio, the vibration intensity is less and vice versa. In this mode, amplitude of vibration is varied between 0 and 1.4 G and frequency of vibration remains same which is 200 Hz. In SpCV mode, vibration with constant intensity is provided during the swing phase, regardless of the symmetry ratio and stance time of the healthy leg. In this mode, amplitude of vibration is 1.4 G and similarly frequency of vibration is 200 Hz.

2.3. Study Participants. To use the system for gait rehabilitation in individuals with stroke, it was first necessary to check the credibility and functionality of the system. For this purpose, five healthy young subjects (age 26.2 ± 3.27 years, males, weight 72.3 ± 5.63 kg, height 170.8 ± 10.68 cm) were recruited to check the effectiveness of influencing gait parameters by our proposed system. The subjects had no history of musculoskeletal or neurological disorders. Trials with healthy

young subjects were performed to show whether gait parameters measured with the proposed system could be used effectively to identify gait symmetry and provide biofeedback.

We also performed trials for proof-of-concept with four individuals with stroke to validate the use of our proposed system in increasing gait symmetry for patients and to demonstrate the possibility of implementing biofeedback in a gait training system. Demographic details of these subjects are provided in Table 1.

All individuals with stroke were inpatients of the Rehabilitation Center of Gyeongsang National University Hospital (Jinju, Republic of Korea). All subjects suffering stroke had clear symptoms of lower extremity weakness on the paretic side. All subjects gave written informed consent in accordance with the rules of our local Ethics Committee.

2.4. Experimental Protocol. Each subject was first introduced to the system and its use, and given instructions on how to interpret the feedback. Each subject installed the insole



FIGURE 3: Device attachment: (a) healthy young subject and (b) individual with stroke.

system inside their shoes and affixed the device to their waist over their clothes, using the easily attachable Velcro belts, which also handle the compact wire connections between the Arduino board and the insoles (Figure 3). Once the initial setup was complete, the subject was asked to walk in an empty, spacious area. FSR values acquired from the insoles on ground contact may vary depending on the participant, so prior to trials a preliminary walk was performed by each subject to determine the ground contact detection threshold. Each trial was conducted with different tasks given to the subject randomly. During each walking trial, the system is initialized from the PC via the XBee transceiver, which receives commands from the PC according to trial conditions and initializes the onboard processor. The system starts sending gait data to the PC and the PC logs the gait data for post-experimental analysis. All subjects performed trials at their self-preferred walking speed.

In our experimental trials different vibration modes were selected for the subjects (Table 2).

Healthy young subjects were asked to participate in walking tests to assess the system’s ability to influence gait. The trials on healthy young subjects were conducted with seven different scenarios: normal walk, walk with left-side handicapped without vibration, walk with left-side handicapped with StMCV mode, walk with left-side handicapped with SrMPV mode, walk with right-side handicapped without vibration, walk with right-side handicapped with StMCV mode, and walk with right-side handicapped with SrMPV mode. In the normal walk scenario, the subjects were asked

TABLE 2: Trial modes for subjects.

Vibration mode	Subjects	
	Healthy young	Individual with stroke
Without vibration	(1) Normal walk	
	(2) Left-side handicapped walk	(1) Normal walk
	(3) Right-side handicapped walk	
StMCV mode	(4) Left-side handicapped walk	(2) Normal walk
	(5) Right-side handicapped walk	
SrMPV mode	(6) Left-side handicapped walk	
	(7) Right-side handicapped walk	
SpCV mode		(3) Normal Walk

to walk with their natural gait and gait data were gathered. In the handicapped situation, the subjects were asked to induce the effect of gait asymmetry, so that the stance time of the handicapped side was double that of the healthy side (target symmetry ratio = 0.5). The aim of the trial was to demonstrate that a specific target symmetry ratio could be achieved by providing feedback. A 10 m randomized walking trial was set up for the healthy young subjects.

Individuals with stroke suffer from temporal asymmetry in their normal walk. Our experiments with such subjects were intended to demonstrate how the use of biofeedback could be helpful in improving temporal symmetry in gait. For

these subjects, a 6 m walking trial was set up. Trials with subjects suffering from stroke were conducted in three different scenarios: normal walk, walk with StMCV mode, and walk with SpCV mode. Subjects suffering from stroke were more comfortable in walking trials with use of their ordinary walking aid (single cane); thus all subjects used their canes in all trials. To improve gait symmetry using the vibrotactors' cue provided, the patients were asked to match the stance time on both lower limbs (target symmetry ratio = 1.0) by interpreting the vibrational feedback.

2.5. Data Collection and Analysis. All walking trials were conducted with coordination of the PC and an operator. A custom-built MATLAB GUI (Figure 4) was used to handle a two-way real-time communication with the Arduino board. The live link was set up between Arduino and MATLAB with the use of XBee transceivers ensuring real-time communication. The Arduino communicates with MATLAB at the baud rate of 57600 bps. Through the GUI, command signals (decimal format) were sent to Arduino board, which identify these command signals for determining the vibration mode, target symmetry ratio, and handicapped/paretic side (right or left) with a communication delay of approximately 10 ms. The gait data as a packet (sent from Arduino as a decimal format) was sent at the end of each gait cycle with the nearly same communication delay of 10 ms. Calibration of the system was performed by analyzing the sampled data of FSRs from an insole (Figure 4); utilizing this data, threshold for ground contact detection was determined. In each walking trial conducted with the subjects who suffered stroke, an Android smartphone was also used to identify mediolateral (ML) tilt and acceleration. The smart phone was physically attached to the waist with a leather belt. The frontal plane of the body was aligned with the X_s, Y_s plane of the phone to allow measurement of ML tilt and acceleration (Figure 4). An Android application running continuously on the smartphone calculated and sent data (String format) over Wi-Fi. The data sent from the smartphone were received on a router physically connected to the particular PC used in the experiment. The PC was also running a custom-built software written in Visual C++. It monitored the network card continuously, decoded data packets from the smart phone, and stored data for post-experiment analysis. Recently, we used smartphone as a reliable tool to assess body sway parameters and designed a biofeedback system [52]. Now our custom-made android program can identify ML tilt and ML acceleration and provide this information to a socket program on the PC along with information of time at 100 Hz. Walking distance (6 m) was a known parameter and time spent during each walk was extracted from the smartphone data to calculate the gait speed during trials. For trials of subjects who suffered stroke, gait speed was calculated after experiments, to observe how it was affected under the use of our vibrotactile device.

The distance of walking trial was 10 m and 6 m for participants who were healthy young and who suffered stroke, respectively. For trials of both subject groups, we utilized a margin of 2 m, before and after the specified distances, to make sure of the exclusion of the gait initiation and termination steps. Each subject (healthy young and individual

with stroke) performed each trial twice, an average of the measured gait data was utilized for analysis. The gait data logged for post-experimental analysis can be assessed in a more comprehensive and easily interpretable way by the use of symmetry ratio (R) [53], defined as

$$R = \frac{\text{Stance time of healthy side}}{\text{Stance time of Paretic or Handicapped side}} \quad (1)$$

The symmetry ratio (R) is considered for assessing gait modification/improvement. For individuals with stroke, ML tilt (RMS) and ML acceleration (RMS) were observed to determine the balance condition. To assess the significance of gait modification/improvement upon provision of feedback, a one-way ANOVA was used.

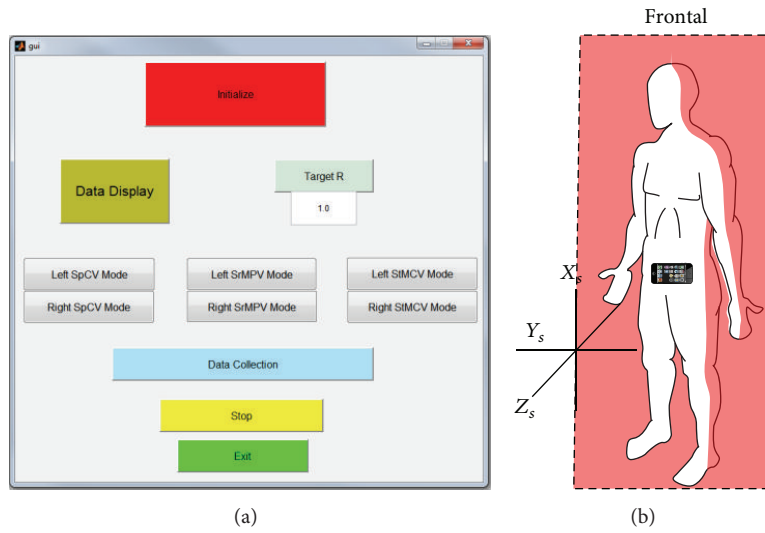
3. Results

3.1. Results of Healthy Young Subjects. The vibrotactile cues provided intuitive feedback to the subjects; it helped in influencing gait symmetry without intensive training. In the normal walking test conducted with healthy young subjects, the ratio was calculated using right leg stance time over left leg stance time, which is expected to be unity as the subjects walked with their natural gaits. The results of this trial were as follows for the five subjects: 1.098 ± 0.02 , 1.022 ± 0.03 , 0.991 ± 0.01 , 1.041 ± 0.02 , and 0.983 ± 0.01 . The data stored from this experiment are displayed in Figure 5.

Trials with healthy young subjects performing left-side handicapped walk and right-side handicapped walk were also conducted in three separate conditions for each: without vibration, StMCV mode, and SrMPV mode. Table 3 shows the symmetry ratio (R) determined from the gait data of these trials. Figure 6 shows a more comparative analysis of the effects of different vibration modes in achieving the target symmetry ratio. These values are the means and standard deviation of R collected over the 10 m walking trial.

Here, $Exp. R$ is the expected symmetry ratio and $S [1-5]$ is the subject number. Using ANOVA, we determined p -values for left handicapped without vibration versus StMCV mode ($p = 0.0008$), left handicapped without vibration versus SrMPV mode ($p = 0.0065$), right handicapped without vibration versus StMCV mode ($p = 0.0002$), and right handicapped without vibration versus SrMPV mode ($p = 0.0823$). In all five participants, lateral dominance resulted in reduced efforts and deviations in achieving target symmetry ratio during the right-side handicapped trials. The p -values indicate that feedback effectively provided cues to modify the gait of healthy young subjects in achieving the target symmetry ratios.

3.2. Results of Subjects Suffering from Stroke. Trials with subjects suffering from stroke were conducted in a similar manner, in which subjects were asked to walk in three scenarios: normal walk, walk with StMCV mode, and walk with SpCV mode. Patients used the vibration modes and attempted to improve their temporal symmetry in stance time. Tables 4 and 5 show the results for these subjects.



Online
 * Gait data acquisition and logging using MATLAB
 * Balance data acquisition and logging using visual C++

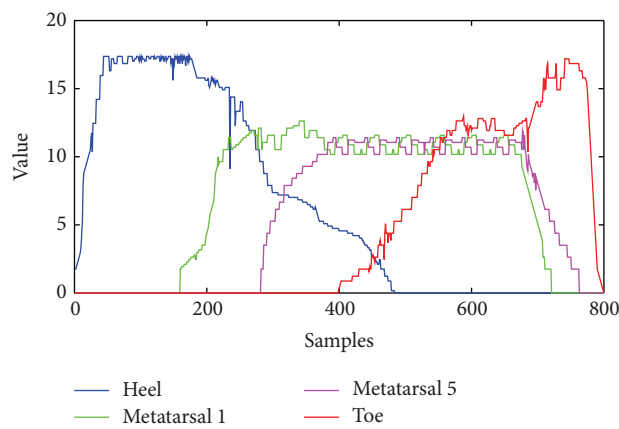
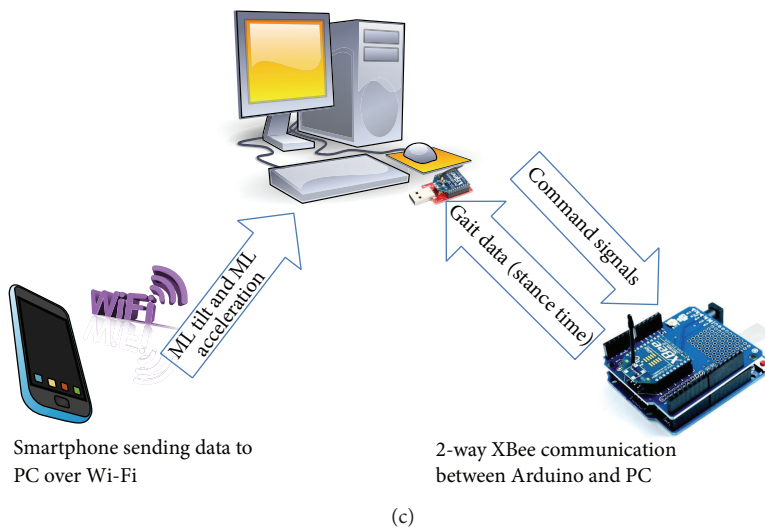


FIGURE 4: (a) MATLAB GUI, (b) smartphone placement, (c) communication network of the system, and (d) FSR data of one insole as read for calibration of the system.

TABLE 3: Results of healthy young subjects.

Exp. <i>R</i>	Left-side handicapped			Right-side handicapped		
	Without vibration	StMCV mode	SrMPV mode	Without vibration	StMCV mode	SrMPV mode
	0.5	0.5	0.5	0.5	0.5	0.5
S1	0.891 (± 0.16)	0.604 (± 0.07)	0.573 (± 0.08)	0.605 (± 0.20)	0.478 (± 0.09)	0.472 (± 0.11)
S2	0.745 (± 0.19)	0.540 (± 0.09)	0.617 (± 0.05)	0.587 (± 0.19)	0.503 (± 0.10)	0.556 (± 0.06)
S3	0.703 (± 0.20)	0.539 (± 0.11)	0.621 (± 0.10)	0.592 (± 0.16)	0.504 (± 0.08)	0.560 (± 0.09)
S4	0.718 (± 0.17)	0.594 (± 0.04)	0.475 (± 0.11)	0.539 (± 0.18)	0.469 (± 0.11)	0.489 (± 0.07)
S5	0.729 (± 0.12)	0.543 (± 0.10)	0.656 (± 0.09)	0.594 (± 0.13)	0.506 (± 0.09)	0.585 (± 0.10)

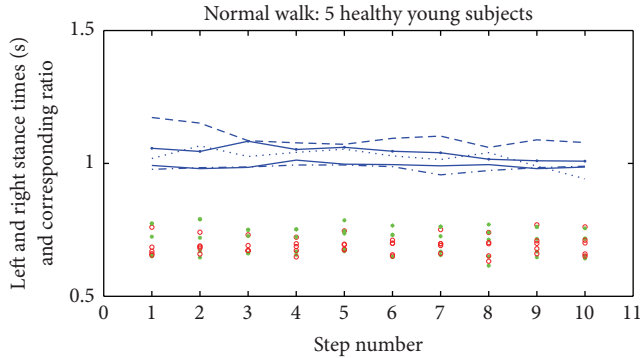


FIGURE 5: Normal walking trials of healthy young subjects. The stance time of the right side is marked by red circles and the stance time of the left side is marked by green asterisks. The distinct lines show the corresponding ratio (right to left) for each subject.

In Table 4, the symmetry ratio (R) is the mean value collected over 6 m walking to identify the effect of the proposed system on gait symmetry. The ML tilt (RMS) and acceleration (RMS) shows the body balance measured during trials. Using ANOVA for symmetry ratios listed in the table, we determined p -values for without vibration versus StMCV mode ($p = 0.0493$) and without vibration versus SpCV mode ($p = 0.0427$). Using ANOVA for ML tilt gave p -values for without vibration versus StMCV mode ($p = 0.8489$) and without vibration versus SpCV mode ($p = 0.9143$). Similarly, p -values for ML acceleration were calculated using ANOVA for without vibration versus StMCV mode ($p = 0.6077$) and without vibration versus SpCV mode ($p = 0.8006$). The results are shown in Figure 7 and represent a comprehensive analysis of the trials conducted for individuals with stroke.

Comparative analysis of the right leg stance time, left leg stance time, and the gait speed, over 6 m walking is shown in Table 5. Improvement in stance time of the paretic side is evident with comparison of without vibration and vibration modes. Similar to balance of these subjects, gait speed was not disturbed on provision of vibrotactile feedback (without vibration versus StMCV mode $p = 0.7810$ and versus SpCV mode $p = 0.8823$). Increase in stance time on paretic side was noticeable (without vibration versus StMCV mode $p = 0.1014$ and versus SpCV mode $p = 0.2106$) but not significant enough to have p -value < 0.05 . Nonparetic side experienced slight changes in stance times but they were highly insignificant (without vibration versus StMCV mode $p = 0.7913$ and versus SpCV mode $p = 0.4401$).

Change in stance time on the provision of vibration modes is represented in Figure 8. On the paretic side provision of feedback caused an increase of stance time for both vibration modes. Mean increase in stance time of the paretic side was 72 milliseconds for the StMCV mode and 59 milliseconds for the SpCV mode.

4. Discussion

Stroke induces gait asymmetry as an after effect, resulting in decreased ambulatory activities and increased energy expenditure for mobility. The current methods for addressing a gait abnormality in the clinical setting are to establish a diagnosis and then prescribe a treatment [13]. Error-reduction and error-augmentation are two of the major control strategies employed for gait training robots [49]. Error-reduction is applied more often and it includes the impedance control and assist-as-needed paradigm. Impedance control may ensure correct kinematics but may impair motor learning effects. In the assist-as-needed paradigm gait training robot interferes in phases which cannot be performed independently by the patients. Error-augmentation based controllers make a function or movement more difficult than real task. This is based on the assumed importance of error correction in motor learning, with the hypothesis that error amplification leads to an increased rate of motor skill acquisition. Currently we employed error-reduction method and plan to consider the comparison of error-reduction and error-augmentation in the vibration feedback as a future work. A recent study demonstrated the possibility that poststroke asymmetric walking patterns could be remediated utilizing the split-belt treadmill as a long-term rehabilitation strategy [54]. Likewise, turning-based treadmill training may be a feasible and effective strategy to improve turning ability, gait symmetry, muscle strength, and balance control for individuals with chronic stroke [55]. These treadmill based rehabilitation strategies outcome promising results on the expense of high cost, complex protocols, and therapists' involvement throughout the training. Gait asymmetry usually occurs as a result of the difficulty in loading the paretic lower extremity during stance [56–58]. Thus, our system is based on the idea of matching stance time for both legs and adopting temporal symmetry in the gait cycle. Our system proposes a tool to gather gait data on the subject, as well as a subsequent treatment device. The inexpensive and compact system features the measurement of gait data in real-time, which can be further logged wirelessly on a PC for post-experimental analysis. Also, biofeedback

TABLE 4: Results of subjects suffering from stroke (symmetry ratio, ML tilt, and ML acceleration).

Index Patient	Symmetry ratio (R)			ML Tilt-RMS (degree)			ML acceleration-RMS (m/s ²)		
	Without vibration	StMCV mode	SpCV mode	Without vibration	StMCV mode	SpCV mode	Without vibration	StMCV mode	SpCV mode
1 (left hemi)	1.236 (±0.05)	1.136 (±0.19)	1.132 (±0.17)	4.910 (±0.65)	4.516 (±0.29)	4.802 (±0.96)	0.329 (±0.12)	0.295 (±0.23)	0.317 (±0.26)
2 (right hemi)	1.334 (±0.01)	1.078 (±0.26)	1.102 (±0.19)	6.329 (±0.89)	6.199 (±0.83)	6.505 (±0.52)	0.525 (±0.21)	0.469 (±0.16)	0.498 (±0.17)
3 (left hemi)	1.152 (±0.06)	1.114 (±0.10)	1.026 (±0.24)	4.491 (±0.77)	4.616 (±0.92)	4.768 (±0.60)	0.391 (±0.17)	0.339 (±0.11)	0.348 (±0.19)
4 (right hemi)	1.148 (±0.07)	1.095 (±0.24)	1.104 (±0.15)	5.985 (±0.71)	5.896 (±0.64)	5.914 (±0.88)	0.50 (±0.09)	0.497 (±0.14)	0.511 (±0.20)

TABLE 5: Results of subjects suffering from stroke (right stance, left stance, and gait speed).

Mode Patient	Without vibration			StMCV mode			SpCV mode		
	Right stance (s)	Left stance (s)	Gait speed (m/s)	Right stance (s)	Left stance (s)	Gait speed (m/s)	Right stance (s)	Left stance (s)	Gait speed (m/s)
1 (left hemi)	0.981 (± 0.02)	0.803 (± 0.02)	0.48	0.977 (± 0.02)	0.860 (± 0.02)	0.45	0.957 (± 0.02)	0.847 (± 0.02)	0.46
2 (right hemi)	0.760 (± 0.02)	1.013 (± 0.01)	0.40	0.885 (± 0.02)	0.958 (± 0.03)	0.38	0.848 (± 0.02)	0.945 (± 0.01)	0.41
3 (left hemi)	0.998 (± 0.01)	0.867 (± 0.02)	0.46	0.993 (± 0.02)	0.892 (± 0.01)	0.48	0.912 (± 0.02)	0.887 (± 0.02)	0.49
4 (right hemi)	0.890 (± 0.01)	1.021 (± 0.01)	0.39	0.972 (± 0.03)	1.059 (± 0.02)	0.38	0.976 (± 0.01)	1.076 (± 0.01)	0.39

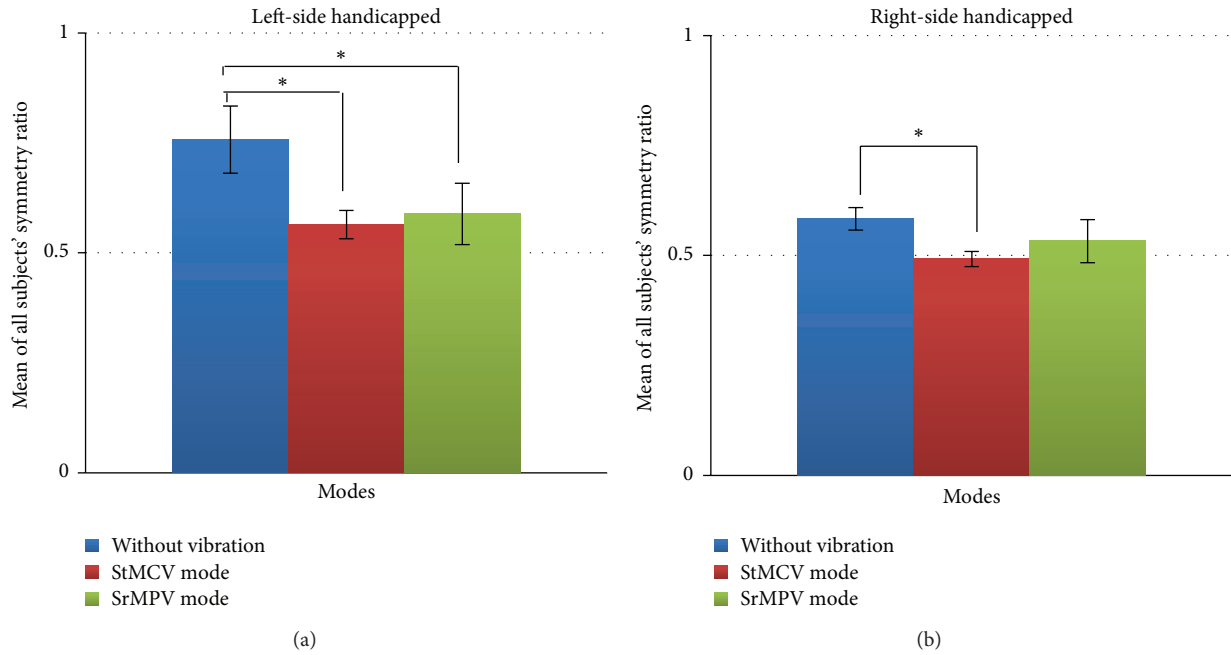


FIGURE 6: Comparison of vibration modes for trials of healthy young subjects in achieving target symmetry ratio (* $p < 0.05$).

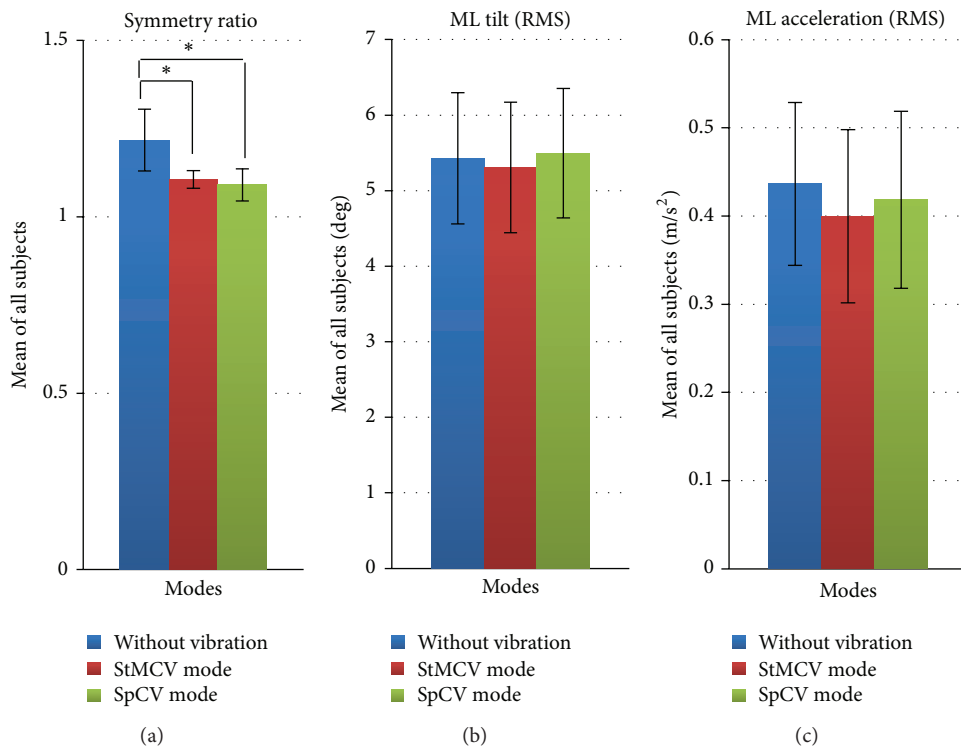


FIGURE 7: Comparative analysis of different vibration modes in trials conducted with subjects suffering from stroke (* $p < 0.05$).

based on the gait data, which can influence gait symmetry, can be provided by our system through vibrotactors. Human tactile perception is robust and suitable for multimodal sensing [59]. Our system influenced gait symmetry with a feedback signal provided as a vibration to the subject. They

were able to use the cue and significantly modify gait without extensive training. This form of feedback could easily help the users during daily life activities. With an estimated prototype cost of US\$ 300, our system provides an economical solution, compared with the more expensive ones currently available.

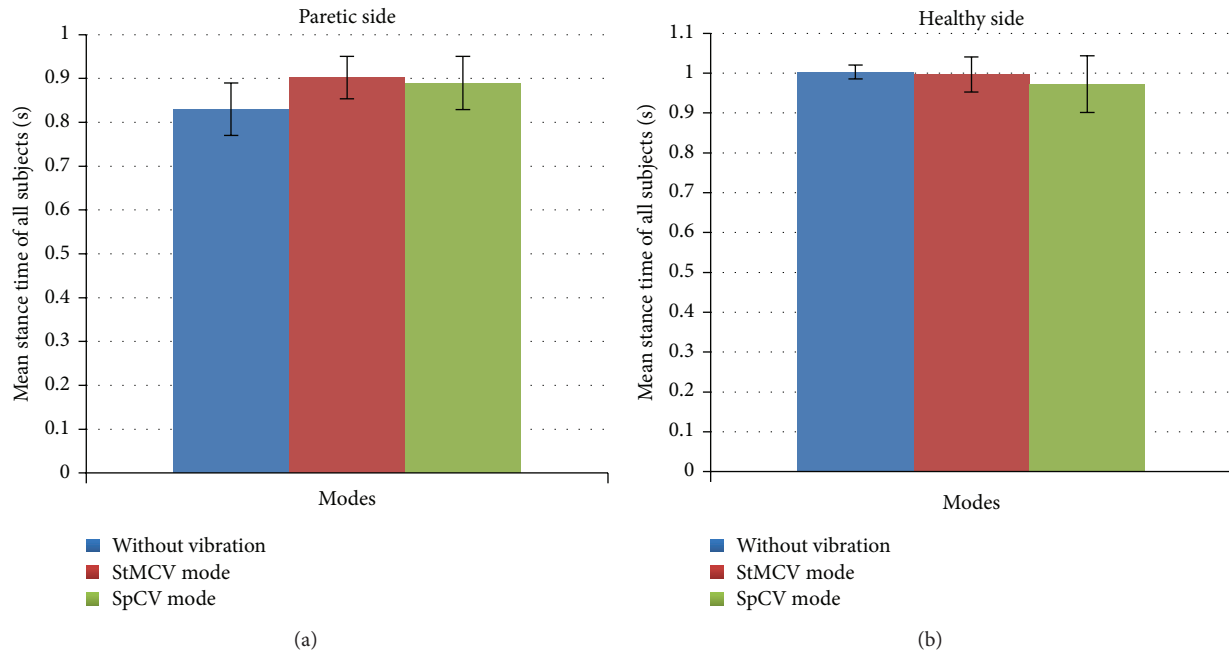


FIGURE 8: Comparative analysis of stance time on provision of different vibration modes.

Customizable feedback can be designed because the system is modular and easily modifiable.

4.1. Effects of Vibrotactile Feedback on Gait Symmetry. Experiments conducted on healthy young subjects supported the validity of the system. Trial results from normal walking by healthy young subjects confirmed that the system can measure gait data and useful information for providing biofeedback can be extracted from it. In the trials with a handicapped scenario, the healthy young subjects were asked to achieve a target symmetry ratio of 0.5; that is, the stance time of the handicapped side should be double the stance time of the healthy side. Without vibration signals, the subjects were unable to achieve the target in either left or right handicapped situations with large deviations from the achieved symmetry ratio. When using StMVCV mode, the results were improved significantly, as indicated by the p -values ($p = 0.0008, 0.0002$) compared with the results of trials without feedback, with smaller deviation from the achieved symmetry ratio. Similarly, using SrMPV mode, healthy young subjects had smaller deviations from the achieved symmetry ratio and, compared with the no vibration mode, the target symmetry ratio was approached well, as indicated by the p -values ($p = 0.0065, 0.0823$). Provision of feedback contributed to the reduced deviation in achieving target symmetry ratio in all trials. Healthy young subjects acquainted well with the matching temporal information provided from StMVCV mode in comparison to the proportional intensity information provided from SrMPV, which may be due to the difficulty of identification in variation of vibration intensity during walk. Time is objective and absolute, so it can be easily interpreted, whereas intensity is relative and depends on personal perception. Although both biofeedback modes improved the

chances of achieving the target symmetry ratio, neither was actually able to comprehensively achieve an exact value. This inability to achieve a target symmetry ratio may be due to the lack of prior training on the system. From these results, it was decided to use StMVCV mode for tests with subjects suffering from stroke. Before conducting trials on individuals with stroke, rehabilitation therapists in our team suggested use of SpCV mode and that it might provide another effective dimension of feedback.

The trials conducted with subjects suffering from stroke allowed the clinical assessment of the system and its effectiveness for rehabilitation. It was observed from the results that gait asymmetry existed even with the use of a walking aid (cane). During clinical trials, LED light allowed therapists to observe the vibration signals being generated visually. In two of the patient trials, toe contact was not detectable consistently due to an irregular walking pattern, so FSRs placed at the metatarsal were used to calculate the stance time. The biofeedback provision with the use of our system induced an effective influence on the gait symmetry as observed in the StMVCV mode ($p = 0.0493$) although target ratio was not fully achieved since it requires extensive training programs and rehabilitation. Also, measured symmetry ratio indicates large deviations while utilizing the feedback to improve gait symmetry. This result correlates with the earlier findings from the LEAFS system [17] that large permanent gait changes must be made gradually. The SpCV mode provided a constant vibration during swing phase to reduce the spasticity and hence improving the smoothness of lower extremity during gait cycle. Trials conducting with SpCV mode also showed significant improvements in gait symmetry ($p = 0.0427$). This result may be due to broader role of proprioception and some central structures during human locomotion. Similarly, step-synchronized vibration stimulation of the soles

TABLE 6: Pearson correlation coefficient for balance analysis of individuals with stroke.

	ML tilt (RMS)		ML acceleration (RMS)	
	Without vibration versus StMCV mode	Without vibration versus SpCV mode	Without vibration versus StMCV mode	Without vibration versus SpCV mode
Pearson correlation coefficient	0.998	0.995	0.970	0.975

improved gait steadiness in Parkinson's disease patients with predominantly balance impairment, presumably by enhancing sensory feedback [60]. Proprioceptive afferents can play a key role in calibrating the spatial motor frame of reference and provide a powerful sensory augmentation to the central nervous system [61]. The afferent signals due to vibration increase the excitability of several segments of the spinal cord and could facilitate triggering of locomotor-like movements [50, 51]. In a recent study it was found that auditory-motor synchronization was more stable during treadmill walking for double-metronome than single-metronome conditions, with subjects suffering from stroke exhibiting an overall weaker coupling of footfalls to metronome beats than controls [62], and this result could be due to the high cognition demands of audio-biofeedback in such system as the patients with least Mini Mental State Examination (MMSE) exhibited least adoption. A case study has been reported with two subjects suffering from stroke, providing combined visual and proprioceptive feedback employed with treadmill walking. 6-week training with the system resulted in improved gait speed and spatiotemporal symmetry [35]. Use of vibrotactile feedback for individuals with stroke in improvement of somatosensory function resulted in reduced body sway during quite stance and normal walk [63]. Our system provides a simplified vibrotactile cuing to modify gait. Our trials were conducted with no prior training to the system, yet significant improvement was observed in stance time symmetry during normal gait. After trials, individuals with stroke discussed the convenience of vibration modes and reported that SpCV mode was comfortable, which in their words "provided an effect of massage during swing phase of the walk and helped in reducing plasticity."

In the post-experiment data analysis, Pearson correlation coefficients were calculated for ML tilt (RMS) and ML acceleration (RMS), with modes of without vibration, StMCV mode, and SpCV mode, and were found to be linear (Table 6).

These results clearly show that the balance of the body is not disturbed regardless of vibrational cues generated from the device. The cues were intuitive and helpful in reducing asymmetry, showing a high level of effectiveness in influencing the gait with no significant disturbance in the ML tilt (RMS) or ML acceleration (RMS), in conjunction with the results of Figures 7(b) and 7(c). The vibrational cues provided by the system helped the individuals with stroke in loading the paretic lower extremity during stance (Table 5), contributing effectively to reducing gait symmetry (Table 4). Moreover, balance and gait speed were not disturbed by provision of the vibrotactile feedback.

Biofeedback method selection is an imperative task; various researches have shown the pros and cons of utilizing the

specific feedback method in poststroke rehabilitation. In our system, StMCV mode provided a vibrational cue of time and challenged subjects to follow that time of vibration to match with their stance time of handicapped/paretic side. Lee et al. reported a similar approach of attractive cuing [64], where healthy young subjects successfully replicated the task of slowly bending at waist using attractive vibrotactile instructional cues. Likewise in our system, SrMPV mode provided a vibrational cue of varied intensity, inspiring the users to reduce the vibrations until they could match their symmetry ratio with target. Such a method for achieving target symmetry ratio showed promising results in a recent research of gait feedback and training [65], where healthy young subjects were provided with vibrotactile feedback on a smartphone to match their symmetry ratio with target. The therapists' team suggested a SpCV mode, in which direct muscle stimulation during swing phase contributed in enhancing the gait modification through afferent signal of vibration. In the current study, the proof-of-concept was demonstrated with a few subjects, but future studies with a larger population are needed to further evaluate and analyze these effects.

4.2. Study Limitations and Future Works. Following these positive initial results, the next step is to use this device in a study to determine long-term rehabilitation effects on subjects with gait abnormalities. In our current analysis the small number of participants is limitation of the data set; future research with a larger group of participants is obligatory. The implementation of rehabilitation devices in the daily life environment can help with progress in individuals with stroke. The proposed system is not limited to use with subjects suffering from stroke; it can also be applied to other patients suffering from gait asymmetry. Our current system features an inexpensive, portable, and easily operable device, the clinical functionality of which was demonstrated in this research. FSR-based insoles have 10–25 ms delay for gait phase detection mainly due to FSR properties. The vibrotactors used in our system have lag time of 40 ms and rise time of 87 ms. But these were oblivious to the participants and did not contribute in functionality of feedback provision. Currently, the system requires pretrial calibration of the FSRs for precise gait measurements. Furthermore, the system's biofeedback update is based on information from the previous gait cycle; velocity changes during the subject's walking are not considered. The current implementation does not incorporate a double-stance phase during feedback assignment, which will be addressed in a future study. Further modifications in the current system can result in a fully patient-operable device to assist the subject in rehabilitation. Perhaps, the system paired with smart phone (using a Bluetooth transceiver instead

of XBee) can provide data logging and analysis, for daily life use of the device outside the rehabilitation clinic. These modifications will provide a cost-effective, complete, self-usable rehabilitation system, which will be a valuable tool for wearable and independent gait feedback.

5. Conclusion

It is evident from this research that the portable system described is suitable for clinical applications relating to gait symmetry and functional improvements. The system is capable of assisting physical therapists in training individuals with stroke suffering from hemiparesis. The portability and effectiveness of the system are the key features demonstrated in these experiments. From trial results with healthy young subjects, it was concluded that temporal information provided in StMCV mode was more effective than proportional intensity information provided from SrMPV, due to the difficulty of identifying variation in vibration intensity during walking. The vibrotactile feedback influenced the improvements in symmetry of gait with negligible disturbance to the balance of individuals with stroke during walking. The results show the importance of biofeedback in helping the subjects to simulate target symmetry ratios, which points towards an important addition to rehabilitation procedures. With further recommended modifications, the system will provide assistance to therapists during gait rehabilitation sessions. This will help in reducing the therapy cost with increased patient effort in recovering the gait abnormalities.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publishing of this paper.

Acknowledgments

This work was supported by the National Research Foundation Korea (NRF) (2012R1A2A2A01047344 and 2014R1A2A1A11053989 and 2012-0009524) and Technology Development Project for Advancement of NIPA SW Convergence Technology and Dual Use Technology Program of Civil and Military. Jungwon Yoon and Min-Kyun Oh contributed equally to this work as corresponding authors.

References

- [1] R. W. Bohannon, A. W. Andrews, and M. B. Smith, "Rehabilitation goals of patients with hemiplegia," *International Journal of Rehabilitation Research*, vol. 11, no. 2, pp. 181–183, 1988.
- [2] S. E. Lord, K. McPherson, H. K. McNaughton, L. Rochester, and M. Weatherall, "Community ambulation after stroke: how important and obtainable is it and what measures appear predictive?" *Archives of Physical Medicine and Rehabilitation*, vol. 85, no. 2, pp. 234–239, 2004.
- [3] S. E. Lord and L. Rochester, "Measurement of community ambulation after stroke: current status and future developments," *Stroke*, vol. 36, no. 7, pp. 1457–1461, 2005.
- [4] I. G. L. Van De Port, G. Kwakkel, V. P. M. Schepers, and E. Lindeman, "Predicting mobility outcome one year after stroke: a prospective cohort study," *Journal of Rehabilitation Medicine*, vol. 38, no. 4, pp. 218–223, 2006.
- [5] P. J. Friedman, "Gait recovery after hemiplegic stroke," *Disability & Rehabilitation*, vol. 12, no. 3, pp. 119–122, 1990.
- [6] B. L. Davis, M. Ortolano, K. Richards, J. Redhed, J. Kuznicki, and V. Sahgal, "Realtime visual feedback diminishes energy consumption of amputee subjects during treadmill locomotion," *Journal of Prosthetics and Orthotics*, vol. 16, no. 2, pp. 49–54, 2004.
- [7] K. K. Patterson, I. Parafianowicz, C. J. Danells et al., "Gait asymmetry in community-ambulating stroke survivors," *Archives of Physical Medicine and Rehabilitation*, vol. 89, no. 2, pp. 304–310, 2008.
- [8] M. M. Platts, D. Rafferty, and L. Paul, "Metabolic cost of over ground gait in younger stroke patients and healthy controls," *Medicine and Science in Sports and Exercise*, vol. 38, no. 6, pp. 1041–1046, 2006.
- [9] K. M. Michael, J. K. Allen, and R. F. MacKo, "Reduced ambulatory activity after stroke: the role of balance, gait, and cardiovascular fitness," *Archives of Physical Medicine and Rehabilitation*, vol. 86, no. 8, pp. 1552–1556, 2005.
- [10] L. Nolan, A. Wit, K. Dudziński, A. Lees, M. Lake, and M. Wychowański, "Adjustments in gait symmetry with walking speed in trans-femoral and trans-tibial amputees," *Gait & Posture*, vol. 17, no. 2, pp. 142–151, 2003.
- [11] D. C. Norvell, J. M. Czerniecki, G. E. Reiber, C. Maynard, J. A. Pecoraro, and N. S. Weiss, "The prevalence of knee pain and symptomatic knee osteoarthritis among veteran traumatic amputees and nonamputees," *Archives of Physical Medicine and Rehabilitation*, vol. 86, no. 3, pp. 487–493, 2005.
- [12] C. M. Kim and J. J. Eng, "Symmetry in vertical ground reaction force is accompanied by symmetry in temporal but not distance variables of gait in persons with stroke," *Gait and Posture*, vol. 18, no. 1, pp. 23–28, 2003.
- [13] H. Sadeghi, P. Allard, F. Prince, and H. Labelle, "Symmetry and limb dominance in able-bodied gait: a review," *Gait & Posture*, vol. 12, no. 1, pp. 34–45, 2000.
- [14] K. O. Berg, S. L. Wood-Dauphinee, J. I. Williams, and B. Maki, "Measuring balance in the elderly: validation of an instrument," *Canadian Journal of Public Health*, vol. 83, supplement 2, pp. S7–S11, 1991.
- [15] F. A. Rubino, "Gait disorders," *The Neurologist*, vol. 8, no. 4, pp. 254–262, 2002.
- [16] M. J. Cole, S. Durham, and D. Ewins, "An evaluation of patient perceptions to the value of the gait laboratory as part of the rehabilitation of primary lower limb amputees," *Prosthetics and Orthotics International*, vol. 32, no. 1, pp. 12–22, 2008.
- [17] L. Yang, *Lower extremity ambulatory feedback system for people with amputations: gait asymmetry training [M.S. thesis]*, Department of Mechanical Engineering, University of Utah, Salt Lake City, Utah, USA, 2010.
- [18] Kistler force plate, 2014, <http://www.kistler.com>.
- [19] ATMI force plate, 2014, <http://www.amti.biz/>.
- [20] E. R. C. Draper, "A treadmill-based system for measuring symmetry of gait," *Medical Engineering & Physics*, vol. 22, no. 3, pp. 215–222, 2000.
- [21] Paromed, Parotec in-shoe pressure measurement system, 2014, <http://www.paromed.biz>.

- [22] B&L Engineering, *Portable Gait Analysis Stride Analyzer*, B&L Engineering, Tustin, Calif, USA, 2014, <http://bleng.com>.
- [23] Novel electronics, Inc., Pedar-X., 2014, <http://www.novelusa.com/>.
- [24] A. L. Randolph, M. Nelson, S. Akkapeddi, A. Levin, and R. Alexandrescu, "Reliability of measurements of pressures applied on the foot during walking by a computerized insole sensor system," *Archives of Physical Medicine and Rehabilitation*, vol. 81, no. 5, pp. 573–578, 2000.
- [25] Z.-P. Luo, L. J. Berglund, and K.-N. An, "Validation of F-scan pressure sensor system: a technical note," *Journal of Rehabilitation Research and Development*, vol. 35, no. 2, p. 186, 1998.
- [26] H. L. P. Hurkmans, J. B. J. Bussmann, R. W. Selles et al., "Validity of the Pedar Mobile system for vertical force measurement during a seven-hour period," *Journal of Biomechanics*, vol. 39, no. 1, pp. 110–118, 2006.
- [27] M. Benocci, L. Rocchi, E. Farella, L. Chiari, and L. Benini, "A wireless system for gait and posture analysis based on pressure insoles and inertial measurement units," in *Proceedings of the 3rd International Conference on Pervasive Computing Technologies for Healthcare—Pervasive Health (PCTHealth '09)*, IEEE, April 2009.
- [28] K. Kong and M. Tomizuka, "A gait monitoring system based on air pressure sensors embedded in a shoe," *IEEE/ASME Transactions on Mechatronics*, vol. 14, no. 3, pp. 358–370, 2009.
- [29] J. Bae, K. Kong, N. Byl, and M. Tomizuka, "A mobile gait monitoring system for gait analysis," in *Proceedings of the IEEE International Conference on Rehabilitation Robotics (ICORR '09)*, pp. 73–79, IEEE, June 2009.
- [30] M.-Y. Lee, C. F. Lin, and K. S. Soon, "New foot pressure activated sensory compensation system for posture-control enhancement in amputees," *IEEE/ASME Transactions on Mechatronics*, vol. 12, no. 3, pp. 236–243, 2007.
- [31] G. Chelius, C. Braillon, M. Pasquier et al., "A wearable sensor network for gait analysis: a six-day experiment of running through the desert," *IEEE/ASME Transactions on Mechatronics*, vol. 16, no. 5, pp. 878–883, 2011.
- [32] M. de Haart, A. C. Geurts, M. C. Dault, B. Nienhuis, and J. Duysens, "Restoration of weight-shifting capacity in patients with postacute stroke: a rehabilitation cohort study," *Archives of Physical Medicine and Rehabilitation*, vol. 86, no. 4, pp. 755–762, 2005.
- [33] A. Srivastava, A. B. Taly, A. Gupta, S. Kumar, and T. Murali, "Post-stroke balance training: role of force platform with visual feedback technique," *Journal of the Neurological Sciences*, vol. 287, no. 1-2, pp. 89–93, 2009.
- [34] R. Banz, M. Bolliger, C. Colombo, V. Dietz, and L. Lünenburger, "Computerized visual feedback: an adjunct to robotic-assisted gait training," *Physical Therapy*, vol. 88, no. 10, pp. 1135–1145, 2008.
- [35] M. D. Lewek, J. Feasel, E. Wentz, F. P. Brooks Jr., and M. C. Whitton, "Use of visual and proprioceptive feedback to improve gait speed and spatiotemporal symmetry following chronic stroke: a case series," *Physical Therapy*, vol. 92, no. 5, pp. 748–756, 2012.
- [36] E. Isakov, "Gait rehabilitation: a new biofeedback device for monitoring and enhancing weight-bearing over the affected lower limb," *Europa Medicophysica*, vol. 43, no. 1, pp. 21–26, 2007.
- [37] A. A. Gopalai and S. M. N. A. Arosha Senanayake, "A wearable real-time intelligent posture corrective system using vibrotactile feedback," *IEEE/ASME Transactions on Mechatronics*, vol. 16, no. 5, pp. 827–834, 2011.
- [38] A. U. Alahakone and S. M. N. A. Senanayake, "A real-time system with assistive feedback for postural control in rehabilitation," *IEEE/ASME Transactions on Mechatronics*, vol. 15, no. 2, pp. 226–233, 2010.
- [39] C. Wall III, D. M. Wrisley, and K. D. Statler, "Vibrotactile tilt feedback improves dynamic gait index: a fall risk indicator in older adults," *Gait and Posture*, vol. 30, no. 1, pp. 16–21, 2009.
- [40] F. B. Horak, M. Dozza, R. Peterka, L. Chiari, and C. Wall III, "Vibrotactile biofeedback improves tandem gait in patients with unilateral vestibular loss," *Annals of the New York Academy of Sciences*, vol. 1164, pp. 279–281, 2009.
- [41] K. H. Sienko, V. V. Vichare, M. D. Balkwill, and C. Wall III, "Assessment of vibrotactile feedback on postural stability during pseudorandom multidirectional platform motion," *IEEE Transactions on Biomedical Engineering*, vol. 57, no. 4, pp. 944–952, 2010.
- [42] C. Wall, "Application of vibrotactile feedback of body motion to improve rehabilitation in individuals with imbalance," *Journal of Neurologic Physical Therapy*, vol. 34, no. 2, pp. 98–104, 2010.
- [43] B.-C. Lee, J. Kim, S. Chen, and K. H. Sienko, "Cell phone based balance trainer," *Journal of NeuroEngineering and Rehabilitation*, vol. 9, no. 1, article 10, 2012.
- [44] K. H. Sienko, M. D. Balkwill, L. I. E. Oddsson, and C. Wall, "The effect of vibrotactile feedback on postural sway during locomotor activities," *Journal of NeuroEngineering and Rehabilitation*, vol. 10, no. 1, article 93, 2013.
- [45] W. Nanhoe-Mahabier, J. H. Allum, E. P. Pasma, S. Overeem, and B. R. Bloem, "The effects of vibrotactile biofeedback training on trunk sway in Parkinson's disease patients," *Parkinsonism and Related Disorders*, vol. 18, no. 9, pp. 1017–1021, 2012.
- [46] 2015, <https://www.tekscan.com/products-solutions/force-sensors/a401>.
- [47] 2015, <http://www.digi.com/products/wireless-wired-embedded-solutions/zigbee-rf-modules/point-multipoint-rfmodules/xbee-series1-module#specs>.
- [48] 2015, <https://catalog.precisionmicrodrives.com/order-parts/product/310-103-10mm-vibration-motor-3mm-type>.
- [49] A. Pennycott, D. Wyss, H. Vallery, V. Klamroth-Marganska, and R. Riener, "Towards more effective robotic gait training for stroke rehabilitation: a review," *Journal of NeuroEngineering and Rehabilitation*, vol. 9, article 65, 2012.
- [50] Y. P. Ivanenko, R. Grasso, and F. Lacquaniti, "Influence of leg muscle vibration on human walking," *Journal of Neurophysiology*, vol. 84, no. 4, pp. 1737–1747, 2000.
- [51] V. S. Gurfinkel, Y. S. Levik, O. V. Kazennikov, and V. A. Selionov, "Locomotor-like movements evoked by leg muscle vibration in humans," *European Journal of Neuroscience*, vol. 10, no. 5, pp. 1608–1612, 1998.
- [52] M. R. Afzal, H. Byun, M. Oh, and J. Yoon, "Effects of kinesthetic haptic feedback on standing stability of young healthy subjects and stroke patients," *Journal of NeuroEngineering and Rehabilitation*, vol. 12, no. 1, article 27, 2015.
- [53] K. K. Patterson, W. H. Gage, D. Brooks, S. E. Black, and W. E. McIlroy, "Evaluation of gait symmetry after stroke: a comparison of current methods and recommendations for standardization," *Gait & Posture*, vol. 31, no. 2, pp. 241–246, 2010.
- [54] D. S. Reisman, R. Wityk, K. Silver, and A. J. Bastian, "Locomotor adaptation on a split-belt treadmill can improve walking symmetry post-stroke," *Brain*, vol. 130, no. 7, pp. 1861–1872, 2007.
- [55] I.-H. Chen, Y.-R. Yang, R.-C. Chan, and R.-Y. Wang, "Turning-based treadmill training improves turning performance and

- gait symmetry after stroke,” *Neurorehabilitation and Neural Repair*, vol. 28, no. 1, pp. 45–55, 2014.
- [56] J. Perry and J. M. Burnfield, *Gait Analysis: Normal and Pathological Function*, SLACK, Thorofare, NJ, USA, 2010.
- [57] J.-H. Kim, Y. Chung, Y. Kim, and S. Hwang, “Functional electrical stimulation applied to gluteus medius and tibialis anterior corresponding gait cycle for stroke,” *Gait and Posture*, vol. 36, no. 1, pp. 65–67, 2012.
- [58] J. W. Krakauer, “Motor learning: its relevance to stroke recovery and neurorehabilitation,” *Current Opinion in Neurology*, vol. 19, no. 1, pp. 84–90, 2006.
- [59] J. B. F. van Erp and H. A. H. C. van Veen, “Vibrotactile in-vehicle navigation system,” *Transportation Research Part F: Traffic Psychology and Behaviour*, vol. 7, no. 4-5, pp. 247–256, 2004.
- [60] P. Novak and V. Novak, “Effect of step-synchronized vibration stimulation of soles on gait in Parkinson’s disease: a pilot study,” *Journal of NeuroEngineering and Rehabilitation*, vol. 3, article 9, 2006.
- [61] C. Bard, M. Fleury, N. Teasdale, J. Paillard, and V. Nougier, “Contribution of proprioception for calibrating and updating the motor space,” *Canadian Journal of Physiology and Pharmacology*, vol. 73, no. 2, pp. 246–254, 1995.
- [62] M. Roerdink, C. J. C. Lamoth, J. Van Kordelaar et al., “Rhythm perturbations in acoustically paced treadmill walking after stroke,” *Neurorehabilitation and Neural Repair*, vol. 23, no. 7, pp. 668–678, 2009.
- [63] A. A. Priplata, B. L. Patritti, J. B. Niemi et al., “Noise-enhanced balance control in patients with diabetes and patients with stroke,” *Annals of Neurology*, vol. 59, no. 1, pp. 4–12, 2006.
- [64] B.-C. Lee, S. Chen, and K. H. Sienko, “A wearable device for real-time motion error detection and vibrotactile instructional cuing,” *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, vol. 19, no. 4, pp. 374–381, 2011.
- [65] C. B. Redd and S. J. M. Bamberg, “A wireless sensory feedback device for real-time gait feedback and training,” *IEEE/ASME Transactions on Mechatronics*, vol. 17, no. 3, pp. 425–433, 2012.

Clinical Study

The Effects of Aquatic Exercises on Physical Fitness and Muscle Function in Dialysis Patients

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Received 16 September 2014; Accepted 28 November 2014

Academic Editor: Stephen Goss

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Purpose. The aim of this study was to assess the impact of a 3-month physical training program, conducted in an aquatic environment with end-stage renal disease patients (ESRD), on the physical fitness and functional parameters of the knee joint muscles. *Patients and Methods.* The study included 20 ESRD patients with mean age 64.2 ± 13.1 y. treated with hemodialysis in Dialysis Center of the University Hospital in Wrocław. Before and 3 months after the physical training in water, a test was performed to evaluate the physical fitness of each patient; additionally, a measurement was taken of force-velocity parameters. The 3-month training program took place on nonhemodialysis days, in the recreational pool of the University of Physical Education in Wrocław. *Results.* After aquatic training cycle, an improvement was observed in all parameters measured using the Fullerton test. The value of peak torque and its relation to body mass increased in the movement of flexors and extensors of left and right lower extremities in all tested velocities. *Conclusions.* In assessing the physical fitness of studied women, the biggest improvement was achieved in tests assessing the strength of upper and lower extremities as well as lower body flexibility. Higher values of force-velocity parameters are conducive to women achieving better physical fitness test results.

1. Introduction

Chronic kidney disease (CKD) is a syndrome that evolves as a result of progressive and irreversible impairment of renal function. End-stage renal disease (ESRD) or CKD stage V is characterized by structural and functional damage to the kidneys (loss of glomerular filtration) resulting in many metabolic disturbances, due to accumulation of waste products in the blood which are toxic to the body. In ESRD any form of renal replacement therapy (kidney transplantation, hemodialysis, or peritoneal dialysis) must be started. Hemodialysis treatments are most frequently chosen

in developed countries. Standard chronic hemodialysis program consists of 3 times per week sessions with a duration of 4 to 6 hours, the length of which is determined individually depending on the patient's condition.

The ongoing nature of the disease and the length of life-long renal replacement therapy are factors that significantly deteriorate the physical fitness of patients with CKD. Patients with ESRD undergoing hemodialysis treatments have a significantly reduced exercise tolerance, exercise capacity, strength, and endurance compared to healthy individuals and patients with a lighter form of the disease, who do not require dialysis treatments [1, 2].

Most dialysis patients lead a sedentary lifestyle and are functionally limited due to deteriorating health. It should be noted that the hemodialysis treatment itself takes place in a supine or semisitting position from 4 to 6 hours per visit, which adds up to around 400 to 900 hours per year without any physical activity. A low level of physical fitness is associated with significant impairment of daily activities, including those related to self-care (e.g., bathing, housework, dressing, and shopping), paid work, functioning in the community, and recreation [3, 4]. It is unknown to what extent limitations in physical functioning are inevitably a result of renal failure and/or dialysis treatment and to what extent a result of reduced physical activity. We do know, however, that a reduction in daily physical activity lowers the quality of life of the patient and that it is an independent predictor of mortality [3–6].

Patients on hemodialysis who lead a sedentary lifestyle are exposed at a risk of mortality by 62% per annum compared to physically active patients [7]. It is estimated that each month of dialysis reduces their physical activity level by 3.4% [8].

Many studies have shown that patients on dialysis have weaker muscle strength and endurance than healthy individuals. This applies to both the phasic and postural muscles [1, 8–11]. The causes of muscle weakness are complex and have not been fully elucidated. The main reasons for the reduced muscle strength and endurance are loss of muscle mass, atrophy of both types of fibers (especially type II), decline of the ability to generate force per unit of mass (myopathy), and decrease in the motoneurons activity [1, 9–12]. This also leads to a reduction in the muscle capillarization [11]. Structural changes within the ailing muscles, resulting from CKD, translate into functional changes, including changes in muscle strength, muscle endurance, and activity of muscle ergoreceptors, which is an indication that regular exercise needs to be undertaken, even by patients with end-stage renal failure.

The effects of regular physical exercise of moderate-intensity performed during or between dialysis treatments have many physiological and functional benefits [3, 4, 13–15]. Regardless of whether the physical training is performed on a nondialysis day or during the first two hours of dialysis treatment, it leads to an improvement in aerobic capacity, resulting in, among other positive effects, an increase in left ventricular ejection fraction (LVEF), a decrease in blood pressure, and modification of other risk factors [16]. An adaptation to physical exercise also causes skeletal muscle hypertrophy (increases in surface area of fibers type I as well as fibers types IIa and IIx in cross-section) [12] and subsequently leads to improved muscular strength, power, reduction in the level of fatigability, and an overall improvement in physical fitness of patients with end-stage renal disease [17]. Their quality of life and daily functioning also improve [18].

Introducing endurance and strength training to a rehabilitation program for patients on hemodialysis provides various health benefits. Aerobic training increases insulin sensitivity, improves lipid profile, raises hemoglobin concentrations, leads to increased endurance, lowers blood pressure,

and improves quality of life. Resistance training, however, improves muscle strength, increases the level of physical fitness, and causes elevated concentrations of insulin-like growth factor 1 (IGF-1) to decrease, particularly when accompanied by persisting acidosis and the use of a low-protein diet [19, 20].

A combination of endurance-strength training is possible under aquatic conditions, in which water features like buoyancy and resistance are used with a minimal risk of musculoskeletal injury. Exercises in water are therefore a safe form of physical activity for people with multiple illnesses, the effectiveness of which is confirmed by research results [21].

In the literature, there are only a few studies on health benefits gained from aquatic exercises in patients with chronic renal failure [22–24]. Therefore, the purpose of this work is to assess the impact of a 3-month physical training program, conducted in an aquatic environment with end-stage renal disease patients, on the physical fitness and functional parameters of the knee joint muscles.

2. Material and Methods

2.1. Patients Characteristics. The study included 20 ESDR patients (16 females and 4 males) with mean age 64.2 ± 13.1 y. treated with hemodialysis in Dialysis Center of the University Hospital in Wroclaw.

Review of medical contraindication in all patients in hemodialysis was maintained in Dialysis Center of University Hospital; $n = 86$. 30 patients were excluded due to dementia, disability or leg amputation, deafness, blindness, heart failure, skin dermatitis, skin wound/hematoma, pleural effusion, recurrent infections, or severe malnutrition.

Inclusion study criteria were arteriovenous fistula as vascular access for hemodialysis (permanent central catheter was considered as contraindication), patient being able to reach swimming pool and to swim, stable clinical condition (controlled hypertension, no congestion or edemas, and no chest pain), and acceptable parameters of dialysis adequacy. 40 patients met inclusion criteria and were proposed to participate in the study. Finally, 20 of them gave informed consent and were enrolled in the study.

In order to carry out the study, an approval from the Bioethics Committee of the University of Physical Education in Wroclaw was obtained. All patients gave their informed written consent to participate in the study.

Hemodialysis treatment period before the program ranged from 4 to 174 months, 42.3 ± 6 months on average.

A list of causes of chronic renal failure in the study group is presented in Table 1.

Patients were informed at the beginning that they may opt out of exercises at any stage without giving a reason, and that is why the dropout rate is 35%. There was one death in study group (5%) unrelated to physical training. A full cycle of 3 months of physical training in water was completed by 12 women out of 20 persons entering the program (60%).

Before and 3 months after the physical training in water, a test was performed to evaluate the physical fitness of each patient; additionally, a measurement was taken of

TABLE 1: Summary of the causes of chronic renal failure in the study group.

Causes of chronic renal failure	Number of patients	%
Hypertensive nephropathy	10	50
Chronic glomerulonephritis	4	20
Interstitial nephropathy	2	10
Polycystic kidney disease	1	5
Diabetic nephropathy	2	10
Renal cortical necrosis	1	5

force-velocity parameters. We performed these tests at the Laboratory of Functional Studies in Internal Medicine of the University of Physical Education in Wrocław. The 3-month physical training program took place on nonhemodialysis days, in the recreational pool of the University of Physical Education in Wrocław (measuring 16.5 m by 4.5 m with a depth of 0.9 m). Training was performed in groups.

2.2. Description of Aquatic Exercises. Physical aquatic training was conducted in water for a period of 3 months, once a week for 60 minutes at a time. It was in the form of specialized gymnastics in water with music, using various types of gear (including foam tubes, buoyancy belts, foam dumbbells, and gloves). The training consisted of a warm-up, the main part (including endurance exercises, exercises strengthening particular muscle groups, and coordination exercises), and the end part, which consisted of stretching, breathing, and relaxation exercises. Withdrawal from exercise took place in the case of a patient feeling unwell or tired, experiencing nausea, vomiting, shortness of breath, dizziness, muscular, joint, or coronary pain. During the training, the participants were under constant supervision of a physiotherapist, a doctor, and a lifeguard.

3. Study Methods

The respondents' physical fitness was assessed on two occasions by the Fullerton Functional Fitness Test by Rikli and Jones, whereas the force-velocity parameters were taken using functional dynamometry in isokinetic conditions.

3.1. Fullerton Functional Fitness Test by Rikli and Jones (Senior Fitness Test). The Fullerton test assesses functional capacity of the elderly and patients undergoing a process of rehabilitation. It provides an opportunity to assess the level of basic motor skills: strength, flexibility, coordination, and physical endurance, which are evaluated in 6 motor tasks, carried out in the following order.

- (1) Arm curl is an indirect test evaluating the strength of the upper body. The result of the test comprises the number of bends made with supination of the dominant forearm, holding a hand weight of 8 lbs (for men) and 5 lbs (for women), during a period of 30 seconds in a seated position on a chair without backrest.

- (2) Chair stand is an indirect test evaluating the strength of the lower body. The result of the test comprises the number of rises made from the chair, with arms across the chest to a full upright position, during a period of 30 seconds.

- (3) Back scratch is an indirect test evaluating the flexibility of the upper body. A measurement is made using a 30 cm ruler to determine the distance between the middle finger of the dominant hand placed on the top of the back (fingers pointing down) and the middle finger of the nondominant hand placed on the bottom of the back (fingers pointing upward).

If the fingertips touch then the score is zero. If they do not touch, measure the distance between the finger tips (a positive score); if they overlap, measure by how much (a negative score). Practice two times, and then test two times, selecting the best result. Stop the test if the subject experiences pain.

- (4) Chair sit-and-reach is an indirect test evaluating the lower body flexibility. A measurement is made using a ruler, to determine the distance between the tip of the fingertips and the toes. If the fingertips touch the toes then the score is zero. If they do not touch, measure the distance between the fingers and the toes (a negative score); if they overlap, measure by how much (a positive score). The test is performed twice, selecting the best result.

- (5) Eight-foot up and go is an indirect test evaluating the motor agility and dynamic balance in conjunction with the respondent's balance. A measurement is made of the shortest possible time it takes the respondent to rise from a chair, walk around a cone placed at a distance of 8 foot, return to his or her chair, and take a sitting position. The test is performed twice, selecting the best result.

- (6) A 6-minute walk test (6MWT) is an indirect test evaluating the level of exercise capacity. The outcome of the test comprises the distance covered along a marked 30-meter corridor in 6 minutes at a marching pace: one that the respondent uses daily. Prior to the test, the respondent is informed of the possibility of stopping for a moment if needed during the test. The test is discontinued when the respondent reports dizziness, occurrence of nausea, extreme fatigue, pain, or alarming symptoms noticed by the researcher. For the subjective assessment of fatigue, a 10-point Borg scale was used (where 0 means no fatigue or dyspnea, and 10 indicates maximum fatigue or dyspnea) (ATS Statement, 2002). Prior to commencement of the Fullerton test and after trials 1, 2, and 6, measurements of hemodynamic parameters of blood pressure and heart rate were made using an arm-type electronic sphygmomanometer. Before commencing these tests, subjects were given specific instructions; in addition, each test was preceded by a demonstration [25–28].



FIGURE 1: Patient using Biodex station during the test (own source).

3.2. Assessment of Muscle Strength of the Lower Extremities in Isokinetic Conditions. Studies of the force-velocity parameters were performed using the Biodex Multi-Joint System 3 isokinetic dynamometer (Figure 1). An assessment was made of the functionality of flexors and extensors of the knee joint.

Before each test, the seat, dynamometer, and a suitable knee attachment were adjusted so that the tip of the dynamometer became an extension of the axis of rotation in the examined joint. For all respondents, the same range of flexion and extension of the knee joint was established at 90° (S 0-0-90), with an allowance for gravity adjustment. The thigh and pelvis of a patient were stabilized using straps attached to the chair so as to eliminate movements in neighboring joints. A starting position for the test was a maximal flexion of the lower extremity at the knee joint.

The test consisted of a warm-up—the subject performed 3 submaximal flexion and extension movements in each knee and 1 maximum movement in order to become familiar with a given load—and the main part, which involved measuring peak torque (Nm) at preset angular velocities, respectively, $60^\circ/s$, $180^\circ/s$, and $300^\circ/s$.

With the angular velocity of $60^\circ/s$, respondents performed 5 repetitions, while at $180^\circ/s$ and $300^\circ/s$ they performed 10 reps. Muscle function parameters were recorded: peak torque [Nm], peak torque/body weight [%], total work [J], and average power [W]. There was a 60-second break between subsequent attempts. It was imperative for participants to exert maximum muscle strength in the shortest possible time for each movement [29–31].

4. Methods Used for Statistical Analysis

A basic statistical description of the analyzed material determined the mean values and standard deviation. The significance of changes in measured values (PT: peak torque, TW: total work, and AvP: average power) was assessed using Student's *t*-test for dependent samples. A relationship of

TABLE 2: Summary of comorbidities in the studied group.

Comorbidities	Number	%
Hypertension	18	90
Ischemic heart disease	8	40
Occlusive artery disease	5	25
Pacemaker	1	5
Artificial aortic valve	1	5
Mitral regurgitation	1	5
Atrial fibrillation	2	10
Stroke	1	5
Diabetes type 1	1	5
Diabetes type 2	2	10

change in the muscle strength and angular velocity of movement of the knee joint was determined using a nonparametric Friedman test [32].

An interdependence of the characteristics of physical fitness (results of Fullerton test) and the force-velocity parameters (BIODEX) was analyzed by determining Spearman's rank-order correlation coefficient- ρ .

5. Research Results and Discussion

The most common comorbidities that were identified in the study group were hypertension, which had prevailed in 18 patients (90%), ischemic heart disease (IHD) in 7 patients (35%), and peripheral artery disease of the lower extremities in 5 patients (25%) (Table 2).

5.1. Physical Fitness. The results of six Fullerton tests are shown in Table 3.

After a 3-month specialized aquatic training cycle, an improvement was observed in all parameters measured using the Fullerton test. The biggest increase was recorded in the “arm curl” and “chair stand” test trials, corresponding to the strength of upper and lower extremities. Flexibility of the lower part of the body also increased significantly (chair seat and reach, 1.5 cm further). An improvement was also achieved in the agility and dynamic balance of exercising respondents, at a borderline significance ($P = 0.05$). Subjects obtained a faster time by 1.22 seconds (average).

5.2. Force-Velocity Parameters of the Flexor and Extensor Muscles of the Knee Joint. After a 3-month cycle of aquatic training, the value of peak torque and its relation to body mass increased in the movement of flexors and extensors of left and right lower extremities in all tested velocities.

Most of the observed changes in torque are statistically significant; however, in the case of left extremity, these changes concern a movement performed at a velocity of $300^\circ/s$ for extensors and a velocity of 180° and $300^\circ/s$ for the flexor muscles (Table 4).

In isokinetic conditions, the lesser the angular velocity, the more the movement becomes resistive for the

TABLE 3: Results of Fullerton test before and after aquatic gymnastics.

Fullerton test	Before water exercises		After 3-month water exercises		Student's <i>t</i> -test	
	Mean	SD	Mean	SD	<i>t</i>	<i>P</i> value
Eight foot up and go [s]	7.02	3.02	5.80	1.48	2.240	0.050
Arm curl [n]	15.8	4.7	18.4	5.3	7.005	<0.001
Chair stand [n]	12.3t	4.1	15.5	4.8	6.550	<0.001
Back scratch [cm]	10.9	11.8	8.1	9.0	2.950	0.016
Chair seat and reach [cm]	5.5	2.4	4.0	2.6	5.582	<0.001
6-minute walk test [m]	345.0	101.0	424.5	76.0	3.185	0.011

respondent, provoking muscles to generate maximum force. At a high velocity, the speed of executing movement increases with force, which indirectly determines the muscular strength/resistance being examined.

Analyzing the data, it can be concluded that as a result of a 3-month specialized aquatic training cycle, there has been a significant increase in the total work and average power of flexors and extensors of the knee joint in all measured velocities. Only in the case of the lower left extremity was there no significant change in the values of TW and AvP for the extensors at a velocity of 60°/s ($P = 0.1535$, $P = 0.1794$); similarly, for flexor muscles, there was no statistical improvement of AvP ($P = 0.1074$) (Table 4).

5.3. Peak Torque Gain of Flexors and Extensors of the Knee Joint at Different Angular Velocities. The process of changes in the average values of particular parameters, describing the torque of flexors and extensors of the knee joint, is presented in Table 5.

We observe that an increase in angular velocity causes a decrease in peak torque [N·m]. In the case of the lower right extremity, these changes are statistically significant, while in the case of the lower left extremity, these changes are slightly smaller. A significant relationship between torque with reference to body mass and angular velocity can only be determined in the case of knee joint extensors ($P = 0.011$). Changes in peak torque produced by the lower left extremity were insignificant. It should be noted, however, that the effect of diminishing muscle torque with increasing angular velocity has been observed in all tested values, and the lack of statistical significance in the left extremity is a consequence of a small amount of data.

5.4. Physical Fitness and Peak Torque. Table 6 shows Spearman's rank-order correlation coefficient- ρ between the results of individual Rikli and Jones test trials and peak torque at angular velocities of 60°/s, 180°/s, and 300°/s.

Higher correlations of statistical significance (and therefore stronger) in both examined velocities were found in tests that measured the following: balance and coordination (8-foot up and go test), strength of the lower extremities (chair stand), and exercise capacity/endurance (6MWT). At a velocity of 60°/s, PT correlates positively with the strength of upper extremities. Higher values of force-velocity parameters

therefore contribute towards better test results of physical fitness in women.

6. Discussion

Chronic renal failure and prolonged or even lifelong processes of dialysis treatments cause deterioration of physical fitness in patients, which translates into their daily functioning and quality of life [3, 4, 18, 33]. Comorbid disorders are a common reason for deliberate reduction of physical activity by patients with ESRD, for fear of health deterioration. However, substantial research shows beneficial effects of a properly selected exercise program for this group of patients as an integral part of the rehabilitation process [5, 13]. The type of physical rehabilitation for patients with ESRD is associated with obtaining various physiological and functional benefits. Training where one unit encompasses both endurance and strength exercises gives more benefits than a one-track unit [19]. Physical training in an aquatic environment provides the opportunity to develop all motor skills; therefore, undertaking the problem of the impact of water exercises on the physical fitness of hemodialysis patients became a goal of this work.

Aquatic exercise was chosen since only data on beneficial effect on CKD (stage 2–4) patients (no dialysis population) were published (usually small groups) but no data on dialysis (high risk of cardiovascular event) patients were available. This mode of physical activity was chosen as the efficacy of physical exercises in aquatic environments has confirmed their cardioprotective effect in patients with CKD, including a reduction in systolic and diastolic blood pressure (hypertension in present in 90% of renal patient) as well as increased oxygen uptake.

Results of our own research confirm a significant impact of specialized aquatic training on the increase of physical fitness, especially in the strength of the extremities. This is a desirable effect of rehabilitation due to muscular atrophy, structural changes of muscle fibers, and accompanying neurodegenerative changes in the motor unit as well as atrophy of capillaries [1, 9, 11, 12].

Studies by Konstantinidou et al. [34] which evaluated the effectiveness of three rehabilitation programs of patients with ESRD—supervised exercises on days without dialysis, exercises during dialysis, and unsupervised exercises at

TABLE 4: Values of force-velocity parameters of flexors and extensors of the knee joint before and after aquatic exercise.

Joint angle	Parameter	Leg	Knee extensors				Student's <i>t</i> -test		
			Before exercise		After exercise		<i>t</i>	<i>P</i>	
			Mean	SD	Mean	SD			
60°/s	Peak torque [N-m]	Right	62.31	16.55	68.84	15.25	4.621	0.0024	
		Left	65.26	24.52	66.64	21.10	0.360	0.7293	
	Peak torque/body weight [%]	Right	106.16	26.10	124.48	20.92	4.478	0.0029	
		Left	109.33	36.13	120.16	25.21	1.347	0.2199	
	Total work [J]	Right	375.73	98.88	438.56	83.89	5.695	0.0007	
		Left	368.51	137.09	399.80	113.82	1.601	0.1535	
	Average power [W]	Right	41.89	12.40	48.38	10.89	7.326	0.0002	
		Left	41.96	15.67	45.85	13.46	1.492	0.1794	
	180°/s	Peak torque [N-m]	Right	44.44	10.66	49.13	9.13	4.727	0.0021
			Left	41.93	11.78	44.63	10.61	1.783	0.1178
Peak torque/body weight [%]		Right	68.39	11.11	77.49	8.41	6.974	0.0002	
		Left	65.14	15.37	69.81	13.04	1.984	0.0877	
Total work [J]		Right	531.39	145.57	607.19	123.65	4.760	0.0021	
		Left	484.05	157.76	548.48	162.82	4.324	0.0035	
Average power [W]		Right	71.34	16.78	83.23	14.61	7.031	0.0002	
		Left	67.38	21.63	74.90	22.29	2.974	0.0207	
300°/s		Peak torque [N-m]	Right	38.39	3.57	39.94	3.62	4.116	0.0045
			Left	36.63	5.03	39.24	6.31	2.457	0.0436
	Peak torque/body weight [%]	Right	61.85	5.07	63.15	5.32	3.111	0.0171	
		Left	60.16	11.99	61.24	12.10	0.422	0.6857	
	Total work [J]	Right	383.69	91.82	467.25	84.62	10.933	<0.0001	
		Left	357.13	97.64	419.35	92.24	3.672	0.0079	
	Average power [W]	Right	72.13	17.76	85.55	16.63	9.695	0.0000	
		Left	67.69	22.38	79.55	25.58	2.508	0.0405	
	Joint angle	Parameter	Leg	Knee flexors				Student's <i>t</i> -test	
				Before exercise		After exercise		<i>t</i>	<i>P</i>
Mean				SD	Mean	SD			
60°/s	Peak torque [N-m]	Right	34.80	7.80	40.36	6.74	3.341	0.0124	
		Left	33.53	9.88	37.25	8.99	1.500	0.1774	
	Peak torque/body weight [%]	Right	57.54	13.84	67.55	11.28	4.678	0.0023	
		Left	58.09	18.19	63.63	15.39	1.344	0.2208	
	Total work [J]	Right	188.25	48.42	237.53	41.56	4.137	0.0044	
		Left	191.46	69.09	223.81	53.06	2.469	0.0429	
	Average power [W]	Right	20.24	5.30	24.16	4.52	6.871	0.0002	
		Left	19.79	7.78	22.73	6.33	1.846	0.1074	
	180°/s	Peak torque [N-m]	Right	26.20	4.91	31.38	7.36	2.815	0.0260
			Left	24.83	5.91	30.41	7.89	2.834	0.0253
Peak torque/body weight [%]		Right	43.64	8.70	48.78	9.04	3.744	0.0072	
		Left	41.18	12.17	45.95	12.49	4.779	0.0020	
Total work [J]		Right	235.31	54.22	280.59	67.94	5.006	0.0016	
		Left	211.30	63.32	266.34	70.07	6.898	0.0002	
Average power [W]		Right	30.49	6.25	37.35	8.52	5.053	0.0015	
		Left	27.96	8.48	35.29	8.86	8.909	0.0000	
300°/s		Peak torque [N-m]	Right	25.61	3.93	26.48	4.42	1.842	0.1080
			Left	25.96	3.93	27.24	4.04	4.295	0.0036
	Peak torque/body weight [%]	Right	42.13	4.89	42.84	5.26	1.164	0.2826	
		Left	42.11	6.80	43.88	6.50	4.760	0.0021	
	Total work [J]	Right	154.54	48.26	175.24	56.40	2.604	0.0352	
		Left	138.93	60.54	183.31	62.88	3.297	0.0132	
	Average power [W]	Right	27.21	7.28	31.28	8.45	2.908	0.0227	
		Left	23.84	10.01	31.99	9.53	4.289	0.0036	

*Significance of changes at level $P < 0.05$; $P < 0.01$; $P < 0.001$.

TABLE 5: Peak torque of flexor and extensor muscles of the knee joint at different angular velocities.

Move	Parameter	Leg	Increase muscle strength						Friedman test	
			60°/s		180°/s		300°/s		χ^2	P value
			Mean	SD	Mean	SD	Mean	SD		
Extension	Peak torque [N-m]	Right	6.53	3.99	4.69	2.80	1.55	1.07	7.75	0.021
		Left	1.38	10.80	2.70	4.28	2.61	3.01	2.25	0.325
	Peak torque/body weight [%]	Right	18.31	11.57	9.10	3.69	1.30	1.18	10.75	0.005
		Left	10.84	22.75	4.68	6.66	1.08	7.21	9.00	0.011
Flexion	Peak torque [N-m]	Right	5.56	4.71	5.18	5.20	0.86	1.32	7.00	0.030
		Left	3.73	7.03	5.59	5.58	1.28	0.84	4.75	0.093
	Peak torque/body weight [%]	Right	10.01	6.05	5.14	3.88	0.71	1.73	10.75	0.005
		Left	5.54	11.65	4.78	2.83	1.76	1.05	3.25	0.197

TABLE 6: The coefficients of Spearman's- ρ rank correlation between Fullerton test results and peak torque value at angular velocities of 60°/s, 180°/s, and 300°/s in the group of studied women. Coefficients that were statistically significant at $P < 0.05$ were highlighted in bold.

Fullerton test	Peak torque PT [N-m]											
	Extensor		Flexor		Extensor		Flexor		Extensor		Flexor	
	60 R	60 L	60 R	60 L	180 R	180 L	180 R	180 L	300 R	300 L	300 R	300 L
Eight foot up and go [s]	-0.71	-0.66	-0.64	-0.46	-0.69	-0.66	-0.38	-0.51	-0.67	-0.65	-0.35	-0.48
Chair stand [n]	0.66	0.65	0.35	0.42	0.66	0.65	0.26	0.35	0.65	0.65	0.24	0.31
Arm curl [n]	0.65	0.66	0.31	0.36	0.61	0.60	0.32	0.36	0.60	0.59	0.30	0.28
Chair seat and reach [cm]	0.17	0.31	0.26	0.31	0.13	0.03	0.16	0.14	0.10	0.05	0.20	0.16
Back scratch [cm]	0.15	0.11	0.22	0.14	0.06	0.09	0.12	0.21	0.05	0.03	0.1	0.03
6-minute walk test [m]	0.71	0.65	0.41	0.47	0.69	0.65	0.39	0.53	0.67	0.65	0.37	0.51

R—right, L—left.

home—showed dominance of the first program in achieving significant improvements in the body's aerobic fitness. In the literature on the subject, there have been assessments of physical exercise programs most often conducted on dialysis days and less frequently on days without dialysis, the frequency of which varies from two to three times a week with training cycle duration from three to six months [13, 16]. The functional benefits attained by the female patients who participated in a 3-month supervised aquatic training program once a week are confirmed by the results of this study, which indicate a high efficacy of the proposed training.

To date, studies evaluating the efficacy of physical exercises in aquatic environments have confirmed their cardio-protective effect in patients with ESRD, including a reduction in systolic and diastolic blood pressure, increased oxygen uptake (VO₂max), and lower levels of both the urinary protein excretion rate (proteinuria) and levels of cystatin C, which indicate an improvement of renal function [22, 23]. As a result of the long-term regular aquatic training undertaken by patients with CKD, discontinuance of progression of the disease has taken place as well as a reduction in mortality rate in a 10-year observation period [24].

Ali et al. [35] measured the effect of swimming exercise (three days a week for 45 min) on adenine-induced CKD in nephrectomized rats. They observed that swimming exercise did not affect the salutary action of dietary supplement

gum acacia on renal histology, but it partially improved some biochemical and physiological analyses, suggesting that addition of this mode of exercise may improve further the benefits of dietary supplementation of gum acacia.

The level of muscle strength and endurance measured by the functional dynamometry is a significant factor conditioning the physical capacity of the patient [36, 37].

Peak torque (PT) is considered the most important indicator of muscle strength. It can be used to identify early impairment of muscle performance as well as to evaluate the maximum level of muscular strength [36].

The total work (TW) is work performed by muscle groups throughout the entire test, indicating endurance capability of particular muscle groups. It is considered the most sensitive parameter for the assessment of muscle fatigue [36].

Maximum force, developed in a few seconds during the most intense workouts, is more useful than muscle strength as an indicator of the ability to perform dynamic efforts. It conditions the physical capacity of moving about and performing many daily tasks, especially in the elderly [37].

A three-month physical training program performed in an aquatic environment led to an improvement in almost all force-velocity parameters assessed at three angular velocities (60°, 180°, and 300°/s), in both the flexor and extensor muscles of the knee joint. Only in the case of the left lower extremity is the significance of test results not fully

confirmed; this may be associated with habitual use of the dominant lower extremity, which in this case was the right extremity and because of a small number of respondents the functional improvement of this extremity was not significant.

In a study by Kouidi et al. [12], a 6-month rehabilitation of hemodialysis patients led to an increase in the proportion of type II fibers (by 51%) as well as an increase of the area of muscle fibers (by 29%) in the quadriceps (thigh) muscle. Changes have also been confirmed in the capillarization; moreover, the number of mitochondria has increased [12]. The results of these studies are supported by the increase in strength and muscular endurance, expressed as peak torque, average power, and total work, achieved after a 3-month rehabilitation program in an aquatic environment.

Confirmation of our research also follows research by Headley et al. [38], in which force-velocity parameters were measured using the Cybex Norm isokinetic dynamometer. After a 12-week cycle of resistance training in patients with ESRD, a significant increase was reported in peak torque at an angular velocity of 90°/sec (139.1 +/- 19.3 N-m), in addition, an increased distance was reported in the 6-minute corridor test (548.3 +/- 52.1 m), as well as a time reduction in performance of ten repetitions of “sit-to-stand-to-sit” test (17.8 +/- 1.9 sec) [38].

An improvement in physical fitness of hemodialysis patients was also shown in selected trials of the Fullerton test in a study by Painter et al. [18]. It led to a significant increase in the distance covered and acceleration of walking speed (6MWT test) as well as to an increase in strength of lower extremities measured in the “sit-to-stand” test [18]. In the results of our own research, a statistical significance of changes has been observed in all Fullerton tests; however, only the “arm curl,” “chair stand,” and “chair sit-and-reach” tests showed a high level of significance ($P < 0.001$).

The relationship between muscular strength and particular test trials that evaluate physical fitness can be helpful in determining the patient’s level of functioning in everyday life. In our study, this relationship applies to strength of lower extremities, marching capacity, dynamic balance, and coordination of the studied women. Csuka and McCarty [39] have demonstrated a significant correlation of peak torque and muscle strength of lower extremities assessed by the “chair stand” test. This indicates that changes in muscle function translate into overall physical fitness in patients with chronic renal failure.

Findings on the effects of exercise in an aquatic environment on the health and functioning of dialysis patients show many positive changes; however, a small number of studies leave a significant gap in defining its scope. Our findings refer to the improvement of physical fitness in most investigated parameters; however, continuation of further studies is warranted, in order to further assess various aspects of life of patients with ESRD, including social functioning.

Twelve female patients who regularly exercised in water willingly took part in the classes.

The variety of exercises, use of attractive aiding tools, and physical activity in an aquatic environment have all contributed to the full involvement of respondents in the rehabilitation process. An additional motivating factor was

the group nature of the activities, which contributed to the making of social contacts among the respondents.

Among patients with end-stage renal failure, the safety that the water offers during classes in a recreational pool is also an important factor in undertaking regular physical effort as was observed in this study. Both the endurance and strength aspects of water activities should be important elements of a comprehensive rehabilitation program for this group of patients.

The study patients were highly motivated to continue aquatic exercise (role of social and emotional factors).

7. Conclusions

- (1) After a 3-month physical training course in water, an improvement has been recorded in the force-velocity parameters and physical fitness of women on hemodialysis.
- (2) In assessing the physical fitness of studied women, the biggest improvement was achieved in tests assessing the strength of upper and lower extremities as well as lower body flexibility.
- (3) Higher values of force-velocity parameters are conducive to women achieving better physical fitness test results.

Conflict of Interests

No competing financial interests exist.

References

- [1] K. L. Johansen, J. Doyle, G. K. Sakkas, and J. A. Kent-Braun, “Neural and metabolic mechanisms of excessive muscle fatigue in maintenance hemodialysis patients,” *American Journal of Physiology: Regulatory Integrative and Comparative Physiology*, vol. 289, no. 3, pp. R805–R813, 2005.
- [2] C. W. McIntyre, N. M. Selby, M. Sigris, L. E. Pearce, T. H. Mercer, and P. F. Naish, “Patients receiving maintenance dialysis have more severe functionally significant skeletal muscle wasting than patients with dialysis-independent chronic kidney disease,” *Nephrology Dialysis Transplantation*, vol. 21, no. 8, pp. 2210–2216, 2006.
- [3] K. Chojak-Fijałka, O. Smoleński, A. Miłkowski, and W. Piotrowski, “The effects of 6-months physical training during hemodialysis in ESRD patients,” *Rehabilitacja Medyczna*, vol. 10, no. 2, pp. 25–36, 2006.
- [4] T. Gołębowski, M. Kusztal, W. Weyde et al., “A program of physical rehabilitation during hemodialysis sessions improves the fitness of dialysis patients,” *Kidney & Blood Pressure Research*, vol. 35, no. 4, pp. 290–296, 2012.
- [5] G. C. Kosmadakis, A. Bevington, A. C. Smith et al., “Physical exercise in patients with severe kidney disease,” *Nephron: Clinical Practice*, vol. 115, no. 1, pp. c7–c16, 2010.
- [6] K. E. Sietsema, A. Amato, S. G. Adler, and E. P. Brass, “Exercise capacity as a predictor of survival among ambulatory patients with end-stage renal disease,” *Kidney International*, vol. 65, no. 2, pp. 719–724, 2004.

- [7] A. M. O'Hare, K. Tawney, P. Bacchetti, and K. L. Johansen, "Decreased survival among sedentary patients undergoing dialysis: results from the dialysis morbidity and mortality study wave 2," *American Journal of Kidney Diseases*, vol. 41, no. 2, pp. 447–454, 2003.
- [8] G. R. Adams and N. D. Vaziri, "Skeletal muscle dysfunction in chronic renal failure: Effects of exercise," *American Journal of Physiology: Renal Physiology*, vol. 290, no. 4, pp. F753–F761, 2006.
- [9] K. L. Johansen, G. A. Kaysen, B. S. Young, A. M. Hung, M. da Silva, and G. M. Chertow, "Longitudinal study of nutritional status, body composition, and physical function in hemodialysis patients," *The American Journal of Clinical Nutrition*, vol. 77, no. 4, pp. 842–846, 2003.
- [10] K. L. Johansen, T. Shubert, J. Doyle, B. Soher, G. K. Sakkas, and J. A. Kent-Braun, "Muscle atrophy in patients receiving hemodialysis: effects on muscle strength, muscle quality, and physical function," *Kidney International*, vol. 63, no. 1, pp. 291–297, 2003.
- [11] G. K. Sakkas, D. Ball, T. H. Mercer, A. J. Sargeant, K. Tolfrey, and P. F. Naish, "Atrophy of non-locomotor muscle in patients with end-stage renal failure," *Nephrology Dialysis Transplantation*, vol. 18, no. 10, pp. 2074–2081, 2003.
- [12] E. Kouidi, M. Albani, K. Natsis et al., "The effects of exercise training on muscle atrophy in haemodialysis patients," *Nephrology Dialysis Transplantation*, vol. 13, no. 3, pp. 685–699, 1998.
- [13] B. S. B. Cheema and M. A. Fiatarone Singh, "Exercise training in patients receiving maintenance hemodialysis: a systematic review of clinical trials," *American Journal of Nephrology*, vol. 25, no. 4, pp. 352–364, 2005.
- [14] K. Chojak-Fijałka and O. Smoleński, "Rehabilitacja chorych przewlekle dializowanych—wyniki badań własnych," *Problemy Lekarskie*, vol. 45, no. 6, pp. 247–256, 2006.
- [15] K. Girija and R. Radha, "Beneficial effect of physical activity in hemodialysis patients," *Universal Journal of Engineering Science*, vol. 1, no. 2, pp. 40–44, 2013.
- [16] E. J. Kouidi, "Central and peripheral adaptations to physical training in patients with end-stage renal disease," *Sports Medicine*, vol. 31, no. 9, pp. 651–665, 2001.
- [17] T. W. Storer, R. Casaburi, S. Sawelson, and J. D. Kopple, "Endurance exercise training during haemodialysis improves strength, power, fatigability and physical performance in maintenance haemodialysis patients," *Nephrology Dialysis Transplantation*, vol. 20, no. 7, pp. 1429–1437, 2005.
- [18] P. Painter, L. Carlson, S. Carey, S. M. Paul, and J. Myll, "Physical functioning and health-related quality-of-life changes with exercise training in hemodialysis patients," *American Journal of Kidney Diseases*, vol. 35, no. 3, pp. 482–492, 2000.
- [19] I. Moinuddin and D. J. Leehey, "A comparison of aerobic exercise and resistance training in patients with and without chronic kidney disease," *Advances in Chronic Kidney Disease*, vol. 15, no. 1, pp. 83–96, 2008.
- [20] M. Szkudlarek, K. Woliński, D. Sikorska et al., "Hormonal disorders in patients with chronic kidney disease. Part I—the hypothalamus and pituitary; hypogonadism," *Medical News*, vol. 82, no. 6, pp. 474–481, 2013.
- [21] T. Honda and H. Kamioka, "Curative and health enhancement effects of aquatic exercise: evidence based on interventional studies," *Journal of Sports Medicine*, vol. 3, pp. 27–34, 2012.
- [22] Ü. Pechter, J. Maarros, S. Mesikepp, A. Veraksits, and M. Ots, "Regular low-intensity aquatic exercise improves cardio-respiratory functional capacity and reduces proteinuria in chronic renal failure patients," *Nephrology Dialysis Transplantation*, vol. 18, no. 3, pp. 624–625, 2003.
- [23] Ü. Pechter, M. Ots, S. Mesikepp et al., "Beneficial effects of water-based exercise in patients with chronic kidney disease," *International Journal of Rehabilitation Research*, vol. 26, no. 2, pp. 153–156, 2003.
- [24] U. Pechter, M. Raag, and M. Ots-Rosenberg, "Regular aquatic exercise for chronic kidney disease patients: a 10-year follow-up study," *International Journal of Rehabilitation Research*, vol. 37, no. 3, pp. 251–255, 2014.
- [25] R. E. Rikli and C. J. Jones, "Assessing physical performance in independent older adults: issues and guidelines," *Journal of Aging and Physical Activity*, vol. 5, no. 3, pp. 244–261, 1997.
- [26] R. E. Rikli and C. J. Jones, "Development and validation of a functional fitness test for community-residing older adults," *Journal of Aging and Physical Activity*, vol. 7, no. 2, pp. 129–161, 1999.
- [27] R. E. Rikli and C. J. Jones, "Functional fitness normative scores for community-residing older adults, ages 60–94," *Journal of Aging and Physical Activity*, vol. 7, no. 2, pp. 162–181, 1999.
- [28] R. Rikli and C. J. Jones, *Senior Fitness Test Manual*, Human Kinetics, Champaign, Ill, USA, 2001.
- [29] G. Davies, *Compendium of Isokinetics in Clinical Usage and Rehabilitation Techniques*, S&S Publishers, Onalaska, Wis, USA, 4th edition, 1992.
- [30] Z. Dvir, *Isokinetics: Muscle Testing, Interpretation and Clinical Applications*, Churchill Livingstone, Edinburgh, UK, 1995.
- [31] D. Perrin, *Isokinetic Exercise and Assessment*, Human Kinetics Publisher, Champaign, Ill, USA, 1993.
- [32] G. A. Ferguson and Y. Takane, *Analiza Statystyczna w Psychologii i Pedagogice*, PWN, Warsaw, Poland, 1997.
- [33] M. C. Cruz, C. Andrade, M. Urrutia, S. Draibe, L. A. Nogueira-Martins, and R. D. C. C. Sesso, "Quality of life in patients with chronic kidney disease," *Clinics*, vol. 66, no. 6, pp. 991–995, 2011.
- [34] E. Konstantinidou, G. Koukouvou, E. Kouidi, A. Deligiannis, and A. Tourkantonis, "Exercise training in patients with end-stage renal disease on hemodialysis: comparison of three rehabilitation programs," *Journal of Rehabilitation Medicine*, vol. 34, no. 1, pp. 40–45, 2002.
- [35] B. H. Ali, S. Al-Salam, M. Al Za'abi et al., "Does swimming exercise affect experimental chronic kidney disease in rats treated with gum acacia?" *PLoS ONE*, vol. 9, no. 7, Article ID e102528, 2014.
- [36] P. Kannus, "Isokinetic evaluation of muscular performance: implications for muscle testing and rehabilitation," *International Journal of Sports Medicine*, vol. 15, supplement 1, pp. S11–S18, 1994.
- [37] R. S. Mazzeo, P. Cavanagh, W. J. Evans et al., "Exercise and physical activity for older adults," *Medicine & Science in Sports & Exercise*, vol. 30, no. 6, pp. 992–1008, 1998.
- [38] S. Headley, M. Germain, P. Mailloux et al., "Resistance training improves strength and functional measures in patients with end-stage renal disease," *American Journal of Kidney Diseases*, vol. 40, no. 2, pp. 355–364, 2002.
- [39] M. Csuka and D. J. McCarty, "Simple method for measurement of lower extremity muscle strength," *The American Journal of Medicine*, vol. 78, no. 1, pp. 77–81, 1985.

Clinical Study

The Effect of Park and Urban Environments on Coronary Artery Disease Patients: A Randomized Trial

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Received 28 July 2014; Accepted 18 December 2014

Academic Editor: Gianluca Castelnuovo

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Aim. To test the hypothesis that walking in a park has a greater positive effect on coronary artery disease (CAD) patients' hemodynamic parameters than walking in an urban environment. *Methods.* Twenty stable CAD patients were randomized into two groups: 30-minute walk on 7 consecutive days in either a city park or busy urban street. Wilcoxon signed-rank test was employed to study short-term (30 min) and cumulative changes (following 7 consecutive days of exposure) in resting hemodynamic parameters in different environments. *Results.* There were no statistically significant differences in the baseline and peak exercise systolic blood pressure (SBP), diastolic blood pressure (DBP), heart rate (HR), exercise duration, or HR recovery in urban versus park exposure groups. Seven days of walking slightly improved all hemodynamic parameters in both groups. Compared to baseline, the city park group exhibited statistically significantly greater reductions in HR and DBP and increases in exercise duration and HR recovery. The SBP and DBP changes in the urban exposed group were lower than in the park exposed group. *Conclusions.* Walking in a park had a greater positive effect on CAD patients' cardiac function than walking in an urban environment, suggesting that rehabilitation through walking in green environments after coronary events should be encouraged.

1. Introduction

There is some evidence that green environments are associated with better self-reported health [1], lower blood pressure [2], lower psychophysiological stress [3, 4], and lower mortality risks [5]. However, the benefits of physical activity in green environments of CAD patients in terms of functional capacity are uncertain. Rehabilitation after coronary events, such as myocardial infarction, requires a specific approach to increase physical activity taking into account low cardiorespiratory fitness, impaired coronary flow reserve, and cardiac autonomic nervous system response [6–8]. The appropriate level of physical strain on the heart may improve these unfavourable changes. Long-term exercise training in

patients with CAD is associated with a relative enhancement of vagal tone, improved HR recovery after exercise, and improved prognosis [9–13]. The effects of physical training in patients after acute MI on hemodynamic parameters may occur through improved autonomic nervous system function: HR recovery, resting HR, and SBP [8, 14–17]. Cardiac rehabilitation programmes include low- and moderate-intensity exercise such as walking. Regular walking has been shown to reduce anxiety and tension, improve cholesterol profile, and control blood pressure [18] and can help to lower SBP and DBP in hypertensive patients [19]. However, some authors have found that comprehensive rehabilitation after MI has no significant effect on risk factors, health-related quality of life, or physical activity [20]. The discrepancies

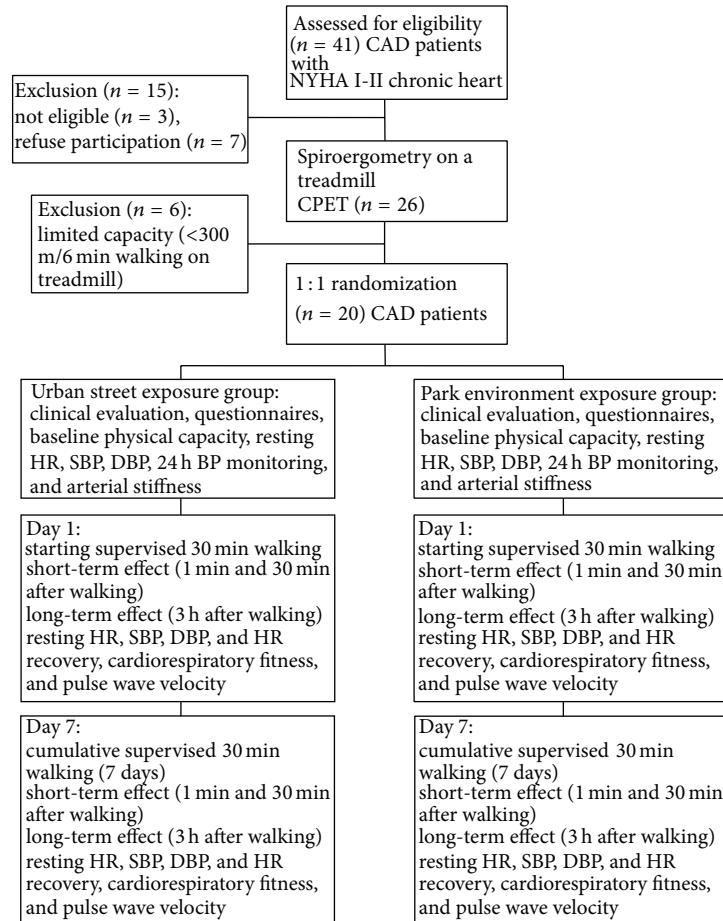


FIGURE 1: Flowchart, illustrating randomization and investigations scheme of urban street and park environment exposure groups.

between the studies' results may be a result of differences in study design and the environment where physical activity is conducted.

The underlying mechanisms for health benefits of green spaces are not fully understood. Recent studies have reported that green space, such as city parks, can reduce noise and air pollution [21, 22], enhance mood and related psychological outcomes [23], positively influence self-reported health [24–26], lower cumulative risk of cardiometabolic diseases [27], and lower metabolic syndrome scores [28].

There is some evidence that walking in a natural environment compared to an urban environment has benefits in terms of psychological and physical restoration in young subjects [2, 29] and also in hypertensive elderly patients [30]. Therefore we hypothesize that CAD patients walking in park will experience greater improvements in hemodynamic parameters than those walking in urban environment. Targeting patients with established CAD will have direct clinical applications for the use of different types of natural environment in cardiac rehabilitation. This study was conducted as part of EC FP7 PHENOTYPE project (Positive Health Effects of the Natural Outdoor Environment in Typical Populations in Different Regions in Europe) [31, 32]. This randomized study is the first to investigate whether the effect

of walking for 30 min per day for seven days in a city park has greater positive impact on the CAD patients' hemodynamic parameters than walking in an urban environment.

2. Methods

2.1. Design of the Experiment. The study was conducted in Kaunas, Lithuania. Twenty male and female Kaunas city residents (62.3 ± 12.6 years of age) with CAD (functional class by the New York Heart Association (NYHA) I-II chronic heart failure) participated in the study. The patients were treated at the Cardiology Clinic of the Hospital of Lithuanian University of Health Sciences because of MI or unstable angina pectoris and were consecutively selected from the patients register. The mean duration since the last period of CAD hospitalization and cardiac rehabilitation was 1.03 ± 0.5 years. Inclusion criteria were as follows: 45–75 years of age, men or women, who survived MI or unstable angina pectoris, and signed informed consent to take part in the study. Exclusion criteria were as follows: unstable angina pectoris, cardiomyopathy, idiopathic or organic valvular disease, hypertension with SBP > 160/110 mm Hg, diabetes mellitus type 2, electrocardiostimulation, neurological diseases, and limited capacity (less than 300 m achieved after 6 min walking on treadmill) (Figure 1).

The study was performed under the regulations of the Lithuanian Bioethics Committee and in accordance with the Declaration of Helsinki.

2.2. Study Protocol. Patients were randomly assigned to either green or urban exposure groups. The urban exposure ($n = 10$) was a busy street behind the Cardiology Clinic (10,000 cars/d). The green exposure ($n = 10$) was a pine park located within a 5 min walk of the Cardiology Clinic, accessed through clinic park (in total 30 min green exposure). Patients' normal medication regimens were not changed during the study. We used standardised protocols for environmental exposure and measurement of physiological responses. Both groups were similar, clinically and in terms of their residential environmental characteristics. Physical activity, eating, and drinking were controlled during the study periods. Data collection took place at the clinic between 12:00 and 15:00, May–September 2013. To minimise the social interaction effects during the environmental exposure, the same trained researcher supervised all subjects, their walking intensity, and their social interaction during the 30 min walk. Exercise capacity testing using a spiroergometer on a treadmill and with ECG monitoring was performed at baseline and day 7. The test provides an accurate assessment of maximal and functional aerobic capacity. Walking intensity was estimated to be 10% lower of the capacity determined during spiroergometry. Patients walked for 30 min each day in their allocated environment, for 7 consecutive days. We studied the short-term (1 min and 30 min after walk) and cumulative 7-day effects of walking alone in the urban or park environment and 7-day changes in specific exercise capacity parameters. Changes in hemodynamic parameters at rest and at peak exercise (HR, SBP, and DBP, cardiorespiratory fitness, and HR recovery) were assessed. Before and after 7 days of walking in different environments, we compared changes in hemodynamic parameters between those walking in the urban and the park environments including resting data before walking, 1 min after walking, 30 min after walking, and 3 hours after walking.

2.3. Measurements. On the day prior to the experiments, subjects before signing the Informed Consent Form were informed of the aims and procedures and then completed the standard PHENOTYPE questionnaires and took part in the 1st laboratory test to estimate baseline physical capacity. The standard questionnaires included questions regarding the respondent's personal characteristics, wellbeing and health, health behaviour, CAD anamnesis, residence history, and neighbourhood. We used the CS-200 Schiller spiroergometer on a treadmill following the Naughton protocol, after evaluation of indication and contraindication for the exercise test [33]. We evaluated cardiac autonomic nervous system effects on hemodynamic parameters by measuring resting HR, SBP, DBP, and HR recovery following exercise [11, 16]. Resting cardiovascular parameters were measured in a seated position at least 15 min before the start of the spiroergometric testing. At baseline, the exercise intensity was determined according to the baseline HR at the individual level of the ventilatory level threshold, assessed by spiroergometry. The

treadmill exercise test began at 3 km/h with a 10% incline. This increased every 3 min by 1.8 km/h and 2% incline. HR recovery was estimated by difference between HR at peak exercise and HR 1 min after completion of exercise. The exercise was terminated when the patients reached 75% of their maximal HR or displayed limiting symptoms (chest pain or pressure, dizziness, dyspnoea, weakness) or ST depression on the ECG of more than 2 mm. This was followed by a 10 min recovery and assessment of exercise capacity and cardiovascular parameters. To estimate physical capacity in W, we measured workload which refers to the work done with a given load and total energy output. We assessed changes in physical capacity by the cardiopulmonary exercise test before and after 7 days of different environment exposures. On day 1 and day 7, arterial distensibility was estimated by pulse wave velocity (PWV) using SphygmoCor. Subjects also completed 24-hour ambulatory BP monitoring (ABPM) using the Microlife WatchBP 03, which took measures at 15 min intervals during the day (09:00–21:00) and at 30 min intervals overnight. Peak SBP and DBP were recorded as the highest values achieved when walking in the different environments.

2.4. Statistical Analysis. We used the exact Fisher tests to compare the personal characteristics of the urban and park exposed patients. Quantitative variables are reported as means and standard error. Quantitative clinical and environmental variables in both groups were compared using the Mann-Whitney U test and the chi-square test. We used nonparametric tests because the data were not normally distributed. The Wilcoxon signed-rank test was used to compare measurements before and after each walk and between day 1 and day 7. The level of statistical significance was $P < 0.05$. All statistical analyses were performed using SPSS version 18.0 (SPSS Inc. Released 2009; PASW Statistics for Windows, Version 18.0; Chicago: SPSS Inc).

3. Results

There were no statistically significant differences in the demographic or clinical characteristics between the two exposure groups (Table 1).

The mean age, body mass index (BMI), duration of CAD anamnesis, and time since last CAD hospitalisation were all similar for patients in the urban and park groups. Residential environmental characteristics were also similar: the mean residential NO_2 concentration of patients exposed to urban environment was $18.5 \pm 5.4 \mu\text{g}/\text{m}^3$ and that exposed to park environment was $20.1 \pm 5.3 \mu\text{g}/\text{m}^3$ ($P = 0.37$), while the residential proximity to the nearest city park was 321.7 ± 251 m and 490 ± 356 m, respectively ($P = 0.114$). There were significant differences in the characteristics of the urban versus park environments, with higher levels of air pollution (NO_2 concentration $3.84 \mu\text{g}/\text{m}^3$ higher, $\text{PM}_{2.5}$ $6.41 \mu\text{g}/\text{m}^3$ higher) and noise (19.03 dBA higher) compared with the park environment.

The two groups did not differ significantly in terms of mean SBP, DBP, and HR before exposure (Table 2).

TABLE 1: Baseline characteristics of the urban street and park environment study groups (data shown as mean values \pm standard deviation or numbers and percentages).

Baseline characteristics	Urban street mean \pm SD	Park environment mean \pm SD	<i>P</i> *
Men	6 (60%)	7 (70%)	0.500
Age, years	66.0 \pm 12.5	58.5 \pm 12.2	0.162
Body mass index, kg/m ²	27.9 \pm 1.8	27.9 \pm 4.9	0.264
CAD anamnesis, years	9.3 \pm 8.8	8.8 \pm 11.7	0.353
Duration after the last CAD hospitalization, years	1.16 \pm 0.6	0.90 \pm 0.4	0.176
NO ₂ in living environment, μ g/m ³	18.5 \pm 5.4	20.1 \pm 5.3	0.370
Residence proximity to park, m	321.7 \pm 251	490 \pm 356	0.114
NO ₂ during walking, μ g/m ³	24.15 \pm 1.69	20.31 \pm 0.93	0.026
PM2.5 during walking, μ g/m ³	24.64 \pm 0.97	18.23 \pm 0.85	0.001
Noise during walking, dBA	65.20 \pm 1.31	46.17 \pm 0.78	0.000

*Exact one-tailed *P* value of Mann-Whitney *U* test.

TABLE 2: Comparison of baseline and the seventh day exposure hemodynamic data at rest and at peak exercise as mean (SE) in patients of urban or park environment exposure.

Measurements	Urban exposure Mean (SE)	Park exposure Mean (SE)	<i>P</i> * value
First day baseline			
Systolic BP baseline, mm Hg	134.7 (6.8)	135.9 (5.5)	0.382
Diastolic BP baseline, mm Hg	80.3 (3.3)	81.4 (1.7)	0.398
Heart rate baseline, beats/min	77.7 (4.0)	71.3 (3.8)	0.125
Peak SBP, mm Hg	181.4 (6.5)	191.2 (4.2)	0.133
Peak DBP, mm Hg	94.1 (3.1)	94.3 (1.6)	0.232
Peak heart rate, beats/min	125.1 (6.7)	139.7 (4.5)	0.039
Exercise duration, min	4.97 (1.43)	5.66 (0.80)	0.205
Work load, W	159.5 (24.9)	184.8 (26.0)	0.144
Heart rate recovery, beats/min	20.6 (5.6)	23.4 (2.7)	0.122
Pulse wave velocity m/s	9.94 (0.8)	9.67 (1.0)	0.452
Seventh day baseline			
Systolic BP baseline, mm Hg	135.9 (5.7)	131.2 (6.0)	0.217
Diastolic BP baseline, mm Hg	80.2 (3.9)	77.2 (2.7)	0.324
Heart rate baseline, beats/min	76.1 (4.1)	70.0 (3.2)	0.163
Peak SBP, mm Hg	186.9 (7.4)	187.4 (5.5)	0.340
Peak DBP, mm Hg	94.1 (3.1)	90.0 (2.9)	0.209
Peak heart rate, beats/min	127.8 (6.8)	139.2 (5.5)	0.043
Exercise duration, min	5.23 (1.31)	6.69 (0.90)	0.158
Work load, W	169.3 (32.0)	215.4 (26.3)	0.076
Heart rate recovery, beats/min	27.4 (3.5)	31.0 (2.9)	0.152
Pulse wave velocity m/s	10.3 (0.9)	10.0 (1.0)	0.475

*Exact one-tailed *P* value of Mann-Whitney *U* test.

Baseline exercise capacity testing, which provides an accurate assessment of maximal and functional aerobic capacity, showed that there was no significant difference between the urban and park exposure groups for exercise duration (where longer duration indicates greater capacity) (4.97 ± 1.43 and 5.66 ± 0.80 min, $P = 0.205$, resp.), work load, or postexercise HR recovery. Pulse wave velocity was

also similar. After 7 days of walking there were no statistically significant changes between the urban and park groups in terms of hemodynamic parameters. However, work load was slightly higher (169.3 W and 215.4 W, $P = 0.076$), and SBP and DBP were slightly lower in park group. Both groups demonstrated slight decreases in HR and increases in exercise capacity test duration and HR recovery as a consequence

TABLE 3: The difference in hemodynamic parameters between baseline and 1 min and baseline and 30 min after walking in urban or park environment on the first and the seventh day.

Measurements	Difference 1 min after walking			Difference 30 min after walking		
	Mean (SE)	<i>P</i> * value	<i>P</i> ** value	Mean (SE)	<i>P</i> * value	<i>P</i> ** value
Urban exposure						
SBP, mm Hg day 1	14.5 (3.3)	0.008		2.3 (4.4)	0.199	
DBP, mm Hg day 1	10.1 (2.5)	0.008		2.0 (2.5)	0.148	
HR, b/min day 1	23.1 (6.5)	0.004		-7.6 (5.6)	0.125	
SBP, mm Hg day 7	19.1 (5.5)	0.010		12.8 (6.8)	0.064	
DBP, mm Hg day 7	6.1 (4.3)	0.150		7.4 (3.9)	0.023	
HR, b/min day 7	28.3 (4.9)	0.002		10.9 (5.1)	0.037	
Green exposure						
SBP, mm Hg day 1	11.4 (5.7)	0.035	0.236	7.2 (6.7)	0.125	0.483
DBP, mm Hg day 1	1.7 (2.3)	0.227	0.018	3.6 (6.7)	0.086	0.264
HR, b/min day 1	15.1 (4.7)	0.010	0.223	3.6 (4.1)	0.275	0.152
SBP, mm Hg day 7	22.3 (5.2)	0.002	0.389	5.0 (5.2)	0.172	0.091
DBP, mm Hg day 7	4.0 (3.9)	0.238	0.356	-2.4 (3.2)	0.258	0.045
HR, b/min day 7	12.7 (4.0)	0.008	0.015	5.3 (4.2)	0.172	0.252

*Exact one-tailed *P* value of Wilcoxon test between baseline and 1 min after exposure.

**Exact one-tailed *P* value of Mann-Whitney *U* test between exposure groups.

of regular walking. There were no statistically significant changes between the groups in pulse wave velocity ($P = 0.475$).

Analysis of short-term (1 min and 30 min after exercise) changes in hemodynamic parameters on days 1 and 7 revealed statistically significant differences in hemodynamic indices at 1 min after walking compared with baseline (Table 3). On day 1, 1 min after walking, patients in both groups had higher SBP and HR than at baseline, and higher DBP was evident in the urban group. After 30 min rest, SBP, DBP, and HR decreased to baseline levels in both groups. On day 7, 1 min after walking, increases observed in HR (from baseline levels) were significantly lower for the park exposure than the urban exposure group. After a week of exposure in both groups, increases in SBP and HR measured 1 min after walking were again evident but decreases to baseline levels in the hemodynamic parameters at 30 min postexposure were found only in those exposed to park environment; that is, those walking in green environments showed faster favourable hemodynamic changes compared with the urban group. When we tested for significance of these apparent differences, on day 1, 1 min after walking only DBP differed (due to the slower reduction in DBP from a higher postexposure level in the urban group). The difference in DBP on day 7, 30 min after walking, was statistically significant between the urban and park groups (+4.0 and -2.4 mm Hg, resp., $P = 0.045$).

The difference in resting hemodynamic parameters measured at baseline of days 1 and 7 is presented in Table 4. After seven days of exposure, we found a slight decrease in resting DBP and HR before the exercise test and a decrease in resting HR three hours after the test (mean value derived from ambulatory monitoring) in patients exposed to urban environment. However, there was evidence of a positive training effect on hemodynamic parameters in patients exposed to park environment; on day 7, three hours after exercise

we found a stable and statistically significant decrease in SBP (6.50 mm Hg) and DBP (6.29 mm Hg) compared with pretraining data ($P = 0.049$ and $P = 0.014$, resp.). Significant increases in exercise duration (increase of 1.1 min, $P = 0.004$) and HR recovery (5.89 beats/min, $P = 0.037$) were also observed in the park group, while in urban environment exposed patients, changes in these parameters were not statistically significant.

4. Discussion

The present study aimed to use objective measures to assess the physiological effects of controlled walking in urban and park environments in CAD patients. Data showed that regular 30 min walks of moderate intensity in a park environment performed on 7 consecutive days led to greater favorable changes in resting SBP and DBP, improvements in exercise tolerance, and increases in exercise duration, compared with equivalent walks in an urban environment. Walking in the park also increased patients' HR recovery after everyday physical exercise. Because HR recovery (fall in HR 1 min after exercise) is treated as an indicator of autonomic function [8, 16, 17], the increase in HR recovery could be the result of improved autonomic nervous function regulation induced by physical training in green environment. The results presented offer some support for our hypothesis that walking in the park environment has better restorative effect on impaired hemodynamic in CAD patients compared with walking in a busy urban street.

To our knowledge, no previous studies have compared the effects of controlled walking in urban and park environments on hemodynamic parameters in CAD patients. Our results are consistent with evidence from healthy young adults. The comparison of physiological effects of 15 min of walking in forest and urban environment in 12 Japanese students

TABLE 4: The changes (mean (SE)) of hemodynamic parameters between the first and the seventh day exposure in urban and park environments.

Measurements at day 1 and day 7	Urban exposure changes in mean (SE)	<i>P</i> * value	Park exposure changes in mean (SE)	<i>P</i> * value
SBP, mm Hg before test	1.22 (3.9)	0.336	-4.70 (6.0)	0.456
DBP, mm Hg before test	-0.11 (2.3)	0.453	-4.20 (2.2)	0.031
HR, b/min before test	-1.56 (1.9)	0.348	-1.3 (3.3)	0.500
SBP, mm Hg 3 h after test	1.30 (2.8)	0.469	-6.5 (3.7)	0.049
DBP, mm Hg 3 h after test	1.93 (3.8)	0.422	-6.29 (2.4)	0.014
HR, b/min 3 h after test	-4.16 (3.5)	0.172	-1.79 (1.6)	0.188
Peak SBP, mm Hg	5.5 (3.2)	0.156	-3.8 (5.8)	0.262
Peak DBP, mm Hg	0 (2.3)	0.453	-4.3 (3.3)	0.234
Peak heart rate, b/min	2.63 (4.0)	0.223	0.33 (3.7)	0.422
Exercise duration, min	0.26 (0.3)	0.230	1.10 (0.28)	0.004
Work load, W	9.8 (9.8)	0.500	30.9 (13.0)	0.063
Heart rate recovery, b/min	6.75 (4.5)	0.121	5.89 (2.6)	0.037
Pulse wave velocity m/s	0.37 (0.9)	0.410	0.35 (0.8)	0.321

* Exact one-tailed *P* value of Wilcoxon test.

revealed significantly lower SBP, DBP, and HR and higher HR variability in subjects exposed to a forest environment showing suppressed sympathetic nervous activity and enhanced parasympathetic nervous activity in the forest area [34]. The greater positive effect on young adults BP during and after 30 min walking was found among those exposed to a green environment versus urban environment [2]; however, the effect soon disappeared after walking. The study of forest walking in young Japanese males showed cardiovascular relaxation, decreased SBP, lower HR, and reduced negative psychological symptoms in the forest environment exposed young males. These results suggested that physical activities in park environment can promote cardiovascular relaxation [35].

In our study improvements observed in exercise tolerance and increased HR recovery after 7 days of 30 min walks in a park environment may be explained by the positive influence of forest-related activities on cardiovascular relaxation and recovery of homeostasis in CAD patients. This mechanism may be partially confirmed by the findings of young Japanese adult males, indicating that walking in the forest environment can facilitate homeostasis [35]. Physiological studies support that green environment effects can manifest on homeostasis through positive effects on the central and autonomic nervous systems and endocrine systems [34].

Our findings are in accordance with the results of epidemiological studies, which show positive relationships

between the physical activity in natural environment and cardiovascular health. A Kaunas cohort study that investigated associations between the accessibility and use of urban city parks and cardiovascular health showed that the prevalence of cardiovascular risk factors was statistically significantly lower among park users than among nonusers. Men living further away from parks and rarely using them had a higher risk of nonfatal and fatal CVD combined, compared with those living nearby; that is, regular use of green space in a city setting was linked to reduced risk of heart disease [36]. An observational study in Perth, Western Australia [37], showed that higher greenness level within a neighbourhood was associated with lower heart disease or stroke risk, and a randomized controlled trial [38] indicates that even short exercise-based rehabilitation may improve long-term outcomes.

In our study, differences in measured characteristics of the two environments may also partially explain our findings. During walking in the urban street, NO₂ was higher by 3.84 μg/m³, PM_{2.5} by 6.41 μg/m³, and noise level by 19.03 dBA (compared with the park environment). Such differences may have impact on psychophysiological stress, homeostasis, and hemodynamic parameters. Previously published data from Kaunas [39, 40] and studies elsewhere [41, 42] indicate that such an increase of urban NO₂ pollution, noise level, and PM_{2.5} pollution may increase the risk of hypertension and that this, through increase in SBP and

DBP, may promote atherosclerosis and CAD. Short-term increases in exposure to ambient PM_{2.5} are associated with acute increases in blood pressure in adults [43]. The particle pollution in CAD patients during physical activity may increase systemic arterial vascular narrowing, as manifested by increased peripheral blood pressure and HR [44, 45], and promote arterial vasoconstriction via altering cardiovascular autonomic nervous system balance [46–48]. These findings support our conclusions that physical activity in the park environment has a greater positive impact on cardiovascular health than physical activity in an urban street and that to increase the efficacy of exercise-based cardiac rehabilitation for urban residents, walking in green environments should be recommended.

The study results will have direct practical applications for the use of natural environments in cardiac rehabilitation. However, some limitations are recognised. First, the sample size was relatively small, albeit large enough to detect some significant effects. Second, we are unable to identify which specific characteristics of the natural and urban environments were responsible for the observed effects. During walking, patients were affected not only by the traffic emissions but also by the view of trees planted in front of the houses and that may have impact on the decrease of psychophysiological stress level and obtained results.

These limitations notwithstanding, this study appears to be the first to analyse the relationship between the controlled physical activity in different environments and CAD patient's hemodynamic parameters, further adding to the growing support for the therapeutic potential of natural environments. Natural environments should be considered for inclusion in physical rehabilitation after CAD, but further research with larger samples is required to draw generalized scientific conclusions on the impact of natural environmental quality on CAD patients.

Abbreviations

CAD: Coronary artery disease
 HR: Heart rate
 SBP: Systolic blood pressure
 DBP: Diastolic blood pressure
 min: Minute.

Conflict of Interests

The authors declare no conflict of interests.

Authors' Contribution

Regina Grazuleviciene conceived the idea and was the lead writer. Jone Vencloviene performed statistical analysis and assisted with interpretation. Raimondas Kubilius participated in the randomization of study participants and in clinical investigations. Vytautas Grizas participated in the clinical investigations. Audrius Dedele undertook the environmental exposure modelling. Tomas Grazulevicius drafted the tables and assisted with the writing of the paper. Indre Ceponiene

participated in the experimental study and assisted with the writing of the paper. Egle Tamuleviciute-Prasciene participated in the experimental study and the drafting of the methods. Mark J. Nieuwenhuijsen conceptualized and supervised the study and critically reviewed the paper. Marc Jones contributed to the design of the study. Christopher Gidlow designed the experimental study and critically reviewed the paper. All authors critically reviewed and revised the paper and approved the final version of it as submitted.

Acknowledgments

This work was supported in part by the European Commission Grant no. FP6-036224; the original study on which the present paper is based received Grant no. FP7-282996 and the grant of Lithuanian Agency for Science Innovation and Technology (MITA) 2013-07-31 no. 2V-127.

References

- [1] T. Sugiyama, E. Leslie, B. Giles-Corti, and N. Owen, "Associations of neighbourhood greenness with physical and mental health: do walking, social coherence and local social interaction explain the relationships?" *Journal of Epidemiology and Community Health*, vol. 62, no. 5, article e9, 2008.
- [2] T. Hartig, G. W. Evans, L. D. Jamner, D. S. Davis, and T. Gärling, "Tracking restoration in natural and urban field settings," *Journal of Environmental Psychology*, vol. 23, no. 2, pp. 109–123, 2003.
- [3] D. E. Bowler, L. M. Buyung-Ali, T. M. Knight, and A. S. Pullin, "A systematic review of evidence for the added benefits to health of exposure to natural environments," *BMC Public Health*, vol. 10, article 456, 2010.
- [4] J. Lee, B.-J. Park, Y. Tsunetsugu, T. Ohira, T. Kagawa, and Y. Miyazaki, "Effect of forest bathing on physiological and psychological responses in young Japanese male subjects," *Public Health*, vol. 125, no. 2, pp. 93–100, 2011.
- [5] R. Mitchell and F. Popham, "Effect of exposure to natural environment on health inequalities: an observational population study," *The Lancet*, vol. 372, no. 9650, pp. 1655–1660, 2008.
- [6] D. Lucini, R. V. Milani, G. Costantino, C. J. Lavie, A. Porta, and M. Pagani, "Effects of cardiac rehabilitation and exercise training on autonomic regulation in patients with coronary artery disease," *American Heart Journal*, vol. 143, no. 6, pp. 977–983, 2002.
- [7] R. S. Taylor, A. Brown, S. Ebrahim et al., "Exercise-based rehabilitation for patients with coronary heart disease: systematic review and meta-analysis of randomized controlled trials," *The American Journal of Medicine*, vol. 116, no. 10, pp. 682–692, 2004.
- [8] L. Danilowicz-Szymanowicz, M. Figura-Chmielewska, W. Ratkowski, and G. Raczak, "Effect of various forms of physical training on the autonomic nervous system activity in patients with acute myocardial infarction," *Kardiologia Polska*, vol. 71, no. 6, pp. 558–565, 2013.
- [9] E. T. Rosenwinkel, D. M. Bloomfield, M. A. Arwady, and R. L. Goldsmith, "Exercise and autonomic function in health and cardiovascular disease," *Cardiology Clinics*, vol. 19, no. 3, pp. 369–387, 2001.
- [10] P. Giannuzzi, H. Saner, H. Björnstad et al., "Secondary prevention through cardiac rehabilitation: position paper of the working group on cardiac rehabilitation and exercise physiology of

- the European Society of Cardiology," *European Heart Journal*, vol. 24, no. 13, pp. 1273–1278, 2003.
- [11] M. K. Lahiri, P. J. Kannankeril, and J. J. Goldberger, "Assessment of autonomic function in cardiovascular disease: physiological basis and prognostic implications," *Journal of the American College of Cardiology*, vol. 51, no. 18, pp. 1725–1733, 2008.
 - [12] D. G. Martinez, J. C. Nicolau, R. L. Lage et al., "Effects of long-term exercise training on autonomic control in myocardial infarction patients," *Hypertension*, vol. 58, no. 6, pp. 1049–1056, 2011.
 - [13] N. Rius-Ottenheim, J. M. Geleijnse, D. Kromhout, R. C. van der Mast, F. G. Zitman, and E. J. Giltay, "Physical activity after myocardial infarction: is it related to mental health?" *European Journal of Preventive Cardiology*, vol. 20, no. 3, pp. 399–408, 2013.
 - [14] J. Mimura, F. Yuasa, R. Yuyama et al., "The effect of residential exercise training on baroreflex control of heart rate and sympathetic nerve activity in patients with acute myocardial infarction," *Chest*, vol. 127, no. 4, pp. 1108–1115, 2005.
 - [15] F. Giallauria, A. de Lorenzo, F. Pileri et al., "Long-term effects of cardiac rehabilitation on end-exercise heart rate recovery after myocardial infarction," *European Journal of Cardiovascular Prevention and Rehabilitation*, vol. 13, no. 4, pp. 544–550, 2006.
 - [16] S. Michael and M. S. Lauer, "Autonomic function and prognosis," *Cleveland Clinic Journal of Medicine*, vol. 76, supplement 2, pp. S18–S22, 2009.
 - [17] F. Ribeiro, A. J. Alves, M. Teixeira et al., "Exercise training enhances autonomic function after acute myocardial infarction: a randomized controlled study," *Revista Portuguesa de Cardiologia*, vol. 31, no. 2, pp. 135–141, 2012.
 - [18] H. M. Dalal, A. Zawada, K. Jolly, T. Moxham, and R. S. Taylor, "Home based versus centre based cardiac rehabilitation: cochrane systematic review and meta-analysis," *British Medical Journal*, vol. 340, Article ID b5631, 2010.
 - [19] L. P. T. Hua, C. A. Brown, S. J. M. Hains, M. Godwin, and J. L. Parlow, "Effects of low-intensity exercise conditioning on blood pressure, heart rate, and autonomic modulation of heart rate in men and women with hypertension," *Biological Research for Nursing*, vol. 11, no. 2, pp. 129–143, 2009.
 - [20] R. R. West, D. A. Jones, and A. H. Henderson, "Rehabilitation after myocardial infarction trial (RAMIT): multi-centre randomised controlled trial of comprehensive cardiac rehabilitation in patients following acute myocardial infarction," *Heart*, vol. 98, no. 8, pp. 637–644, 2012.
 - [21] D. Krewski and D. Rainham, "Ambient air pollution and population health: overview," *Journal of Toxicology and Environmental Health Part A: Current Issues*, vol. 70, no. 3-4, pp. 275–283, 2007.
 - [22] A. Tiwary, D. Sinnett, C. Peachey et al., "An integrated tool to assess the role of new planting in PM₁₀ capture and the human health benefits: a case study in London," *Environmental Pollution*, vol. 157, no. 10, pp. 2645–2653, 2009.
 - [23] J. Barton and J. Pretty, "What is the best dose of nature and green exercise for improving mental health? A multi-study analysis," *Environmental Science and Technology*, vol. 44, no. 10, pp. 3947–3955, 2010.
 - [24] S. de Vries, R. A. Verheij, P. P. Groenewegen, and P. Spreeuwenberg, "Natural environments—healthy environments? An exploratory analysis of the relationship between greenspace and health," *Environment and Planning A*, vol. 35, no. 10, pp. 1717–1731, 2003.
 - [25] J. Maas, R. A. Verheij, P. P. Groenewegen, S. de Vries, and P. Spreeuwenberg, "Green space, urbanity, and health: how strong is the relation?" *Journal of Epidemiology and Community Health*, vol. 60, no. 7, pp. 587–592, 2006.
 - [26] R. Mitchell and F. Popham, "Greenspace, urbanity and health: relationships in England," *Journal of Epidemiology and Community Health*, vol. 61, no. 8, pp. 681–683, 2007.
 - [27] C. Paquet, T. P. Orschulok, N. T. Coffee et al., "Are accessibility and characteristics of public open spaces associated with a better cardiometabolic health?" *Landscape and Urban Planning*, vol. 118, pp. 70–78, 2013.
 - [28] D. R. Dengel, M. O. Hearst, J. H. Harmon, A. Forsyth, and L. A. Lytle, "Does the built environment relate to the metabolic syndrome in adolescents?" *Health and Place*, vol. 15, no. 4, pp. 946–951, 2009.
 - [29] B.-J. Park, Y. Tsunetsugu, T. Kasetani, T. Morikawa, T. Kagawa, and Y. Miyazaki, "Physiological effects of forest recreation in a young conifer forest in Hinokage Town, Japan," *Silva Fennica*, vol. 43, no. 2, pp. 291–301, 2009.
 - [30] G. X. Mao, Y. B. Cao, X. G. Lan et al., "Therapeutic effect of forest bathing on human hypertension in the elderly," *Journal of Cardiology*, vol. 60, no. 6, pp. 495–502, 2012.
 - [31] M. J. Nieuwenhuijsen, H. Kruize, C. Gidlow et al., "Positive health effects of the natural outdoor environment in typical populations in different regions in Europe (PHENOTYPE): a study programme protocol," *BMJ Open*, vol. 4, no. 4, Article ID e004951, 2014.
 - [32] "Phenotype," 2013, <http://www.Phenotype.eu>.
 - [33] H. E. Corey and D. W. Russell, *Exercise Testing for Primary Care and Sports Medicine Physicians*, Springer Science+Business Media, LLC, New York, NY, USA, 2009.
 - [34] Y. Tsunetsugu, B.-J. Park, H. Ishii, H. Hirano, T. Kagawa, and Y. Miyazaki, "Physiological effects of Shinrin-yoku (taking in the atmosphere of the forest) in an old-growth broadleaf forest in Yamagata Prefecture, Japan," *Journal of Physiological Anthropology*, vol. 26, no. 2, pp. 135–142, 2007.
 - [35] J. Lee, Y. Tsunetsugu, N. Takayama et al., "Influence of forest therapy on cardiovascular relaxation in young adults," *Evidence-Based Complementary and Alternative Medicine*, vol. 2014, Article ID 834360, 7 pages, 2014.
 - [36] A. Tamosiunas, R. Grazuleviciene, D. Luksiene et al., "Accessibility and use of urban green spaces and cardiovascular health: findings from a Kaunas cohort study," *Environmental Health*, vol. 13, article 20, 2014.
 - [37] G. Pereira, S. Foster, K. Martin et al., "The association between neighbourhood greenness and cardiovascular disease: an observational study," *BMC Public Health*, vol. 12, article 466, 2012.
 - [38] P. R. Lawler, K. B. Filion, and M. J. Eisenberg, "Efficacy of exercise-based cardiac rehabilitation post-myocardial infarction: a systematic review and meta-analysis of randomized controlled trials," *American Heart Journal*, vol. 162, no. 4, pp. 571–584, 2011.
 - [39] R. Grazuleviciene, L. Maroziene, V. Dulskiene et al., "Exposure to urban nitrogen dioxide pollution and the risk of myocardial infarction," *Scandinavian Journal of Work, Environment & Health*, vol. 30, no. 4, pp. 293–298, 2004.
 - [40] I. Bendokiene, R. Grazuleviciene, and A. Dedele, "Risk of hypertension related to road traffic noise among reproductive-age women," *Noise and Health*, vol. 13, no. 55, pp. 371–377, 2011.

- [41] W. Babisch, "Transportation noise and cardiovascular risk: updated review and synthesis of epidemiological studies indicate that the evidence has increased," *Noise and Health*, vol. 8, no. 30, pp. 1-29, 2006.
- [42] K. Fuks, S. Moebus, S. Hertel et al., "Long-term urban particulate air pollution, traffic noise, and arterial blood pressure," *Environmental Health Perspectives*, vol. 119, no. 12, pp. 1706-1711, 2011.
- [43] J. T. Dvornch, S. Kannan, A. J. Schulz et al., "Acute effects of ambient particulate matter on blood pressure: differential effects across urban communities," *Hypertension*, vol. 53, no. 5, pp. 853-859, 2009.
- [44] A. Zanobetti, M. J. Canner, P. H. Stone et al., "Ambient pollution and blood pressure in cardiac rehabilitation patients," *Circulation*, vol. 110, no. 15, pp. 2184-2189, 2004.
- [45] J. D. Sacks, L. W. Stanek, T. J. Luben et al., "Particulate matter-induced health effects: who is susceptible?" *Environmental Health Perspectives*, vol. 119, no. 4, pp. 446-454, 2011.
- [46] J. Widdicombe and L.-Y. Lee, "Airway reflexes, autonomic function, and cardiovascular responses," *Environmental Health Perspectives*, vol. 109, no. 4, pp. 579-584, 2001.
- [47] R. D. Brook, B. Urch, J. T. Dvornch et al., "Insights into the mechanisms and mediators of the effects of air pollution exposure on blood pressure and vascular function in healthy humans," *Hypertension*, vol. 54, no. 3, pp. 659-667, 2009.
- [48] P. M. Mannucci, "Airborne pollution and cardiovascular disease: burden and causes of an epidemic," *European Heart Journal*, vol. 34, no. 17, pp. 1251-1253, 2013.

Research Article

Co-Designing Ambient Assisted Living (AAL) Environments: Unravelling the Situated Context of Informal Dementia Care

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Received 30 November 2014; Accepted 20 February 2015

Academic Editor: Stephen Goss

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Ambient assisted living (AAL) aims to help older persons “age-in-place” and manage everyday activities using intelligent and pervasive computing technology. AAL research, however, has yet to explore how AAL might support or collaborate with informal care partners (ICPs), such as relatives and friends, who play important roles in the lives and care of persons with dementia (PwDs). In a multiphase codesign process with six (6) ICPs, we envisioned how AAL could be situated to complement their care. We used our codesigned “caregiver interface” artefacts as *triggers* to facilitate envisioning of AAL support and unpack the situated, idiosyncratic context within which AAL aims to assist. Our findings suggest that AAL should be designed to support ICPs in fashioning “do-it-yourself” solutions that complement tacitly improvised care strategies and enable them to try, observe, and adapt to solutions over time. In this way, an ICP could decide which activities to entrust to AAL support, when (i.e., scheduled or spontaneous) and how a system should provide support (i.e., using personalized prompts based on care experience), and when adaptations to system support are needed (i.e., based alerting patterns and queried reports). Future longitudinal work employing participatory, design-oriented methods with care dyads is encouraged.

1. Introduction

As the most important contributors to dependence and institutionalization, dementia and cognitive impairment [1] profoundly impact not only persons living with impairment, but also their significant others, relatives, and friends. While public health systems strive to assist persons with dementia (PwDs) to live at home [2], Canadian home care resources continue to fall short in meeting real-world needs [3], consequently shifting care responsibilities to informal care partners (ICPs)—most commonly family members [4]. The role of an ICP involves responding to increasing care needs and dependency over time. With or without formal support, an ICP will typically transition from supporting instrumental activities of daily living (ADLs) (e.g., finances and shopping)

to assisting with basic ADLs (e.g., bathing and dressing) and to providing constant care and supervision [1]. Although the stress and burden associated with caring for a PwD is well documented (e.g., [5–9]), ICPs may wish to continue caring for as long as possible for reasons that include fulfilling filial duties [10] or continuing their relationships with PwDs [11, 12]. Taken together, there is a need for policies, services, and interventions that can better support and collaborate with ICPs in the care of PwDs [3, 13].

Concurrently, the emerging field of ambient assisted living (AAL) has positioned itself to enable older adults, including PwDs, to “age-in-place” (i.e., at home and in their communities) through the support of intelligent and pervasive computing (also referred to as “smart home”) technologies. This class of technologies aims to deliver unobtrusive,

context-aware assistance by sensing and learning patterns of behaviour and, in turn, tailoring its support to specific users (e.g., [14]). Beyond studies that have aimed to demonstrate technological efficacy to this end, user studies have involved PwDs to investigate AAL applications to promote memory, safety, and functional independence in the home [15]. Although many have suggested the importance of also considering ICPs in AAL research and development [15–18], the field has yet to address how these technologies might coexist with ICPs in the care of PwDs, as opposed to replacing the care they provide. In a qualitative study with ICPs, which followed on earlier longitudinal work together with PwDs [19], Rosenberg et al. [20] found that ICPs showed overall readiness to use everyday technology to support their caring roles. In another study using home visits and interviews with PwDs and their ICPs, Wherton and Monk [21] identified dressing, medications, personal hygiene, food preparation, and social communication as potential areas for prompting and sensing technologies. Another quantitative study with ICPs concluded that these stakeholders lacked knowledge of the capabilities of intelligent technologies and recommended future user-centred design approaches to address this knowledge gap in the research process [22, 23]. This previous work recognizes ICPs as an important stakeholder group in AAL research whose needs should be considered in the design of holistic AAL solutions to meet the needs of multiple key stakeholders.

To this end, this study extends our earlier discussion of the design considerations for this context [24] to a deeper description of how ICPs envision AAL support alongside their own care of PwDs. Guided by the philosophy that AAL supporting PwDs should be designed, not to replace but rather to *complement and collaborate* with ICPs, our key study objectives were to explore (1) when or with which day-to-day, home-based activities ICPs envisioned AAL could support their care and (2) how ICPs envision interacting with the technology to specify and obtain the desired support. We pursued these objectives through an inductive codesign process with ICP participants. This participatory approach aimed to scope the needs and perspectives of ICPs in an envisaged future with AAL support; educate these stakeholders on the capabilities and potential of AAL technologies; and, together, creatively explore new possibilities for AAL design.

2. Method

2.1. Study Design. As AAL represents an imagined technological future in which the roles of ICPs have yet to be explored, our study employed a codesign approach [26] that involved ICP participants in group design workshops, followed by paper prototyping sessions with individual participants in their homes. Codesign utilizes the “collective creativity of designers working together with nondesigners” and is well suited for early stages of the design process, where complex challenges and embodiments of imagined future user experiences can be explored [26]. Integral to this process was the use of “creativity triggers”—visual artefacts that explained the concept and capabilities of AAL, guided our questions, and facilitated participants’ envisioning of the design space

[27]. The first trigger was an animated video demonstrating an activity-assistance AAL system, “COACH” [28], which acted as a point of departure from which participants could envision, ideate, and design their interactions with similar AAL systems. Subsequent triggers were presented in the forms of user interface designs and paper prototypes to focus participants on the codesign of a “caregiver interface”—a tool to enable an ICP to set up and specify AAL support. In this way, prototypes helped to “concretize and externalize conceptual ideas” [29] and our codesign process reflected *research through design*, an approach whereby “artefacts [are] intended to be carefully crafted questions . . . [that] stimulate discourse around a topic” [30]. In addition to serving as triggers, the codesigned artefacts also constituted data, together with the discussion, reflection, and interpretation they facilitated. Similar to how “technology probes” aim, in part, to collect sociological data about the contextualized use of technology [31], we focused our study on what these artefacts revealed about the needs, perspectives, and particularities of ICPs in their care contexts, rather than issues of user interface aesthetics, usability, and form factor.

2.2. Participants and Recruitment. Six participants were recruited from a community-based agency supporting PwDs and ICPs. Agency staff members facilitated recruitment through word-of-mouth promotion and recruitment flyers, referring all prospective participants to the research team. The first author conducted a telephone screen to qualify each prospective participant based on our study inclusion criteria: providing at least seven hours (i.e., approximately half the average provided to persons with mild dementia [32]) of unpaid care each week for a community-dwelling PwD (i.e., diagnosed or assumed dementia); assisting with most or all listed ADLs (i.e., bathing, toileting, hand-washing, toothbrushing, dressing, meal preparation, and taking medications); and having been providing care for at least six months. Table 1 summarizes the six ICP participants who participated in Phase 1 and Phase 2, and the asterisks indicate the two participants who participated in Phase 3.

2.3. Our Codesign Process. Our codesign method was informed by two relevant models. The conventional four-stage user-centred design (UCD) model [33]—*studying* users, *designing* for the problem space, *building* prototypes, and *evaluating* prototypes—guided our design process, and the usability, safety, attractiveness participatory (USAP) design model [25] formed the successive phases of this study, as shown in Figure 1. Moreover, our study adopted a participatory approach whereby, over multiple phases, we shared control with participants in design decisions and exchanged our respective expertise (i.e., researchers on technological capabilities and participants on informal care practices) that could then be articulated through collaboratively designed artefacts [34].

Phase 0: Design Preparation. This preparatory phase aimed to set the stage for active participant engagement by developing tools to guide them in imagining a future with AAL support.

TABLE 1: Description of participants. The activities of daily living (ADLs) participants reported with assisting were among bathing, toileting, hand-washing, toothbrushing, dressing, meal preparation, and taking medications.

Participant (pseudonyms)	Age	Relationship	Living with the PwD?	Severity of dementia (PwD)	Assists with how many ADLs (of 7)
Jacklyn	55	Daughter	No, same apartment building	Mild to moderate	6
Heather	67	Daughter	No, within a five-minute drive	Moderate	7
Kristine	74	Spouse	Yes	Mild to moderate	7
Tabitha	77	Spouse	Yes	Moderate	7
Melissa*	37	Daughter	No, father was moved to nursing home two months ago	Moderate to severe	7
Hilda*	62	Daughter	Yes	Severe	7

The asterisks indicate the two participants selected to participate in Phase 3.

We developed an animated video based on the COACH system, which has demonstrated efficacy in guiding a PwD through an ADL (e.g., hand-washing) using context-aware prompts and learning from a specific user’s behaviours to improve prompting over time [28]. This video was to serve as a creativity trigger [27] to familiarize participants with the capabilities of AAL and demonstrate how an AAL system might assist a PwD who requires prompts and cues to complete an activity. As shown in Figure 2, the video depicts an older man (PwD) washing his hands in the bathroom with successive audio, picture, and video prompts from COACH, delivered only as needed, if the man experiences difficulty progressing to the next correct step of hand-washing. The man’s daughter is shown in the video to be preparing dinner in the kitchen while he is able to wash his hands independently.

Phase 1: Concept Development. This phase aimed to address the first research objective—to explore when and with which activities ICPs envisioned AAL support. The first 90-minute group design workshop, held in the boardroom of the recruitment agency, involved a professional facilitator, the first and last authors, and the recruited participants. Upon collecting consent, we played the animated video and followed it with a discussion of participants’ initial questions and comments. Participants were then given 20 minutes to complete an individual reflection/design activity: they were asked to describe (i.e., through text or sketches) how they envisioned seeking care assistance from COACH. Following this, each participant presented her idea(s) to the group, stimulating others’ comments and generating new ideas. The facilitator summarized and clarified discussion themes aloud before closing the session. After the workshop, the first author reviewed field notes, participants’ design submissions, audio transcripts, and workshop video. Guided by a general inductive approach [35], data were coded and categorized into activities and situations participants suggested for AAL support. Categories relevant to how participants envisioned interacting with an AAL system (i.e., our second research question) were also generated from data analysis, including aspects of AAL support participants wished to control or customize, and information they wished to receive from

an AAL system. To prepare for the second workshop (Phase 2), the first author emailed a summary of findings to all participants to promote additional reflections and generated preliminary caregiver interface artefacts (“Design v1”) to trigger participants in Phase 2.

Phase 2: Concept Refinement. This phase aimed to steer discussion and codesign from the activities/situations for which ICPs envisioned AAL support (first research objective) toward how participants envisioned specifying and obtaining this support (second research objective). During this group design workshop, we asked participants to review, critique, annotate, and discuss their design recommendations for Design v1, first in two small groups, each of which was audiorecorded, followed by a discussion altogether. After the workshop, audio transcripts, session video, field notes, and annotated copies of Design v1 were analyzed, again using a general inductive approach [35]. This analysis generated five scenarios for specifying and obtaining AAL support: (1) setting up and orientating an AAL system for the first time; (2) modifying how the system assists the PwD with a selected activity (i.e., toothbrushing); (3) creating and customizing how the system assists the PwD with a new activity; (4) generating a report on how the PwD is responding to system assistance; and (5) using the system to “check up” on the PwD while the ICP is away from home. Following this workshop, the first author developed the next iteration of caregiver interface artefacts (“Design v2”), which would serve as triggers to participants in Phase 3.

Phase 3: User Trials. To continue exploring how ICPs would specify and obtain AAL support in the generated scenarios, the first author constructed a paper prototype of Design v2 and, in collaboration with the second author, developed a two-hour prototype evaluation session, guided by [36]. The session was then piloted with three domain experts affording early design recommendations, consistent cofacilitation, session timing, and anticipated responses to participants’ interactions with the prototype. During the evaluation session, each of the five scenarios was posed as a task for the participant to complete. For each task, the participant read aloud the task instruction sheet (i.e., scenario

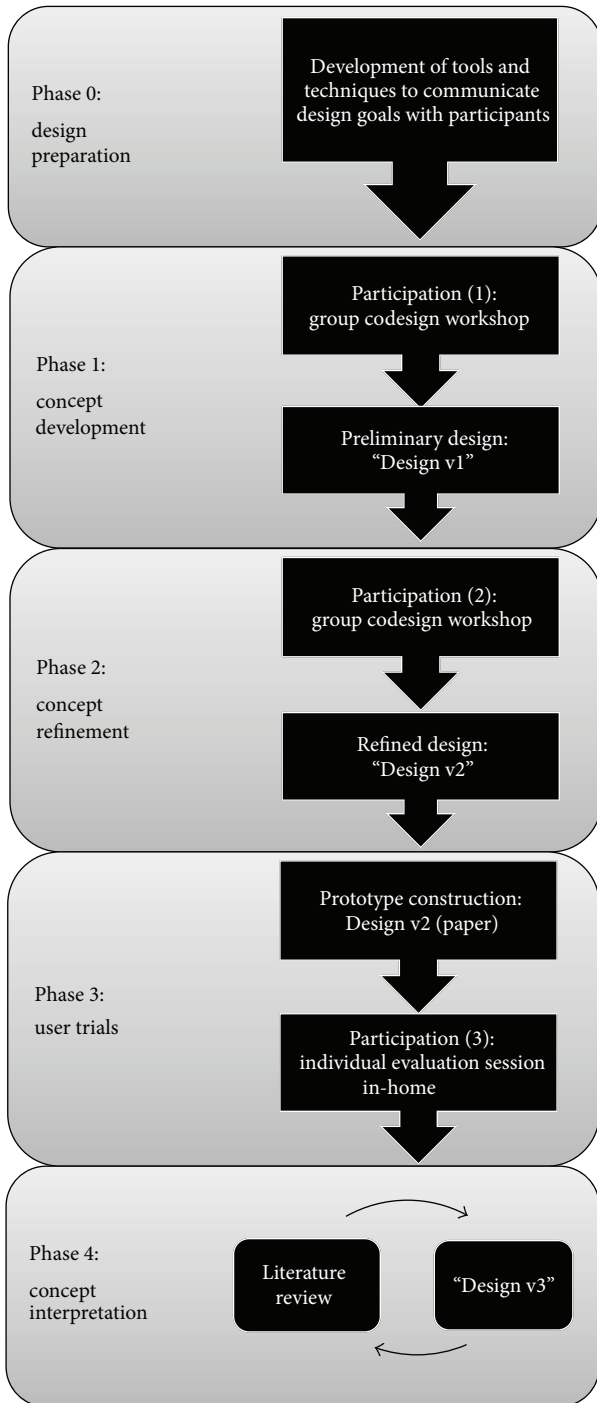


FIGURE 1: Our research/design method adapted from the USAP design model [25]. Phase 0 and Phase 4 indicate our additional/adapted stages from the original USAP model.

description, task goals, and pertinent information needed to complete the task) before attempting to complete the task. As she progressed through the task using a pen to select actions or input information on the paper prototype, the first author flipped the prototype to the next "screen" based on her interaction. Throughout each task, the participant performed

a think-aloud strategy [37] (i.e., ongoing commentary on her actions and thought processes [38]), critiqued the content and sequence of the prototype, and reflected on the appropriateness of the design to her own situation. If the participant was unsure about how to proceed in a task, the lead facilitator (second author) explained the expected actions and paused to discuss the participant's design recommendations, which were then annotated on the prototype. After all tasks were completed, we discussed the participant's overall reflections on the tasks, scenarios, prototype, and its applicability to her context. We conducted the sessions with the two selected participants in their respective homes. We selected these participants based on their interest and engagement with the research problem and process, as emphasized by [39] for participatory design in this context and participants' availability and diversity of care experiences from mild through to late-stage dementia. After both evaluation sessions, the first and second author debriefed and reviewed all field notes together with the paper prototypes annotated with participants' feedback. Over multiple discussions and the review of selected video footage (by the first author), the first and second author organized the key findings into contextual influences to specifying AAL support; AAL design "tensions"; and new design concepts for Design v3.

Phase 4: Concept Interpretation. This final phase involved a literature review, which aimed to facilitate our interpretation of the conceptual findings manifested in our prototypes [30] and explore new design possibilities ("Design v3") that reflect the current knowledge base. The first author conducted a focused literature review across several databases (i.e., MEDLINE, EMBASE, PsycINFO, CINAHL, AgeLine, Scopus, Web of Science, Social Work Abstracts and ASSIA), combining the search terms (carer* OR caregiv*), (burden OR strain OR stress), and (elder* OR senior* OR older adult*). After reviewing titles and abstracts for relevance to ICPs of PwDs, we selected qualitative studies that discussed ICPs' care experiences, routines, and strategies of ICPs. We then synthesized and linked relevant themes to the key findings from Phase 3 (i.e., contextual influences, AAL design tensions, and new design concepts). Concurrent with the literature review, the first author collaborated with undergraduate engineering design students to produce Design v3 artefacts, which aimed to harmonize Phase 3 findings and themes from the synthesized literature.

The original study protocol and all amendments proposed throughout this multiphase study were approved by the University of Toronto Research Ethics Board (Protocol ID 26622).

3. Results

In the following sections, we describe our key findings across successive research phases. To address our first research objective, we first discuss the activities and situations for which participants envisioned AAL support alongside their own care. We then address our second research objective by describing how participants envisioned specifying and obtaining the desired support—by setting up and orientating



FIGURE 2: Our developed video demonstrating to participants how COACH, an AAL environment, could guide a PwD (father) in independently completing an ADL (e.g., hand-washing) while his ICP (daughter) performs other tasks.

the AAL system to persons and the home setting; by specifying and personalizing how the system would assist their relatives (PwDs) in activities; by scheduling and spontaneously requesting system support; and by retrieving from the system care-related information and using the system to “check up” on PwDs if and when left home unattended. Although our codesigned artefacts may refer to “COACH,” we note that this system name was maintained in discussion with participants for consistency throughout the codesign process. From the perspective of the research team, the animated video of COACH was used as trigger to help participants conceptualize the capabilities of AAL support. We contend that our findings are not limited to the capabilities of the actual COACH system but are also relevant to the broader class of AAL technologies designed to guide PwDs through home-based activities. As such, we hereafter use “the system” to refer to these technologies. In addition, as our participants were all family members of PwDs, we use “relatives” to refer to the PwDs to whom they provide care.

3.1. Envisioned Activities and Situations for Which AAL Can Complement Care. Overall, participants shared varying opinions about when and with which activities they would entrust or desire AAL support in the care of their relatives. They were amenable to the idea of AAL enabling their relatives to complete ADLs and other home-based activities independently, while concurrently relieving them of some care duties. Participants envisioned AAL support for several activities (i.e., hand-washing, toothbrushing, toileting, grooming, dressing, preparing and dispensing meals, making telephone calls, watching television, and gardening) but maintained mixed opinions about which they would feel comfortable entrusting to technology. Participants also enthusiastically agreed they would find it valuable to be able to create and specify how AAL could assist with “custom” activities that were particularly meaningful to their relatives. For example, Melissa felt it was important to keep her

father “as independence as possible” in his valued activities: *“Gardening [was my father’s] passion... so, for my mom, [she couldn’t show him what to do, she could only] repeat herself, like ‘the shovel’s over there, don’t you see it?’ So something [to help him with] tool recognition - like ‘this is what a shovel looks like... it’s by the recycling bin’... [using my mom’s] voice recording, or mine, or somebody familiar... to [help my father stay] a little independent.”* This finding was reinforced by our review of the literature (Phase 4) emphasizing the need to support PwDs in continuing meaningful activities [40] and maintaining as much control as possible over their everyday occupations [41]. In doing so, however, participants shared feelings of stress and frustration in having to constantly repeat information, prompts, and cues and suggested that this AAL could potentially alleviate some of this repetition. Situations demanding these reminders included orientating their relatives to day and time, helping them remember and recognize others, reminding them of the scheduled outings, and double-checking their personal belongings before outings. Ultimately, participants believed that AAL could be valuable if an ICP could select the activities and situations to which they would delegate and specify its support.

3.2. Specifying and Obtaining the Desired AAL Support

3.2.1. Orientating the AAL Environment to Persons and Spaces in the Home. As with familiarizing a new formal care worker to persons, care routines, and the home, participants felt that a similar orientation would be needed when specifying “personalized” support from an AAL environment, we codesigned a “setup wizard” through which an ICP could indicate which locations in the home were “augmented” with the necessary hardware (e.g., sensors, cameras) to enable AAL assistance; specify for the system who else shared in the care of their relatives (including other ICPs and formal care workers) and how they could be contacted (Figure 3); specify the preferred prompt types (e.g., verbal, picture, and video)



FIGURE 3: Design v2 showing how ICPs might initially set up and orientate the system to the home setting, including the protocol for sending alerts to a specific care partner.

and prompting language most suitable for their relatives; and receive an initial tutorial on how to select activities and define situational reminders for AAL support.

3.2.2. Personalizing How the System Will Assist the PwD with the Selected Activities. Participants insisted that activity assistance would need to be personalized to the PwD. Over Phase 2 and Phase 3, we gradually interpreted personalization to mean specifying the appropriate prompt type, prompt content, and triggers. Participants envisioned specifying *prompt type* (e.g., verbal, picture, and video) based on their relatives' intact abilities and their own established prompting and cueing strategies. For example, some participants felt that displaying visual prompts through the mirror was clever and congruent with their own current care practices; others, however, were concerned that this may startle or confuse their relatives. To be effective, *prompt content* would need to be based on established strategies used by ICPs and be delivered in a supportive, nonpatronizing manner: *"I see how my husband reacts... if anybody would say 'great job', he would be kind of put down... at the early stage, you really have to worry an awful lot about their pride... and consider their feelings, you can't take over."* As it seemed the system would need to learn from and adopt ICPs' established support strategies, we co-designed caregiver interface artefacts reflecting functionality that would enable an ICP to audiorecord, take a photo/video, or select a saved media file to define a personalized prompt (Figure 4). In Phase 3, our discussions indicated the need to specify *activity steps* and *triggers* as prerequisites to defining the content of a prompt. Triggers referred to their relatives' specific actions at a particular activity step (e.g., erroneous or inappropriate action, amount of time elapsed since the PwD's last action, and verbal phrase uttered) that would signal to the system that a prompt was needed. The need for such detailed specification raised participants' concerns about the practicality of AAL, particularly in the context of caring for a relative whose fluctuating and declining abilities may demand frequent system modification. They also described prompting and cueing strategies to be highly idiosyncratic, intuitive, and tacit; explicating and "programming" this information into the system was perceived as onerous. Despite these concerns, however, we observed participants to be enthusiastic about the potential of AAL support. In particular, upon completion

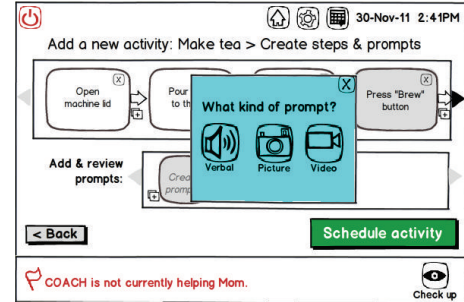


FIGURE 4: Design v2 showing how an ICP may specify an activity's steps and create (e.g., audio- or video-record) personalized prompts that they believe would assist the PwD in completing the activity (e.g., making tea).

of Phase 3 in their respective homes, both participants engagingly recommended more naturalistic interaction methods or heuristics by which they could quickly specify AAL support for their relatives.

In Phase 4, we explored a future design concept (Design v3) that aimed to respond to this design recommendation, build on the literature in support of technology-mediated peer support between ICPs [42–47], and draw inspiration from emerging social media applications (e.g., Pinterest). The concept proposed a social network that would allow ICP "subscribers" to create, specify, and share with one another (i.e., via uploading and downloading) AAL activity support solutions using a common AAL platform. On the simplest level, sharing may enable the exchange of supportive narratives to inspire new care strategies for other ICPs. On a more sophisticated level, sharing could allow subscribers to create and upload "activity templates" containing activity's steps, prompts, and triggers, which other subscribers could then view, download, and personalize for their own use.

3.2.3. Scheduling and Spontaneously Seeking AAL Support. Through codesign with participants, we also explored how ICPs could specify the appropriate timing of AAL support. In Phase 2, participants initially expressed a desire to preschedule AAL support as far in advance as possible. While completing Phase 3, however, they reflected on the practical limitations of prescheduling all system support: *"How do you program the unpredictable? How do you program something that's not routine? How do you program into the technology the specific personality of [the PwD]?"* Consistent with our review of the literature in Phase 4, improvisation was discussed as both a care strategy [48] and a natural characteristic of home life [49], which would demand sufficient flexibility for ICPs to spontaneously request, put on hold, or cancel its support as needed. Moreover, our discussion also exposed the multidimensionality of supporting home-based activities for their relatives. On a time dimension, some activities must occur at specific times (e.g., scheduled transportation pick-ups), while other activities must only be appropriately ordered (e.g., medications to be taken immediately after a meal); there are activities that are important but can occur at any time and frequency (e.g., drinking water).

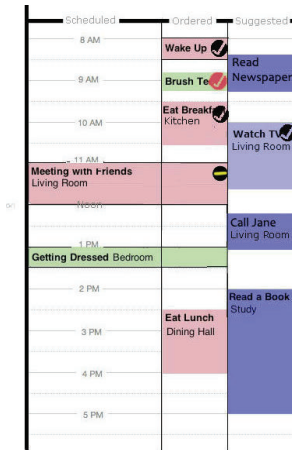


FIGURE 5: Design v3 screenshot illustrates a working mock-up of an alternative calendar design that organizes scheduled, ordered, and suggested (leisure) activities, in order of decreasing priority. The red and green coloured items indicate support by an ICP and the system, respectively. The check marks indicate whether the activity has been completed, where the red check mark indicates that an ICP was called to help the PwD complete the activity after the system's prompting was not successful. The top-right circular icon in the scheduled "Meeting with Friends" item indicates that the ICP has paused (delayed) this activity. If the scheduled item is not reinitiated after 12:15 p.m., the system may help initiate "Call Jane" if the PwD is in the living room.

On a necessity dimension, there are activities that are necessary but cannot be scheduled (e.g., toileting) and others that are entirely optional (e.g., watching television). On a support dimension, certain activities might only be initiated based on their relatives' moods or abilities, an ICP's availability or stress level, or certain logistic factors. The latter led to participants' enthusiasm for AAL support in mentally or socially stimulating their relatives.

In Phase 4, we translated these findings into a new design concept, reflected in Figure 5, an alternative calendar design that accommodates scheduled, ordered, and suggested (i.e., optional leisure) activities. To support improvisation, we added functionality that would allow an ICP to spontaneously cancel, pause (i.e., delay), or initiate AAL support to their relatives with leisure activities.

3.3. Retrieving Relevant Care Information and "Checking Up" While Away. Participants also perceived receiving care-related information from the system as another means of seeking AAL support in the care of their relatives. They agreed that being alleviated from care duties, even briefly, could be immensely valuable to them. They also shared a common desire for reassurance about if and when their relatives were home alone, though mixed opinions were discussed on which activities they would entrust to the system in their absence. Unpacking these needs and preferences over study phases led to the codesign of multiple options for conveying the desired information from the system to ICPs: "checkup" functionality, status updates, alerts, and reports.

While being away from their relatives, participants expressed the need to "check up" if they were to entrust the system to look after their relatives in their absence. In Phase 2, we initially codesigned passive video monitoring with optional two-way video communication through the AAL system. This would allow an ICP to review video, at a later time, if activities were completed in their absence (Figure 6(a)) or check up in real time and communicate if needed. In Phase 4, however, we strived toward a more "mediating" design that could both reassure an ICP of a relative's safety while reducing "surveillance" that may only exacerbate a PwD's feeling of restricted freedom [50]. Here, we considered enabling video monitoring and communication only in situations of safety risks (e.g., wandering) (Figure 6(b)) or replacing live video with less invasive sensor data (e.g., motion, light, and temperature), as Vines et al. [51] explored in a recent telecare system field trial.

Our codesign of *status updates* also aimed to address how AAL could potentially mediate the safety versus freedom conundrum. Initially, we designed passive real-time *status updates* that were displayed on the home screen of the caregiver interface and presented in text format (e.g., "COACH is currently helping Dad brush his teeth."). In Phase 4 (Design v3), we built on this design by adding more status details (e.g., current activity step, percentage of activity complete), speculating that this additional information may adequately reassure ICPs of their relatives' safety without the need for surveillance.

Alerts were another codesigned function that participants felt could afford them more peace of mind to leave their relatives at home unattended. Unsurprisingly, they wished to be immediately alerted of any potentially dangerous situations (e.g., leaving the stove on). During AAL activity assistance, if the system detected no action from a PwD over a specific time period, participants desired to be alerted for further assistance. Notably, alerts were perceived as a means of enabling a PwD to attempt activities independently while relieving ICPs of worry and constant assistance. In Phase 4, we compiled all codesigned alerting options that an ICP could specify in advance (Figure 7(a)) and explored the notion of "smart alerts," where the system could recommend information to an ICP based on geographic location and learned patterns of information retrieval (Figure 7(b)).

Lastly, participants were enthusiastic to receive from the system "on-demand" activity reports that could describe functional patterns or indicate functional decline. In Phase 3, we used Design v2, shown in Figure 8, to probe and clarify with participants their desired reporting parameters. These included: activity completion (partial or full), number of prompts (total and by type), time to activity completion, identification of problematic steps, identification of incorrect actions, and summary of alerts they received (e.g., for additional support when COACH could no longer assist). Participants anticipated that this information could signal the need for health care consultation and facilitate communication with health care providers: "I'm not saying [there should be] printout on a regular basis, [just] as required...because sometimes my mother has a bad evening [and the] next day

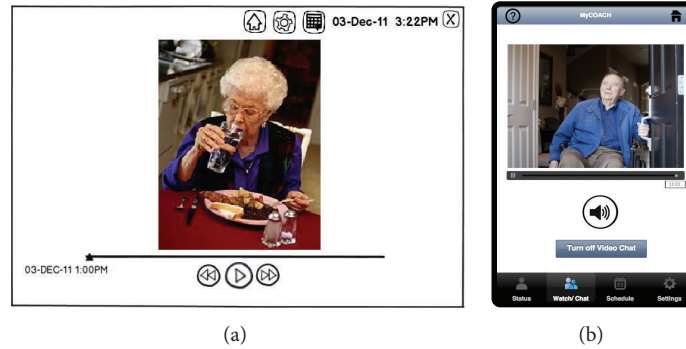


FIGURE 6: Illustrating how an ICP might be able to use the system to (a) view recorded video to check up to determine whether a PwD had completed an activity (e.g., eaten lunch) (Design v2) or (b) initiate a video call in response to an alert a potentially unsafe action that is detected (e.g., leaving the house without communicating with the ICP) (Design v3).

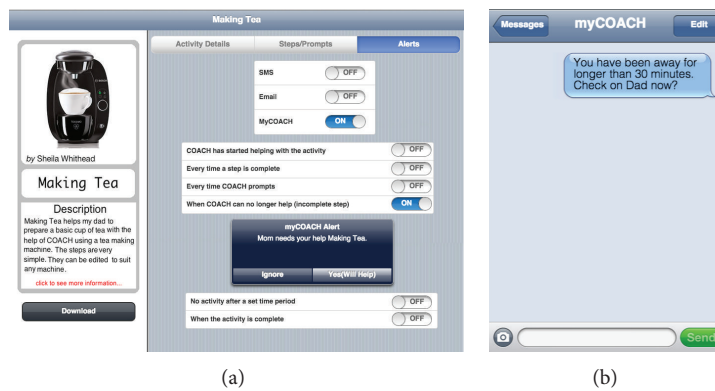


FIGURE 7: (a) Design v3 screenshot illustrating different alerting options (i.e., SMS, email, and “myCOACH” mobile application) that ICPs can specify for a particular activity and (b) sample SMS alert.

she’s fine...but then if that runs several days in a row, you’ve got to know when it’s time to talk to the doctor”.

4. Discussion

Our findings demonstrate the need for AAL design to consider how technologies can be situated to complement the care of ICPs and emphasize the important role we expect ICPs to play in AAL customization, adoption, and ongoing use. Toward our first research objective, we learned that ICPs envisioned being able to choose which activities and situations they wished to entrust to system and indicate when they would desire this support (i.e., via care schedules or spontaneous requests). Such choices would vary based on dynamic interrelationships between home routines; their relatives’ abilities, moods, and preferences; and their own availability, priorities, and emotional states. Exploring our second research objective, we gained insight into *how* ICPs envisioned specifying and obtaining AAL support. This specification may involve first-time system setup, activity selection, and detailed activity and prompt specification, processes in which ICPs would be called to translate their care expertise into system instructions. “Personalized” assistance was

considered necessary for both effective support (i.e., correct activity completion) and preserving their relatives’ abilities and dignity. ICPs may also desire relevant information from the system related to care. This information could be in the form of real-time monitoring and bimodal communication with their relatives, less invasive status updates on current support, alerts based on predefined triggers, and activity reports based on ICPs’ specified parameters. Overall, our codesign method afforded us depth in envisioning the needs, preferences, and imagined interactions from the perspectives of ICPs. We now synthesize our findings and reflect on their strengths, limitations, and implications for future work.

Our findings reinforce that AAL technologies should be designed to be flexible, customizable, and potentially with “do-it-yourself” (DIY) capabilities to complement care routines, relationships, and experiences. From an ICP’s perspective, seeking AAL support means sharing and/or turning over an aspect(s) of care, from a menial task to more complex activity assistance. Whether an ICP enlists the system to provide direct assistance (e.g., activity prompting), retrieve care-related information, and coordinate care between AAL and multiple care partners, the decision and process by which ICPs entrust care to another party cannot be taken for granted. For instance, while an ICP may find caring

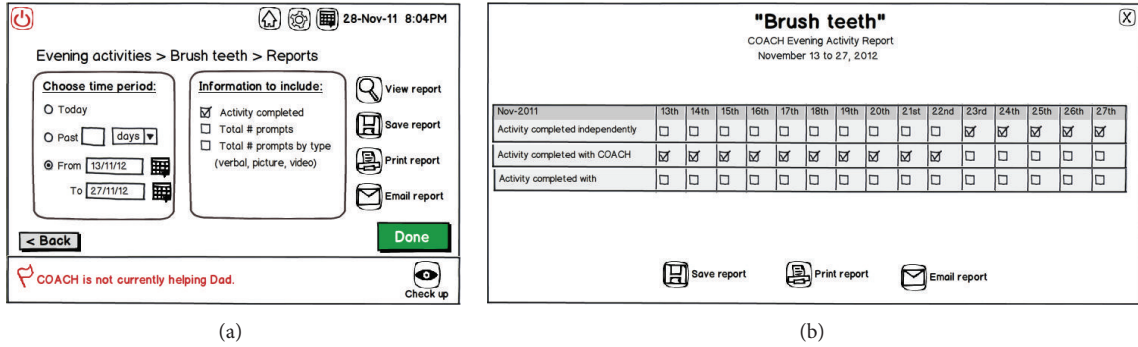


FIGURE 8: Design v2 illustrating how ICPs might (a) query and (b) retrieve reports that summarize how a PwD is managing in a particular activity with support from the system.

stressful or burdensome, he or she may also ascribe significant meaning to their care roles; they may derive a sense of pride or view caring as a natural continuation of bonds with PwDs [10, 12, 52–54]. Such mixed feelings may lend themselves to fluctuating preferences for AAL support, depending on moods, stress levels, and current circumstances. Entrusting care to a technology may also require some means of orientating and instructing the system to provide support based on ICP’s established strategies. The need to explicate such detailed specifications is challenged by the often tacit, improvised nature of care routines and support strategies (e.g., prompting), which previous work confirms [48, 55]. We therefore continue to advocate (i.e., in [56, 57]) that AAL technologies should be designed with “do-it-yourself” (DIY) capabilities, to the greatest extent possible, allowing users to iteratively build and modify custom AAL solutions. First, in early-stage support, DIY capabilities may enable collaborative solution-building between ICPs and PwDs, affording both users a sense of control, whose related work stresses are a central concern for smart home users [49]. Secondly, it may allow users (i.e., again, where possible, both stakeholders) to flexibly try, modify, and scale up solutions over time, as care needs, experience, and technological proficiency evolve. As developing DIY solutions may challenge users to develop technological proficiency, doing so could promote positive feelings of mastery and self-efficacy [13], as well as reflective learning and technology adoption at one’s own pace, two central principles of the “Slow Design” philosophy that aims to achieve more meaningful and sustained technology use [58, 59].

We can also extend the concept of DIY to how ICPs specify and obtain system support, problematizing this in relation to AAL technologies. Unlike most AAL approaches that “overemphasize the importance of smart devices” [17], our findings reveal that ICPs wish to maintain control in specifying, personalizing, and customizing support (e.g., activity steps, prompts, triggers, and alert preferences). Although codesign afforded us insight into their learned and largely tacit support strategies, we speculate that this assumption led to participants’ concerns about the time and effort such detailed specification would demand. Ongoing work [56, 57] aims to address this by exploring more naturalistic ways in

which ICPs can express and specify this information in order to iteratively build DIY AAL solutions. Moreover, to exploit the value of AAL technologies, it is also crucial to determine the appropriate degree of human interaction and control vis-à-vis the autonomy of an intelligent system—a discussion that Sun et al. [17] encourage AAL researchers to consider. Here, we may apply the Scale of Degrees of Automation [60] that places system automation and human interaction on a continuum. Applied to our context, AAL support might range from the system providing *no assistance* (i.e., the ICP assists the PwD with no AAL support); to *offering suggestions* to the ICP (i.e., AAL support with ICP’s permission) and to providing fully *autonomous assistance*, where the AAL system assists without any input or confirmation from the ICP. For instance, giving an ICP the option to accept or reject AAL support in the moment may mitigate the stress of post hoc alerts from an autonomous system that is difficult to spontaneously act upon. Future work is needed to investigate the desired balance between interaction and automation in AAL applications.

Arguably, the biggest insight from this study suggests an opportunity for AAL, not only to assist a PwD while alleviating an ICP(s), but also to support both stakeholders as they transition to greater dependency. Our study provided insight into the situated context in which dependency on an ICP(s) involves learning, adapting, and negotiating with PwDs. Although our study confirmed ICPs’ concerns for safety and respite [50], our participants continually advocated for the needs, values, personalities, and dignity of their relatives. The enthusiastic emphasis on enabling their relatives to continue meaningful activities was most relevant to our context and supported by studies with PwDs, even if adaptive strategies and dependency were needed [40, 41]. These findings suggest ICPs may be seeking solutions that satisfy both the needs of PwDs, for whom they advocate, and their own needs. We believe AAL solutions are positioned to play this mediating role, where ICPs and PwD can negotiate support from early stages of dependency, through a shared process of exploring and fashioning technology-enabled support strategies. In this way, this study afforded us a new conceptualization of this research/design problem, where AAL design should be based on an understanding of the contextual and temporal

particularities of the “caregiving dyad” [13] and consider the “user” as the PwD together with his or her ICP(s) as an interconnected, interactional unit undergoing constant negotiation and transition.

Our described substantive findings were afforded by a fluid codesign process for which we acknowledge study limitations, strengths, and future research directions. First, our study recruited a small sample, female-only sample, from a single community-based support agency, thus, biasing the described findings to ICPs who have accessed some degree of formal care support (e.g., psychosocial, educational, and respite care) and who likely share similar cultural, socioeconomic, and environmental characteristics. Secondly, we acknowledge that participants’ feedback may have been influenced or constrained by our creativity triggers, including our animated video of the COACH system, caregiver interface artefacts, and constructed scenarios/tasks. We, however, advocate for our codesign method, as it facilitated focused, productive participant involvement; richly contextualized information about current care strategies and envisioned AAL support; and enthusiastic attitudes toward AAL, as compared to previous attitudinal findings by colleagues [23]. In particular, our meticulous pilot sessions in Phase 3 allowed us to rehearse cofacilitation that would promote participants’ envisioning beyond the actual capabilities of COACH or any other specific AAL system. Lastly, we recognize that this study reflects only the perspectives of these ICPs and their accounts of the needs and values of PwDs in the discussed context of AAL. As emphasized, future work should involve PwD-ICP dyads to investigate how AAL can potentially support different needs and positive relationships as dependency is negotiated over time. Our next study, for example, will involve care dyads to codesign “technology probes” [31] that can then be deployed and longitudinally studied in real-world home settings. We expect this subsequent investigation to produce a “toolkit” of design guidelines, techniques, and methods that can holistically interpret social contexts of care, creatively explore AAL design opportunities [61], and guide empathic codesign collaboration between researchers, designers, and the beneficiary end stakeholders.

5. Conclusion

With a better understanding of the role of AAL in everyday dementia management, we advocate that technologies should be designed to complement and collaborate with the care of ICPs to PwDs. As the care experience involves a nuanced and evolving relationship between two (or more) people, designing AAL with DIY capabilities may enable ICPs to organically craft context-appropriate solutions to support and balance the needs of PwDs with their own needs. As we attempted to reflect in this paper, delivering such capabilities relies on a situated understanding of care contexts and, most centrally, the value-driven needs of the intended technology users. To this end, we plan and encourage others toward future work that investigates PwDs together with their ICPs as an interactional user “dyad” and employs longitudinal designs with participatory, design-oriented methods to promote envisioning of experiences in a technological future.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

Acknowledgments

The authors wish to thank Stephen Czarnuch, Jennifer Boger, Frank Li, Sen Hirano, Rita Vanderlaan, and Jieun Veronica Kim for assisting with this study; the paper reviewers at the Division of Occupational Therapy at the Karolinska Institutet (Sweden); and the Alzheimer’s Association, Toronto Rehabilitation Institute, and Canadian Institutes of Health Research for funding this study.

References

- [1] M. Prince, M. Prina, and M. Guerchet, *World Alzheimer Report 2013: Journey of Caring*, Alzheimer’s Disease International (ADI), London, UK, 2013.
- [2] Alzheimer Society of Canada, *Rising Tide: The Impact of Dementia on Canadian Society*, Alzheimer Society of Canada, Toronto, Canada, 2010.
- [3] C. Ward-Griffin, J. Hall, R. Deforge et al., “Dementia home care resources: how are we managing?” *Journal of Aging Research*, vol. 2012, Article ID 590724, 11 pages, 2012.
- [4] K. Cranswick and D. Dosman, *Eldercare: What We Know Today*, Statistics Canada, 2008.
- [5] M. G. Ory, R. R. Hoffman III, J. L. Yee, S. Tennstedt, and R. Schulz, “Prevalence and impact of caregiving: a detailed comparison between dementia and nondementia caregivers,” *The Gerontologist*, vol. 39, no. 2, pp. 177–185, 1999.
- [6] L. I. Pearlin, J. T. Mullan, S. J. Semple, and M. M. Skaff, “Caregiving and the stress process: an overview of concepts and their measures,” *Gerontologist*, vol. 30, no. 5, pp. 583–594, 1990.
- [7] L. Eppers, D. Goodall, and B. E. Harrison, “Caregiver burden among dementia patient caregivers: a review of the literature,” *Journal of the American Academy of Nurse Practitioners*, vol. 20, no. 8, pp. 423–428, 2008.
- [8] E. Papastavrou, A. Kalokerinou, S. S. Papacostas, H. Tsangari, and P. Sourtzi, “Caring for a relative with dementia: family caregiver burden,” *Journal of Advanced Nursing*, vol. 58, no. 5, pp. 446–457, 2007.
- [9] S. Sörensen and Y. Conwell, “Issues in dementia caregiving: effects on mental and physical health, intervention strategies, and research needs,” *The American Journal of Geriatric Psychiatry*, vol. 19, no. 6, pp. 491–496, 2011.
- [10] E. Holroyd, “Hong Kong Chinese daughters’ intergenerational caregiving obligations: a cultural model approach,” *Social Science & Medicine*, vol. 53, no. 9, pp. 1125–1134, 2001.
- [11] C. D. Caron and B. J. Bowers, “Deciding whether to continue, share, or relinquish caregiving: caregiver views,” *Qualitative Health Research*, vol. 13, no. 9, pp. 1252–1271, 2003.
- [12] C. Quinn, L. Clare, T. McGuinness, and R. T. Woods, “Negotiating the balance: The triadic relationship between spousal caregivers, people with dementia and Admiral Nurses,” *Dementia*, vol. 12, no. 5, pp. 588–605, 2013.
- [13] M. Nolan, P. Ingram, and R. Watson, “Working with family carers of people with Dementia: ‘negotiated’ coping as an essential outcome,” *Dementia*, vol. 1, no. 1, pp. 75–93, 2002.

- [14] J. N. Boger and A. Mihailidis, "The future of intelligent assistive technologies for cognition: devices under development to support independent living and aging-with-choice," *NeuroRehabilitation*, vol. 28, no. 3, pp. 271–280, 2011.
- [15] A. J. Bharucha, V. Anand, J. Forlizzi et al., "Intelligent assistive technology applications to dementia care: current capabilities, limitations, and future challenges," *The American Journal of Geriatric Psychiatry*, vol. 17, no. 2, pp. 88–104, 2009.
- [16] D. Ding, R. A. Cooper, P. F. Pasquina, and L. Fici-Pasquina, "Sensor technology for smart homes," *Maturitas*, vol. 69, no. 2, pp. 131–136, 2011.
- [17] H. Sun, V. D. Florio, N. Gui, and C. Blondia, "Promises and challenges of ambient assisted living systems," in *Proceedings of the 6th International Conference on Information Technology: New Generations*, 2009.
- [18] M. Chan, D. Estève, C. Escriba, and E. Campo, "A review of smart homes—present state and future challenges," *Computer Methods and Programs in Biomedicine*, vol. 91, no. 1, pp. 55–81, 2008.
- [19] L. Rosenberg and L. Nygård, "Persons with dementia become users of assistive technology: a study of the process," *Dementia*, vol. 11, no. 2, pp. 135–154, 2012.
- [20] L. Rosenberg, A. Kottorp, and L. Nygård, "Readiness for technology use with people with dementia: the perspectives of significant others," *Journal of Applied Gerontology*, vol. 31, no. 4, pp. 510–530, 2012.
- [21] J. P. Wherton and A. F. Monk, "Technological opportunities for supporting people with dementia who are living at home," *International Journal of Human-Computer Studies*, vol. 66, no. 8, pp. 571–586, 2008.
- [22] S. Czarnuch and A. Hwang, "Research study debrief meeting," 2011.
- [23] S. Czarnuch and A. Mihailidis, "The design of intelligent in-home assistive technologies: assessing the needs of older adults with dementia and their caregivers," *Gerontechnology*, vol. 10, no. 3, 2011.
- [24] A. S. Hwang, K. N. Truong, and A. Mihailidis, "Using participatory design to determine the needs of informal caregivers for smart home user interfaces," in *Proceedings of the 6th International Conference on Pervasive Computing Technologies for Healthcare and Workshops (PervasiveHealth '12)*, pp. 41–48, San Diego, Calif, USA, May 2012.
- [25] O. Demirebilek and H. Demirkan, "Universal product design involving elderly users: a participatory design model," *Applied Ergonomics*, vol. 35, no. 4, pp. 361–370, 2004.
- [26] E. B. N. Sanders and B. Westerlund, "Experiencing, exploring and experimenting in and with co-design spaces," in *Proceedings of the Nordic Design Research Conference: "Making Design Matter"*, pp. 298–302, 2011.
- [27] A. Pommeranz, U. Ulgen, and C. M. Jonker, "Exploration of facilitation, materials and group composition in participatory design sessions," in *Proceedings of the 30th European Conference on Cognitive Ergonomics (ECCE '12)*, pp. 124–130, Edinburgh, UK, August 2012.
- [28] A. Mihailidis, J. N. Boger, T. Craig, and J. Hoey, "The COACH prompting system to assist older adults with dementia through handwashing: an efficacy study," *BMC Geriatrics*, vol. 8, no. 1, article 28, 2008.
- [29] Y.-K. Lim, E. Stolterman, and J. Tenenberg, "The anatomy of prototypes: prototypes as filters, prototypes as manifestations of design ideas," *ACM Transactions on Computer-Human Interaction*, vol. 15, no. 2, pp. 1–27, 2008.
- [30] J. Zimmerman, J. Forlizzi, and S. Evenson, "Research through design as a method for interaction design research in HCI," in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '07)*, pp. 493–502, Carnegie Mellon University, Pittsburgh, Pa, USA, January 2007.
- [31] H. Hutchinson, W. Mackay, B. Westerlund et al., "Technology probes: inspiring design for and with families," in *Proceedings of the New Horizons Conference: Conference on Human Factors in Computing Systems (CHI '03)*, pp. 17–24, ACM, April 2003.
- [32] K. M. Langa, M. E. Chernew, M. U. Kabeto et al., "National estimates of the quantity and cost of informal caregiving for the elderly with dementia," *Journal of General Internal Medicine*, vol. 16, no. 11, pp. 770–778, 2001.
- [33] Microsoft Research, *Being Human: Human-Computer Interaction in the Year 2020*, Microsoft Research, Cambridge, UK, 2008.
- [34] J. Vines, R. Clarke, P. Wright, J. McCarthy, and P. Olivier, "Configuring participation: on how we involve people in design," in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '13)*, pp. 429–438, ACM, Paris, France, April-May 2013.
- [35] D. R. Thomas, "A general inductive approach for analysis of qualitative evaluation data," *The American Journal of Evaluation*, vol. 27, no. 2, pp. 237–246, 2006.
- [36] C. Snyder, *Paper Prototyping: The Fast and Easy Way to Design and Refine User Interfaces*, Morgan Kaufman Publishers, San Francisco, Calif, USA, 2003.
- [37] J. Nielsen, T. Clemmensen, and C. Yssing, "Getting access to what goes on in people's heads?: reflections on the think-aloud technique," in *Proceedings of the 2nd Nordic Conference on Human-Computer Interaction (NordCHI '02)*, pp. 101–110, ACM, New York, NY, USA, October 2002.
- [38] J. Nielsen and J. Levy, "Measuring usability: preference vs. performance," *Communications of the ACM*, vol. 37, no. 4, pp. 66–75, 1994.
- [39] S. Lindsay, K. Brittain, D. Jackson, C. Ladha, K. Ladha, and P. Olivier, "Empathy, participatory design and people with dementia," in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '12)*, vol. '12, pp. 521–530, Vancouver, Canada, May 2012.
- [40] A. Phinney, H. Chaudhury, and D. L. O'Connor, "Doing as much as I can do: the meaning of activity for people with dementia," *Aging and Mental Health*, vol. 11, no. 4, pp. 384–393, 2007.
- [41] L. Nygård, "Responses of persons with dementia to challenges in daily activities: a synthesis of findings from empirical studies," *American Journal of Occupational Therapy*, vol. 58, no. 4, pp. 435–445, 2004.
- [42] E. Marziali, T. Damianakis, and P. Donahue, "Internet-based clinical services: virtual support groups for family caregivers," *Journal of Technology in Human Services*, vol. 24, no. 2-3, pp. 39–54, 2006.
- [43] E. Marziali, P. Donahue, and G. Crossin, "Caring for others: internet health care support intervention for family caregivers of persons with Alzheimer's, stroke, or Parkinson's disease," *Families in Society*, vol. 86, no. 3, pp. 375–383, 2005.
- [44] E. Marziali and P. Donahue, "Caring for others: internet videoconferencing group intervention for family caregivers of older adults with neurodegenerative disease," *The Gerontologist*, vol. 46, no. 3, pp. 398–403, 2006.
- [45] T. Chiu, E. Marziali, A. Colantonio et al., "Internet-based caregiver support for Chinese Canadians taking care of a

- family member with alzheimer disease and related dementia,” *Canadian Journal on Aging*, vol. 28, no. 4, pp. 323–336, 2009.
- [46] S. Nelis, C. Quinn, and L. Clare, *Information and Support Interventions for Informal Caregivers of People with Dementia*, John Wiley & Sons, Chichester, UK, 2007.
- [47] M. L. Lewis, J. V. Hobday, and K. W. Hepburn, “Internet-based program for dementia caregivers,” *The American Journal of Alzheimer’s Disease and other Dementias*, vol. 25, no. 8, pp. 674–679, 2010.
- [48] C. de la Cuesta, “The craft of care: family care of relatives with advanced dementia,” *Qualitative Health Research*, vol. 15, no. 7, pp. 881–896, 2005.
- [49] S. Davidoff, M. K. Lee, C. Yiu, J. Zimmerman, and A. K. Dey, “Principles of smart home control,” in *UbiComp 2006: Ubiquitous Computing*, vol. 4206 of *Lecture Notes in Computer Science*, pp. 19–34, Springer, Berlin, Germany, 2006.
- [50] P. Topo, “Technology studies to meet the needs of people with dementia and their caregivers: a literature review,” *Journal of Applied Gerontology*, vol. 28, no. 1, pp. 5–37, 2009.
- [51] J. Vines, S. Lindsay, G. W. Pritchard et al., “Making family care work: dependence, privacy and remote home monitoring telecare systems,” in *Proceedings of the ACM International Joint Conference on Pervasive and Ubiquitous Computing (UbiComp ’13)*, pp. 607–616, Zurich, Switzerland, September 2013.
- [52] World Health Organization, *Dementia: A Public Health Priority*, 2012.
- [53] M. C. Lin, M. Macmillan, and N. Brown, “A grounded theory longitudinal study of carers’ experiences of caring for people with dementia,” *Dementia*, vol. 11, no. 2, pp. 181–197, 2012.
- [54] E. McDonnell and A. A. Ryan, “The experience of sons caring for a parent with dementia,” *Dementia*, vol. 13, no. 6, pp. 788–802, 2014.
- [55] E. Lindqvist, *Assistive technology as cognitive support in everyday life for persons with dementia or stroke [Ph.D. thesis]*, Karolinska Institutet, Solna, Sweden, 2012.
- [56] A. Hwang and J. Hoey, “Smart home, the next generation: closing the gap between users and technology,” in *Proceedings of the AAAI Fall Symposium*, pp. 14–21, Arlington, Va, USA, November 2012.
- [57] A. Hwang and J. Hoey, “DIY smart home: narrowing the gap between users and technology,” in *Proceedings of the Interactive Machine Learning Workshop, 2013 International Conference on Intelligent User Interfaces*, Santa Monica, Calif, USA, 2013.
- [58] C. Strauss and A. Fuad-Luke, “The slow design principles,” in *Proceedings of the Changing the Change*, 2008.
- [59] B. Grosse-Hering, J. Mason, D. Aliakseyeu, C. Bakker, and P. Desmet, “Slow design for meaningful interactions,” in *Proceedings of the the SIGCHI Conference on Human Factors in Computing Systems (CHI ’13)*, Paris, France, April 2013.
- [60] T. B. Sheridan and R. Parasuraman, “Human-automation interaction,” *Reviews of Human Factors and Ergonomics*, vol. 1, no. 1, pp. 89–129, 2005.
- [61] Y. Rogers, M. Scaife, E. Harris et al., “Things aren’t what they seem to be: innovation through technology inspiration,” in *Proceedings of the 4th Conference on Designing Interactive Systems: Processes, Practices, Methods, and Techniques (DIS ’02)*, pp. 373–378, ACM, New York, NY, USA, June 2002.

Research Article

A Bidimensional System of Facial Movement Analysis Conception and Reliability in Adults

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Received 6 October 2014; Revised 22 April 2015; Accepted 29 April 2015

Academic Editor: Giancarlo Mauri

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Objective. To design a bidimensional facial movement measuring tool and study its reliability. *Methods.* We utilized the free video-analysis software Kinovea that can track preselected points during movements and measure two-point distances off-line. Three raters positioned facial markers on 10 healthy individuals and video-taped them during maximal bilateral contractions of frontalis, corrugator, orbicularis oculi, zygomaticus, orbicularis oris, and buccinator, on two occasions. Each rater also analyzed the first video twice, one week apart. For each muscle, intrarater reliability was measured by percent agreements (PA) and intraclass correlation coefficients (ICC) between two assessments of the same video one week apart and between assessments of two videos collected one week apart. Interrater reliability was measured by PA, ICC, and coefficients of variation (CV) between assessments of the first video-recording by the three raters. *Results.* Intrarater and interrater reliabilities were good to excellent for frontalis (PA and ICC > 70%; CV < 15%), moderate for orbicularis oculi, zygomaticus, and orbicularis oris, and poor for corrugator and buccinators. *Discussion.* Without formal prior training, the proposed method was reliable for frontalis in healthy subjects. Improved marker selection, training sessions, and testing reliability in patients with facial paresis may enhance reliability for orbicularis oculi, zygomaticus, and orbicularis oris.

1. Introduction

Peripheral facial paresis following facial nerve injuries (traumatic, infectious, tumoral, autoimmune, and postneurosurgery) or conditions such as stroke, multiple sclerosis, myasthenia, and parkinsonian syndromes causes facial movement impairment that might be important to quantify for purposes of refined diagnosis or follow-up. In the management of peripheral facial paresis, a number of assessment methods have been proposed, initially by surgical teams and later also by rehabilitation physicians [1–8]. Among these, subjective clinical assessments comprise facial grading scales such as the House-Brackmann or Sunnybrook scales [9–12]. Objective quantitative facial assessments, using bidimensional and three-dimensional measurements, have often focused on one or very few facial muscles, omitting the rest of facial mobility [13–15]. Bidimensional techniques use photography or

videography to measure distance between facial points at rest and during movement [15–24]. Three-dimensional assessments have used automation technologies and sophisticated algorithms, often to the cost of time-consumption, expensive equipment, and uneasy applicability to daily practice [25–28].

A quantitative facial movement assessment tool that would be easy-to-reproduce, fast, free, accurate, and reliable for a sufficient number of muscles remains an unmet need. Such a tool might help clinicians to quantify facial paresis at onset, during follow-up, and after interventions such as medical, surgical, and rehabilitative programs. In the present study we have used the free and open-source software Kinovea and selected specific facial markers to quantify movements of six key muscles. From standard subject videos, we measured normal resting facial distances and maximal excursions of the selected markers during movement. We explored the intrarater and interrater reliability of this method.

2. Methods

2.1. Subjects, Raters, and Procedures. The following procedures were administered in compliance with the Helsinki convention. Ten healthy subjects (6 women; age 39 ± 12) with no cervicofacial injuries or neurologic disorders participated in the study. Three raters (two physicians and one occupational therapist) who underwent short training about the method before used face paint to draw dots on the face of each subject on 10 preselected anatomic facial markers (Figure 1(a)):

- (i) one at nasion (fixed marker);
- (ii) one at mid-upper lip;
- (iii) one at each mid eyebrow;
- (iv) one at each inner eyebrow tip;
- (v) one at each mid-upper and each mid-lower lid;
- (vi) one at each oral commissure;
- (vii) one at a cheek point 4 centimeters from each oral commissure on the line from oral commissure to the mandibular angle.

To calibrate distances, two dots 5 centimeters away were also painted on the forehead.

Using these markers, we quantified 6 movements that each subject was to perform bilaterally using maximal contractions:

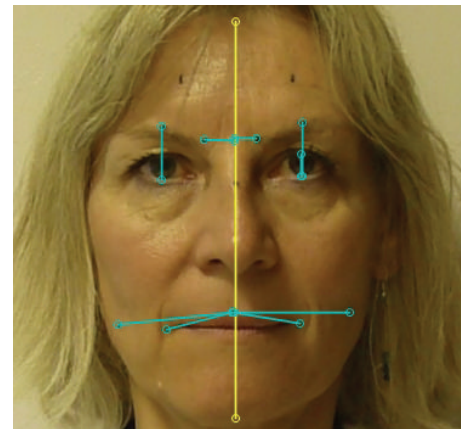
- (i) raising eyebrows (frontalis muscle);
- (ii) frowning (corrugator muscle);
- (iii) eye closure (orbicularis oculi muscle);
- (iv) smile (zygomaticus muscle);
- (v) puffing (orbicularis oris muscle);
- (vi) cheek incursion with attempted blowing (buccinator muscle).

2.2. Head Position and Movements. Facial movements were measured while subjects were comfortably seated on a fixed stool, with the upper buttocks, scapulas, and occiput leaning back against a wall. Subjects looked straight ahead towards a specified target fixed on the facing wall and were asked not to move during video acquisitions. The head was to be kept resting against the wall, at rest and during the 6 tested movements. Video-recording was performed at rest and during the 6 bilateral maximal facial contractions. Standardized, straightforward verbal commands were used for brow elevation (“raise your eyebrows”), frowning (“frown”), eye closure (“close your eyes”), smiling (“smile, showing your teeth”), puffing cheeks (“blow your cheeks keeping the air inside”), and cheek incursion (“bring your cheeks in”), using additional mimicking by the investigator as needed.

2.3. Kinovea Software. Kinovea is a free and open-source (GPL2) French software created in 2009 as a tool for movement analysis (Kinovea, 0.8.15; Copyright © 2006–2011, Joan Charmant & Contrib, <http://www.kinovea.org/>) [29, 30]. Its



(a)



(b)

FIGURE 1: Principle of the Kinovea-derived method. Rest. (a) Each dot was drawn on the subject's face with face paint, corresponding to the preselected markers. The two dots on the forehead are 5 cm apart and are used for calibration. (b) Each line indicates distance measurements corresponding to the 6 selected muscles at rest. The lines from mid upper lip to the cheek point 4 cm out are used for both buccinator and orbicularis oris measurements.

straightforward functionalities are targeted to both movement science specialists and clinicians such as physical, occupational, or speech therapists. From plain video-recordings of movements, the software allows measuring distances and times, manually or using semiautomated tracking to follow points and check live values or trajectories. To our knowledge, Kinovea has not been used for facial analysis to date. Figure 1(b) shows facial distances measured at rest using the software. Figures 2(a) to 2(f) show facial distances measured after the movements caused by maximal contractions of 6 selected facial muscles: frontalis (Figure 2(a)), corrugator (Figure 2(b)), orbicularis oculi (Figure 2(c)), zygomaticus (Figure 2(d)), orbicularis oris (Figure 2(e)), and buccinator (Figure 2(f)).

2.4. Assessment Procedure. All videos were analyzed using manual importing of the videos into the Kinovea software and calibrating each video to the 5 centimeter mark painted on the forehead of each subject (Figure 1(a)). A vertical midline

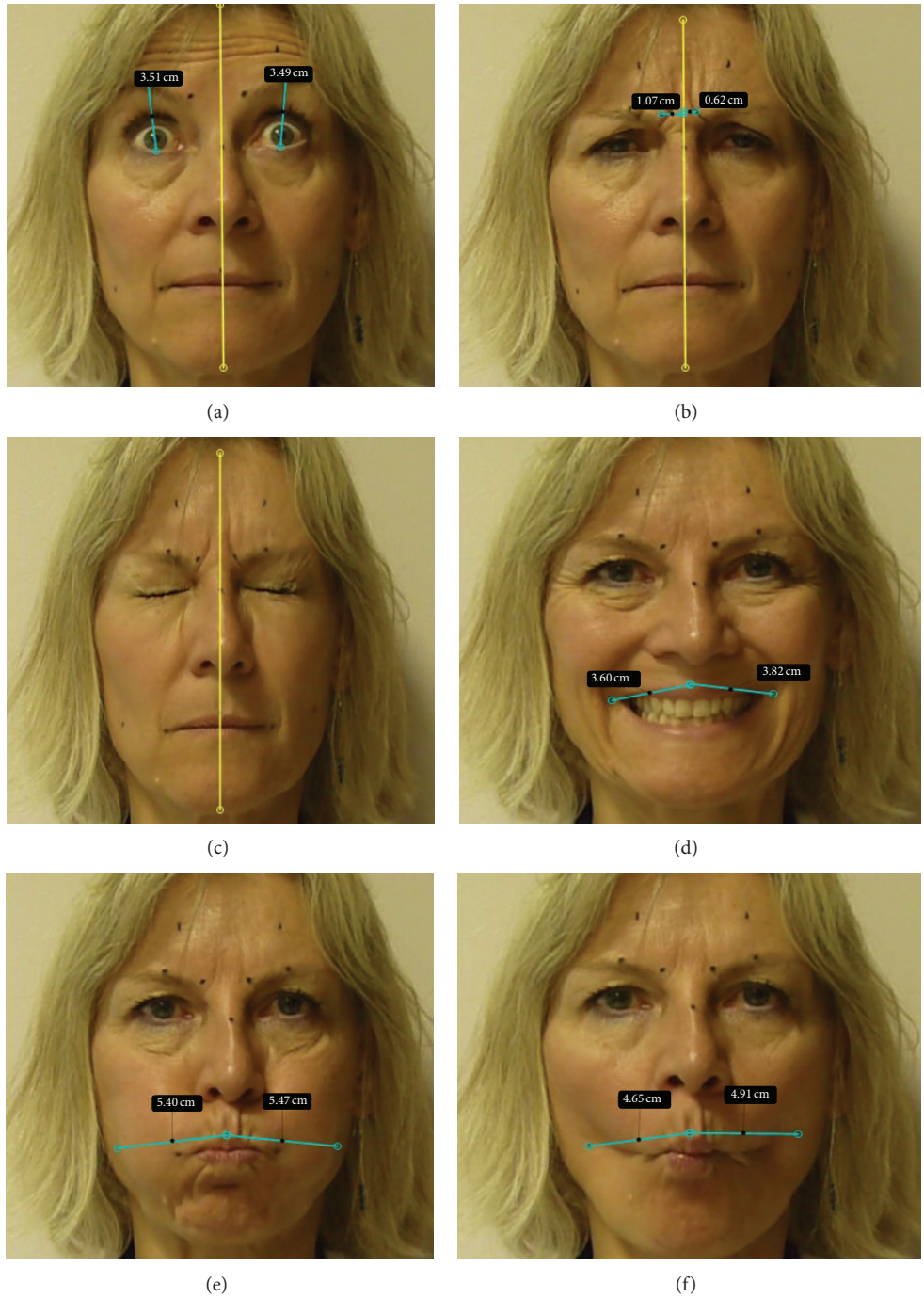


FIGURE 2: Principle of the Kinovea-derived method. Maximal contractions. Each blue line indicates distance measurements corresponding to the selected muscles during maximal contractions: (a) frontalis; (b) corrugator; (c) orbicularis oculi; (d) zygomaticus; (e) orbicularis oris; (f) buccinator. Note in (e) and (f) that in the subject selected the two cheek markers 4 cm out from the oral commissure fail to capture the maximum lateral cheek in/excursions.

was drawn through the nasion and mid-upper lip points to facilitate measures of corrugator movements (Figure 1(b)). The time to draw markers and perform each video acquisition was recorded, as well as the time to perform analysis using Kinovea. Measurements were taken on both sides of the face.

2.5. *Statistical Analysis.* Intrarater reliability was assessed for two different procedures, video analysis and marker positioning. First, we measured the intrarater reliability for video analysis (“interreview”) by calculating intraclass correlation coefficients and agreement frequencies between distances

TABLE 1: Distances covered and symmetry ratios (first analysis of the first video, mean of 3 raters, and 10 patients).

Muscles	Side	Mean distance (cm)	Standard deviation (cm)	20% distance (cm)	Minimum (cm)	Maximum (cm)	Symmetry ratio (%)
Frontalis	R	1.32	0.26	0.26	0.59	1.77	97
	L	1.36	0.28	0.27	0.66	1.87	
Orbicularis oculi	R	0.42	0.16	0.08	0.07	0.70	95
	L	0.40	0.14	0.08	0.13	0.64	
Corrugator	R	1.07	0.15	0.21	0.80	1.32	99
	L	1.08	0.15	0.22	0.80	1.36	
Zygomaticus	R	0.88	0.17	0.18	0.57	1.23	83
	L	0.73	0.17	0.15	0.49	1.10	
Orbicularis oris	R	0.56	0.21	0.11	0.14	1.04	86
	L	0.48	0.25	0.10	0.08	1.25	
Buccinator	R	0.70	0.29	0.14	0.25	1.26	80
	L	0.87	0.29	0.17	0.32	1.53	

Each number in Column 3 indicates the mean distance covered during displacement due to maximal contraction of the muscle indicated in Column 1. R: right; L: left. Note that the 20% difference selected to represent disagreement is lower than or equal to the standard deviation for all muscles except for corrugator.

measured twice one week apart from the same video acquisition, for each muscle on each side. Then, we measured the intrarater reliability for marker positioning (“intermarking”), by calculating intraclass correlation coefficients and agreement frequencies between the distances measured in two video acquisitions performed one week apart for each patient, for each muscle on each side. For a given muscle, agreement was defined as a difference between two measurements equal to or lower than 20% of the mean distance measured across all subjects and raters over that movement (see Table 1). The level of agreement was defined as excellent above 85%, good between 70% and 85%, insufficient between 50% and 70%, and poor below 50%. To assess interrater variability we calculated intraclass correlation coefficients and agreement frequencies between distances measured by each rater from the first video acquisition, in addition to coefficients of variation (ratio of the standard deviation to the arithmetic mean) of the values between the three raters [31].

3. Results

The 10 healthy individuals who participated in the study were 6 women and 4 men, mean age 39 ± 12 . All the videos acquired were deemed acceptable for analysis by the Kinovea software. In particular, there was no major head rotation noted from the plane of the camera.

3.1. Time Consumption. The entire acquisition, including marker painting, subject positioning, video-taping during rest, and the 6 maximal bilateral facial contractions, and marker removal took 4.0 ± 0.2 minutes (mean \pm SD) to perform. Video-analysis took 20 ± 2 minutes for each video.

3.2. Raw Measurements. Table 1 shows the mean excursions of the selected markers in our subject group and the side-to-side symmetry ratios for each muscle on the first analysis of

the first video (mean of 3 raters and 10 patients). The mean marker excursions covered by the different muscles ranged from 0.40 cm (left orbicularis oculi) to 1.36 cm (left frontalis); symmetry between right and left remained beyond 90% for upper face muscles and beyond 80% for lower face muscles.

3.3. Intrarater Reliability. Figures 3(a) and 3(b) display the mean intrarater ICC (with standard deviation) and agreement frequencies (AF) per muscle on each side, between two video-analyses from the same marker positioning (“inter-view”, Figure 3(a)) and between analyses from two different markings made one week apart (“intermarking”, Figure 3(b)). Regarding interreview reliability, both ICC and AF were good to excellent ($>70\%$) for frontalis, orbicularis oculi, zygomatics, and buccinator; for corrugator and orbicularis oris, only ICCs were also good to excellent. There was a clear right-left symmetry in the intrarater reliability of measurements for each muscle (Figure 3(a)).

When facial marking was performed on two different days, only frontalis measurements retained excellent intrarater reliability, as well as orbicularis oculi but for agreement frequencies only. The other 4 muscles, corrugator, zygomaticus, orbicularis oris, and buccinator (particularly the latter two), fall below 70% reliability whichever the parameter considered. A sharp discrepancy was noted between poor ICCs and much higher AFs for orbicularis oculi and zygomaticus (Figure 3(b)).

3.4. Interrater Reliability. Figure 4 displays the mean interrater ICC (with standard deviation), agreement frequencies, and coefficients of variation per muscle on each side. Interrater reliability was again good only for frontalis and questionable for orbicularis oculi and zygomaticus, these two muscles being characterized by small coefficients of variation (less than 16%) and agreement frequencies close to 70% on average, but by ICCs far below 70%.

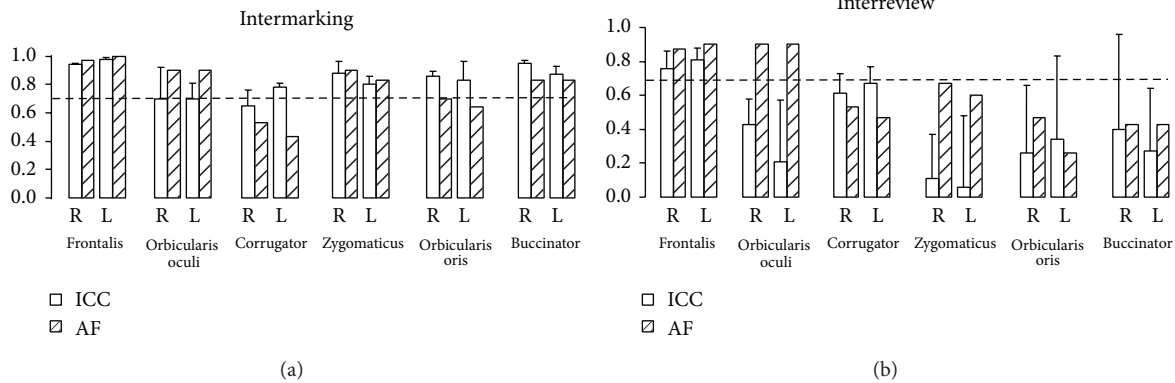


FIGURE 3: Intrarater reliability of the Kinovea-derived method. (a) Interreview corresponds to the reliability of two consecutive measurements, when the same rater reviews the same video twice one week apart. The dashed line at 0.7 represents the threshold for good to excellent reliability. ICC: intraclass correlation coefficients; AF: agreement frequency; R: right; L: left. (b) Intermarking corresponds to the reliability of two measurements made by the same rater using two different marker positioning sessions one week apart.

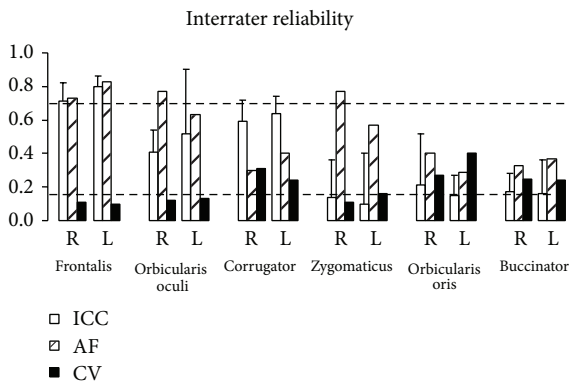


FIGURE 4: Interrater reliability. ICC: intraclass correlation coefficients; AF: agreement frequency; CV: coefficients of variation; R: right; L: left. The dashed line at 0.7 represents the threshold for good to excellent reliability and that at 0.15 represents the limit below which coefficients of variation are deemed acceptable.

4. Discussion

Despite substantial research on facial motion evaluation for the past decades, no single outcome instrument has become common practice among surgical or rehabilitation teams [14, 15, 17–28, 32–35]. This study shows that the first version of a method using the free and open-source Kinovea software applied without any prior formal training on plain video-recordings of facial movements was reliable for frontalis measurements. For zygomaticus and orbicularis oculi, reliability was suboptimal but might be expected to improve when examined in subjects with facial paresis because of higher intersubject variability in that population (see below). For the other tested muscles (corrugator, orbicularis oris, and buccinator), reliability was unacceptable with the current paradigm. Reliability improvement for these muscles might require refined marker selection and prior formal training before using the method. To best interpret the present findings, a number of methodological issues deserve discussion.

4.1. Intrarater Reliability: Interreview versus Intermarking. We broke down overall intrarater reliability into two components: the ability to agree with oneself when looking twice at a given video (“interreview” reliability) and the ability to agree with oneself when positioning markers twice on the same face (“intermarking” reliability). It must be acknowledged that the latter reliability measurement also involved two video-recordings and therefore also depended upon the first “interreview” reliability. Thus, the true “intermarking” reliability (or lack thereof) was really shown in the difference between the first and the second reliability, a difference that proved particularly obvious in some measurements for zygomaticus, orbicularis oculi, orbicularis oris, and buccinator (see Section 4.3).

4.2. Measures of Agreement, ICC versus Agreement Frequencies (AF). Remarkable discrepancies were noted between AFs and ICCs on a number of occasions, in particular for intrarater intermarking and interrater reliability, regarding orbicularis oculi and zygomaticus on one hand (AF > ICC) and corrugator on the other hand (ICC > AF). One goal of this study was to answer two questions: “how often does a rater obtain the same results when looking at the same subject on two occasions?” (intrarater agreement rates, both interreview and intermarking) and “how often do two raters get the same result when observing the same subject?” (interrater agreement rate). The intraclass correlation coefficients answer a different question, which is a comparative one, as it is designed to compare the reliabilities of different tools used by the same group of raters on the same group of subjects [36]. The ICCs are thus devised to depend upon the homogeneity of the subjects used in a study [37–40]. Indeed, the ICC is the proportion of variability in all records, which is due to differences between subjects. This coefficient ranges from 0 to 1; the closer to 1, the more variability in the data comes from differences between subjects, the higher the agreement between raters or ratings. Mathematically, $\rho_{ICC} = \sigma_S^2 / (\sigma_S^2 + \sigma_R^2 + \sigma_E^2)$ where σ_S^2 , σ_R^2 , and σ_E^2 represent, respectively, the

variance in the data that comes from the subjects, the rater, and random noise. For each muscle, these variances result from the fitting of the 2-way random effects ANOVA model: $x_{i,j} = \mu + s_i + r_j + e_{i,j}$ where $x_{i,j}$ is the displacement measured on a given muscle of subject i by rater j (in this study, $j = 1, 2, 3$ and $i = 1, \dots, 10$). μ is the average rating over all patients by all raters; s_i is the effect of subject i on rating, used as a random effect; r_j is the effect of rater j on rating, used as a random effect; and $e_{i,j}$ is a random error. Formulas for its estimate, 95% confidence bounds, and the F -test for testing the null hypothesis of $\rho = \rho_0$ are given in McGraw and Wong, 1996 (ICC [A,1], Case 2A model) [36]. The computation of that coefficient is thus meaningful as a comparative statistic between different measurement tools [36]. This was not the purpose of this study. To be clinically relevant we have thus opted to also report the agreement frequency, that is, the percent of matches, here defined as differences within 20% of the mean. Finally, when measuring interrater reliability of displacement measurements (Figure 4), we have additionally displayed the actual variability of ratings (coefficient of variation) between the 3 raters to complete the information.

A potential disadvantage of the agreement frequency method lies in the need for an arbitrary choice of a threshold difference below which “agreement” or “match” is defined. Here, our choice of a 20% difference for defining disagreement between two ratings corresponds to a range of differences from 0.8 to 2.7 mm depending on the muscles (20% of the mean distances covered, see Table 1). These differences are in fact small, as they fall within the parameters of facial asymmetry, which have been shown to be easily overlooked by human observers naive to the presence of a facial difference when asymmetry is less than 3 mm in the brow and oral commissure regions [41].

We thus elected to use the two statistics methods ICC and AF jointly and to compare their findings. In that respect, situations of frank discrepancies between the two reliability measurements may yield valuable information. For example, intermarking reliability for orbicularis oculi and zygomaticus was characterized by high agreement frequencies, while ICCs were low. This may have to do with high between-subject homogeneity of displacement values for these two muscles in a healthy population, which might lead to underestimate the reliability of the measure if using ICCs only. Such situation might be less likely to occur in a group of patients with peripheral facial paresis, in which differences from patient to patient would be expected to be higher than between healthy subjects moving all their facial muscles normally. Evaluations of the reliability of zygomaticus and orbicularis oculi measurements with the Kinovea-derived method in patients with facial paresis will be needed to confirm this hypothesis.

4.3. Muscle by Muscle Analysis, Marker Positioning Reliability. We initially selected 3 upper face muscles (frontalis, orbicularis oculi, and corrugator) and 3 lower face muscles (zygomaticus, orbicularis oris, and buccinator) to represent facial nerve function as extensively as possible. It is interesting to note that right-left symmetry was consistently about 10% higher for the upper face than for the lower face muscles, which is consistent with the bilateral descending innervation

of upper face muscles only. Yet, varying degrees of reliability results for some of the selected muscles deserve analysis, particularly when comparing interreview and intermarking intrarater reliability.

For corrugator displacement, there was little loss of reliability between interreview and intermarking intrarater reliability, which may suggest that the issue may have to do with a difficulty in visually estimating the position of the markers on the inner angle of the eyebrow. Regarding zygomaticus and orbicularis oculi, the sole drops in ICCs from interreview to intermarking, which then dissociated from AFs, were discussed above. Orbicularis oris and buccinator might pose greater difficulties as Table 1 reveals standard deviations well beyond 20% of the mean in the estimations of their associated displacements, together with major discrepancies between interreview and intermarking intrarater reliability. This may reveal difficulty in finding reliable marker positions to reflect their associated movements (see examples of marker inadequation for orbicularis oris and buccinator in Figures 2(e) and 2(f)). In fact, the cheek displacements due to orbicularis oris and buccinator contractions are not only mediolateral but also anteroposterior and 3-dimensional technology might be more relevant to explore these muscles. Finally, the lack of previous training sessions might also have participated in high standard deviations for these 2 muscles in particular, as subjects had more difficulties in smiling or puffing than with the other requested movements. The reliability of frontalis measurements proved satisfactory probably because the marker positioning at mid eyebrow seems straightforward and its contraction-induced displacement occurs within a single frontal plan.

4.4. Limitations and Technical Issues, Head Movements, Choice of Marker Positions, Calibration, and Software Resolution. The first limitation is that this is not a study of the construct validity of the method. In other words, we have no information of systemic errors attached to the method [42]. Therefore additional studies will be required to deliver such information: how does this method compare to reference methods and actual measurements of the physical distance covered by cutaneous points during muscle contractions. Comparisons with 3D measurements in particular might be helpful in that respect.

Compensation for head movement with devices such as jigs or immobile reference points has been suggested, while many researchers consider on the other hand that restrictive fixation of the head or face may hamper natural facial movements [13, 32, 33, 43–47]. A number of measuring systems for facial motion analysis use markers that are attached to the facial skin instead of being painted as in the method described here. The use of physical markers in measuring systems is often time-consuming for both operator and patient, especially in 3-dimensional technologies. In addition, physical markers stuck on the face may alter or inhibit spontaneous facial motion. Some authors analyzed facial motion without markers [45] or positioned markers directly with the software [42]. Our choice of painted markers seems relevant because it is fast, cheap, and acceptable for individuals and operators.

Calibration scaling photographs to the iris diameter (11.8 mm in humans) have been reported [41, 42]. Here, a calibration using the distance nasion-tragus (not available except in 3/4 or profile incidences) as the more fixed points of the face could also be tested for comparison with our 5-centimeter frontal distance method. However, since at least one of the selected muscles proved to have very good reliability with all measures in the present study, calibration is probably not a critical issue here.

4.5. Comparison with Other Tracking Systems. In comparison with the available literature on bidimensional analysis, the presently described technique is free, open-source, fast to use, and presents with interesting advantages. In the system used by Hadlock and Urban [42] of a bidimensional Facial Assessment by Computer Evaluation (FACE) derived from Photoshop but using a MATLAB interface that allows faster analysis than the regular Photoshop technique the authors analyzed only 5 movements that were not specific of individual facial muscles and work on photographs only, as opposed to videos that we could freeze at the appropriate time of maximal muscle excursion, like with the present method.

To ascertain reliability for important muscles such as orbicularis oculi, zygomaticus, and perhaps corrugator, it seems important to reevaluate these muscles, together with frontalis, in patients with peripheral facial paresis. Such evaluation may be carried out without and with a formal prior training session for both patients and raters, and in parallel with clinical scales (Sunnybrook, Creteil) [48]. The case of buccinator and orbicularis oris is likely to need new marker selection to try to improve the Kinovea-derived method for these muscles.

4.6. Conclusion. A simple and easy-to-reproduce facial movement evaluation method has been designed using a free, open-source software to perform bidimensional analysis of movements related to 6 facial muscles. Without prior formal training, neither for subjects nor for investigators, intrarater and interrater reliability proved good to excellent in healthy subjects for the frontalis muscle only. For the other tested muscles, we may seek reliability improvement by refining the preselection of anatomic markers, by using formal training sessions for patients and raters and by testing the method in patients with facial paresis.

Conflict of Interests

The authors declare no conflict of interests with respect to the present study.

Acknowledgments

The authors are grateful to the participants who helped them carry out the study. They also thank the *Société Française de Médecine Physique et de Réadaptation* (SOFMER) and IPSEN, Ltd. for their precious support.

References

- [1] K. Harii, "Refined microvascular free muscle transplantation for reanimation of paralyzed face," *Microsurgery*, vol. 9, no. 3, pp. 169–176, 1988.
- [2] D. H. Harrison, "Surgical correction of unilateral and bilateral facial palsy," *Postgraduate Medical Journal*, vol. 81, no. 959, pp. 562–567, 2005.
- [3] R. T. Manktelow, R. M. Zuker, and L. R. Tomat, "Facial paralysis measurement with a handheld ruler," *Plastic and Reconstructive Surgery*, vol. 121, no. 2, pp. 435–442, 2008.
- [4] M. May, "Muscle transposition for facial reanimation: indications and results," *Archives of Otolaryngology*, vol. 110, no. 3, pp. 184–189, 1984.
- [5] L. R. Rubin, "The anatomy of a smile: its importance in treatment of facial paralysis," *Plastic and Reconstructive Surgery*, vol. 53, no. 4, pp. 384–387, 1974.
- [6] L. R. Rubin, G. W. Lee, and R. L. Simpson, "Reanimation of the long-standing partial facial paralysis," *Plastic and Reconstructive Surgery*, vol. 77, no. 1, pp. 41–49, 1986.
- [7] J. K. Terzis and D. Karypidis, "Outcomes of direct muscle neurotisation in adult facial paralysis," *Journal of Plastic, Reconstructive and Aesthetic Surgery*, vol. 64, no. 2, pp. 174–184, 2011.
- [8] K. Ueda, K. Harii, H. Asato, and A. Yamada, "Neurovascular free muscle transfer combined with cross-face nerve grafting for the treatment of facial paralysis in children," *Plastic and Reconstructive Surgery*, vol. 101, no. 7, pp. 1765–1773, 1998.
- [9] T. Berg, L. Jonsson, and M. Engström, "Agreement between the Sunnybrook, House-Brackmann, and Yanagihara facial nerve grading systems in Bell's palsy," *Otology and Neurotology*, vol. 25, no. 6, pp. 1020–1026, 2004.
- [10] S. E. Coulson, G. R. Croxson, R. D. Adams, and N. J. O'Dwyer, "Reliability of the 'Sydney,' 'Sunnybrook,' and 'House Brackmann' facial grading systems to assess voluntary movement and synkinesis after facial nerve paralysis," *Otolaryngology—Head and Neck Surgery*, vol. 132, pp. 543–549, 2005.
- [11] J. W. House, "Facial nerve grading systems," *Laryngoscope*, vol. 93, no. 8, pp. 1056–1069, 1983.
- [12] J. W. House and D. E. Brackmann, "Facial nerve grading system," *Otolaryngology—Head and Neck Surgery*, vol. 93, no. 2, pp. 146–147, 1985.
- [13] M. Frey, P. Giovanoli, H. Gerber, M. Slameczka, and E. Stüssi, "Three-dimensional video analysis of facial movements: a new method to assess the quantity and quality of the smile," *Plastic and Reconstructive Surgery*, vol. 104, no. 7, pp. 2032–2039, 1999.
- [14] M. Frey, M. Michaelidou, C.-H. J. Tzou et al., "Three-dimensional video analysis of the paralyzed face reanimated by cross-face nerve grafting and free gracilis muscle transplantation: quantification of the functional outcome," *Plastic and Reconstructive Surgery*, vol. 122, no. 6, pp. 1709–1722, 2008.
- [15] L. R. Tomat and R. T. Manktelow, "Evaluation of a new measurement tool for facial paralysis reconstruction," *Plastic and Reconstructive Surgery*, vol. 115, no. 3, pp. 696–704, 2005.
- [16] R. L. Denlinger, J. M. VanSwearingen, J. F. Cohn, and K. L. Schmidt, "Puckering and blowing facial expressions in people with facial movement disorders," *Physical Therapy*, vol. 88, no. 8, pp. 909–915, 2008.
- [17] M. Frey, A. Jenny, E. Stüssi, S. Handschin, and R. Manktelow, "Development of a new paresis scoring system for pre- and postoperative evaluation of facial paresis," *European Archives of Oto-Rhino-Laryngology*, pp. S182–S184, 1994.

- [18] M. Isono, K. Murata, H. Tanaka, M. Kawamoto, and H. Azuma, "An objective evaluation method for facial mimic motion," *Otolaryngology—Head and Neck Surgery*, vol. 114, no. 1, pp. 27–31, 1996.
- [19] P. C. Johnson, H. Brown, W. M. Kuzon Jr., R. Balliet, J. L. Garrison, and J. Campbell, "Simultaneous quantitation of facial movements: the maximal static response assay of facial nerve function," *Annals of Plastic Surgery*, vol. 32, no. 2, pp. 171–179, 1994.
- [20] C. J. Linstrom, "Objective facial motion analysis in patients with facial nerve dysfunction," *Laryngoscope*, vol. 112, no. 7 I, pp. 1129–1147, 2002.
- [21] C. J. Linstrom, C. A. Silverman, and D. Colson, "Facial motion analysis with a video and computer system after treatment of acoustic neuroma," *Otology and Neurotology*, vol. 23, no. 4, pp. 572–579, 2002.
- [22] E. W. Sargent, O. A. Fadhli, and R. S. Cohen, "Measurement of facial movement with computer software," *Archives of Otolaryngology: Head and Neck Surgery*, vol. 124, no. 3, pp. 313–318, 1998.
- [23] K. L. Schmidt, J. F. Cohn, and Y. Tian, "Signal characteristics of spontaneous facial expressions: automatic movement in solitary and social smiles," *Biological Psychology*, vol. 65, no. 1, pp. 49–66, 2003.
- [24] K. L. Schmidt, J. M. Van Swearingen, and R. M. Levenstein, "Speed, amplitude, and asymmetry of lip movement in voluntary puckering and blowing expressions: implications for facial assessment," *Motor Control*, vol. 9, no. 3, pp. 270–280, 2005.
- [25] M. Frey, A. Jenny, P. Giovanoli, and E. Stüssi, "Development of a new documentation system for facial movements as a basis for the international registry for neuromuscular reconstruction in the face," *Plastic and Reconstructive Surgery*, vol. 93, no. 7, pp. 1334–1349, 1994.
- [26] B. F. O'Reilly, J. J. Soraghan, S. McGrenary, and S. He, "Objective method of assessing and presenting the House-Brackmann and regional grades of facial palsy by production of a facogram," *Otology and Neurotology*, vol. 31, no. 3, pp. 486–491, 2010.
- [27] G. S. Wachtman, J. F. Cohn, J. M. van Swearingen, and E. K. Manders, "Automated tracking of facial features in patients with facial neuromuscular dysfunction," *Plastic and Reconstructive Surgery*, vol. 107, no. 5, pp. 1124–1133, 2001.
- [28] K. Yuen, S. Kawakami, T. Ogawara, I. Inokuchi, M. Maeta, and Y. Masuda, "Evaluation of facial palsy by Moiré topography index," *Otolaryngology—Head and Neck Surgery*, vol. 117, pp. 567–572, 1997.
- [29] R. Aiguade, J. M. Fernández, X. A. Jodar, and L. M. Romero, "Effets du bandage neuromusculaire (Kinesiotaping) sur le tonus du trapézius supérieur," *Kinésithérapie, la Revue*, vol. 13, no. 134, pp. 58–59, 2013.
- [30] A. V. Bruyneel and A. Plan, "Influence de la vitesse d'exécution du mouvement sur les stratégies angulaires du membre inférieur lors du passage assis-debout et debout assis," *Kinésithérapie, la Revue*, vol. 13, pp. 30–31, 2013.
- [31] W. Reh and B. Scheffler, "Significance tests and confidence intervals for coefficients of variation," *Computational Statistics & Data Analysis*, vol. 22, no. 4, pp. 449–452, 1996.
- [32] S. E. Coulson, G. R. Croxson, and W. L. Gilleard, "Quantification of the three-dimensional displacement of normal facial movement," *Annals of Otology, Rhinology and Laryngology*, vol. 109, no. 5, pp. 478–483, 2000.
- [33] V. F. Ferrario, C. Sforza, N. Lovecchio, and F. Mian, "Quantification of translational and gliding components in human temporomandibular joint during mouth opening," *Archives of Oral Biology*, vol. 50, no. 5, pp. 507–515, 2005.
- [34] V. Meier-Gallati, H. Scriba, and U. Fisch, "Objective scaling of facial nerve function based on area analysis (OSCAR)," *Otolaryngology—Head and Neck Surgery*, vol. 118, no. 4, pp. 545–550, 1998.
- [35] J. G. Neely, J. Y. Cheung, M. Wood, J. Byers, and A. Rogerson, "Computerized quantitative dynamic analysis of facial motion in the paralyzed and synkinetic face," *American Journal of Otology*, vol. 13, no. 2, pp. 97–107, 1992.
- [36] K. O. McGraw and S. P. Wong, "Forming inferences about some intraclass correlation coefficients," *Psychological Methods*, vol. 1, no. 1, pp. 30–46, 1996.
- [37] J. M. Bland and D. G. Altman, "A note on the use of the intraclass correlation coefficient in the evaluation of agreement between two methods of measurement," *Computers in Biology and Medicine*, vol. 20, no. 5, pp. 337–340, 1990.
- [38] D. A. Bloch and H. C. Kraemer, "Two by two Kappa coefficients: measures of agreement or association," *Biometrics*, vol. 45, no. 1, pp. 269–287, 1989.
- [39] H. C. Kraemer, V. S. Periyakoil, and A. Noda, "Kappa coefficients in medical research," *Statistics in Medicine*, vol. 21, no. 14, pp. 2109–2129, 2002.
- [40] L. G. Portney and M. P. Watkins, "Statistical measures of reliability," in *Foundations of Clinical Research: Applications to Practice*, chapter 26, pp. 508–517, Prentice Hall, Upper Saddle River, NJ, USA, 2000.
- [41] E. A. Chu, T. Y. Farrag, L. E. Ishii, and P. J. Byrne, "Threshold of visual perception of facial asymmetry in a facial paralysis model," *Archives of Facial Plastic Surgery*, vol. 13, no. 1, pp. 14–19, 2011.
- [42] T. A. Hadlock and L. S. Urban, "Toward a universal, automated facial measurement tool in facial reanimation," *Archives of Facial Plastic Surgery*, vol. 14, no. 4, pp. 277–282, 2012.
- [43] C. J. Linstrom, C. A. Silverman, and W. M. Susman, "Facial-motion analysis with a video and computer system: a preliminary report," *American Journal of Otology*, vol. 21, no. 1, pp. 123–129, 2000.
- [44] K. Mishima, T. Yamada, K. Fujiwara, and T. Sugahara, "Development and clinical usage of a motion analysis system for the face: preliminary report," *Cleft Palate-Craniofacial Journal*, vol. 41, no. 5, pp. 559–564, 2004.
- [45] K. Mishima, T. Yamada, A. Ohura, and T. Sugahara, "Production of a range image for facial motion analysis: a method for analyzing lip motion," *Computerized Medical Imaging and Graphics*, vol. 30, no. 1, pp. 53–59, 2006.
- [46] C.-A. Trotman, J. J. Faraway, and G. K. Essick, "Three-dimensional nasolabial displacement during movement in repaired cleft lip and palate patients," *Plastic and Reconstructive Surgery*, vol. 105, no. 4, pp. 1273–1283, 2000.
- [47] C.-A. Trotman, C. S. Stohler, and L. E. Johnston Jr., "Measurement of facial soft tissue mobility in man," *Cleft Palate-Craniofacial Journal*, vol. 35, no. 1, pp. 16–25, 1998.
- [48] M. Baude, E. Hutin, A. Behnegar, and J. M. Gracies, "Self-rehabilitation program of fatiguing series of maximal contraction exercises in chronic peripheral facial paresis," *Annals of Physical and Rehabilitation Medicine*, vol. 55, article e295, 2012.