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Automated Movement Feedback for Recovering Independence in the Sit-to-Stand Movement in an Older Population: A Pilot Randomised Controlled Trial of a Novel System

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Abstract

Background: The sit-to-stand (StS) movement is a frequently performed task critical to independent living that is both difficult to perform and associated with falls in older populations. Consequently, the recovery of this movement through supervised practice is a priority during the rehabilitation of older people. Technology may enable self-practice, potentially improving rehabilitation outcomes. The purpose of this study was to evaluate the clinical feasibility and effectiveness of an automated movement feedback system for recovering the StS movement in an older population.

Methods: This was a phase two pilot randomised controlled trial. Participants were in-patients on a geriatric rehabilitation unit with an impaired StS ability. Following baseline outcome measurements, including quantifying the number of StS executions 48 hours preand post- trial, participants were block randomised to either a control group receiving standard rehabilitation or an experimental group receiving standard rehabilitation augmented with a novel automated movement feedback system for the StS training sessions. The intervention aimed to last four weeks with outcome measures repeated following completion.

Results: Eighteen participants (81.25+/- 7.31 years) were evenly distributed between the two groups and interventions were completed without incident. The novel feedback group provided positive feedback on their experience, reporting the system to be motivating and instructive. Differences between the groups were statistically significant (p<0.05) for change in clinical measures (Tinetti and Elderly Mobility Score) with greater improvement in the technology-based feedback group. Daily StS movements increased in the experimental group (5.75±1.97 to 29.5± 6.22) but decreased in the control group (17.00 ± 4.86 to 11.88 ± 3.37) a difference that was statistically significant (p=0.02).

Conclusions: This randomised controlled trial evaluated a novel automated movement feedback system for recovering independence in the StS movement in an older population. The positive findings demonstrate the system to be suitable for use in a clinical environment and provide preliminary evidence of improved outcome in terms of StS capacity when compared to standard therapy.

Keywords

Automated feedback; sit-to-stand; geriatric; rehabilitation; visual reality

1. Introduction

Ageing is a natural physiological process that can ultimately lead to frailty, a multidimensional geriatric syndrome of increased vulnerability due to ageing-associated deterioration of physiological functions. The sit-to-stand (StS) movement is key to independent living, performed around seventy times a day, on average, by older adults living in the community [1]. Despite being an everyday movement, the balance and strength requirements create difficulties for older people [2-4] limiting their ability to lead an independent life and creating a risk of falling [5].

Rehabilitation, in the form of practicing functional movements with physical support and feedback from physical therapists can help restore mobility, delay functional decline and reduce mortality in older people [6, 7] Studies have shown that by repeatedly practicing the STS movement during geriatric rehabilitation, STS ability can be stored [5, 8]. The dependency on staff to deliver this rehabilitation, however, limits practice opportunity and potentially rehabilitation outcomes.

Technology can enable patients to continue practicing the movement on their own by providing feedback on key elements of the movement to help motivate as well as correct errors. This type of technology-based feedback has already been used successfully in neurorehabilitation, particularly for the upper limb function and, to a lesser extent, for recovering walking ability in patients post-stroke [9, 10]. It has not, however, been widely tested for the StS movement or with a general older adult population. This paper presents a pilot randomised controlled trial evaluating the clinical feasibility and effectiveness of a novel computerised feedback system that provides feedback on key components of the StS movement.

The system simulates a virtual reality environment. It consists of a sensor and a balance plate for measuring real-time StS performance. When the user is practising the movement, visual and auditory biofeedback are provided in real-time and at the end of training for upper trunk posture, force symmetry and force impulse without the need for physical therapists. For example, “please try to lean more to your right” (if the body lateral bending angle exceeded 25 degrees) or “you need to lean a little further forward” (if trunk forward angle did not reach 30 degrees (Kerr et al 2019), as well providing motivational feedback, “you are standing up well” (if the individual met the trunk lean and force distribution criteria).

The primary aim of this study was to test the acceptability and feasibility of this novel StS training system in a geriatric rehabilitation environment. A secondary aim was to gather preliminary evidence of effectiveness, such as improved mobility based on mobility tests, to inform a future trial.

2. Materials and Methods

2.1 Study Design

The study was a phase-two, pilot, randomised controlled trial. Participants were randomly allocated to either an experimental group consisting of conventional rehabilitation with all StS training sessions augmented with the automated training system described above or the control group, which received conventional rehabilitation. The study protocol was designed collaboratively with the clinical team to improve the transferability of the study outcomes.

The study was approved by a local research ethics committee (West of Scotland NHS Research Ethics 4) in accordance with the Helsinki declaration. The trial was registered with ClinicalTrials.gov (NCT02925039).

2.2 Participants

The trial, including recruitment, intervention and data collection, took place in a single geriatric rehabilitation unit. Patients are admitted to this unit to receive intensive rehabilitation for a range of orthopaedic and neurological conditions as well as general frailty. Any patient admitted to the ward who was referred for active rehabilitation that included a goal of improving StS ability were eligible to participate and were initially identified by the clinical team using the criteria listed in Table 1. Eligible participants were then provided with an information sheet and invited to participate by a member of the research team. Through this process 20 patients consented to participate from 26 identified by the clinical team, more details are provided in the results.

Table 1 Study recruitment criteria.

Inclusion	Exclusion
Current in-patient on the geriatric rehabilitation unit. Impaired ability to stand up from chair, as determined by a clinical physiotherapist. Medically stable, as determined by a consultant geriatrician. Able to give informed consent. Able to complete at least one StS movement with or without the help of a mobility aid or one other person. Able to follow three-word instructions in English.	Inability to read feedback on a computer screen with/without visual aids. Epilepsy Coexisting physical impairments that prevent StS practice. Not expected to survive the study period. Cognitive impairment preventing informed consent.

2.3 The Technology-Based StS Feedback System

Data from a balance-plate (Bertec, Columbus, USA) and an inertial sensor (Phidgets, Calgary, USA) were integrated through a bespoke software programme (Labview, National Instruments, Texas, USA) to present participants with a range of movement feedback variables. The inertial sensor was placed within the lining of a vest worn by the users so that it was located around the waist. This sensor gathers real-time three-dimensional movement data at a frequency of 20 Hz filtered with a second-order low-pass filter with a cut-off frequency of 12 Hz. A calibration procedure was initiated with the user at rest in a neutral sitting position as the inertial sensor's and balance plate's data were reset. The balance-plate was placed on the ground in front of the chair in such a way that participants could comfortably place both their feet on it when seated, this instrument measures force location and magnitude at a frequency of 20 Hz filtered with a second-order low-pass filter with a cut off frequency of 12 Hz. The whole system was designed to be portable allowing training to take place next to the participant's bed on the ward. See Figure 1 for illustration.

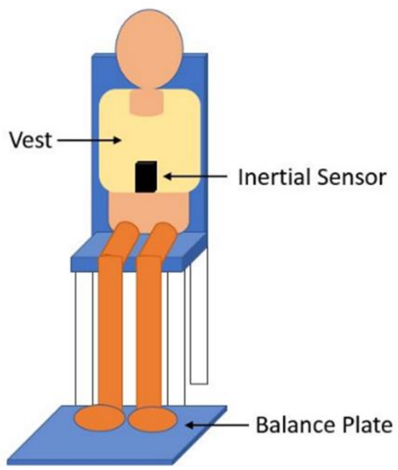

Figure 1 Sensor setup.

Data from both sensors (inertial sensor at waist and balance-plate under the feet) were combined through a sensor fusion algorithm to create a range of movement feedback variables. The variables ultimately selected for feedback were identified from the literature as being important for successful StS transfers, this included; 1) trunk forward lean, 2) left/right force symmetry [11], and 3) force impulse during the rising phase [12-14].

The trunk forward lean angle was defined as the flexion angle created by the upper trunk during the StS movement whereas the force symmetry was measured by a balance plate (see Figure 1) placed under both feet. The rising phase was detected by the plate as soon as the participant's weight was no longer supported by the seat.

This feedback was presented to participants in three ways. Firstly, a virtual reality image, modelled on the interior of a public bus, was displayed on a screen in front of users. This specific environment was developed through focus groups undertaken during the design process. An avatar, linked to the inertial sensor, recreated the user's StS motion, in real time. Secondly, on the same screen, a horizontal colour bar showed force distribution between both sides. Finally, audio feedback on trunk position, force magnitude and distribution were provided.

During the first StS attempt reference values for the three key parameters (trunk lean, force distribution (left/right) and force magnitude during rising were used to create automated instructions for subsequent attempts. For example, "please try to lean more to your right" or "you need to lean a little further forward, as well providing motivational feedback ("you are standing up well").

If the system detected an unsuccessful movement attempt, specific instructions were selected through a bespoke fuzzy logic based diagnostic system for subsequent attempts using feedback from the sensors.

For example, a lack of forward lean would prompt the instruction (audio and text) "try to move your head forward over your knees".

When the user had successfully executed one StS movement, progress was indicated by moving around a bus route map and feedback provided on their performance e.g. "you leaned a little too far to the right" or "try to push down harder". These were provided visually on a "message board". After each training session summative feedback were provided in text and graphical form. The user was then able to repeat the cycle as appropriate.

Randomisation was in blocks of four to ensure balance between the groups. Opaque envelopes containing the allocation sequence were opened by a member of the clinical team independent of the study.

2.4 Primary Outcome Measures for Efficacy

The primary outcome measures used to test efficacy were standard clinical measures used routinely in geriatric rehabilitation. These were the Tinetti Assessment Tool (TAT) and the Elderly Mobility Scale (EMS) [15, 16]. These measures of general mobility are based on ordinal ratings of a functional task performance, such as StS, where a trained rater scores an individual's attempt at the task as 0 = unable to achieve with full support, 1 = able to achieve with support and 2 = able to achieve with no support. They and have been extensively validated in this population [17].

2.5 Secondary Outcome Measure

Physical activity including time spent in sitting, standing and walking as well as postural transitions (e.g. StS) were recorded with an ActivPAL (PALtechnologies, Glasgow, UK) physical activity monitor which was attached to each participant's thigh (dominant side) for 48 hours. This sensor has been validated in a wide range of populations including older people [18].

Outcome measures were conducted as soon as informed consent was given and before randomisation. The TAT and EMS were carried out by clinical staff from the rehabilitation unit who were not involved in the delivery of the interventions. The ActivPAL was applied by the researcher (S-H) to the thigh of the dominant side. This accelerometer-based sensor allows inclination of the thigh (with respect to gravity) to be measured, a proprietary algorithm is then applied to this inclination data to determine whether the thigh has moved from a horizontal (seated) to a vertical (standing) posture. These changes in posture are automatically logged at 10Hz and were downloaded to a computer for analysis.

The outcome tests were then repeated within two days of completing the intervention or two days before discharge, if this was earlier.

2.6 Intervention

Participants allocated to the technology-based feedback group received their usual therapy as determined by the staff on the unit, with the exception of any planned StS training which was replaced with the technology-based feedback system set up by the researcher (SH) and overseen by the therapy staff who provided supervision only, i.e. no verbal feedback or manual guidance. Participants were free to use mobility aids, such as standing frames and sticks for support during the practice as advised by the clinical physical therapist. The control group received conventional rehabilitation as per usual practice. The StS training for this group consisted of a combination of supervised practice, with or without feedback (manual and verbal).

2.7 Data Analysis

To assess the system's acceptability participants were interviewed following the intervention with participants in the experimental group asked specifically about the user-friendliness of the feedback system. This information was added to any informal feedback offered by participants during and after practice sessions and a thematic theory approach was then applied to the total qualitative data [19].

Following checks for normality (Anderson-Darling) differences between the two groups (age, mobility) at baseline were tested for significance using an independent t-test. Changes in the primary outcome measures (EMS and TAT) were subsequently tested for statistical differences also using an independent t-test. Finally, the change in number of daily StS transitions and steps (i.e. number of StS movements and steps conducted within a 24 hour period) were tested with a Mann-Whitney due to the data being not normally distributed (Anderson-Darling, $P<0.05$).

3. Results

Over a two-month period (February to April 2017), 20 patients from a total of 26 identified by the clinical team as being eligible to participate, consented to participate. Seven patients were subsequently excluded due to cognitive impairment and one patient declined to participate. All 18 consenting participants were successfully randomised to either the experimental group (n=9) or the control group (n=9), see Table 2 for details. After randomisation one participant (experimental group) voluntarily withdrew due to hospital transfer and another participant (control group), refused to continue. Participants in both groups received three StS training sessions per week for four weeks, see Figure 2 for an overview.

Table 2 Characteristics of participants separated by group allocation.

	Experimental Group Mean (SD), n=9	**Control Group Mean (SD), n=9**
Age	80.75 (7.81)	81.74 (6.88)
Gender (Male / Female)	2/7	3/6
Primary admission reason	Fracture = 6, Pain = 1, Stroke = 2	Fracture= 5, Osteomyelitis= 1, Leg amputation= 1, Parkinson's Disease= 1, Pain= 1;

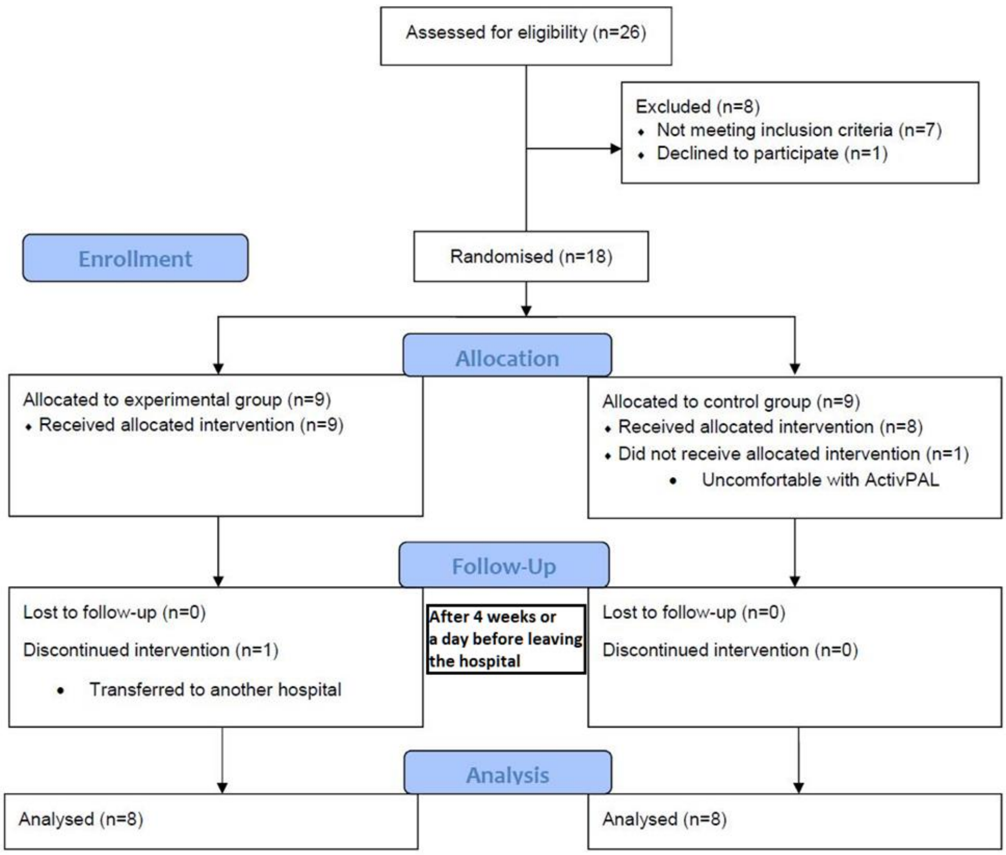

Figure 2 Outline of participant flow through the study.

3.1 Acceptability of the Technology-Based Feedback System

Participants in the experimental group had a 100% adherence to the training sessions and there were no recorded adverse events. There was a generally very positive response from participants using the feedback system with two distinctive themes emerging from the thematic theory process.

The first theme was motivation. The feedback from the system was felt to be very encouraging by participants, for example; “I feel your system gave me something very different.” Participants reacted positively to the system, typically offering non-verbal signals such as smiling and giving the thumbs up sign to indicate they were enjoying the session. The virtual reality environment was described as "fun". Several participants requested an opportunity to attempt the session again after they had read the summative feedback with the aim of improving their performance.

Several participants reported that simply wearing the vest (containing the sensor) put them in a positive frame of mind. They described feelings akin to being in an athletic or military environment, symbolising determination and physical effort. Wearing the vest reminded one participant of when they used to run marathons and this memory triggered feelings of determination such as to “try harder than running a marathon”. Another participant described the vest as a “uniform”. “I am wearing my uniform”. They also suggested that the vest instilled a sense of pride.

The second theme was the authenticity of the experience as several participants reported that the automated instructions (e.g. lean forward, push down and keep your body straight) helped them execute a successful StS movement, for example “I am sure what this computer says is more truthful.” Participants commented that they enjoyed the simulation of a bus environment commenting they felt like they "were sitting on a bus".

3.2 Change in STS Ability

The mean change in the TAT score was 11.63 (SD 4.5) in the experimental group compared to 5.88 (SD 4.76) in the control group, this difference was statistically significant according to an independent t-test (t=2.48, P=0.013) and exceeds minimal detectable change [20]. The mean change in EMS was 11.13 (SD 3.60) in the experimental group compared to 3.75 (SD 3.11) in the control group, this difference was also statistically significant (t=4.39, P=0.000) and was greater than the estimated minimal clinically important difference (2) [21], see Table 3.

The median increase in daily StS movements was 8.75 (from 14.25 to 25.00) in the experimental group compared to 0.00 (from 12 to 9.50) in the control group. This was statistically significantly different according to a Mann-Whitney test (W=82, p=0.020). The median increase for daily steps in the experimental was 179 compared to 15.5 in the control group. This was not statistically significant according to a Mann-Whitney test (W=82, p=0.078). These results excluded any steps and StS movements performed during therapy sessions.

Table 3 Outcome measures at baseline and outcome.

	Control Group			**Experimental Group**			**Group differences**		
	Baseline	Outcome	Change	Baseline	Outcome	Changes	Baseline	Outcome	Change
Tinetti Assessment Tool Mean (SD)	9.38 (5.55)	15.25 (6.61)	5.88 (4.76)	8.75 (3.92)	20.38 (4.44)	11.63 (4.50)	t=-0.26, p=0.60	t=1.82, p=0.05	t=2.48, p=0.01
Elderly Mobility Scale Mean (SD)	5.00 (3.42)	8.75 (4.33)	3.75 (3.11)	2.75 (2.12)	13.88 (4.58)	11.13 (3.60)	t=-1.58, p=0.93	t=2.30, p=0.02	t= 4.39, p=0.00
Daily Sit-to-Stand Median (IQR)	12.0 (23.5)	9.50 (18.75)	0.00 (34.63)	14.25 (7.63)	25.0 (24.50)	8.75 (14.88)	w=72, p=0.36	w=89, p=0.016	w=88, p=0.02
Daily Steps Median (IQR)	40.0 (255)	51.0 (254.5)	15.5 (355)	126.0 (334.5)	385 (610)	179 (621)	w=79, p=0.14	w=88, p=0.02	w=82, p=0.08

4. Discussion

This is the first clinical trial evaluating acceptability and preliminary effectiveness of a technology-based feedback system designed to support the recovery of the StS movement in an older population. Based on participant interviews, absence of adverse events and full adherence to the sessions the system can be considered safe to use, acceptable and feasible in a clinical environment.

Feedback from participants in the experimental group suggest the system may have some advantages over traditional methods in terms of motivation and increasing engagement with the activity, which may help explain the better outcomes for this group. The use of technology in rehabilitation is widely recommended to increase practice intensity and improve the efficiency of rehabilitation services [22-24]. Their routine adoption into therapy practice, however, is reported to be disappointing [25]. The promising findings from this study suggests the introduction of technology into geriatric rehabilitation may be more acceptable than the stroke populations tested in previous research [26]. Possible reasons for this difference should be explored in future studies to better understand how technology can be more widely integrated into rehabilitation.

Training with the feedback system increased the number of daily StS transitions in the experimental group. This may be explained by greater awareness of the key movement parameters, 1) trunk forward lean, 2) left/right weight symmetry and 3) force impulse during the rising phase or simply raised attention on the importance of practicing the movement. While it is unlikely that any change was derived from a physiological change in muscle strength this change in StS behaviour may create the necessary environment for improving muscle strength and general physical activity with longer term positive outcomes on function and health.

The training improvements were not confined to the StS movement, with significantly improved mobility and balance in the experimental group, as measured by the EMS and TAT, implying some carry over to general mobility although this effect did not appear to alter the daily steps.

The engaging nature of the feedback and inclusion of different forms of feedback (visual and audio) that focussed on the three simple, yet critical, features of the movement meant that a wide range of patients were able to participate and find it a motivating and enjoyable addition to their rehabilitation. This is underpinned by the importance of feedback during motor learning to help individuals correct errors and provide the motivation to continue [27-29]. In addition, the visual feedback provided by an animated avatar, which participants found to be attractive, triggered interest and made the training sessions more engaging. This may have helped improve adherence to therapy as well as raising awareness of the movement itself.

While the study was not set up to assess cost-effectiveness there are undoubtedly cost savings from using a low cost rehabilitation technology (estimated cost price <£1000) that might support more intensive self-practice. Not only is it conceivable that such a system could reduce labour time but the better outcomes suggested by this pilot study might reduce the burden of care by improving individual's ability to self-care. Cost effectiveness should be explored in any future study of this rehabilitation technology.

4.1 Study Limitations

The findings of the study should be considered in context of the limitations, particularly the small sample size. While 438 individuals were admitted to the rehabilitation unit over the recruitment period only 219 patients were considered eligible with the majority being excluded due to cognitive impairment. The low recruitment of the remaining eligible participants may have related to a lack of staff familiarity with the study protocol which could have been addressed with an explicit educational package and regular recruitment updates at staff meetings.

The possibility that a Hawthorne effect influenced the results is highly likely, particularly in the technology-based group due to the additional attention from using a novel system as well as the presence of the researcher during the training sessions [30]. This is a common feature of rehabilitation trials that can only really be resolved through repetition and use of larger samples to minimise the effect of any bias.

4.2 Recommendations for Future Research

This novel technology–based feedback system is not ready to be adopted routinely into clinical practice as efficacy has not been statistically established. Future research should focus on testing efficacy through a statistically powered trial, a longer period of follow up and using general tests of mobility.

5. Conclusions

This paper demonstrates the feasibility and acceptability of a novel rehabilitation technology to enhance the StS training experienced by older people during their rehabilitation. The findings of improved functional ability and increased daily StS movements, when using this system compared to conventional therapy alone, should be considered in light of the small sample. Nevertheless, the results suggest potential for the adoption of rehabilitation technologies into geriatric rehabilitation to enhance and complement current practice.

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Author Contributions

Siu Fai Ho: Contributed to the development of the rehabilitation system, arranged and conducted the clinical trial, analysed and presented the data and this paper.

Avril Thomson: Contributed to the development of the rehabilitation system.

Tricia Moylan and Julie McGuckin: Arranged and help to conduct the clinical trial.

Andrew Kerr: Principle Investigator, contributed to every part of this paper, including the development of the rehabilitation system, arranged and conducted the clinical trial, analysed and presented the data and this paper.

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Competing Interests

The authors have declared that no competing interests exist.

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