The impact of a self-regulated pneumatic resistance intervention on variables related to balance, gait and lower extremity muscle function in community dwelling older adults

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ABSTRACT

Purpose: To evaluate the impact of self-regulated pneumatic resistance exercise on variables related to balance, gait and lower extremity muscle function in community dwelling older adults.
Materials and methods: Thirty-six older adults, aged ≥65 years completed the testing procedure as either the 10 week control (n=18) or intervention (n=18) group. Outcome measures included spatiotemporal gait variables, double leg standing balance assessment (with eyes open and closed), and the five times sit-to-stand measurement. Results were analysed using ANCOVA tests, with baseline values included as a covariate.
Results: No change to balance or gait was identified in either group. Participants within the intervention group significantly decreased time taken to complete the five times sit-to-stand test (p=0.006, η_p^2 =.218), while no change was reported within the control group.
Conclusion: Positive findings of increased lower extremity muscle function indicate that self-regulated pneumatic resistance may represent an appropriate exercise intervention for use in older adults, although the lack of improvement to balance and gait parameters suggest that further research is required to develop delivery modalities for optimum effectiveness in this population.
Key words: active ageing; pneumatic resistance; physical function.

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INTRODUCTION

The ageing process is associated with a range of physiological, psychological and biomechanical changes all of which contribute to the development of frailty. This condition is recognised as a state of increased vulnerability due to age related functional decline [1], compromising ability to resist minor stressors and maintain physiological homeostasis [2]. Balance, gait and lower extremity muscle function are all known to decline with the development of frailty [2-4], with associated consequences to the ability to maintain an active and independent lifestyle. Although some physiological decline in these parameters is considered a natural consequence of ageing [5], participation in physical activity has been shown to positively impact on the extent of physiological decline [6] and has been reported as the only strategy known to consistently prevent or delay the development of frailty [7]. Given the current population shift toward an ageing society, “active-ageing” based interventions are required to prevent the development of frailty and associated individual, societal and economic impacts. Research is ongoing as to the most effective physical training modalities for use within this population, however resistance based training has been suggested as a core component of older adult exercise programs [5] and is thought to represent the optimum means of inducing beneficial adaptation to muscle mass, strength and function [7-9].

Pneumatically controlled resistance exercise is gaining popularity as an exercise intervention for individuals that may experience difficulty with more traditional resistance training due to physical impairments caused by age, disability or general deconditioning, and there are elements of its design that render it particularly suitable for this purpose. This form of exercise requires the use of specialised equipment, the defining feature of which is the use of a pneumatic cylinder to provide resistance instead of weight stacks, wires and other moving parts used in more traditional gym equipment. The pneumatic cylinder is preloaded with compressed air, which compresses further as pressure is applied, thereby increasing the resistance provided [10]. The opposing movement subsequently requires the individual to control the speed of expanding gas, ensuring that both the agonist and antagonist muscles are loaded during each cyclic movement, facilitating a balanced work-out of major muscle groups and functional movements [11]. The extent of air compression is dependent on the force produced and the rate of movement, which ultimately provides resistance that is relative to the ability and effort of the individual performing the exercise. This self-regulating design feature creates an individualised workout, and is particularly relevant when considered within the context of older adult populations, where the large variation in health and fitness parameters can render individualised training within a group setting difficult. In addition, traditional resistance equipment generally provide a constant load that limits the ability of the user to continue to work past a critical joint configuration or “sticking point”, subsequently reducing the overall load and force produced throughout the movement. In contrast, the ability of the pneumatic cylinder to adjust the load and subsequent force production within the exercise repetition allows the muscle to be loaded throughout the full range of motion, theoretically increasing the overall load throughout the movement [12]. This may be particularly relevant for an older adult population, many of whom have more limited range of motion [13-14] rendering it additionally important that the exercise intervention facilitates loading throughout the full available range. The risk of injury is always a concern when considering the suitability of a resistance based intervention for an older adult population [15]. The pneumatic design of this equipment is thought to reduce variability in the muscle force required to complete the movement [10] and this, along with the self-regulated nature of the exercise intervention may potentially reduce injury risk, while subsequently increasing the individual’s confidence in their ability to undertake the exercise.

Although the use of self-regulated pneumatic resistance equipment for older adults appears theoretically justified, limited research is available to empirically assess the impact of such an intervention on specific variables related to physical function in older adults. Research regarding the influence of explosive resistance training using pneumatic equipment in older adults has shown positive results [16-17], however community based “active-ageing” programs using this equipment do not typically employ high-intensity power based protocols, but follow a more self-regulated design. The aim of this study, therefore, was to evaluate the impact of a self-regulated pneumatic resistance intervention on variables related to gait, balance and lower extremity muscle function in healthy community dwelling older adults.

MATERIALS AND METHODS

Research Design Overview

A repeated measures controlled design was employed whereby participants were invited to take part in a 10 week intervention and allocated to either the control or pneumatic resistance based exercise group. Outcome measures included spatiotemporal gait parameters collected using an automated analysis walkway; double leg standing balance assessment (with eyes open and closed) assessed by centre of pressure (COP) displacement measured from a force platform; and lower extremity muscle function as assessed by the five times sit-to-stand measurement.

Participants

Community dwelling older adults, both male and female were recruited to take part in this project and allocated to either the control or intervention group. A waiting list of community dwelling individuals expressing interest in attending the pneumatic resistance training classes was used to recruit the intervention group, while a purposive sampling approach was taken to subsequently recruit a matched control group. Inclusion criteria for this study were ≥ 65 years of age and community dwelling status. Exclusion criteria included any medical condition or injury that contra-indicated exercise participation, and current or recent participation in a structured exercise or training program. Body mass and height were measured pre and post intervention using standard techniques. Ethical approval for the study was granted by the Robert Gordon University School of Health Sciences Research Review Group and participants provided written informed consent prior to taking part in the study.

Intervention

The circuit based training session consisted of nine stations of pneumatically controlled resistance based equipment, with each station designed to target a specific movement and muscle group (Easyline Range, Technogym Ltd, UK). Details of each piece of equipment, the movement required and muscle groups targeted are presented in Table 1.

Three pressure ranges were available and the mid-level setting was used as the default setting, with individual participants increasing or decreasing the compression as required. At each station participants undertook two sets of 60 seconds of continuous effort on each machine, with 30 seconds of rest allocated between each set, before getting up and moving to the next station. This was continued until each participant had completed a full circuit of nine exercises. Participants were not provided specific instructions on intensity, but were encouraged to fully engage in each set. Each session was preceded by a warm-up session that lasted approximately 10 minutes comprising seated mobilisation and pulse raising movements and concluded with a cool-down using similar movements. Each session lasted approximately one hour in total. Four regular time slots were made available per week, with a capacity of nine participants per session. Participants were requested to attend a minimum of one class per week, but had the option to attend more than that if they so wished, simulating the manner in which these sessions are made available within the community in which this study was based.

Balance assessment

Two standing balance tasks were selected to assess participant’s ability to maintain postural control. These balance tests included double limb standing with eyes open and closed. Participants were instructed to position hands on their hips and remain as stationary as possible for the duration of the test. COP data were collected using a single force platform (Accupower, AMTI, Massachusetts, USA) over a period of 20 s. The outcome measure used to assess balance was the total COP path length. Given that each trial was of fixed duration, these COP path lengths are equivalent to the average COP velocity. A total of three trials were performed for each balance task, with the average of the two closest COP path lengths selected for further analysis. Force platform data were sampled at 200 Hz and based on a frequency content analysis filtered using a digital fourth-order low-pass Butterworth filter with a cut-off frequency of 20 Hz.

Gait assessment

Temporal and spatial gait variables were assessed using a 6 m long walkway, incorporating 18,432 pressure sensors (GaitRite®, CIR Systems Inc.). As the participant ambulated across the walkway, the system captured the geometry and the relative arrangement of each footfall as a function of time. Variables assessed included distance, ambulation time, velocity, mean normal velocity, cadence and a functional ambulatory profile (FAP) score, which combined a number of the spatial and temporal variables to provide a single, valid and reliable numerical representation of gait [18]. Participants walked across the walkway three times, with the average of the two closest recordings selected for further analysis. Shoes were worn, but walking aids were not permitted.

Table 1. Pneumatic resistance equipment

Machine	Movement	Muscle Group
Shoulder press – lat pull down	Upper body push and pull movement in the frontal plane.	Deltoid, trapezius, latissimus dorsi
Chest press – Seated row	Upper body push and pull movement in the sagittal plane.	Pectorals, lattisimus dorsi, rhomboids
Hip adductor – hip abductor	Lower body adduction and abduction	Tensor fascia latae, gluteus, adductors
Leg extension – leg curl	Flexion and extension at the knee.	Quadriceps, hamstrings
Pec dec – rear delt fly	Upper body abduction and adduction.	Pectorals, rhomboids, deltoid
Arm curl – arm extension	Flexion and extension at the elbow in the sagittal plane.	Biceps, triceps
Squat	Bending to extension movements from a standing position.	Quadriceps, gluteus, hamstrings
Leg press	Bending to extension movements from a seated position.	Quadriceps, gluteus, hamstrings, gastrocnemius, soleus.
Abdominal curl – back extension	Flexion and extension in the sagittal plane.	Abdominal rectus, erector spinae.

Information sourced from the *“Technogym Wellness Collection Professional Edition Catalogue”*.

Sit to stand test

A chair (43 cm in height) with a solid back and no armrests was placed against a wall for stability. Participants sat down with arms crossed over the chest. They were then instructed to stand up and sit down five times keeping their arms crossed. They were timed throughout this procedure and the watch was stopped on completion of their fifth repetition. The five times sit to stand test is a commonly used physical performance assessment used in clinical geriatric studies and has been shown to demonstrate strong relative and absolute reliability in older adults [19].

Data analysis

Intra-trial reliability of gait and balance assessments were quantified using two-way, random-effects, single measure intraclass correlation coefficients ($ICC_{(2,1)}$). For all variables, analysis of covariance (ANCOVA) was applied to examine the effects of the intervention versus the control. Group was selected as the independent variable, posttest performance was selected as the dependent variable, and pretest performance was selected as the covariate. For each of the variables analysed a linear relationship between pre- and post-intervention values were obtained. Assumption of homogeneity of regression slopes was tested and met for each of the variables analysed ($p>0.05$). Finally, transformations were not required as within-group residuals appeared normally distributed based on results from Shapiro-Wilk tests ($p>0.05$). Effect sizes were calculated for all variables using partial eta squared (η_p^2).

RESULTS

Descriptive and anthropometric characteristics

Forty participants volunteered to take part in the study and were allocated to either the control (n = 20) or intervention group (n = 20). Thirty-six participants (control n = 18: 13F, 5M; intervention n = 18: 10F, 8M) returned for post testing having successfully fulfilled all requirements of their allocated group, representing an attrition rate of 10%. Participants within the intervention group took part in 13 ± 3 sessions. Participant descriptive and anthropometric characteristics are presented in Table 2.

No significant differences for any parameter were identified at baseline and no significant difference in post-intervention body mass was obtained after adjustment for pre-intervention values (F (1,34)=.683, $p=.414$, $\eta_p^2=.020$).

Table 2. Descriptive and anthropometric characteristics

	Control Group		**Intervention Group**	
Age (yrs)	75.6 ± 5.7		72.4 ± 5.3	
Height (m)	162.9 ± 8.9		163.6 ± 8.6	
	Pre	*Post*	*Pre*	*Post*
Body Mass (kg)	70.4 ± 24.6	70.1 ± 24.4	74.1 ± 26.9	74.0 ± 27.0

Data presented as mean ± standard deviation

Outcome measures

Intra-class correlation coefficients for all balance and gait parameters are presented in Table 3.

All parameters showed strong reliability, with all ICC's $_{(2,1)}$ > 0.90 (range 0.94 – 0.99). Unadjusted and adjusted post intervention outcome measures are presented in Table 4 with no significant group differences identified for any post-intervention values related to balance or gait. In contrast, a significant difference between groups was identified for post-intervention five times sit to stand results ($F(1,34)=8.431$, p=0.006, $\eta_p^2=.218$), with the intervention group reducing their time to complete the test by 5.8 ± 10.4 sec (Pre: 16.2 ± 13.4 VS Post: 10.3 ± 3.0) The large standard deviation reported within the mean change scores was due to two participants who substantially improved their scores post intervention, by 30.6 and 39.4 sec, and results were also analysed excluding these data points, resulting in a mean change of 2.2 ± 1.1 sec (Pre: 11.7 ± 2.9 VS Post: 9.5 ± 1.8 sec). Analysis of results excluding these outlying data points did not meaningfully influence the outcome of the statistical results.

Table 3. Intra-class correlation coefficients for variables related to balance and gait

	Pre-Intervention ICC (95%CI)	**Post-Intervention ICC (95%CI)**
Balance		
COP path length, eyes open	0.94 (0.89, 0.97)	0.94 (0.88, 0.97)
COP path length, eyes closed	0.98 (0.96, 0.99)	0.95 (0.91, 0.98)
Gait Analysis		
Distance	0.93 (0.87, 0.96)	0.94 (0.89, 0.97)
Ambulation time	0.98 (0.97, 0.99)	0.98 (0.97, 0.99)
Velocity	0.97 (0.95, 0.99)	0.99 (0.98, 1.0)
Mean normal velocity	0.99 (0.98, 1.0)	0.98 (0.97, 0.99)
Cadence	0.98 (0.97, 0.99)	0.98 (0.97, 0.99)
FAP score	0.95 (0.90, 0.97)	0.97 (0.93, 0.99)

Table 4. Pre and unadjusted and adjusted scores for post-intervention variables with pre-intervention scores used as a covariate

	Pre	**Unadjusted Post**	**Adjusted Post**	**P Value**	η_p^2
	Mean ± SD	Mean ± SD	Mean ± SE		
COP path length, eyes open					
Control (mm)	29.5 ± 3.8	28.1 ± 5.5	29.2 ± 1.4	**.059**	**.104**
Intervention (mm)	32.3 ± 6.5	34.3 ± 8.7	33.2 ± 1.4		
COP path length, eyes closed					
Control (mm)	47.6 ± 10.7	43.5 ± 14.1	43.8 ± 2.9	**.498**	**.014**
Intervention (mm)	48.7 ± 13.5	46.8 ± 13.5	46.5 ± 2.9		
Distance					
Control (cm)	353.5 ±24.7	361.5 ± 24.2	363.1 ± 6.0	**.414**	**.020**
Intervention (cm)	359.6 ± 18.4	357.7 ± 30.2	356.2 ± 5.8		
Ambulation time					
Control (sec)	2.86 ± .593	2.83 ± .476	2.89 ± .09	**.794**	**.002**
Intervention (sec)	2.99 ± .576	2.90 ± .719	2.89 ± .09		
Velocity					
Control (cm/sec)	128.4 ± 22.3	130.9 ± 18.2	128.6 ± 2.5	**.977**	**.000**
Intervention (cm/sec)	122.9 ± 18.4	126.3 ± 21.4	128.5 ± 2.5		
Mean normal velocity					
Control (leg length/sec)	1.49 ± .296	1.51 ± .233	1.46 ± .03	**.866**	**.001**
Intervention (leg length/sec)	1.40 ± .172	1.43 ± .225	1.47 ± .03		
Cadence					
Control (steps/min)	117.6 ± 11.4	118.1 ± 10.3	115.3 ± 1.6	**.645**	**.006**
Intervention (steps/min)	110.7 ± 9.3	111.6 ± 10.5	114.3 ± 1.5		
FAP score					
Control (%)	96.1 ± 4.2	96.5 ± 4.2	96.9 ± .64	**.369**	**.025**
Intervention (%)	96.8 ± 3.7	96.3 ± 4.1	96.0 ± .63		
Sit to Stand					
Control (sec)	10.9 ± 3.3	10.7 ± 2.5	10.9 ± .38		
Intervention (sec)	11.7 ± 2.9	9.5 ± 1.8	9.3 ± .40	**0.006***	**.218**

M = Mean, SD = Standard Deviation, SE = Standard Error. * Significant difference in post-intervention values between groups after adjustment ($p<0.05$). Intervention group sit to stand results presented excluding the two outlying data points described in section 3.2.

DISCUSSION

The aim of this study was to evaluate the impact of a 10 week exercise intervention using pneumatically controlled resistance based equipment on variables related to balance, gait and lower extremity muscle function in a group of community dwelling older adults. Results revealed no group effect for any of the assessed balance and gait variables, but a statistically significant group effect for the five times sit to stand test was obtained, demonstrating enhanced lower extremity muscle function within the intervention group following participation in the intervention. The positive findings related to lower extremity muscle function, indicate that pneumatic resistance training may be considered a suitable and effective intervention for use in this group, particularly as performance on this test has been shown to be reflective of a number of parameters related to physical function [20]. Further research and evolution of intervention delivery may be required, however, in order to elicit beneficial adaptations in the assessed parameters related to balance and gait in community dwelling older adults.

The results reported on balance and gait within the current study appear to correspond to others when considered within the context of the specific design and outcome measures used within the current and previous studies [21-23]. In particular, factors related to frequency and specificity of training stimulus, along with consideration of the baseline abilities of the participants may have contributed to the results attained. Participants completed 13 ± 3 sessions, which may have represented an insufficient training stimulus frequency, particularly as two to three resistance based sessions per week have previously been suggested as appropriate for this group [5, 24]. In addition, the specificity of the training stimulus must also be considered. The neuromuscular system adapts in accordance with the specific stimulus applied, and although gains in muscle mass, strength and function which may occur as a result of resistance training could contribute to balance and gait ability, a number of other factors are involved, including proprioception and co-ordination [25]. It is possible that any gains in muscle strength and function may not have been of a sufficient magnitude to enable transference and adaptation of general balance and gait performance. The incorporation of exercise stations that specifically challenge the proprioceptive ability of the participants using less stable movements within the existing circuit may be more effective in causing improvements in balance and gait.

The results of the current study must also be considered within the context of the population under investigation. Many of the studies that have previously reported a positive effect of resistance training on balance and gait have been conducted on frail older adults [21,26,27].

The participants within the current study were healthy, community dwelling older adults and consideration of the baseline data in accordance with normative values [28] suggests that their baseline capabilities were similar to or exceeded those previously reported for this age group. The degree of neuromuscular adaptation in response to training will be dependent on baseline capabilities and further improvements in individuals who report high scores at baseline is difficult. In addition, more challenging and dynamic tests may be more sensitive to neuromuscular changes that occur as a result of training. It is possible therefore that greater improvement may have been noted for more challenging dynamic tests, in which the initial ability of the participants is lower, or within a group of physiologically frail older adults, although further research is required to test this hypothesis.

Some of the exercises which featured in this particular intervention could be considered to more specifically mimic the movement patterns required to complete the sit to stand test, which may explain the statistically significant improvement reported for this parameter ($F(1,34)=8.431$, $p=.006$, $\eta_p^2=.218$). For example, three of the nine stations (e.g. the squat machine) specifically mimicked the movement patterns required to perform this test, through targeting the quadriceps, hamstrings and gluteal muscles. In addition, throughout the circuit the participants were required to climb on and off each piece of equipment as they completed the nine station circuit, again mirroring the movement pattern required to complete the sit to stand test. Consideration of baseline characteristics revealed that mean baseline results from both groups were within reference ranges for their age category (10.8 ± 3.3 vs 11.7 ± 2.9 s for control and intervention group respectively) [29]; however, on completion of the exercise program, the mean time taken by the intervention group to complete the test (9.5 ± 1.8 s) were within the reference ranges reported as normative for a group a decade younger (60 – 69). The large change identified in two of the participants (>30 seconds) is noteworthy, as the original results from these participants indicated that they took substantially longer than the rest of the group at baseline, but were comparable post intervention. Such large changes within a short time period are unlikely to be solely due to physical adaptation, and it is suggested that confidence in movement ability may have had a role to play in this finding.

Further research in a group of physically frail older adults is required in order to test this hypothesis. Performance of the sit-to-stand movement has been associated with a range of parameters, including lower extremity strength, balance and lower limb proprioception [20] and to be predictive of falls risk in community dwelling older adults [30].

This finding may have substantial implications for the participants within this group as the physical attributes required to complete this movement are key elements related to maintenance of an active and independent lifestyle, which has numerous associated benefits to physical, psychological and social well-being and quality of life [8,9,31].

A key factor in determining the success of any intervention is the subjective response of the individuals involved, and their motivation to take part in the intervention. The adherence rates to this intervention were positive with 90% adherence and anecdotal evidence from the instructor that delivered the intervention suggesting a positive response, as evidenced by enthusiastic participation and development of a social atmosphere and group cohesion.

Incorporation of a motivational element within a group exercise program can be difficult given the range of diverse factors involved [32], however self-efficacy and social support have been reported as key motivators for exercise participation and adherence in older adults [33-34].

The self-regulated nature of the pneumatic equipment may enhance the participant's belief in their ability to successfully take part in the resistance session, while the instructor led circuit based class provided opportunity for conversation and interaction throughout the class, thereby facilitating interaction and encouraging group cohesion. Further research is required in order to more fully explore the subjective response of participants to this type of intervention in order to assess if design features such as a self-regulated and circuit based nature may impact on motivation to participate in and adhere to the intervention.

There are a number of limitations associated with this study, which may impact on interpretation of results. A convenience based sampling technique was used and a more truly randomized approach may facilitate enhanced isolation of study outcomes to the intervention. The analysis approach was however selected in order to reduce the likelihood of a biased result or type 1 error due to the sampling approach employed. In addition, the sample size could be considered small, which may increase the potential for type 2 error. Reducing the potential of falsely rejecting the null hypothesis was the primary focus within this project. The possibility of a type 2 error cannot be excluded, however calculation of effect sizes appeared to indicate that the practical impact of the intervention on parameters related to balance and gait were negligible, meaning that even if a larger sample was present and significance was detected the practical implications may not be considered meaningful. The intervention was run in accordance with the manner it would be delivered within the community, enhancing the ecological validity of the results attained; however, further research is recommended in relation to frequency, time and intensity of delivery. In addition, a test battery encompassing more challenging and dynamic balance tests may progress the knowledge gained from the current study. From a practical point of view, results from this study do appear to indicate that pneumatic resistance exercise is a suitable and effective intervention for use in this population; however the mode of delivery may depend on the specific requirements of the group. For example, individuals with specific balance and gait difficulties may benefit from incorporation of more specific proprioceptive exercises within the existing circuit design, while consideration of the aerobic response to this intervention may provide further insight into its use. In addition, the design features suggested as suitable for this particular population may also render this a suitable therapeutic or anticipatory care intervention for other populations experiencing reduced physical ability, be it through age, disease, disability or general de-conditioning, although further research is required to test this theory.

In conclusion, results of this study support the use of self-regulated pneumatic resistance exercise, although further consideration may be required in relation to delivery mode. Results from the current study showed no significant group differences for any parameter related to balance or gait, which may be related to factors such as training specificity and baseline performance of outcome measures. A significant group effect was however identified for lower extremity muscle function as indicated by reduced time taken to complete the 5 times sit to stand test. This may have implications for the maintenance of physical function and independence within this group. This finding along with positive anecdotal reports related to the subjective response of the participants appears to support the use of pneumatically controlled equipment as a means to increase physical activity and subsequent physical function in older adults, although further research is required in order to identify the optimum delivery modality.

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Conflicts of interest

None of the authors have any conflict of interest to report.

Authors' contribution

The study was designed by ED, PS, SMC and PC. Data were collected by SMC and analysed by PS. Data interpretation and manuscript preparation were undertaken by all authors.

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