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Blood flow restriction walking and physical function in older adults: A randomized control trial

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ABSTRACT

Objectives: The progressive age-related declines in muscle health and physical function in older adults are related to muscle size and strength. Walking with an applied blood flow restriction is an alternative to maintain muscle volume in older adults to increase the value for time spent walking. Therefore, the aim of this study was to examine the effect of adding blood flow restriction to low-intensity walking on clinical measures of physical function.

Design/methods: Sedentary older men and women were randomised to either a low-intensity blood flow restriction walking group (BFRW; n = 10), or a non-blood flow restriction walking control group (CON; n = 9). Participants were assessed at baseline, three-weeks and six-weeks for the 30 second sit to stand, six-minute walk test, timed up and go, and a modified Queen's College step test. While a rating of perceived exertion (RPE) for training sessions at baseline, three-weeks and six-weeks.

Results: BFRW typically resulted in a 2.5–4.5 fold greater improvement in performance on all measures of physical function compared with CON among these older adults. However, RPE was greater for BFRW at all time points (for baseline, three-weeks, six-weeks: 14 ± 0; 11 ± 0; 11 ± 0) compared with CON (8 ± 0; 7 ± 0; 8 ± 0), despite declining across the study for BFRW.

Conclusions: The greater improvement in physical function with blood flow restriction demonstrates how this addition can increase the quality of simple walking exercise for populations that may be contraindicated to heavy-load resistance training.

1. Introduction

Age-related muscle atrophy is associated with an increased risk of falls, osteoporosis, cardiovascular complications, declines in functional independence and impaired performance of activities of daily living (ADL).[1] In addition, performance on functional assessments in older adults is a reliable predictor of future physical limitations and disability, as well as increased morbidity.[2] Physical function also correlates with muscle mass, strength, and $\dot{V}O_2$ max, all of which decline into older adulthood.[2] The prevalence of conditions associated with a decline in physical function presents an increasing burden on national health care systems.[3] Therefore, developing effective management strategies for declining physical function is important for reducing this burden and for maintaining the independence of older adults.

Preventative strategies traditionally include prescription of heavy-load resistance training (HLRT) programs to develop muscle mass and strength, alongside some cardiovascular conditioning.[4] However, many older adults are contraindicated to HLRT due to the high mechanical stress and risk of cardiovascular events,[5] and together with the perceived time requirement and lack of knowledge of how to correctly perform HLRT, older adults are often deterred from participation or display reduced adherence to HLRT.[5]

Walking training is an alternative to maintain muscle mass and strength in older adults.[6] Indeed walking may also improve $\dot{V}O_2$max in older adults when intensities are above ~40% $\dot{V}O_2$max.[7] However, given significant populations of older adults are classified as sedentary,[8] walking appears underutilised for maintaining muscle mass and strength, improving $\dot{V}O_2$max, and slowing age-related declines in physical function.[6,8] One training method that may further enhance the physiological and functional benefits of walking training is to combine walking with blood flow restriction (BFR) to the lower limbs.[9,10]

Abbreviations: 6MWT, six-minute walk test; ADL, activities of daily living; BFR, blood flow restriction; BFRW, blood flow restriction walking group; CON, non-blood flow restriction walking group; HLRT, heavy-load resistance training; LOP, limb occlusion pressure; QCST, Queen's College step test; RPE, rating of perceived exertion; STS30, 30 second sit-to-stand; TUG, timed up and go; $\dot{V}O_2$max, maximal oxygen consumption.

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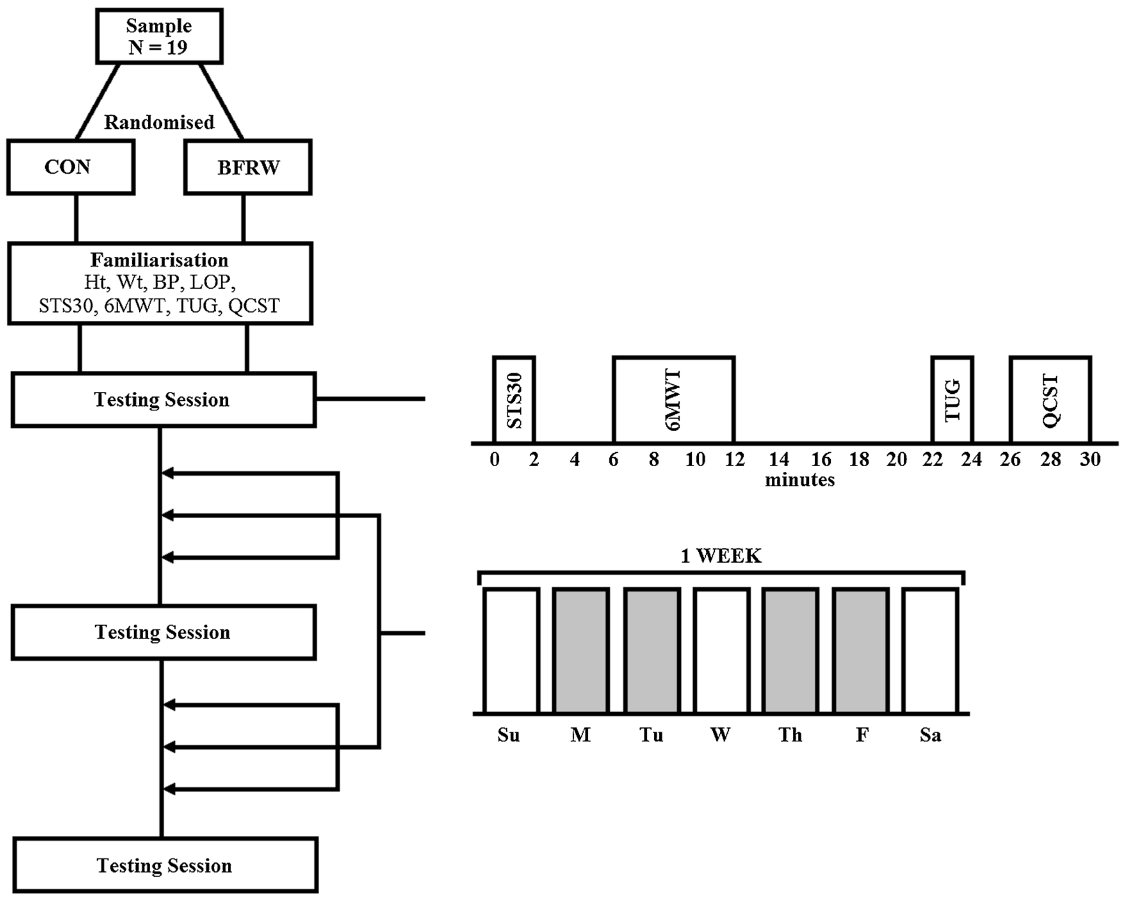

Fig. 1. Study design. Includes breakdown and timing of individual testing sessions and the weekly frequency of training sessions. Shaded bars (M, Tu, Th, F) in the expanded training week indicate the days on which training occurred. CON = non-BFR walking control group; BFRW = BFR walking group; Ht = height; Wt = weight; BP = brachial blood pressure; LOP = limb occlusion pressure; STS30 = 30 second sit-to-stand; 6MWT = six minute walk test; TUG = timed up and go; QCST = modified Queen's College step test.

BFR exercise is characterised by application of a pressurised cuff to the proximal aspect of a limb to provide a restriction of limb blood flow during exercise.[11] While few studies have examined BFR walking training,[9,10,12] the increased strength and muscle mass from low-intensity walking with BFR appears greater than for non-BFR walking training.[9,10,12] In addition, BFR walking increases $\dot{V}O_2$max beyond that of non-BFR walking.[13] Interestingly, despite including measures of physical function as secondary outcomes in one BFR walking study,[12] little is known about how BFR walking affects physical function, and performance on tasks indicative of ADL.

Therefore, with declining physical function among older adults combined with a potential contraindication to HLRT, augmenting simple walking exercise with BFR may provide an alternative exercise to improve physical function for older adults. The purpose of this study was to examine the effects of BFR walking training on physical function among older adults as measured by functional tasks indicative of ADL.

2. Methods

Nineteen men (n = 11) and women (n = 8) participated in the study. Inclusion criteria required participants be aged between 60–80 years, be physically inactive (<150 min physical activity per week), and be otherwise healthy without previous diagnosis of cardiovascular disease. Exclusion criteria included known musculoskeletal or neurological impairments limiting the capacity to undertake the exercise and testing requirements of the study. Two participants were taking prescribed anti-hypertensive medication despite no consistent history of high blood pressure. All participants had not smoked for at least ten years. Prior to inclusion participants were presented with a plain language statement and were informed of the methods, procedures, and risks of participation. Participants underwent a pre-screening and provided written informed consent. The study was conducted according to the Declaration of Helsinki (1975) and ethics approval was granted by the Deakin University Human Ethics Advisory Group. This study was registered with the Australian New Zealand Clinical Trials Registry (ANZCTR): ACTRN12614000649617.

This study was a randomised control trial. Participants were randomly allocated to a BFR walking training group (BFRW, n = 10; 6 male, 4 female), or a non-BFR walking training group (CON, n = 9; 5 male, 4 female) (Fig. 1). Participants completed a familiarisation session followed by a baseline testing session within 24–48 h. Testing sessions (Fig. 1) comprised four primary outcome measures of physical function in the following order: the 30 second sit to stand test (STS30), the timed up and Go (TUG), the six-minute walk test (6MWT), and a modified version of the Queen's College step test (QCST). Participants then completed 24 walking training sessions over 6 weeks comprising 4 training sessions per week (Fig. 1). Subsequent testing sessions were conducted after 3 weeks and 6 weeks of training. Testing sessions were completed within 24–72 h of the last training session. Testing and training sessions were conducted at Deakin University and adjacent community parkland.

Participants were familiarised with each procedure to measure physical function via a verbal explanation and demonstration. Participants attempted each procedure while receiving continuous feedback from the researcher.

For BFRW, familiarisation included the process used to apply BFR during training sessions as described previously,[14] and comprised an initial determination of limb occlusion pressure (LOP)[14] while standing to simulate the expected posture of the walking exercise to be undertaken during the training sessions. Final cuff pressures used during each training session for BFRW were 60% LOP.

Physical function was examined using standard, valid and reliable tests for this population. The STS30 was performed as previously described by Jones et al.,[15] 6MWT by the American Thoracic Society guidelines for the Six-Minute Walk Test,[16] TUG by Schaubert & Bohannon,[17] and QCST as described in the American College of Sports Medicine's Guidelines for Exercise Testing and Prescription (page 312, Box 19–13).[18] However, in the present study all participants were unable to complete the full QCST duration and so the number of steps completed in time with the metronome was used as the outcome measure for all participants.

Both BFRW and CON performed 10 min walking (4 km h^{-1}) around a designated circuit (667 m) in a field setting. The selected speed and duration selected are reflective of common speeds and durations utilised in other BFR walking research.[9,10,12] This was performed with the researcher walking alongside the participants to dictate pace and to carry the BFR equipment. For BFRW training sessions, the BFR cuffs (10.5 cm wide; Dual Port, single bladder cuff) were inflated immediately prior to the training sessions, and pressure was released immediately upon completion of the session.

Participants completed 24 training sessions to reflect previous similar training volumes.[9,19,20] No more than 2 days separated any two training sessions. Training sessions did not occur on more than 3 consecutive days. Participants typically trained on the same days each week, and always at the same time of day between 9:00 am and 2:00 pm.

During training session 1 (baseline), 12 (three weeks), and 24 (six weeks), participants provided a rating of perceived exertion (RPE) in the last minute of each session to gauge perceived difficulty of training as a secondary outcome measure. This used Borg's 6–20 RPE scale.[21]

IBM SPSS Statistics 21 was used to compute the data. Unless otherwise stated, data are expressed as mean ± SEM. All absolute functional test data, RPE scores and percentage change in functional outcomes were analysed via a mixed model analysis of variance (ANOVA) for relevant between factors for Group (CON; BFRW) and within factors for Time (baseline, three weeks, and six weeks). Percentage change data from baseline to six weeks for BFRW and CON was compared for each measure of physical function using two-tailed T tests. Fisher's least significant difference was used for post-hoc pairwise comparisons. For all tests statistical significance was set at $p < 0.05$.

3. Results

Baseline characteristics were not different between BFRW and CON (Table 1).

Repetitions performed during the 30 second sit-to-stand at baseline were not different between CON and BFRW (Fig. 2A). There was a main effect for time ($p < 0.01$), and a group × time interaction ($p < 0.001$). As such, repetitions at three weeks were greater than at baseline for both CON and BFRW ($p < 0.05$) with no difference between groups. For BFRW, repetitions at six weeks were greater than at baseline ($p < 0.001$) and at three weeks ($p < 0.001$). Conversely, repetitions for CON at six weeks were only greater than at baseline and not greater than at three weeks. In addition, only at six weeks were repetitions greater for BFRW compared with CON ($p < 0.05$), although the relative change from baseline to six weeks was greater for BFRW compared with CON (Table 1).

Table 1
Comparisons of group data for blood flow restriction walking (BFRW) and non-blood flow restriction walking (CON). Anthropometric data is displayed as mean ± SD. BMI = body mass index; sBP = systolic blood pressure; dBP = diastolic blood pressure; LOP = limb occlusion pressure; 60% LOP = 60% of limb occlusion pressure (pressure applied during training sessions). Percentage change in functional test performance from baseline to six weeks and ratings of perceived exertion (RPE) data is displayed as mean ± SEM. 30 second sit to stand (30STS), six-minute walk test (6MWT), timed up and go (TUG), and the Queen's College step test (QCST). # denotes different to CON ($p < 0.05$). * denotes different to baseline ($p < 0.01$).

	BFRW (n = 10)	CON (n = 9)
Anthropometric data		
Age (years)	69 ± 6	70 ± 7
Height (cm)	166.9 ± 8.2	166.2 ± 7.5
Body mass (kg)	76.5 ± 11.1	76.7 ± 8.6
BMI (kg m^{-2})	27.4 ± 2.7	27.7 ± 2.2
sBP (mmHg)	123 ± 9	123 ± 6
dBP (mmHg)	81 ± 7	81 ± 7
LOP (mmHg)	224 ± 7	–
60% LOP (mmHg)	134 ± 4	–
Change in functional test performance		
30STS (%)	28 ± 6#	8 ± 4
6MWT (%)	9 ± 1#	2 ± 1
TUG (%)	12 ± 2#	5 ± 1
QCST (%)	80 ± 11#	21 ± 7
RPE		
Baseline	14 ± 0#	8 ± 0
Three weeks	11 ± 0#,*	7 ± 0
Six weeks	11 ± 0#,*	8 ± 0

Distance walked during the six minute walk test at baseline was not different between CON and BFRW (Fig. 2B). There was a main effect for time ($p < 0.01$), and a group × time interaction ($p < 0.001$). As such, distance walked at three weeks was greater than at baseline for both BFRW and CON ($p < 0.05$) with no difference between groups. For BFRW, distance walked at six weeks was greater than at baseline ($p < 0.001$) and at three weeks ($p < 0.001$), but not for CON where distance walked at six weeks was still only greater than at baseline and not at three weeks. The overall improvement from baseline to six weeks was greater for BFRW compared with CON (Table 1).

Time to complete the timed up and go at baseline was not different between CON and BFRW (Fig. 2C). There was a main effect for time ($p < 0.01$), and a group × time interaction ($p < 0.05$). As such, time to complete at three weeks was less than at baseline for BFRW ($p < 0.001$) but not for CON, with no difference between groups. At six weeks, time to complete for both BFRW and CON was less than at baseline ($p < 0.01$) and at three weeks ($p < 0.01$), without any difference between groups. The overall improvement from baseline to six weeks was greater for BFRW compared with CON (Table 1).

Steps achieved in the modified Queen's College step test at baseline were not different between BFRW and CON (Fig. 2D). There was a main effect for time ($p < 0.01$), and a group × time interaction ($p < 0.01$). As such, steps completed at three weeks were greater than at baseline for BFRW ($p < 0.001$) but not for CON, with no difference between groups. For BFRW, steps completed at six weeks were greater than at baseline and at three weeks, but not for CON where the steps completed at six weeks were still only greater than at baseline ($p < 0.05$), but not greater than at three weeks. The overall improvement from baseline to six weeks was greater for BFRW compared with CON (Table 1).

At baseline, 3 weeks and 6 weeks RPE was higher for BFRW than for CON ($p < 0.01$) (Table 1). There was a main effect for time ($p < 0.01$), and a group × time interaction ($p < 0.01$). As such, RPE for BFRW at both three weeks and six weeks was lower than at baseline ($p < 0.001$), whereas RPE was similar between weeks for CON. There was no difference between RPE at three weeks compared with six weeks for either BFRW or CON.

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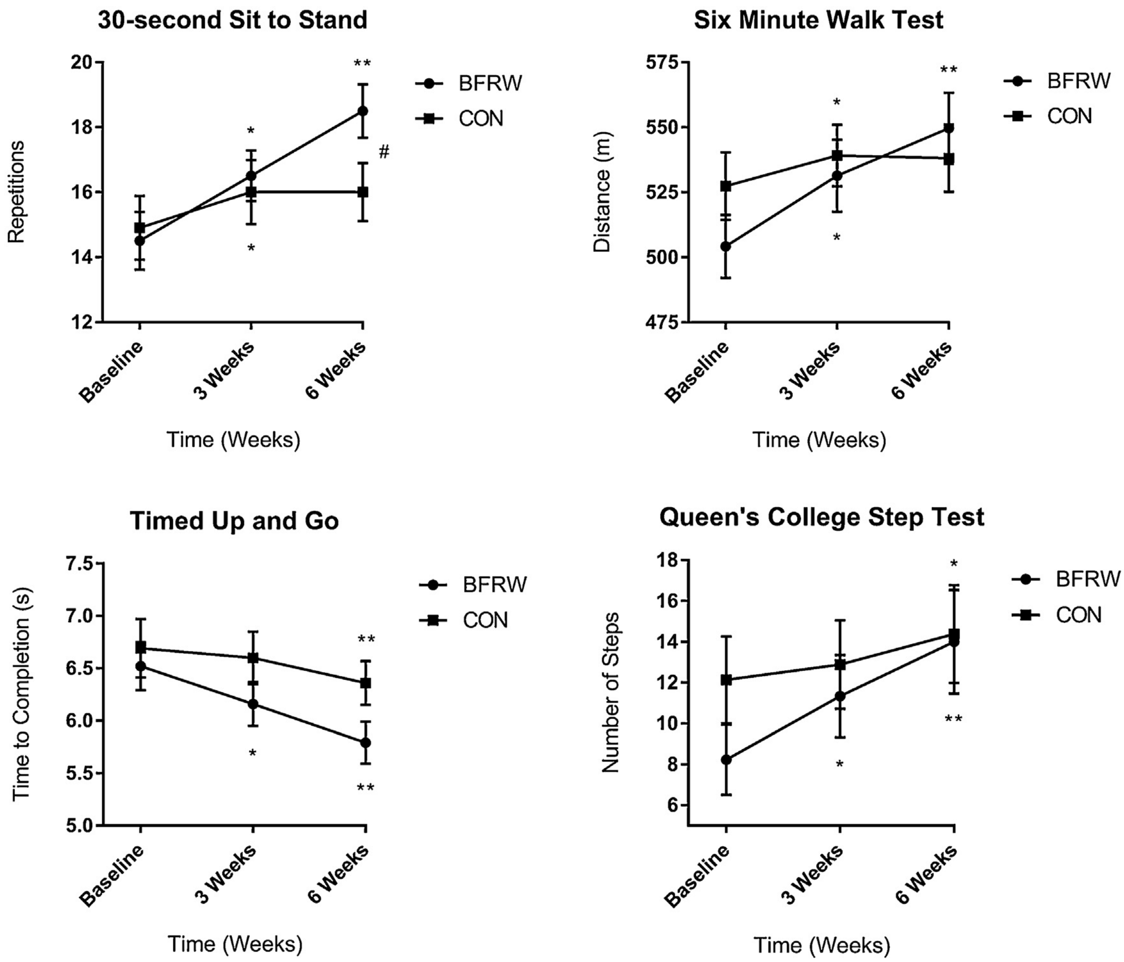

Fig. 2. Functional test performance during and following 6 weeks blood flow restriction walking exercise. A) 30 second sit-to-stand, B) 6 minute walk test, C) timed up & go, D) Queen's College step test. * denotes different from baseline ($p < 0.05$); ** denotes different from baseline and 3 weeks ($p < 0.05$); # denotes difference between groups ($p < 0.05$).

4. Discussion

This study examined the effect of BFR walking training on a range of tests of physical function compared with non-BFR walking among older adults, and demonstrates BFR walking to improve performance on the STS30, 6MWT, TUG and a modified QCST to a greater extent than non-BFR walking. Given these are common clinical measures of physical function for older adults, the findings provide new insight into the functional benefits of BFR walking for older adults. Additionally, the relatively low-intensity utilised throughout the BFR walking may be a useful alternative to HLRT among older adults and other clinical populations where HLRT may be contraindicated.

The STS30 and QCST both showed a 3-fold greater improvement for BFRW than CON. While the present study did not measure muscle strength, it has previously been established that the STS30 and other step tests using a step height >40 cm such as the modified QCST used in the present study are indicative of muscle strength.[15,22] The potential for BFR walking training to increase lower limb muscle strength and muscle size is also well established.[10,12,20] Thus, it was not surprising that the BFR walking training resulted in greater improvements in STS30 and QCST performance. Of the few BFR walking studies examining functional measures, two used the STS30.[9,12] Both demonstrated increased isometric and isokinetic lower limb strength, and while one found no improvement on the STS30 for the BFR group beyond that of the control group[12] there was a significant correlation between the increase in STS30 performance and the increase in knee extension strength.[12] These findings and the present study support BFR walking as a means of improving physical function related to tasks requiring lower limb strength.

The 6MWT was a novel inclusion to the present study as a measure of physical function more commonly associated with aerobic capacity.[23,24] Even though both groups improved distance covered after the initial three weeks, BFRW demonstrated a greater improvement in distance covered during the 6MWT after six weeks of training compared with CON. 6MWT performance is indicative of physical function associated with cardiopulmonary function and strongly correlates with performance on treadmill based assessments of aerobic capacity.[23,24] Therefore, while aerobic capacity was not measured in the present study, the greater 6MWT distance achieved by BFRW is likely in part attributed to improvements in aerobic capacity (e.g. $\dot{V}O_2$max). To date, the effectiveness of BFR walking to improve aerobic capacity has not been extensively explored. One BFR walking study and one BFR cycling study both demonstrate increases in $\dot{V}O_2$max for BFR trained young men and athletes, respectively.[13,25] However, of the two BFR walking studies exploring aerobic capacity among older adults, neither found BFR walking to provide a greater increase in aerobic capacity compared with non-BFR walking over six-to-ten weeks.[9,12] Therefore, this warrants further exploration given the present study demonstrated an increased distance walked on the 6MWT, which may

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suggest an increase in $\dot{V}O_2$max is possible among older adults with BFR walking due to the strong positive correlation between 6MWT distance and tests for aerobic capacity.[23,24]

Both groups showed significant improvement on TUG across the six-week training period, although BFRW demonstrated a greater reduction (2-fold) in time to completion compared with CON. Even though few studies have measured physical function following BFR walking training,[9,12,19] the TUG is the most utilised measure of physical function, with time to completion decreasing for those training with BFR by more than 10%,[9,12,19] a similar magnitude observed in the present study. TUG performance is worse among physically inactive older adults.[26,27] This is partly due to reduced pelvic, lower limb and core muscle strength,[27] which strongly correlates with key factors affecting TUG performance including dynamic balance, mobility, and gait speed.[26,27] A decreased time to completion on the TUG may be related to increased isometric and isokinetic lower limb strength seen in previous BFR walking studies.[9,12,19] Although not measured in the present study, similar improvements in lower limb strength may explain the decreased time to completion on the TUG observed for BFRW in the present study. This may in-part be due to fast-twitch muscle fibres being recruited in larger numbers at a lower intensity during BFR exercise compared with higher intensity alternatives,[11] resulting in increased strength and the speed at which that strength is applied beyond that of equivalent non-BFR exercise. Dynamic balance, which plays a major role in the TUG,[26] is also largely reliant on recruitment of faster motor units for fast reactive strength.[28] These training effects following BFR walking may explain the greater decrease in time to completion on the TUG compared with non-BFR walking.

That RPE was greater for BFRW than CON may suggest the training stimulus was greater for BFRW than CON. This has been demonstrated previously for BFR walking at similar speeds to the present study[29] with mean RPE ranging from 12 to 13 with BFR applied, compared to 11 for non-BFR controls.[29] RPE in the present study was still relatively low, with the mean RPE scores equivalent to 'very light' to 'somewhat hard'.[21] This is still well below RPE scores recorded previously during HLRT (18 ± 2).[30] This supports the findings of the present study whereby BFRW demonstrated greater increases in all measures of physical function compared with CON. Thus, while HLRT is traditionally used to improve physical function, particularly those functions that are partly strength dependent, for those populations that are contraindicated to HLRT BFR walking exercise would seem a valid alternative.

Limitations and future directions

The six week training period used a fixed walking speed for all participants without any progression towards higher (perhaps running) speeds. While this potentially limited the training adaptations achieved over the six week training period, it is reflective of walking (as opposed to running) and is similar to speeds used in previous studies of BFR walking.[9,12,20]

Interestingly, due to the 6MWT being self-paced, 25% of participants in the CON group walked slower during the baseline 6MWT than during the externally paced walking training sessions. This was despite the inclusion of a 6MWT at familiarisation. This likely over-inflated the magnitude of change for CON when making comparisons between baseline testing and the subsequent three and six week time points, and reinforces the larger effect of BFR on functional performance over the six week training period, at least for the 6MWT.

Lastly, direct measures of physiological characteristics such as strength, muscle size, and aerobic capacity were not made in the present study. Future studies should consider recording these measures in parallel with measures of physical function as this may provide greater insight as to the contribution of these physiological characteristics to the change in performance on measures of physical function.

5. Conclusion

The present study demonstrates the value of BFR walking exercise for improving physical function among sedentary older adults. The implication of this study is that a simple, low-intensity modality of exercise (i.e. walking) when combined with BFR, enhances improvements in physical function beyond that of an equivalent non-BFR low-load alternative. This is particularly relevant in situations where high-intensity exercise or HLRT is contraindicated. Thus, BFR walking may have significantly more beneficial outcomes for sedentary older adults and clinical populations where reduced physical function is characteristic. Examples may include end-stage kidney disease, chronic obstructive pulmonary disorder, and post-operative patients with deficits in musculoskeletal function for which further research should be focused.

Practical implications

- Blood flow restriction walking provides a low-load alternative to resistance training for improving the physical function of older adults who may be contraindicated to high-load resistance training.
- Blood flow restriction walking improves physical function beyond that of traditional walking exercise.
- While higher than traditional walking, ratings of perceived exertion for 10 min of blood flow restriction walking were relatively low and improved with training programme duration.

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