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Arm-crank training improves postural stability and physical functioning in older people

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ABSTRACT

Background: Arm crank ergometry (ACE) has been shown to elicit marked improvements in lower body exercise capacity among older individuals. It is currently unknown whether ACE is effective in alleviating functional consequences of aging, such as balance and physical function. **Objective:** To determine the efficacy of ACE training on balance, mobility and cardiorespiratory fitness in older people. **Design and Participants:** Two-arm, randomised parallel trial; assessment at baseline and post-intervention. Participants who were aged $\geq$65 years and community-dwelling. Exclusion criteria included neurological and musculoskeletal disease, cognitive problems and/or cardiovascular/pulmonary diseases. **Interventions:** Participants were randomly assigned to six weeks of seated ACE ($n = 10$) or stationary cycling (control group) ($n = 10$) training, 3 times per week. **Main outcome measures:** The outcomes were functional balance and mobility, postural sway, upper body strength and cardiorespiratory fitness. **Results:** ACE training resulted in increased functional reach distance (d= 0.83 – 1.28), faster timed-up-and-go execution (d= 1.36) and reduced mediolateral postural sway (d= 0.8 - 1.3). Both ACE and CYC interventions elicited similar increases in mode-specific (%Δ ~25) and cross-transfer (%Δ ~13) peak oxygen uptake ($P \leq 0.05$). **Conclusions:** The findings highlight that ACE training is effective in alleviating functional consequences of ageing, such as balance and mobility.

Keywords: Fall-risk · neuromuscular performance · postural balance · aerobic exercise · upper-body exercise · cardiovascular

Highlights

- Arm crank ergometry training can improve lower body cardiorespiratory fitness
- Seated arm training also improved physical function, such as balance and mobility
- This type of exercise may offer a safe alternative training mode for older adults

1. INTRODUCTION

The ability to perform activities of daily living (ADL) declines with advancing age (Stamm *et al.* 2016; Hortobagyi *et al.* 2008). Although the aetiology of age-related functional decline is complex, primary contributors include a loss of muscle mass and/or strength (Hairi *et al*. 2010), reduced postural balance (Horak *et al.* 1989) and declines in cardiorespiratory fitness (Buskirk & Hodgson, 1987), all of which are potentially reversible with exercise interventions. Although cycling (CYC) training facilitates muscle strength/power (Lovel *et al.* 2010; Macaluso *et al.* 2003) and cardiorespiratory fitness in older people (Oja *et al.* 2011), this type of exercise elicits relatively small benefits to balance and mobility performance among older adults (Buchner *et al*. 1997a; Buchner *et al*. 1997b).

Considering that many daily activities require sustained arm work to a greater extent than leg work (Hellerstein 1978), it seems reasonable to encourage healthy older adults to train the arms as well as the legs. Although CYC is more commonly studied and prescribed than upper-body exercise, this alternative exercise mode has many important practical applications. For example, it has been demonstrated that arm-crank ergometry (ACE) is a well-tolerated alternative mode of exercise for improving walking distance in patients with peripheral arterial disease (Tew *et al.* 2009; Zwierska *et al.* 2005). However, the benefits of ACE training are not limited to individuals with clinical disease and appear to extend to otherwise healthy older adults. Pogliaghi *et al.* (2006) reported that ACE and CYC training elicited similar “cross-transfer” training effects (i.e. improved fitness effect of ACE resulted in functional improvements during CYC and vice versa) among healthy older males. These findings suggest that from an aerobic fitness perspective, ACE could be an effective alternative form of training for healthy older adults. However, the broader applicability of ACE training in alleviating functional consequences of aging in otherwise healthy older adults, such as muscle strength, balance and mobility performance, is less clear. Indeed, ACE training has been shown to elicit improvements in walking ability and balance in stroke patients (Kaupp *et al.* 2017). These findings suggest potential for upper body exercise training to improve use of the both the arms and legs during every day activities.

In the absence of a pertinent literature base examining the effects of ACE training on physical functional performance among healthy older people, the objective of this preliminary study was to test the efficacy of ACE training compared to a CYC training to combat functional performance indices among inactive older men and women. As the effects of CYC training have been previously demonstrated in older adults, and no study to date, has examined ACE training, we sought to use the CYC group as a form of control group. We also sought to determine the cross-effect of specific training induced cardiorespiratory adaptations to a different exercise modality (Pogliaghi *et al.* 2006). Based on the available literature, we hypothesised that ACE and CYC training would elicit favourable adaptations in balance and mobility performance. We additionally hypothesised that ACE and CYC training would elicit similar mode-specific and cross-transfer cardiorespiratory training adaptations.

2. MATERIALS AND METHODS

2.1 Participants and screening

We initially invited 37 participants to the first screening stage following recruitment via word of mouth. Following explanation of the study procedures, 16 participants declined to participate. In this stage, 21 participants volunteered to be screened. All adults were screened using a general health screening and physical activity questionnaire (PAR-Q). Initial screening involved a preliminary examination to evaluate potential contraindications to exercise, which included a pulmonary function test (peak expiratory flow) (Mini Wright, Clement Clark international, UK) and measurement of resting systolic and diastolic blood pressure (Emron, M3, Japan). Inclusion criteria were community-dwelling men and women aged $\geq$65 years who had no history of falling, determined by self-report and Berg Balance Scale (BBS) (Berg et al. 1992) score of $\geq$ 52/56. Given the pragmatic and exploratory nature of the present trial, we chose to include only healthy abled-bodied individuals without high risk of falling. All participants could walk without the use of an assistive device and reported that they were not meeting exercise recommendations (three times per week for 20-min at an intensity corresponding to at least 50% of maximal heart rate [Nelson et al. 2007]) but were independently living and engaging in daily activities (i.e., cooking, cleaning, shopping etc). Exclusion criteria were prior stroke, heart attack or heart failure, individuals diagnosed with neurological (e.g., stroke, Parkinson's) (n = 1), musculoskeletal (e.g., tendinitis), severe cognitive problems (e.g. dementia) and/or cardiovascular or pulmonary diseases (e.g., coronary heart disease, chronic obstructive pulmonary disease), residents in nursing homes and those with an inability to ambulate independently. None of the recruited participants reported to any other contraindications to exercise nor did they report to taking any medication which may affect their balance or ability to exercise safely. After providing information relating to the design of the study and potential risks and discomfort experienced during the measurements, participants provided written and informed consent prior to inclusion. The study was carried out in accordance with the guidelines outlined in the declaration of Helsinki (1964) and the study procedures were approved by the institutional ethics committee.

2.2 Study design

We conducted a two-arm randomised parallel trial (Fig. 1). The first two weeks of the study (weeks - 2 to 0) were used as a pre-training control period. During this time participants continued with their habitual physical and recreational activities. During the pre-training period participants visited the laboratory on three separate occasions in the following order; (1) postural stability and physical performance measurements (within session randomisation), (2 and 3) a maximal ACE and a CYC test, in a counterbalanced order, to determine training intensities and aerobic fitness. The pre-training period was followed by an endurance training period consisting of six weeks (0 to 6 weeks) of ACE or CYC, three times per week, separated by at least one full day of rest. Following baseline assessments, twenty participants were assigned in a randomised order to either an ACE (*n* = 10) or CYC (*n* = 10) training group. Randomisation was done using Research Randomizer (www.randomizer.org). During the final two weeks of the study (weeks 7 to 8), pre-training assessments were repeated. Outcome measures (i.e., aerobic fitness, balance, physical performance) and training interventions, were carried out by the principal investigator. A minimum of 80% of exercise program compliance was required for participants to be included in the final statistical analyses.

2.3 *Outcome measures*

2.3.1 *Postural stability*

Postural sway was assessed while standing on a compliant (Balance-pad Plus, Alcan Airex AG, Switzerland) and fixed surface (without Balance-pad) on a force platform (AMTI, AccuGait, Water Town, MA). Data were sampled at 100 Hz (AMTI, Netforce, Watertown, MA) and the total displacement of centre of pressure (COP) in the anteroposterior (COP_{AP}; cm) and mediolateral (COP_{ML}; cm) directions and the average COP velocity (COP_V; $cm \cdot sec^{-1}$) were subsequently calculated using the accompanying balance analysis software (AMTI, BioAnalysis®, Version 2.2, Watertown, MA). Participants stood in a bipedal stance, with their feet 3 cm apart as measured from the medial extremity of the posterior side of the calcaneus. Continuity of foot position between trials was ensured by drawing a stencil around the unshod feet while standing on the force platform. To avoid unnatural postural sway, internal focus of attention and restriction of exploratory behaviour, participants were not specifically asked to stand as still as possible. Participants' arms were left to hang freely by their sides and were instructed to look straight ahead at a target 1.5 m away, which was adjusted to the eye level of each individual, thus preventing vestibular disturbance. Participants performed three 30 s trials for each condition of eyes open (EO) and eyes closed (EC), in a counterbalanced order. A mean of these trials were used in subsequent analysis. Participants practiced each postural task three times prior to recorded trials. Throughout all tests, the investigator stayed close to the participants to prevent falling but without interfering with balance performance.

***** FIGURE 1 ABOUT HERE *****

2.3.2 Physical performance tests

Fast walking velocity was recorded using photoelectric timing gates set a height of 0.5 m (SmartSpeed, Fusion Sports, Australia). Participants were asked to walk as quickly as possible from the start position which was 0.5 m from the photoelectric line to the end point which was 8-m away from the first photoelectric line. Furthermore, participants were also asked to complete the Timed Up and Go Test (TUG) at their preferred walking speed (Podsiadlo and Richardson 1991). The time taken to complete the test was recorded using a stopwatch. Participants were instructed to stand up from a chair without using their hands, walk 3-m as quickly and safely as possible, walk around a cone, walk back to the chair and sit down. The multi-directional functional reach test (MDRT) (Newton 2001), was used to investigate upper body reach distance in the anterior, posterior, right and left directions. A meter stick was fixed to a wall at the level of each participant's acromion process. The instructions given to the participants were “without moving your feet or taking a step, reach as far as you can and try to keep your hand alongside the meter ruler” (Newton 2001). The preferred reaching arm was used for the anterior and posterior directions and the non-preferred arm for right and left directions. The start and end position of the most distal part of the hand were recorded and the distance represented total reach distance for a given direction.

2.3.3 Functional upper body strength assessment

A one-arm bicep curl test (Rikli and Jones 1999) was used to assess functional upper body endurance. Participants were asked to perform as many bicep curls as possible in 30 s while maintaining proper form. Male participants performed arm curls using a 4kg dumbbell while females performed arm curls with a 2.5kg dumbbell. Dominant and non-dominant trials were performed in a randomised order. Maximal hand grip strength was measured using a standard adjustable hand dynamometer (Lafayette Instrument Company, USA) during upright standing. The shoulder was initially flexed to 180°, the elbow was fully extended, and the wrist was pronated. Participants were asked to squeeze the hand as hard as possible while returning the shoulder back to 0°. The best measurement of three was recorded for each hand. The dominant hand was used for both assessments.

2.3.4 Cardiorespiratory fitness assessment

All participants completed graded incremental exercise tests on an arm-crank ergometer (Lode Angio BV, Groningen, Netherlands) and cycle ergometer (Monark 824E Ergomedic, Monark, Varberg, Sweden) to determine ergometer specific peak oxygen uptake ($\dot{V}O_{2PEAK}$) and peak power output (W_{PEAK}). Participants completed the tests before and after the training programme in a counterbalanced order and were separated by a minimum of 72 hours. Following a 5-min warm up (ACE; 25 W, CYC; 50 W) intensity was increased in a stepwise manner by 5 $W\cdot min^{-1}$ and 10 $W\cdot min^{-1}$ for ACE and CYC protocols, respectively. Cadence was set at 60 $rev\cdot min^{-1}$. For both modes, expired gas was analysed using a breath-by-breath online gas system (MetaMax, Cortex Biophsik, Borsdorf, Germany) for oxygen uptake ($\dot{V}O_2$), minute ventilation ($\dot{V}_E$) and respiratory exchange ratio (RER). Heart rate (HR) was continually monitored (Polar Electro, Oy, Finland) and recorded in the final 10 s of each incremental stage and immediately at volitional exhaustion. A rating of perceived exertion for both local (working muscles; RPE_L) and central (cardiorespiratory; RPE_C) effort using the 6–20 point Borg scale (Borg 1982) was obtained at the same time as HR.

2.4 Classification of responders and non-responders

Using previous criteria from exercise intervention trials (Bonafiglia et al. 2016), the interindividual variability in the responses to exercise interventions was categorised as responders or non-responders using the typical error of measurement (TE). The TE was calculated for all physical function and mobility outcome measures using the equation $TE = SD_{diff}/\sqrt{2}$ (Hopkins, 2000). Given that participants completed only one mode specific incremental exercise test before training, TE is not reported for peak physiological responses (e.g., $\dot{V}O_{2PEAK}$). A non-responder to the exercise interventions were defined as an individuals who did not demonstrate an increase that was greater than two times the TE away from zero for anterior (ACE; 3.2 cm, CYC; 2.6 cm), posterior (ACE; 3.8 cm, CYC; 3.4 cm), right, (ACE; 3.1 cm, CYC; 3.5 cm) and left (ACE; 2.4 cm, CYC; 1.9 cm) functional reach distance, TUG (ACE; 0.4 s, CYC; 0.5 s), gait velocity (ACE and CYC; 0.16 m/s^{-1}), hand grip strength (ACE; 1.4 kg, CYC; 2.4 kg) and arm endurance (ACE and CYC; 2 arm curls). A change beyond two times the TE means there is a high probability (i.e. 12:1 odds) that the response is a true physiological adaptation beyond what might be expected from technical and/or biological variability (Hopkins, 2000). Non-responders are illustrated as dashed lines in figures 2 – 4.

2.5 Interventions

Participants underwent a supervised exercise training program three times per week for 6-weeks. We chose a 6-week intervention period to maximise adherence and because this period of training has been shown to elicit marked improvements in physical function, aerobic capacity, and muscular strength among older adults (Falck et al. 2017). The exercise-training interventions were based on the basic principles of training including overload, progression, individualisation and specificity (Table 1). The first exercise class began one week after the baseline measures were administered. Throughout training, participants were encouraged to continue their normal diet and to maintain habitual activity levels. All exercise sessions were performed at a similar time of day (±1h). Training sessions were separated by at least 24 hours (i.e., Monday, Wednesday, Friday). The training was completed at intensities corresponding to 50, 60 and 70% of the pre-training mode specific W_{PEAK}. Exercise durations were progressively increased in three cycles throughout the training period; (1) 20-min during weeks 1-2, (2) 25-min during weeks 3-4, (3) 35-min during weeks 5-6 (Table 1). Training intensities and durations were similar to those previously used in otherwise healthy older adults (Pogliaghi et al. 2006) for both arm and leg training and aligns with exercise recommendations for older adults (i.e., 50 – 70 W_{PEAK} for 20 – 45 mins) (Nelson et al. 2007). Prior to each session, participants were asked to complete a 5-min warm up on the unloaded ergometer at a cadence of 60 $rev \cdot min^{-1}$. Heart rate and both RPE_L and RPE_C were monitored throughout each session.

***** TABLE 1 ABOUT HERE *****

2.6 Statistical analyses

Data were analysed using IBM version 20.0 (SPSS Inc., Chicago, IL). Outcome measures are reported as mean ± SD. All outcome measures (e.g., postural sway, functional reach distance) and peak aerobic fitness were analysed by two-way mixed-model multivariate analysis of variance (MANOVA) (group; *ACE vs. CYC* × training status; *pre vs. post training*). All cardiorespiratory and perceptual variables for submaximal exercise trials were analysed by a three-way MANOVA (e.g., time; *0, 5, 10, 15, 20*; × mode; *ACE and CYC* × training status; *pre and post training*). Dependent variables in each MANOVA relate to those presented in Tables 1 – 3. For all analyses, normality (Shapiro–Wilk test) and homogeneity of variance/sphericity (Levene test) were checked prior to parametric tests. Post hoc analyses with the Bonferroni-adjusted α were conducted to determine comparisons which were statistically significant. When ANOVA was used, effect sizes are reported as partial eta-squared value (η_p^2) and reported where appropriate. Cohen's *d* effect sizes are reported for pairwise comparisons. Effect sizes of 0.2, 0.6, 1.2 and 2.0 indicate small, medium, large and very large effects, respectively. Statistical significance level was set at $P \leq 0.05$ for all tests. As part of our initial exploratory analyses we conducted MANCOVA and used pre-assessment scores as the co-variate to adjust for potential baseline differences. These analyses did not change the outcomes of the original MANOVA therefore are not reported further.

3 RESULTS

3.1 Adherence and adverse events

Two older males withdrew themselves from the CYC training group after three and four weeks of training, respectively (Fig. 1). Both participants cited a loss of interest in the intervention. All 18 participants included in subsequent statistical analyses achieved 100% adherence (36 training sessions) to training which was set *a priori* at ≥ 80%. Baseline demographic and outcome measures were not different between groups ($P \geq 0.05$) (Table 2). There were no exercise related adverse events. As expected, all participants in the ACE training group experienced delayed onset of muscle soreness of the arms and shoulders in week 1, but these complaints had diminished by week 2 and required no further attention. No participants reported trips, slips or falls resulting from a loss of balance during the training period.

***** TABLE 2 ABOUT HERE *****

3.2 Postural stability

Before training there were no differences in postural sway measures between ACE and CYC groups (all $P \leq 0.05$). The two-way MANOVA indicated a group × training status interaction ($F_{(12,21)} = 2.227$, $P = 0.050$, $\eta_p^2 = .560$). Post hoc analysis showed that participants in the ACE training group showed significantly reduced COP_{ML} post-training when standing on a firm (EO; $P = 0.009$) and compliant (EO; $P = 0.002$, EC; $P = 0.039$) surface (Table 3). However, participants in the CYC group showed significant reductions in COP_{AP} post-training when standing on a firm (EO; $P = 0.018$) and compliant (EO; $P = 0.004$, EC; $P \leq 0.001$) surface.

***** TABLE 3 ABOUT HERE ****

3.3 Physical performance tests

Two-way ANOVA showed a significant group × training status interaction for anterior ($F_{(1,32)} = 8.163$, $P = 0.007$, $\eta_p^2 = .203$) and right ($F_{(1,32)} = 5.183$, $P = 0.030$, $\eta_p^2 = .139$) functional reach distance. There was also a main effect of training status for posterior reach distance ($F_{(1,32)} = 2.589$, $P = 0.024$, $\eta_p^2 = .150$). Post hoc analyses revealed that anterior ($P = 0.001$, d= 1.28, mean diff = 8.4 cm), posterior ($P = 0.004$, d= 1.19, mean diff = 9.25 cm) and right ($P = 0.001$, d= 0.83, mean diff = 5.1 cm) functional reach distance were greater post ACE training (Fig. 2). No changes in functional reach distance were observed following CYC training ($P \geq 0.05$). Following ACE training there were 2 to 3 non responders for each reach direction (Fig. 2); however, in all cases these non-responders improved in at least one of the four reach directions following ACE training. Between 1 and 3 responders were observed following CYC training (Fig. 2).

***** FIGURE 2 ABOUT HERE *****

Although the group × training status interaction for TUG was not significant ($F_{(1,32)} = 1.225$, $P = 0.812$, $\eta_p^2 = .002$), there was a main effect of training status ($F_{(1,32)} = 14.138$, $P = 0.001$, $\eta_p^2 = .306$). TUG times were significantly reduced following ACE ($P = 0.005$, $d = 1.36$, mean diff = 1.5 s) and CYC ($P = 0.024$, $d = 0.98$, mean diff = 1.30 s) training (Fig. 3). All participates were classified as responders following both ACE ($n = 10$) and CYC ($n = 8$) training (Fig. 3A). Despite improved TUG time, no significant group × training status interaction ($F_{(1,32)}$ = .283, P = 0.599, η_p^2 = .009) or main effects ($P \geq 0.05$) were found for gait speed, although a small and moderate effect size was observed following ACE (d = 0.27, mean diff = 0.11 m/s) and CYC (d = 0.75, mean diff = 0.20 m/s) training, respectively (Fig . 3). Following ACE training there were two participants classified as responders for gait velocity. A total of five participants were classified as responder following CYC training (Fig. 3B).

***** FIGURE 3 ABOUT HERE *****

3.4 Functional upper body strength

Two-way ANOVA showed a significant group × training status interaction for hand grip strength ($F_{(1,32)}$ = 16.531, $P \leq 0.001$, η_p^2 = .341) and 30 s bicep curl test ($F_{(1,32)}$ = 60.089, P = 0.025, η_p^2 = .148). Post hoc analyses showed that ACE training elicited improvements in grip strength ($P \leq 0.001$, d = 2.49) and number of curls performed in 30-s ($P \leq 0.001$, d = 2.24). No changes in grip strength or bicep curl performance were observed following CYC training ($P \geq 0.05$). All participants in the ACE (n = 10) group were classified as responders for grip strength and arm curl performance. One participants was identified as a responder for arm curl performance in the CYC group.

***** FIGURE 4 ABOUT HERE *****

3.5 Cardiorespiratory fitness

Training adaptations are reported in Table 4. For ACE training, there were main effects of training status for absolute $\dot{V}O_{2peak}$ ($F_{(1,9)}$ = 6.206, P = 0.034, η_p^2 = .408), relative $\dot{V}O_{2peak}$ ($F_{(1,9)}$ = 24.643, P = 0.032, η_p^2 = .415), W_{peak} ($F_{(1,9)}$ = 108.347, P = 0.001, η_p^2 = .923), $\dot{V}_E$ ($F_{(1,9)}$ = 24.256, P = 0.001, η_p^2 = .729) and HR_{MAX} ($F_{(1,9)}$ = 10.726, P = 0.010, η_p^2 = .544). Post hoc analysis showed that ACE training elicited mode specific improvements in absolute and relative $\dot{V}O_{2peak}$ (P = 0.001), W_{peak} (P = 0.001), $\dot{V}_E$ (P = 0.002) and HR_{MAX} (P = 0.028). ACE training also elicited cross-transfer (i.e. CYC) increases in absolute $\dot{V}O_{2peak}$ (P = 0.009), relative $\dot{V}O_{2peak}$ (P = 0.005), W_{peak} (P = 0.001), HR_{MAX} (P = 0.019), while alpha approach significance for $\dot{V}_E$ (P = 0.053). For CYC training, there were main time effects for absolute $\dot{V}O_{2peak}$ ($F_{(1,7)}$ = 17.543, P = 0.004, η_p^2 = .715), relative $\dot{V}O_{2peak}$ ($F_{(1,7)}$ = 24.643, P = 0.002, η_p^2 = .779), W_{peak} ($F_{(1,7)}$ = 18.410, P = 0.004, η_p^2 = .725), $\dot{V}_E$ ($F_{(1,7)}$ = 16.213, P = 0.005, η_p^2 =

.698) and HR_{MAX} ($F_{(1,7)} = 5.361$, $P = 0.054$, $\eta_p^2 = .434$). Post hoc analysis showed that CYC training elicited mode specific improvements in absolute $\dot{V}O_{2peak}$ ($P = 0.004$), relative $\dot{V}O_{2peak}$ ($P = 0.001$), W_{peak} ($P = 0.003$) and $\dot{V}_E$ ($P = 0.009$). CYC training also elicited cross-transfer (i.e. ACE) increases in absolute $\dot{V}O_{2peak}$ ($P = 0.006$), relative $\dot{V}O_{2peak}$ ($P = 0.003$), W_{peak} ($P = 0.004$), $\dot{V}_E$ ($P = 0.009$) and HR_{MAX} ($P = 0.028$). When participants were tested on the same ergometer used for training (specific effect), comparable changes were observed in $\dot{V}O_{2peak}$ (ACE; 25.6 ± 9.94 %, CYC; 26.3 ± 8.90 %). Similarly changes in $\dot{V}O_{2peak}$ were also observed when participants were tested on the non-training ergometer (cross-effect) (ACE; 15.7 ± 18.4 %, CYC; 15.4 ± 12.7 %).

***** TABLE 4 ABOUT HERE *****

4 DISCUSSION

The primary objective of this exploratory trial was to test the efficacy of seated ACE training in improving physical performance and cardiorespiratory fitness in a healthy older population. Both ACE and CYC training elicited potentially beneficial effects on postural stability, physical performance, mobility and aerobic fitness. The moderate to large magnitude of effects in outcome measures following both interventions would suggest that familiarisation due to repeated testing is unlikely to have influenced the results. Although ACE training is more commonly prescribed in the clinical setting, we show for the first time that ACE training could be used as an effective alternative mode of exercise to improve physical functional performance among healthy older people. As such the data presented here is novel and extends the current literature base regarding exercise training for older adults.

4.1 Physical functional performance

Overall, ACE training elicited changes in functional walking performance. There was a 1.36 s reduction in TUG performance following ACE training, which was similar to the change observed in the CYC control group (1.30 s). Although this corresponds to a large magnitude statistical change in the time taken to complete the test, our participants were already well above (faster) the normative values for community dwelling-older adults aged 60 – 69 years (7.1 – 9.0 m/ s) (Bohannon, 2006), confirming that our sample were of good health. For the 8-meter walking test, speed improved by 0.11 m/s following ACE training, which reflects a clinically meaningful, albeit non-significant change (Perera *et al.* 2006). Normative data for healthy older people (60 years) is 1.93 and 1.77 m/s for men and women, respectively (Bohannon, 1997). Therefore, the change in gait speed is notable considering the ACE group (2.01 m/s) were already above (faster) the normative values for community-dwelling older adults. The improvement in gait speed following ACE training is in accordance with recent meta-analytical evidence which demonstrated that exercise interventions can improve fast gait speed by 0.12 m/s (9%) among healthy older people (Hortobagyi *et al.* 2015). It should be noted that our CYC control group improved their fast gait speed further still (0.20 m/s). Although the improvements in gait speed are smaller for ACE training, they are likely true changes and suggest that it is possible to slow the loss of gait speed with advancing age. Given that 8-meter walking speed was not significantly faster after ACE training, the faster execution of the TUG following this type of training suggests that the upper body muscles (trunk and arms) assist during one or more of the tasks of standing up, turning or sitting. It is also possible that normal walking is a more practice movement than the TUG and therefore less sensitive to change. Indeed, Milosevic *et al.* (2011) showed that TUG time was significantly faster among older people when the arms were used freely, compared to limited arm movement. Although methodological restraints preclude us from providing direct adaptive mechanisms for the improved lower body functional performance following ACE, it is clear that arm movements contribute to generating torques in the upper body (Pijnappels *et al.* 2010). In particular, for challenging balance regulation, upper body activity appears to support ankle and hip movements by bringing the centre of mass back over the base of support (Bostrom *et al.* 2018; Marigold, 2002). Although it is not appropriate to generalise the findings from neurologically impaired individuals to those in the present study, some of the adaptive mechanisms to explain functional improvements following ACE training might be gleaned from studies which have examined arm cycling in stroke patients. For example, the present findings correspond to recent evidence which indicates that ACE training is effective in improving both TUG and 10-m walk time in stroke patients (Kaupp *et al.* 2017). ACE training might exploit the inherent neural and mechanical linkage between the arms and legs that are active during locomotion tasks (Zehr *et al.* 2009; Zehr *et al.* 2007). Indeed, Kaupp *et al.* (2017) suggested that ACE training may have activated interlimb networks that contribute to the coordination of rhythmic walking in stroke patients.

Arm-crank training also produced global changes in functional reach distance. The improvements in functional reach reported here are of practical importance indicating that the risk of falling while leaning or reaching for objects would be reduced in older adults following ACE training. Trunk strength gains, an indirect result of ACE training, likely contribute to the increased reach distance seen here. Mean MDRT scores of individuals who reported a trip or fall in the last 6 months are 22.5 (±8.6), 11.8 (±7.9), 17.4 (±7.6) and 16.9 (±7.4) cm for forward, backward right and left directions, respectively (Newton, 2001). As with the walking indices, pre-intervention, our participants were significantly better than the norms, indicating ACE may be effective in balance impaired adults, who have more room for improvement.

4.2 Postural stability

For tasks with relatively low requirements for balance control, such as quiet bipedal standing, the ankle strategy is assumed to predominate for maintaining balance (Winter *et al.* 1996). The reductions in mediolateral postural sway during quiet bipedal standing following ACE training are surprising and the mechanism responsible for the reduced postural sway is unclear. One possible explanation is that ACE places demands on the trunk musculature for stabilisation and posture during torsional movements of the trunk due to the pushing and pulling of the ergometer handles (Di Blasio et al. 2009). Therefore, ACE training may have induced adaptive processes in the neuromuscular system and allowed better use of somatosensory inputs from the trunk musculature to transfer to lateral postural stability. The lower body musculature is also used to stabilise the torso and provide balance during ACE (Sawka, 1986). Recently, Kaupp *et al.* (2017) reported that 5-weeks of seated ACE training improved plantarflexion and soleus activation on the more affected side on stroke patients. Although it is not possible to generalise these findings to otherwise healthy individuals, we cannot rule out the possibility that ACE training improved trunk and ankle muscle strength through stabilisation activities. In contrast, CYC training elicited reductions in anteroposterior sway. Potentially, CYC training, which mainly involves lower limb contractions in the sagittal plane (e.g., flexors and extensors of the ankles, knees and hips) (Ericson et al. 1985), would favour improvements in postural musculature that act primarily to control movement in the anteroposterior direction (Winter et al. 1996). This is to be expected, as the anatomy of the lower limbs allow more movement in the anteroposterior, compared to the mediolateral direction. These adaptations may allow antigravity muscles to detect sway more quickly and respond with a shorter latency thus improving the control of sway in the sagittal plane.

Reductions in postural sway may hold important implications for older people because mediolateral aspects of postural stability have predictive value for fall incidence (Era et al. 2006; Maki, Holliday and Topper 1994). Older people tend to switch to from a distal (i.e. ankle muscles) to proximal (i.e., hip muscles) postural strategy during standing. This is important because the hip strategy is predisposed to lateral movements (Winter et al. 1996), thus making mediolateral sway more susceptible. Although the overall reductions in the COP displacement in the frontal plane (d= 1.0 – 2.0) are interpreted as a favourable adaptation, the reductions in sway ranged from ~0.5 cm (firm) to 1.0 cm (foam) which is unlikely to represent a clinically relevant reduction in postural sway among health older people.

4.3 Cardiorespiratory fitness

In the present study, both ACE and CYC training elicited marked improvements in maximal exercise capacity. Specifically, ACE and CYC training elicited an improvement in mode specific $\dot{V}O_{2peak}$ by ~25 %, which confirms previous literature for healthy older adults. Both modes of exercise also elicited a ~12% increase in cross exercise tolerance (i.e. the untrained muscle mass). These findings are similar to previous research in older people. Pogliaghi *et al.* (2006) reported that 12-weeks of aerobic training using either arms or legs elicited similar potential in increasing mode-specific as well cross-transfer exercise tolerance of ~20% and ~10%, respectively, at both maximal and submaximal intensities. These data suggest that about half of the increase in peak exercise tolerance and/or reduction in submaximal cardiorespiratory strain are transferable to a different type of exercise, while the other half of the adaptation is mode-specific. The cross-transfer effects are generally interpreted as indirect evidence of the central nature of the training adaptation, possibly reflecting improved cardiac output and stroke volume in naïve participants (Loftin et al. 1988). In contrast, the mode-specific improvements in exercise tolerance are likely due to peripheral factors such as increases in capillarisation, conversion of type IIb muscles fibres to type IIa, decreases in the activity of some glycolytic enzymes, increased blood flow and marked increases in mitochondrial respiratory enzyme levels (Meredith et al. 1989).

From a fall-risk perspective, the increased aerobic fitness may contribute to decreased efforts during recreational, occupational and daily activities. Indeed, older adults perform many activities of daily living near their maximal capabilities (Hortobagyi et al. 2003). Substantial evidence shows that acute bouts of lower body exercise can transiently impair balance in older people (Egerton et al. 2009a;b; 2010). In contrast, we previously reported that acute ACE does not impair balance when performed at a similar intensity as CYC or treadmill walking (Hill et al. 2015). This is important because fatigue is a common complaint in older adults, with 50% of those aged 70 years and over reporting fatigue during every day activities (Avlund, 2010). Thus, the adaptations reported here may contribute to delay the skeletal muscle anaerobiosis during physical activity by enhancing resistance to fatigue.

4.4 Practical implications

There are a number of important practical implications to emerge from the present study. It appears that ACE training is effective in alleviating functional consequences of ageing, such as mobility, balance and aerobic fitness. Given that the upper body is used during many daily activities, we think it is reasonable to encourage healthy older adults to train the arms as well as the legs, with the expectation of improving real-life exercise capacity as well as general fitness. Apart from functional reach distance, the CYC control group was generally equally as effective in improving physical functional performance. Therefore, the authors recommend that ACE training is used as an adjunct to traditional exercise interventions (strength and balance training) and may be valuable in acting as a safe starting point as part of a continuum of exercise to progress to more challenging standing programmes (i.e. walking) for those who lack general fitness or individuals recovering from a previous fall (i.e. hip replacement rehabilitation patients).

4.5 Limitations

The current study has some limitations that need to be considered. Firstly, the assessor was not blind to treatment allocation, which may have led to biased effect of treatment estimates for some outcome measures (Wood *et al.* 2008). Further, our sample size was limited (*n* = 18), but is similar to the sample sizes used in other exercise training studies among older people (~10 – 20 participants). The small sample size precludes us from exploring potential moderator variables and generalising our findings to the wider older population. Although we acknowledge that studies with low statistical power may overestimate magnitude of effects (Button et al. 2013), this exploratory study will provide the impetus for further trials involving a larger sample size to more accurately quantify exercise-induced adaptations following ACE. Additionally, we lacked a true no-exercise control group. We are aware that this approach may preclude observations being drawn relating to ACE versus a non-training control group and therefore we are unable to determine causality in our interpretation of the adaptations bought about by the training interventions. However, comparing ACE to CYC in the way we have enables better understanding of whether ACE adds value as an exercise intervention given that stationary CYC training is often prescribed to older adults as a safe and appropriate way to exercise. A further limitation was the relatively short training period (i.e. 6-weeks). Longer training periods may be required to reveal differential effects in outcome measures between ACE and CYC. The choice of a 6-week training intervention was based on training durations used in other studies that elicited significant improvements in physical function and cardiorespiratory fitness and due to practical considerations, such as maintaining adherence. Despite the short training period, we observed large magnitude improvements in outcome measures and longer training periods would likely achieve even better results. Finally, we did not include any assessments determine cross transfer effects of ACE on lower extremity muscle strength.

5 CONCLUSION

To our best knowledge, this is the first study to show that seated ACE can improve physical functional performance, such as mobility, balance and fitness among healthy older people. Although ACE and CYC training were equally as effective in eliciting mode-specific and cross-transfer cardiorespiratory training benefits, ACE training was able to elicit additional benefits (i.e. functional reach). The findings highlight that ACE might be an effective alternative modality of training alleviating functional consequences of ageing.

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Table 1: Overview of the training program

Training session	**Duration (min)**		
	Weeks 1 – 2	Weeks 3 – 4	Weeks 5 – 6
Monday and Friday			
50% W_{peak}	10	12	15
60% W_{peak}	5	7	10
50% W_{peak}	5	6	10
Total duration	20	25	35
Wednesday			
50% W_{peak}	10	10	15
60% W_{peak}	7	9	12
70% W_{peak}	3	6	8
Total duration	20	25	35

Table 2: Baseline participant demographics

	ACE (n = 10)	CYC (n = 10)
Sex (male/female)	4/6	4/6
Age (Years)	66.2 ± 3.9	65.5 ± 7.8
Height (m)	1.63 ± 0.10	1.63 ± 0.07
Mass (kg)	65.3 ± 13.6	65.5 ± 13.2
BMI (kg/m^2)	24.7 ± 4.9	24.7 ± 4.7
Dominant hand grip strength (kg)	25 ± 3	28 ± 12
Physical activity (hr/week)	1.1 ± 1.0	1.2 ± 0.9

Table 3. Mean±SD data for centre of pressure measures during bipedal standing on a fixed and compliant surface with eyes open (EO) and eyes closed (EC) between pre and post arm-cranking and cycling training

		ACE			**CYC**		**Mode × Time ANOVA**		
		Pre	Post	*d*	Pre	Post	*d*	*P*	η_p^2
Fixed surface									
COP$_{AP}$ (cm)	EO	1.72 ± 0.56	1.52 ± 0.43	0.4	1.70 ± 0.22	1.20 ± 0.17*	**2.5**	0.283	.036
	EC	2.63 ± 1.26	2.21 ± 0.83	0.4	2.45 ± 0.58	2.20 ± 0.54	0.4	0.770	.087
COP$_{ML}$ (cm)	EO	1.49 ± 0.43	1.05 ± 0.41*	**1.0**	1.46 ± 0.41	1.12 ± 0.09	**1.1**	0.652	.006
	EC	1.75 ± 0.90	1.41 ± 0.51	0.5	1.66 ± 0.65	1.52 ± 0.74	0.2	0.430	.020
COP$_V$ (cm s^{-1})	EO	2.46 ± 0.59	2.28 ± 0.31	0.4	2.40 ± 0.45	2.04 ± 0.12	**1.1**	0.512	.014
	EC	3.28 ± 0.98	3.18 ± 0.49	0.1	3.04 ± 0.53	3.14 ± 0.37	0.2	0.642	.007
Compliant surface									
COP$_{AP}$ (cm)	EO	2.72 ± 0.64	2.61 ± 0.21	0.2	2.82 ± 0.48	2.08 ± 0.49*	**1.5**	0.059	.107
	EC	6.87 ± 1.07	6.66 ± 0.97	0.2	6.69 ± 2.04	4.10 ± 0.74*	**1.7**	0.008	.197
COP$_{ML}$ (cm)	EO	2.82 ± 0.55	1.97 ± 0.26*	**2.0**	2.65 ± 0.56	2.65 ± 0.77	0.0	0.026	.145
	EC	6.10 ± 1.28	4.86 ± 0.73*	**1.2**	5.89 ± 1.05	5.86 ± 1.92	0.0	0.170	.058
COP$_V$ (cm s^{-1})	EO	3.36 ± 0.73	3.34 ± 0.91	0.0	3.76 ± 1.64	3.46 ± 1.48	0.2	0.728	.004
	EC	5.97 ± 1.95	5.89 ± 2.44	0.0	6.04± 1.80	5.37 ± 1.13	0.4	0.649	.007

*Sig. different compared to pre-training ($P \leq 0.05$). COPAP; anteroposterior centre of pressure displacement, COPML; mediolateral centre of pressure displacement, COPV; mean velocity of the centre of pressure, EO; eyes open, EC; eyes closed, *d*; effect size

Table 4. Peak responses obtained during mode specific and cross transfer CYC and ACE training

Group	**Variable**	**CYC Test**			**ACE Test**			**Mode × Time ANOVA**	
		PRE	POST	*d*	PRE	POST	*d*	*P*	η_p^2
ACE Training	W_{peak} (watts)	98 ± 25	108 ± 23*	0.32	51 ± 14	65 ± 16*	0.66	0.050	.363
	$\dot{V}O_{2\text{peak}}$ (L·min^{-1})	1.44 ± 0.43	1.64 ± 0.46*	0.46	1.12 ± 0.31	1.39 ± 0.36*	0.82	0.115	.253
	$\dot{V}O_{2\text{peak}}$ (ml·min·kg^{-1})	23 ± 7	26 ± 7*	0.45	17 ± 4	22 ± 5*	0.93	0.082	.299
	$\dot{V}_E$ (L·min^{-1})	54 ± 14	58 ± 12	0.32	47 ± 11	55 ± 13*	0.66	0.210	.168
	RER	1.14 ± 0.03	1.15 ± 0.09	0.14	1.14 ± 0.03	1.16 ± 0.06	0.45	0.744	.012
	HR_{MAX} (beats·min^{-1})	147 ± 18	152 ± 16*	0.31	143 ± 16	153 ± 11*	0.70	0.259	.139
	RPE_L	20 ± 1	20 ± 1	0.00	20 ± 1	20 ± 1	0.00	0.213	.167
	RPE_C	19 ± 2	19 ± 2	0.00	18 ± 2	16 ± 2	1.13	0.009	.550
CYC Training	W_{peak} (watts)	103 ± 56	129 ± 73*	0.41	57 ± 27	62 ± 31*	0.21	0.019	.569
	$\dot{V}O_{2\text{peak}}$ (L·min^{-1})	1.55 ± 0.71	1.97 ± 0.56*	0.50	1.17 ± 0.49	1.36 ± 0.58*	0.34	0.035	.493
	$\dot{V}O_{2\text{peak}}$ (ml·min·kg^{-1})	23 ± 8	30 ± 12*	0.62	18 ± 6	20 ± 7*	0.42	0.020	.561
	$\dot{V}_E$ (L·min^{-1})	62 ± 29	71 ± 27*	0.30	43 ± 19	52 ± 24	0.41	0.912	.002
	RER	1.17 ± 0.02	1.15 ± 0.06	0.11	1.14 ± 0.05	1.15 ± 0.01	0.20	0.140	.284
	HR_{MAX} (beats·min^{-1})	153 ± 25	158 ± 16	0.27	144 ± 16	150 ± 13*	0.36	0.957	.000
	RPE_L	20 ± 1	19 ± 1	0.82	20 ± 1	18 ± 1	2.00	0.351	.125
	RPE_C	19 ± 1	19 ± 2	0.26	20 ± 1	16 ± 1	4.00	0.111	.321

*Sig. different compared to pre-training ($P \leq 0.05$). W_{peak}; peak power output, $\dot{V}O_{2\text{peak}}$; peak oxygen uptake, $\dot{V}_E$; pulmonary ventilation, RER; respiratory exchange ratio, HR_{MAX}; maximal heart rate, RPE_L; local ratings of perceived exertion, RPE_C; central ratings of perceived exertion.

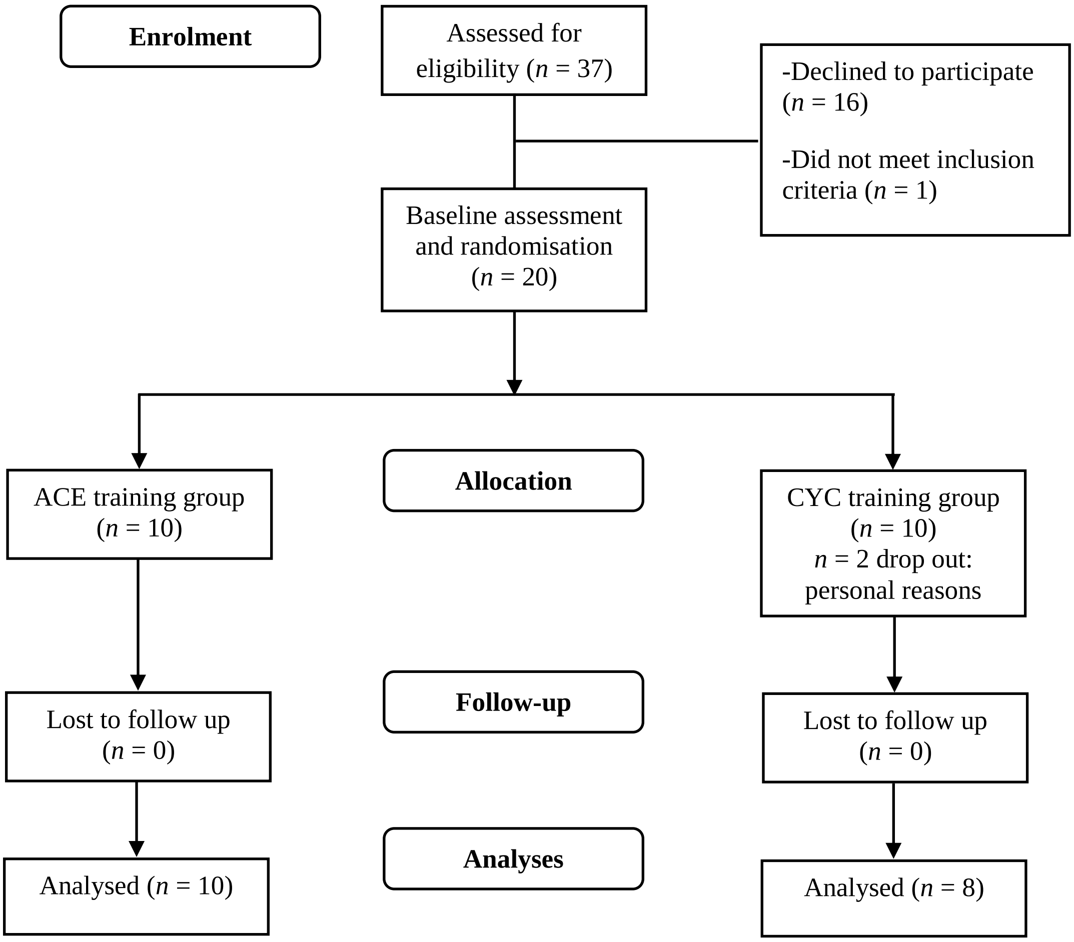

Fig. 1. Enrolment schematic

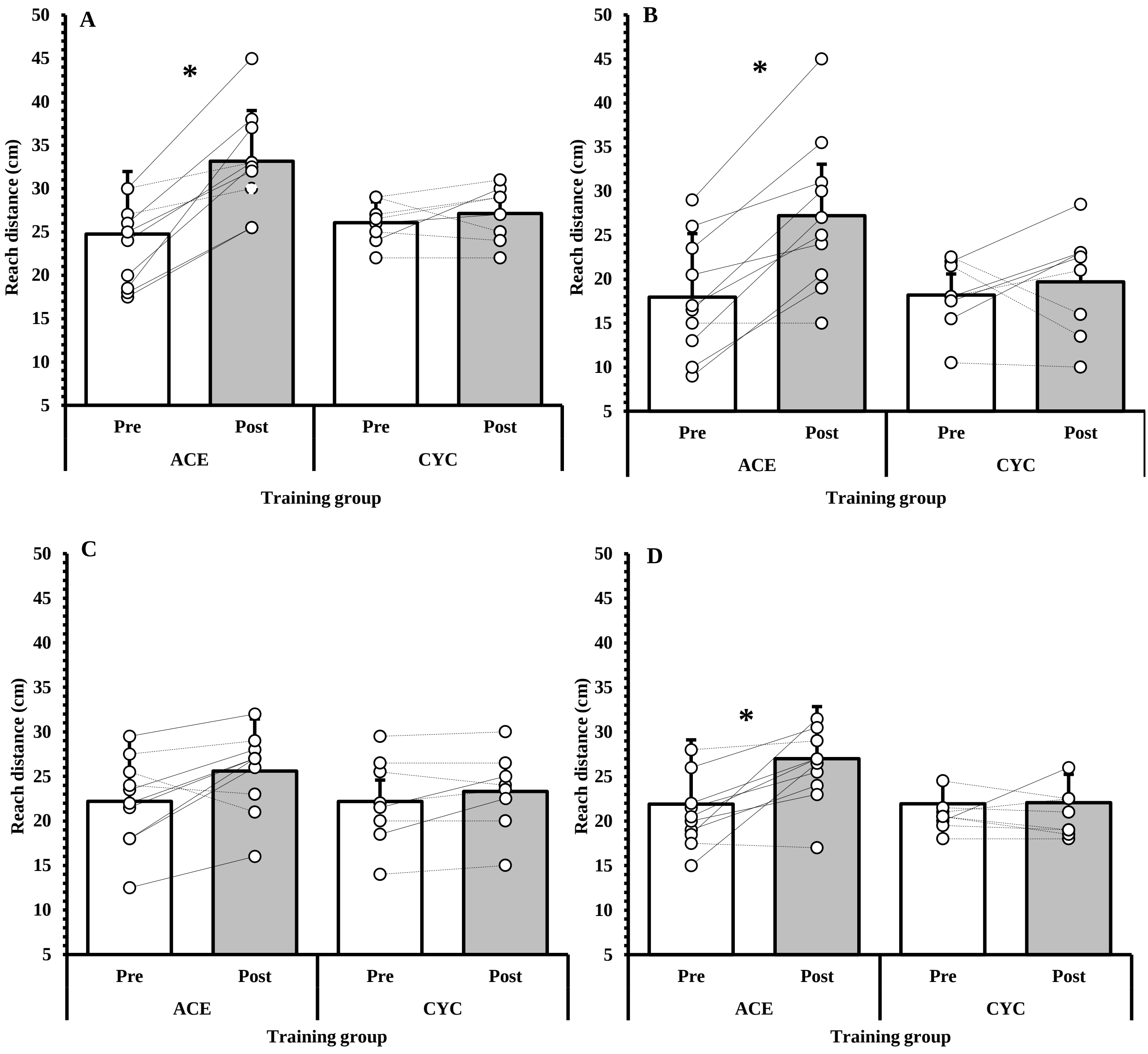

Fig. 2. Anterior (A), posterior (B) left (C) and right (D) functional reach distance before and after 6 weeks of ACE or CYC training. *Time effect ($P \leq 0.05$). Solid lines represent responders. Dashed lines represent non-responders.

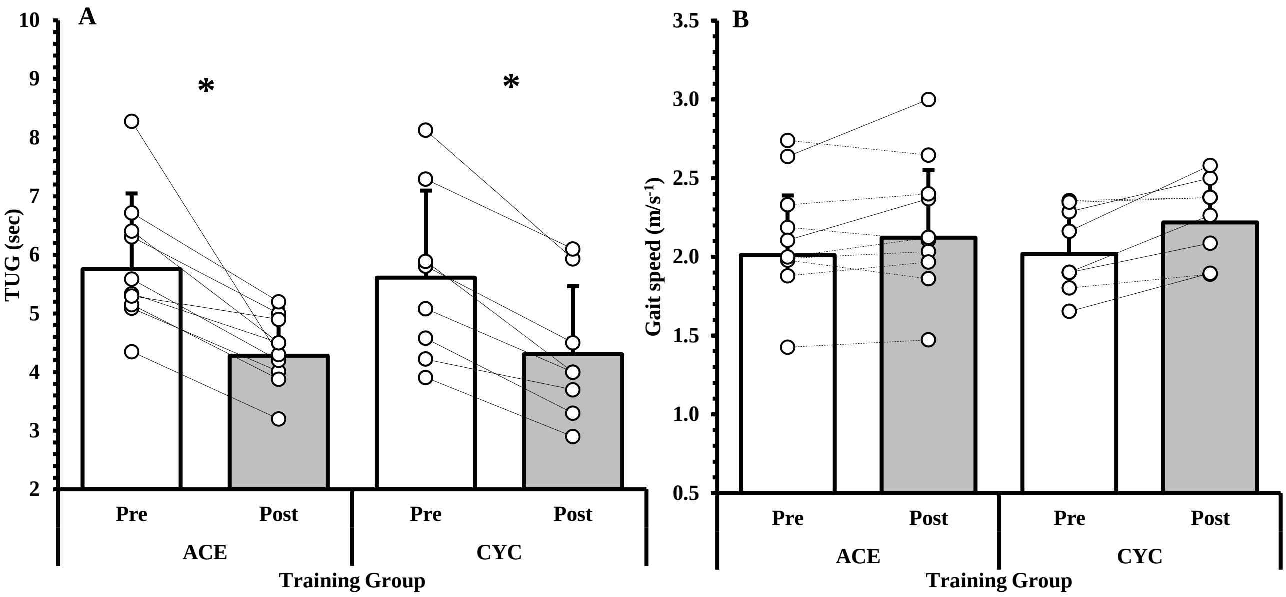

Fig. 3. Timed-up and Go Test (TUG) performance (A) and 8-meter walking speed (B) before and after ACE and CYC training. *Time effect ($P \leq 0.05$). Solid lines represent responders. Dashed lines represent non-responders.

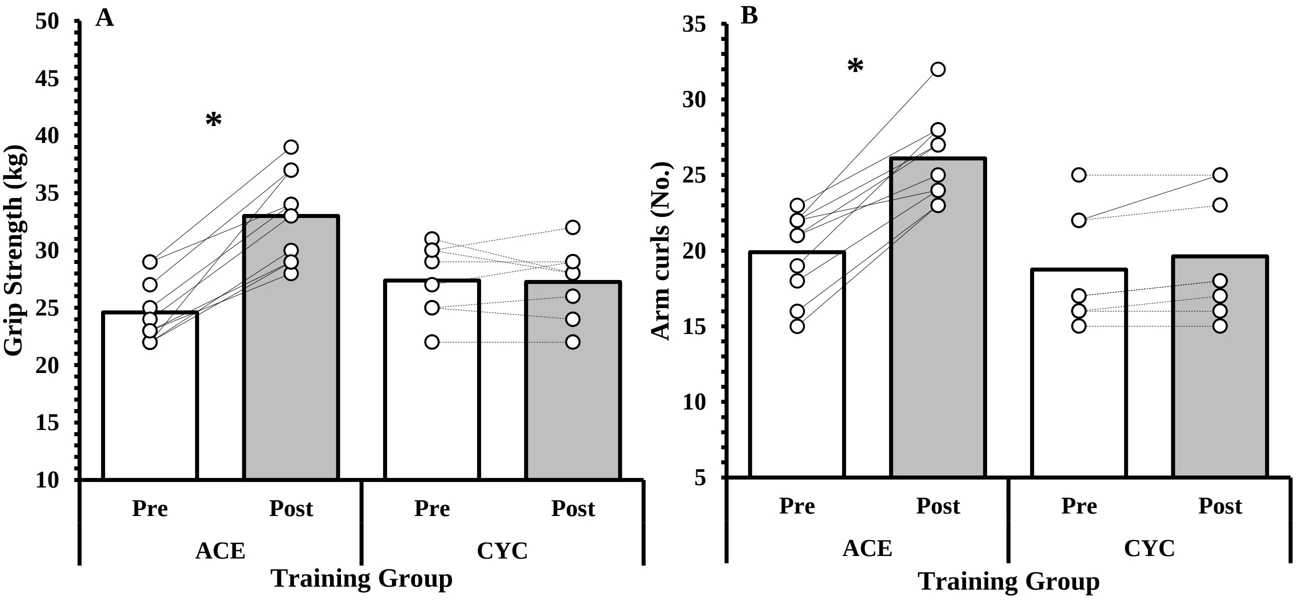

Fig. 4. Hand grip strength (A) and 30-s arm curl test (B) before and after ACE and CYC training. *Time effect (P < 0.05). Solid lines represent responders. Dashed lines represent non-responders.