Functional Anaerobic and Strength Training in Young Adults with Cerebral Palsy

JARRED G. GILLETT1, GLEN A. LICHTWARK2, ROSLYN N. BOYD1, and LEE A. BARBER1

1Queensland Cerebral Palsy and Rehabilitation Research Centre, UQ Child Health Research Centre, Faculty of Medicine, The University of Queensland, South Brisbane, Queensland, AUSTRALIA; and 2Centre for Sensorimotor Performance, Faculty of Health and Behavioural Sciences, School of Human Movement and Nutrition Sciences, The University of Queensland, St Lucia, Queensland, AUSTRALIA

ABSTRACT

GILLETT, J. G., G. A. LICHTWARK, R. N. BOYD, and L. A. BARBER. Functional Anaerobic and Strength Training in Young Adults with Cerebral Palsy. Med. Sci. Sports Exerc., Vol. 50, No. 8, pp. 1549–1557, 2018. Purpose: This study aimed to investigate the efficacy of a 12-wk combined functional anaerobic and strength training program on neuromuscular properties and functional capacity in young adults with spastic-type cerebral palsy. Methods: A total of 17 young adults (21 ± 4 yr, 9 males, Gross Motor Function Classification System I = 11 and II = 6) were randomized to 12 wk, 3 sessions per week, of high-intensity functional anaerobic and progressive resistance training of the lower limbs (n = 8), or a waitlist control group (n = 9). Pre- and posttraining plantarflexor and tibialis anterior muscle volumes and composition, passive and active plantarflexor muscle properties, and functional capacity outcomes were assessed. Results: The training group had higher values compared with the control group (adjusted mean difference) at 12 wk for the following: more- and less-impaired total plantarflexor and tibialis anterior muscle volumes, maximum isometric plantarflexion strength, muscle power sprint test peak power, agility shuttle time, composite functional strength score, and 6-min walk test distance. The change in total plantarflexor muscle volume was associated with the change in plantarflexor muscle strength. There were relationships between the change in plantarflexor muscle strength and the change in functional capacity outcomes (functional strength; 6-min walk test). Conclusions: Combined functional anaerobic and strength training increased muscle size, strength, and functional capacity in young adults with cerebral palsy. The addition of anaerobic training to progressive resistance training programs assists in the transfer to improved functional capacity. Key Words: RESISTANCE TRAINING, HYPERTROPHY, FUNCTIONAL CAPACITY, MUSCLE STRENGTH

Address for correspondence: Jarred Gillett, B.Ex.Sc. (Honours I), Queensland Cerebral Palsy and Rehabilitation Research Centre Level 6, Centre for Children’s Health Research (LCCH), The University of Queensland 62 Graham Street, South Brisbane, Queensland, Australia, 4101; E-mail: j.gillett1@uq.edu.au. Submitted for publication November 2017. Accepted for publication March 2018.

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loads to illicit adaptation, lack of use of PRT guidelines, and
counting effects of multiple impairments in individuals
with CP such as muscle weakness, stiffness, and altered motor
control, which may all influence function (20,21).

The addition of functional training exercises to traditional
PRT programs may lead to increased functional capacity
according to the principle of specificity of training. Two
well-designed studies have reported improvements in func-
tional capacity after specific anaerobic training in children
and adolescents with CP (22,23). Isolated resistance training
does not train the skills or movements required to perform
functional tasks, which may explain the incongruence be-
tween strength and functional adaptations after isolated res-
istance training interventions (15,18).

As most muscle-strengthening interventions in individuals
with CP have focused on improving strength and mobility, the
outcome measures have been predominantly gross motor and
functional capacity measures without examining the muscle
itself (17,24). Key morphological and architectural parama-
ters, such as muscle size, have been extensively evaluated
after PRT interventions in the TD population that provide
a link between changes in muscle structure and functional
outcomes such as increases in strength and power (12,25).
Skeletal muscle hypertrophy in TD adults has been reported
across a wide variety of resistance training interventions, age
ranges, muscle groups, and sexes (26,27). Although the evi-
dence is strong for positive muscle adaptation after PRT in
TD individuals (27,28), a recent systematic review found
only preliminary evidence for improved muscle morphology
and architecture in children and adolescents with CP (14).

To the best of our knowledge, there have been no stud-
ies published in adults with CP that have measured muscle
morphology, architecture, or muscle quality changes after
resistance training interventions. The hypertrophic response
to resistance training could be better understood by testing
the efficacy of PRT interventions in more skeletally mature
individuals with CP, alongside a control group measured at
identical time points. It remains unknown whether muscle in
skeletally mature individuals with CP can adapt similarly to
TD muscle after PRT, and whether any morphological adap-
tations are related to strength and functional outcomes. Measur-
ing muscle quality and muscle stiffness changes would also
assist in understanding the structural mechanisms underpinning
any functional capacity or strength improvements after training.

The purpose of this study was to test the efficacy of a
high-intensity combined progressive resistance and anaer-
obic training intervention in individuals with CP 15–30 yr of
age. We hypothesized that combined functional anaerobic
and strength training would result in increased lower leg
muscle volume, reduced muscle fascicle stiffness, and im-
provements in strength and functional capacity.

METHODS

A waitlist randomized controlled trial was conducted to
test the efficacy of a 12-wk, 3 sessions per week, combined
progressive resistance and functional anaerobic training
program on lower limb neuromuscular properties and func-
tional capacity compared with a waitlist control group.

Participants. Participants were recruited across South
East Queensland, Australia, from the Queensland Cerebral
Palsy Register; Queensland Paediatric Rehabilitation Service;
Cerebral Palsy League Queensland; Brisbane Paralympic
Football Program; and expression of interest advertising from
July 2015 to August 2017. Written informed consent (assent
if 15–18 yr) was obtained from participants and a parent or
guardian (if participant <18 yr). The study was approved by
the Human Research Ethics Committees at The University of
Queensland (2014000066); Children’s Health Queensland
Hospital and Health Service (HREC/15/QRCH/30); and the
Cerebral Palsy League of Queensland (CPL-2016-001). This
study was registered with the Australian New Zealand Clinical
Trials Registry (ANZCTR: 12614001217695). Male and fe-
male participants were included who 1) were between 15 and
30 yr of age; 2) were diagnosed as unilateral or bilateral spastic
type CP; 3) were able to walk independently; 4) were classi-
fied as levels I and II, using the Gross Motor Function
Classification System (GMFCS) (29); and 5) had a maximum
passive ankle dorsiflexion range of <5° (knee fully extended).

Design and procedure. After baseline assessments,
participants were stratified according to age in either 15–18 or
18–30 yr bandwidths and sex. Once stratified, participants
were then randomized into either the immediate interven-
tion group or the waitlist control group using a computer-
generated list of random numbers in concealed envelopes
opened by nonstudy personnel. Participants assigned to the
intervention group began training within 2 wk of the baseline
assessments. The control group received no resistance or
anaerobic training and was allowed to continue with usual
daily activities. Both groups were reassessed within 3 d of
completing the 12-wk intervention or control period. Data
were collected in the Centre for Sensorimotor Performance at
The University of Queensland, Australia, for both baseline
and follow-up assessments. The intervention took place in a
fully equipped tertiary institution gymnasium in Brisbane,
Australia. Blinding for all measures was not possible as par-
ticipants and trainers were aware of group allocation. Assess-
sors were not blinded to group allocation. Adherence to the
training program was recorded by the trainer at the end of each
completed prescribed training session in participant training
diaries. The full study protocol has been published (30).

Sample size. As no previous randomized trials have
measured lower limb muscle volumes after resistance train-
ing in young adults with CP, pilot data from TD individuals
were used to determine the sample size for this study. An 8-wk
pilot study of our training program in 10 TD individuals re-
vealed a mean medial gastrocnemius muscle volume differ-
ence of 11.5 mL posttraining with an SD of the difference
between means of 14.0 mL. An estimated effect size of 0.85
calculated from this pilot data was used in an a priori power
analysis determining that 16 experimental and 16 control
subjects were required to confirm the null hypothesis with a
power of 0.80 and an alpha level set at 0.05. To allow for an estimated 10% attrition rate during the intervention, 20 participants were required for each group.

**Intervention.** A detailed description of the content and progression of the training intervention has been published in the study protocol (30). Participants randomized to the training group undertook three training sessions per week, for 12 wk, totaling 36 sessions. The PRT component was performed first in each session, followed by the functional anaerobic exercises. Participants trained individually or in groups of no more than three, to allow strict supervision and adherence to the prescribed exercise and rest periods. The PRT component of each session consisted of five lower limb resistance exercise stations as follows: seated bent knee calf raise, leg press, seated straight knee calf press, seated tibialis anterior raise, and standing calf raise. The resistance training program was periodized, comprising multiple sets of between 6 and 12 repetitions. Training sets and repetitions progressed according to the training program every 4 wk, and training load was adjusted during any session based on participants completing the required number of sets and repetitions to task failure (30). The functional anaerobic training component consisted of two to three functional anaerobic exercises per session completed at maximal intensity that were adapted from a functional training study in children with CP, related to everyday activities such as stair climbing, bending, changing direction, and stepping over obstacles (22). The number of anaerobic exercises per session, repetitions performed, and work to rest ratio progressed every 4 wk (30).

**Primary outcome.** Full details of the outcome measures and instrumentation have been published in the study protocol (30). Muscle volumes were measured using magnetic resonance imaging pre- and postintervention. Axial plane scans of the lower leg were acquired using a Siemens 3.0 Tesla magnetic resonance imaging scanner (MAGNETOM Verio, Erlangen, Germany) with 2 × 6 channel body matrix array combined with a 24-channel spine coil. Two-point gradient echo Dixon images were acquired in 2D with repetition time/echo time = 970/13 ms, 140° flip angle, 4-mm slice thickness, 240 × 320 acquisition matrix, and 350 × 350 mm field of view. The borders of the individual muscles were manually segmented offline using Stradwin (version 4.2; Mechanical Engineering, Cambridge University, UK) reconstruction software, surface rendered, and then muscle volume (mL) calculations were performed using the measurement modules. This method has high test–retest reliability measuring medial gastrocnemius muscle volumes (intraclass correlation coefficient = 0.99) (31).

**Secondary outcomes.** Ankle and medial gastrocnemius fascicle active and passive mechanical properties were assessed during controlled movements using integrated dynamometry, surface electromyography, and B-mode ultrasound imaging (10). These outcomes were measured on the impaired limb in participants with unilateral CP, and the more-impaired limb in participants who had bilateral CP based on participant report. If the more impaired limb could not be determined, the right side was used. Two maximum voluntary isometric contractions (MVIC) of the plantarflexor muscles were performed at five angles corresponding to 5%, 25%, 50%, 75%, and 95% of the range between maximum plantarflexion and maximum dorsiflexion. The MVIC of the dorsiflexors was also performed at 50% of the participants’ range of movement. The postintervention MVIC in each participant were performed at the same ankle angles used to test their MVIC at baseline. Absolute (N·m) and normalized (N·m·mL⁻¹, to plantarflexor and dorsiflexor volume) maximum torque across this range was used for subsequent analysis. Changes in muscle fascicle length and pennation angle with changes in joint angle or during contraction were assessed using ultrasound imaging and a semiautomated tracking algorithm (32–34).

Fascicle slack length was defined as the measured fascicle length (mm) from a slow passive ankle rotation (10°·s⁻¹) at an ankle joint plantarflexion torque of 1 N·m in all participants. Fascicle stiffness was calculated by fitting an exponential function to the muscle fascicle versus joint torque curve for three successive passive ankle rotations. The stiffness value is the coefficient obtained from the resultant exponential fit. Ankle slack angle (°) and ankle joint stiffness were calculated using the same procedure, fitting an exponential equation to the ankle angle versus joint torque curve. A higher exponential coefficient corresponds to stiffer muscle fascicles or ankle joint.

Intramuscular fat content of the medial gastrocnemius muscle was calculated from two-point gradient echo Dixon magnetic resonance images (9) in a subsample of participants (n = 6 intervention; n = 3 control). Erroneous Dixon image acquisition due to technical issues with the implemented protocol resulted in unusable data in eight participants. The ratios of the water and the fat signal intensities within the regions of interest along the midquartile of the muscle were used to quantify average intramuscular fat using the following equation:

\[
A_f = \frac{1}{n} \sum_{i=1}^{n} \left( \frac{I_f}{I_f + I_w} \right) \times 100, \tag{1}
\]

where \(A_f\) is the average percentage fat, \(I_f\) is the pixel intensity in fat-saturated images, and \(I_w\) is the pixel intensity in watersaturated images.

The muscle power sprint test was used to estimate anaerobic power output (35). Participants completed six 15-m runs as quickly as possible with 10-s rest between sprints. An individual’s ability to change direction rapidly without losing balance was assessed using the 10 × 5-m sprint test (35). Participants performed ten 5-m sprints continuously between two sets of cones. A 30-s repetition maximum test was used as a functional strength assessment involving components of balance, speed, coordination, endurance, and muscular strength (36). Participants completed as many repetitions as possible in 30 s of the following exercises: 1) lateral step-up, 2) sit-to-stand, and 3) stand from half-kneel. The total number of repetitions performed in 30 s for each exercise was summed and used in the analysis. The 6-min
A timed walk test was used to assess the maximum distance participants could walk during a 6-min period on a 30-m, indoor, flat, nonslippery track. A timed stairs test assessed the time taken for participants to ascend and descend a five-step set of stairs as quickly as possible (without running). The clinimetric properties of these outcome measures are reported in the full study protocol (30). Other secondary outcome measures were collected (30); however, these are not reported in this article as they do not contribute to the specific study aims and hypotheses. Assessments made at 12-wk postintervention are not reported in this study.

**Statistical analysis.** Continuous data were examined with the Shapiro–Wilk test for normality. General linear models were used to compare the differences between groups for primary and secondary outcome variables at 12 wk, with group allocation (waitlist, 0; intervention, 1; serving as the main effect within the model). Baseline values, age, and sex were used as covariates in the regression models. Assumptions of the model were met, including homoscedasticity and linearity, and residuals were found to be normal. Data are given as mean (SD), and alpha was set at 0.05 for primary analyses. Results are presented as between-group differences.

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**FIGURE 1—CONSORT study flow diagram. QCPR, Queensland Cerebral Palsy Register; QPRS, Queensland Paediatric Rehabilitation Service.**

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with 95% confidence intervals. The relationships between changes in muscle volume, strength, and functional capacity outcomes were assessed using linear regression. Data analysis was performed using SPSS (version 24; IBM Corporation, Armonk, NY). Analyses were conducted on the basis of intention to treat. Missing values were imputed as last observation carried forward.

RESULTS

Study recruitment, allocation, and follow-up are reported according to CONSORT guidelines in Figure 1. Participants who proceeded to baseline assessments were adolescents and young adults (n = 18) with spastic-type CP (8 unilateral; 9 males; mean ± SD age = 20.7 ± 4.1 yr; age range, 15–28 yr). One participant was excluded during the baseline assessments because of an inability to follow instructions resulting in a total sample size of 17 participants who progressed to the intervention phase. The personal demographics and characteristics at baseline are presented in Table 1. In the intervention group, eight participants started training and were assessed at 12 wk (100% retention); in the waitlist control group, eight participants were assessed at 12 wk (88% retention), with one participant lost to follow-up because of relocation. Sensitivity analysis was performed by removing the one control participant with missing follow-up data from the postintervention analysis to determine whether their removal changed any of the results. The removal of their data did not influence the mean difference or statistical significance for any outcome measure.

On average, participants completed 33.7 (out of 36, 95% adherence) training sessions over the 12-wk period. The mean total dose of the 12-wk training intervention was 38.9 h, comprising 28.5 h of PRT (73%) and 10.5 h of functional anaerobic training (27%). There were two instances of minor musculoskeletal pain recorded during the intervention. One participant reported lateral ankle pain during the last 2 wk of the training period that did not require medical treatment. The other participant reported lower back and knee pain during the last 2 wk of the intervention, which was treated by their physician. In both instances, training continued; however, individual exercises were modified by reducing the resistance training load and progressing once pain had ceased.

Unadjusted baseline and 12-wk follow-up data are presented in Table 2. Adjusted mean differences between groups at 12 wk are presented in Table 3. At 12 wk, plantarflexor and tibialis anterior muscle volumes of the more- and less-impaired limbs were significantly greater in the training group than the control group. The proportion of medial gastrocnemius intramuscular fat content was not significantly different for the usable data in the intervention group (n = 6) compared with the control group (n = 3) at 12 wk. There were no statistical differences in passive muscle or ankle joint properties between the training and the control groups at 12 wk.

Absolute and normalized maximum isometric plantarflexor strength was greater in the training group than the control group at 12 wk (Table 3). Peak anaerobic power, functional strength, agility, and walking distance were greater in the intervention group compared with the control group at 12 wk (Table 3).

The change in total plantarflexor muscle volume was associated with the change in isometric plantarflexor strength ($R^2 = 0.47, P = 0.002$). There were relationships between the change in isometric plantarflexor strength and changes in composite functional strength score ($R^2 = 0.32, P = 0.018$) and the 6-min walk test distance ($R^2 = 0.28, P = 0.028$).

DISCUSSION

A randomized controlled trial of a 12-wk combined progressive resistance and functional anaerobic training program in young adults with CP demonstrated a significant increase in plantarflexor and tibialis anterior muscle volumes, along with a concurrent increase in strength and functional capacity. To our knowledge, this is the first study to report increases in muscle size after PRT in young adults with CP that were significantly related to functional capacity and muscle strength improvements. These findings support the importance of appropriate exercise intervention design to improve neuromuscular impairments and functional capacity in individuals with CP (22,23).

The magnitude of hypertrophy shown within the training group (7.5%–9.6% across plantarflexor muscles) was of a similar magnitude to lower limb muscle hypertrophy in TD adults that has been reported after PRT (12,27). The hypertrophy seen in this study is less, however, than the previously reported muscle volume increases of 23%–24% in the medial and lateral gastrocnemii after targeted plantarflexor strength training in children with CP (19). The large amount of hypertrophy reported in a pre- and postintervention study by McNee et al. (19) may be explained by lower baseline muscle volumes from their younger sample (age range, 6–16 yr), as well as natural muscle growth over the 10-wk intervention period, resulting in a larger absolute increase in muscle size than that reported in this study.

The external training stimulus is responsible for promoting the complex postexercise physiological cascade, shifting

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### Table 1. Participant demographics and baseline characteristics.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Intervention Group (n = 8)</th>
<th>Control Group (n = 9)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age at enrolment, yr:month</td>
<td>20:6 (4:8)</td>
<td>21:8 (4:3)</td>
</tr>
<tr>
<td>Sex, M/F</td>
<td>4/4</td>
<td>5/4</td>
</tr>
<tr>
<td>Height, cm</td>
<td>163.3 (15.7)</td>
<td>170.3 (7.3)</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>67.7 (17.9)</td>
<td>68.4 (13.9)</td>
</tr>
<tr>
<td>Lower limb involvement, n (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unilateral</td>
<td>5 (62.5)</td>
<td>3 (33.3)</td>
</tr>
<tr>
<td>Bilateral</td>
<td>3 (37.5)</td>
<td>6 (66.7)</td>
</tr>
<tr>
<td>GMFCS, n (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level I</td>
<td>6 (75)</td>
<td>5 (55.6)</td>
</tr>
<tr>
<td>Level II</td>
<td>2 (25)</td>
<td>4 (44.4)</td>
</tr>
<tr>
<td>Previous lower limb surgery, n (%)</td>
<td>4 (50)</td>
<td>3 (33.3)</td>
</tr>
</tbody>
</table>

Data are presented as mean (SD).

Surgery types: muscle–tendon lengthening (n = 7), osteotomy (n = 2).

M, male; F, female.
muscle protein balance to favor synthesis over degradation, which ultimately leads to a hypertrophic response (increased contractile tissue size) (37,38). Skeletal muscle hypertrophy has been proposed as the primary mechanism underpinning the growth of contractile tissue volume after PRT in humans (28). Achieving recruitment of the greatest number of available muscle fibers and exposing them to the exercise stimulus seem to be important for attaining skeletal muscle hypertrophy in TD individuals (26).

Recent evidence suggests that children with CP muscle contracture (GMFCS levels II–V), have a reduced number of satellite cells (41). Reduced satellite cell number has therefore been proposed to account for the growth during development (39). There is conjecture in the literature as to whether satellite cell addition is required for skeletal muscle hypertrophy in TD individuals (26). The upregulation of satellite cell activity has been proposed as a key mechanism underpinning skeletal muscle growth during development (39). In high functioning individuals with CP (GMFCS levels I–II), followed prescribed guidelines set down by international strength and conditioning associations that have produced significant skeletal muscle hypertrophy in TD individuals (26).

The upregulation of satellite cell activity has been proposed as a key mechanism underpinning skeletal muscle growth during development (39). In high functioning individuals with CP (GMFCS levels I–II), followed prescribed guidelines set down by international strength and conditioning associations that have produced significant skeletal muscle hypertrophy in TD individuals (26).

The upregulation of satellite cell activity has been proposed as a key mechanism underpinning skeletal muscle growth during development (39). In high functioning individuals with CP (GMFCS levels I–II), followed prescribed guidelines set down by international strength and conditioning associations that have produced significant skeletal muscle hypertrophy in TD individuals (26).
children with CP with severe contracture (42). The heterogeneous presentation of CP poses the question as to whether a reduction in satellite cell activity and altered myogenic signaling pathways occurs in all muscles of individuals with the disorder, who may be of varying functional classification (GMFCS levels I–V), or only in the most severely affected muscles (muscular contracture). The measurement of cellular mechanisms was beyond the scope of this study, making it difficult to know whether skeletal muscle hypertrophy and muscle strengthening were mediated by an increase in satellite cell activity, or via other mechanisms. Further research is needed to determine the cellular mechanisms for muscle adaptation after training interventions in individuals with CP.

Intramuscular fat content did not change after training. An increase in contractile tissue after training may therefore have been accompanied by concurrent increases in non-contractile tissue resulting in similar muscle compartment tissue composition at 12 wk. An absolute increase in contractile tissue, however, would still have a positive effect on the force-generating capacity of the muscle. Any increase in noncontractile tissue that may have occurred did not result in stiffer muscle fascicles, as the passive medial gastrocnemius muscle fascicle stiffness did not increase after training. This finding must be interpreted with caution due to the limited number of Dixon images that could be used in the analysis.

Table 3. Difference between intervention and control groups immediately after intervention (T2) for primary and secondary outcome measures adjusted for baseline values, age, and sex.

<table>
<thead>
<tr>
<th>Outcome Measure</th>
<th>Mean Difference (95% CI)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muscle volume (mL)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>More impaired limb MG</td>
<td>13.21 (0.96 to 25.45)</td>
<td>0.037</td>
</tr>
<tr>
<td>Less impaired limb MG</td>
<td>-1.97 (–8.13 to 4.18)</td>
<td>0.424</td>
</tr>
<tr>
<td>Passive properties</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Passive fascicle stiffness (k)</td>
<td>0.07 (–0.08 to 0.22)</td>
<td>0.336</td>
</tr>
<tr>
<td>Passive ankle stiffness (k)</td>
<td>-0.01 (–0.02 to 0.01)</td>
<td>0.653</td>
</tr>
<tr>
<td>Fascicle slack length (mm)</td>
<td>3.17 (–2.67 to 9.00)</td>
<td>0.260</td>
</tr>
<tr>
<td>Ankle angle (°)</td>
<td>-4.71 (–14.24 to 4.82)</td>
<td>0.303</td>
</tr>
<tr>
<td>Strength and functional capacity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Isometric DF strength (N/m)</td>
<td>2.52 (–0.44 to 5.51)</td>
<td>0.088</td>
</tr>
<tr>
<td>normalized isometric DF strength (N·m⁻¹)</td>
<td>0.05 (0.01 to 0.09)</td>
<td>0.031</td>
</tr>
<tr>
<td>Normalized isometric DF strength (N·m⁻¹)</td>
<td>0.03 (–0.03 to 0.09)</td>
<td>0.266</td>
</tr>
<tr>
<td>Functional strength (total repetitions)</td>
<td>32.64 (21.72 to 43.55)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>MPST peak power (W)</td>
<td>31.25 (4.49 to 58.01)</td>
<td>0.026</td>
</tr>
<tr>
<td>MPST mean power (W)</td>
<td>34.85 (–5.63 to 75.33)</td>
<td>0.085</td>
</tr>
<tr>
<td>10 × 5 m Agility Shuttle (s)</td>
<td>-0.83 (–5.02 to 0.64)</td>
<td>0.168</td>
</tr>
<tr>
<td>6-MWT (m)</td>
<td>47.65 (16.16 to 79.14)</td>
<td>0.006</td>
</tr>
<tr>
<td>Timed up-stairs (s)</td>
<td>-0.25 (–0.62 to 0.12)</td>
<td>0.167</td>
</tr>
<tr>
<td>Timed down-stairs (s)</td>
<td>-0.44 (–1.20 to 0.32)</td>
<td>0.229</td>
</tr>
</tbody>
</table>

*Used as data for intervention group (n = 6), control group (n = 3). CI, confidence interval; MG, medial gastrocnemius; LG, lateral gastrocnemius; SOL, soleus; total PF, summed muscle volume of medial gastrocnemius, lateral gastrocnemius and soleus; TA, tibialis anterior; Functional strength, summed score of 30 s repetition maximum for lateral step-up, lunges, and sit-to-stand; 6-MWT, 6-min walk test; MPST, muscle power sprint test; DF, dorsiflexors; negative time (s) indicates an improvement.
test distance ($R^2 = 0.28$). This finding indicates that an increase in plantarflexion strength underpinned a significant proportion of the improvement in functional capacity outcomes. This finding supports recent evidence that muscle strength is an important predictor of lower limb functional capacity tasks in adults with CP (6). A further explanation of the improvements in functional capacity measures was the specificity of our training program. The functional anaerobic training included activities such as step-ups, shuttle running, stair climbing, and agility drills that were designed to improve anaerobic capacity in a context related to everyday activities. Part of the improvements in functional capacity outcomes were likely due to performing training tasks that closely resembled the outcome measures.

**Limitations.** A potential limitation was that we were unable to definitively separate the contribution of PRT and anaerobic training components to the changes in outcome measures. The PRT component, however, made up more than 70% of the total training volume, so it was the likely contributor to the muscle hypertrophy and strength improvements of the lower leg muscles in this study. The target sample size was not met despite an extensive recruitment strategy being implemented over 2 yr. The recruitment strategy used local CP register databases, targeted mail-outs, social media advertising, and rehabilitation hospitals. The study was constrained by a single-site for the intervention, which limited our recruitment to participants within geographical locations able to access the training facility. The study also had a limited timeframe for completion resulting in recruitment being halted before the targeted sample size being reached. Despite the smaller sample size, this intervention was feasible in high functioning young adults with CP and found differences in muscle volumes, strength, and functional capacity between groups at 12 wk. Additional limitations include the imbalance between groups in terms of lower limb involvement and GMFCS level and the lack of assessor blinding for outcome measures. Future research is required with larger sample sizes in adults with CP, across wider functional classification levels, to further investigate the neuromuscular responses to PRT in this population.

**Implications.** From a clinical perspective, functional strength and measures of functional capacity improved after training, which provides strong evidence for the inclusion of functional anaerobic exercises in PRT interventions for individuals with CP. This type of training is relatively inexpensive, accessible in the community, and provides a potential avenue to address the muscle size deficit seen in adolescents and young adults with CP.

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All authors have read and approved the final manuscript. The authors declare no conflicts of interest. The results of the present study do not constitute endorsement by the American College of Sports Medicine. The results of the study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation.

**REFERENCES**


