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FAST CP: protocol of a randomised controlled trial of the efficacy of a 12-week combined Functional Anaerobic and Strength Training programme on muscle properties and mechanical gait deficiencies in adolescents and young adults with spastic-type cerebral palsy

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ABSTRACT

Introduction: Individuals with cerebral palsy (CP) have muscles that are smaller, weaker and more resistant to stretch compared to typically developing people. Progressive resistance training leads to increases in muscle size and strength. In CP, the benefits of resistance training alone may not transfer to improve other activities such as walking; however, the transfer of strength improvements to improved mobility may be enhanced by performing training that involves specific functional tasks or motor skills. This study aims to determine the efficacy of combined functional anaerobic and strength training in (1) influencing muscle strength, structure and function and (2) to determine if any changes in muscle strength and structure following training impact on walking ability and gross motor functional capacity and performance in the short (following 3 months of training) and medium terms (a further 3 months post-training).

Methods and analysis: 40 adolescents and young adults with CP will be recruited to undertake a 12-week training programme. The training programme will consist of 3×75 min sessions per week, made up of 5 lower limb resistance exercises and 2–3 functional anaerobic exercises per session. The calf muscles will be specifically targeted, as they are the most commonly impacted muscles in CP and are a key muscle group involved in walking. If, as we believe, muscle properties change following combined strength and functional training, there may be long-term benefits of this type of training in slowing the deterioration of muscle function in people with spastic-type CP.

Ethics and dissemination: Ethical approval has been obtained from the ethics committees at The University of Queensland (2014000066) and Children's Health Queensland (HREC/15/QRCH/30). The findings will be disseminated by publications in peer-reviewed journals, conferences and local research organisations' media.

Strengths and limitations of this study

- To the best of our knowledge, this is the first randomised controlled trial to evaluate the impact of functional anaerobic and strength training on muscle structure and function in individuals with cerebral palsy.
- The addition of functional anaerobic training may enhance the transfer of strength gains and structural adaptations to functional performance.
- There may be long-term benefits of this type of training in slowing the deterioration of muscle quality and function.
- The combination of progressive resistance and functional anaerobic training limits the ability to directly attribute study outcomes to either of the two training types.

Trial registration number: Australian and New Zealand Clinical Trials Registry (ACTRN1261400 1217695).

INTRODUCTION

Cerebral palsy

Cerebral palsy (CP) is the largest single cause of childhood physical disability with an economic burden in Australia of $A1.47 billion per year.[1] CP is an umbrella term for a group of motor impairment disorders caused by a non-progressive lesion in the developing child's brain during pregnancy or shortly after birth.[2] Spasticity, a velocity-dependent increase in muscle tone,[3] is the primary sign of spastic-type CP that interferes with normal muscle growth[4] resulting in the development of fixed contractures of the muscle-tendon

unit which compromises strength and function,[5] and may result in skeletal deformity[6] requiring surgery. While the brain lesion responsible for CP is static, it results in secondary musculoskeletal problems such as reduced joint range of motion, increased joint stiffness, and muscle weakness.[7 8] These secondary alterations progress with age[9] and contribute to a gradual loss of functional capacity,[10] characterised by deterioration in gait[11 12] and reduced muscular strength[13] throughout adolescence and young adulthood in individuals with CP. Treatments aim to reduce the progressive secondary musculoskeletal problems in the lower limb and maintain independent mobility and walking into adolescence and adulthood.

CP lower limb neuromuscular adaptations and relationship to function

Architectural adaptations of the lower limb muscles in individuals with CP compared to typically developing individuals include (1) reduced muscle volume,[14–16] (2) increased muscle fascicle stiffness,[17] (3) reduced[18–20] or similar[15 21] muscle fascicle lengths, (4) increased intramuscular fat[22] and (5) increased Achilles tendon length.[23] Alterations to muscle architecture in individuals with CP begin to occur within the first 5 years of life[14 24 25] which may progress into adulthood.[23] Muscle architecture is the primary determinant of muscle function[26] and the specific musculotendinous adaptations in individuals with CP may contribute to a loss of muscle strength[8 27 28] and functional ability.[29] The decline in force-generating capacity of the muscle has been directly attributed to a reduced muscle volume.[23] Increased muscle fascicle stiffness[17] may also result in the inability of the muscle fascicles to reach lengths favourable for high force production.[26] Furthermore, weaker calf muscles with stiffer muscle fascicles interacting with a longer Achilles tendon in series, as observed in individuals with CP,[17 23 27] may result in altered muscle function during walking.[30] A higher intramuscular fat content translates to a reduced proportion of contractile tissue within the muscle.[22] This reduced muscle quality may therefore be a contributing factor to muscle weakness and have implications for functional performance in individuals with spastic CP. The alterations to the musculotendinous unit may also contribute to the reduced power generation during gait,[31] and diminished anaerobic performance[32] in individuals with CP. Moderate to high correlations have also been reported between strength and walking speed (r=0.61)[33] and between strength and activity limitations (r=0.70–0.83)[5] suggesting that muscle weakness plays a role in the mobility difficulties associated with spastic CP.

Neural factors underlying reduced muscle force and the resultant joint torque in individuals with CP include reduced excitatory drive to the agonist muscle and increased coactivation of antagonists.[34–36] The production of muscle force requires sufficient activation of available motor units. It has been hypothesised that reduced excitatory drive to the motoneuron pool due to damaged motor pathways results in an inability to fully activate all available motor units in individuals with CP.[37] The reduction in maximum activation capacity has been shown to account for over 50% of variation in maximum isometric plantar flexion strength between paretic and non-paretic limbs in individuals with CP suggesting that reduced neural drive is a major contributor to muscle weakness.[35] Coactivation, or co-contraction, is muscle activity that occurs simultaneously in agonists and antagonists around a joint, and is usually quantified using electromyography. Coactivation is important because the net muscle moment at a joint is a product of all muscle forces acting around the joint, both agonist and antagonist. The amount of coactivation of antagonistic muscle groups during different activities has been reported to increase with CP.[35 36] An increased coactivation with CP may result in less force being produced to perform the task, and increased energy expenditure during movement.[38] The neural and muscle parameters that influence muscle force generation have collectively been termed neuromuscular properties.[23 39 40]

Impact of progressive resistance training on muscle structure and function

Muscular strength and power, maximum voluntary activation level, muscle volume, muscle fascicle architecture and the force-length properties of muscle are all responsive to progressive resistance training (PRT), and have therefore been targeted in exercise-based interventions in typically developing individuals.[41–46] Neuromuscular adaptations following PRT have been described in healthy adults that provide a link between changes in muscle architecture and functional outcomes such as increases in strength and power.[43 45 46] A whole-body resistance training study in older adults found a 20% increase in isometric maximum voluntary plantar flexor torque was accompanied by triceps surae muscle volume and activation level increases of 12% and 9%, respectively.[47] Following a concentric resistance training programme in healthy young adults, Franchi *et al*[43] demonstrated that vastus lateralis fascicle lengths increased by 5%, along with an 8% increase in muscle volume. Longer fascicle lengths and increased voluntary activation following resistance training can alter the fascicle length–force relation of the muscle.[45] This may result in a greater fascicle force being produced at the corresponding pretraining muscle fascicle length that would be beneficial for individuals performing tasks such as walking and running near their maximum capacities as may be the case for individuals with CP. Specifically, the muscle may operate at more optimum fibre lengths and velocities for force production resulting in more efficient function during challenging tasks such as walking uphill and downhill. Emerging evidence that muscle architecture adapts specifically to the type of training performed (ie, concentric vs eccentric)[43] may provide an opportunity to target the specific

neuromuscular deficiencies present in spastic CP through well designed resistance training programmes. Considering the positive muscle adaptations following PRT in typically developing (TD) individuals, this form of exercise is a low-cost and low-risk treatment option to individuals with CP that may enhance muscle structure and function.

PRT and translation to function in CP

Despite the correlations between strength and mobility in individuals with CP,[5 33] evidence is scarce regarding the translation of strength improvements to gross functional and mobility-related measures such as walking performance.[48–50] Resistance training interventions in individuals with CP have traditionally focused on enhancing muscle strength; hypothesising functional performance would improve as a consequence. There is consensus in the literature that PRT is effective in improving muscle strength in children with CP without negatively impacting on the level of spasticity.[48 51–54] Several randomised control trials (RCTs) of resistance training in individuals with CP have demonstrated increases in muscular strength but without a concurrent increase in functional performance[48 55–57] leading to questions regarding the overall effectiveness of this intervention.[58] Without examining the underlying neuromuscular properties that PRT can impact on in individuals with CP, these studies can only hypothesise as to the mechanisms underlying this incongruity. There is also conjecture in the literature regarding the retention of strength improvements following a period of detraining postintervention.[48 49 59 60] Potential explanations for the inconsistency in findings include failing to account for the confounding effects of growth, natural history, and uncontrolled activity levels during follow-up periods. The retention of effect postintervention in individuals with CP is an important consideration for exercise prescription in order to periodise and plan the timing of future therapies.

The National Strength and Conditioning Association (NSCA) provides guidelines on the prescription of resistance training in youth.[61] The RCTs conducted by Dodd *et al*,[53] Liao *et al*,[56] Lee *et al*[60] and Scholtes *et al*[49] do not meet the NSCA guidelines outlining the type of exercises performed (single and multijoint) and programme duration (8–20 weeks).[58] Similarly, an RCT carried out by Maeland *et al*[57] only performed one exercise (seated leg press) in middle-aged adults with CP and found no effect on mobility. Studies by Liao *et al*,[56] Lee *et al*[60] and Scholtes *et al*[49] also included participants under the age of 7 years which is not in line with the NSCA's guidelines.[61] The mismatch between training programme design in these studies and the NSCA guidelines provides a potential explanation for the ineffectiveness of these studies at influencing functional outcomes in youth with CP.[58] A recent RCT conducted by Taylor *et al*[48] in young adults with CP more closely matched the NSCA training guidelines (participants aged 18 years, trained twice weekly for 12 weeks, 3 sets of 10–12 repetitions per exercise), but participants performed different exercises depending on individually identified deficiencies from gait analysis, and no measures of neuromuscular properties were performed making it difficult to ascertain whether any muscle or neural parameters were altered by the intervention. Nonetheless, Taylor *et al*[48] increased the strength of the targeted muscles by 27% compared to the control group, but showed no transfer to improvements in measures of mobility.

The lack of translation of strength improvements to functional performance may be related to the specificity of training (the training intervention being implemented in a context not related to the functional performance being assessed), the confounding effects of multiple impairments on function (muscle weakness, stiffness and coordination, may all influence function), and unsuitable intervention quality (intensity, duration, frequency and/or type of PRT).[58 62–64] Individuals with CP may also use compensatory movement strategies that prevent the targeted muscle being trained effectively when using multijoint exercises.[58]

Anaerobic muscle power refers to the ability of the neuromuscular system to perform maximum work within a short time period[65] and is reduced in children with CP compared to their TD counterparts.[32] Anaerobic training in youth and adolescents with CP has led to improvements in muscle strength, anaerobic capacity and agility.[66] Given the difficulty in improving functional outcomes following traditional strength training interventions, the addition of anaerobic training may lead to increased mobility and agility that is important for activities in daily living such as climbing stairs and walking over different terrain.

Impact of PRT on muscle properties in CP

Extensive attention has been paid to evaluating the effects of resistance training using functional, performance and gross motor outcome measures, without examining the muscle itself. The relationship of muscle architecture with muscle function suggests that the evaluation of key muscle parameters such as volume, activation level and fascicle behaviour should occur following PRT as a means of examining whether the neuromuscular properties have been altered. RCTs provide the highest level of scientific evidence, and no such studies exist regarding the effect of PRT on skeletal muscle structure in individuals with CP. Recent prospective investigations have shown that muscle volume[59] and cross-sectional area[67] are increased following resistance training in this population, and that muscle architecture may change depending on the type of training performed.[68] The lack of a control group and presence of confounding variables in these studies such as growth, age and degree of skeletal maturity make the results less robust. The impact of PRT on in vivo muscle and tendon function during gait has not been investigated. It is possible that PRT may alter the neuromuscular

properties of muscle in individuals with CP resulting in beneficial effects that may slow the progression of musculoskeletal decline in this population. Such neuromuscular alterations that may occur in vivo cannot be measured from gross functional outcome measures.

Purpose

This current study compares an exercise training model that will combine functional anaerobic and strength training (FAST) with a control group in a wait-list RCT of adolescents and young adults with spastic-type CP. The FAST programme will comprise three 75 min sessions per week for 12 weeks delivered in a group circuit training format (total intervention dose=45 h). We intend to determine if FAST is effective in providing a superior and lasting benefit on skeletal muscle properties and functional performance compared to standard care alone. As there is conjecture in the literature regarding the benefits of strength training as a physical therapy in individuals with CP, it is important to determine if a more intensive programme, such as the combined FAST model presented here, can provide beneficial alterations to skeletal muscle resulting in translation to improved gross motor function compared to standard care. If the FAST programme is effective in altering skeletal muscle properties and improving muscle function then this training intervention may yet be an effective treatment option for individuals with spastic-type CP.

METHODS AND ANALYSES

Study design

An RCT will test the efficacy of a 12-week, 3 sessions per week, combined progressive resistance and functional anaerobic training programme on lower limb neuromuscular properties and functional mobility compared to a control group (performing daily activity and receiving usual care) in adolescents and young adults with spastic hemiplegia or diplegia-type CP. The broad aims of this study are to:

1. Determine whether a 12-week FAST programme leads to changes in medial gastrocnemius (MG), lateral gastrocnemius (LG), soleus (SOL) and tibialis anterior (TA) neuromuscular properties, muscle fascicle function and functional mobility in young adults with spastic-type CP compared to young adults with spastic-type CP not receiving FAST (performing daily activity and receiving usual care).
2. Examine the retention of any changes in MG, LG, SOL and TA neuromuscular properties, muscle fascicle function and functional mobility due to FAST in young adults with spastic-type CP 12 weeks following cessation of the FAST programme.

The primary hypotheses to be tested are:

Neuromuscular properties: H^{1A} adolescents and young adults with spastic-type CP receiving FAST will have a significantly increased MG, LG, SOL and TA muscle volume following a 12-week training programme, compared to adolescents and young adults with spastic-type CP performing daily activities and receiving usual care.

H^{1B} adolescents and young adults with spastic-type CP receiving FAST will have a significantly decreased ankle and muscle fascicle stiffness following a 12-week training programme, compared to adolescents young adults with spastic-type CP performing daily activities and receiving usual care.

The secondary hypotheses to be tested are:

Muscle fascicle function and gait: H^{2A} adolescents and young adults with spastic-type CP receiving FAST will have significantly less MG muscle fascicle lengthening during stance while walking following a 12-week training programme compared to adolescents and young adults with spastic-type CP performing daily activities and receiving usual care.

H^{2B} adolescents and young adults with spastic-type CP receiving FAST will have significantly increased ankle dorsiflexion angle at foot contact and during stance while walking compared to adolescents and young adults with spastic-type CP performing daily activities and receiving usual care.

Intramuscular fat content: H^{3} adolescents and young adults with spastic-type CP receiving FAST will have significantly less MG, LG, SOL and TA intramuscular fat content following a 12-week training programme compared to adolescents and young adults with spastic-type CP performing daily activities and receiving usual care.

Performance: H^{4} adolescents and young adults with spastic-type CP receiving FAST will have significantly increased muscular strength, power output, agility and walking ability following a 12-week training programme compared to adolescents and young adults with spastic-type CP performing daily activities and receiving usual care.

Retention of effect: H^{5} adolescents and young adults with spastic-type CP who received FAST will have significantly less MG, LG, SOL and TA muscle volume; greater ankle and muscle fascicle stiffness; increased muscle fascicle lengthening and decreased ankle dorsiflexion angle at foot contact and during stance while walking; reduced muscular strength, power output and mobility; and increased MG, LG, SOL and TA intramuscular fat 12 weeks after the intervention compared to immediately postintervention.

Study sample and recruitment

Forty individuals aged 15–30 years with spastic-type CP will be recruited across South East Queensland, Australia. Potential study participants will be identified through expression of interest advertising and word of mouth at the following associations: Cerebral Palsy League Queensland; Sporting Wheelies and Disabilities; Brisbane Paralympic Football Program; and Australian Athletes with Disabilities. We will use the Queensland Cerebral Palsy Register (QCPR) as a recruitment frame via a targeted mail out with a project information pack

that will be conducted by the QCPR staff to potential participants who have agreed to be contacted for research projects. Advertisements will also be placed in local newspapers and social media (eg, Facebook information site) as well as other online news media. Friends and colleagues of the young adults with spastic-type CP may also be approached to volunteer for the study.

Inclusion criteria

The study will include male and female young adults:

A. Who are aged between 15 and 30 years;
B. Who have a confirmed diagnosis of spastic hemiplegia or diplegia-type CP;
C. Who are able to walk independently;
D. Who are Gross Motor Function Classification System (GMFCS)[69] level I or II;
E. Who have a maximum passive ankle dorsiflexion range of motion of <5° (knee fully extended).

Exclusion criteria

The study will exclude participants:

A. Who have had previous lower limb surgery in the past 2 years and/or botulinum toxin-A injections to the lower extremities within the past 6 months;
B. Who cannot provide sufficient cooperation and cognitive understanding to participate in the intervention exercises;
C. Who have undertaken lower limb resistance training within the past 6 months.

Sample size

Sample size for the overall FAST CP RCT is based on the study's primary hypothesis comparison between the effect of FAST compared with usual care immediately postintervention (12 weeks) on muscle volume assessed using MRI. No RCTs have measured lower limb muscle volume as an outcome measure following resistance training in young adults with CP. The sample size for the FAST CP RCT is calculated from pre/post cohort data for MG muscle volume change after lower limb strength training in 13 ambulant children with CP.[52] An effect size of 0.88 was calculated using the mean difference in MG muscle volume postintervention of 14 mL with an estimated SD of the difference between means of 16 mL. An 8-week pilot study of the FAST programme in TD individuals revealed a mean gastrocnemius muscle volume difference of 11.5 mL post-training with an SD of the difference between means of 14 mL; an effect size of 0.82. The data from McNee *et al*[59] are from a younger sample than those included in this study and participants may not have been skeletally mature, resulting in an underestimation of muscle hypertrophy. An estimated effect size of 0.85 was used in a one-tailed a priori power analysis requiring 16 experimental and 16 control subjects to enable the null hypothesis to be rejected with a power of 0.80 and an α level set at 0.05. To allow for an estimated 10% attrition rate during the intervention, 20 participants will be needed in each group (40 total).

Randomisation

Participants who are eligible to participate in the study will receive a baseline assessment, and then be randomised to either the FAST (intervention group) or control group (performing daily activity and receiving usual care) using a concealed matched-pairs randomisation method. Participants will be matched in pairs according to age and sex, to minimise group differences at baseline, and a computer-generated sequence of random numbers will be used to allocate a number '1' or '2' to each member of the pair. Treatment allocation will be recorded on a folded piece of paper, placed in sealed, opaque envelopes, held by non-study personnel. Allocations will read either: '1: Control, 2: Intervention', or '1: Intervention, 2: Control'. As each pair is randomised, they will be allocated the next consecutive envelope opened by non-study personnel until all participants have been allocated into the intervention or control group. After the randomisation process is complete, study personnel will be informed of group allocation.

Study procedure

Participants will attend the neuromechanics and biomechanics laboratories at The University of Queensland, Australia, for baseline and follow-up assessments. The intervention will take place in a fully equipped tertiary institution gymnasium in Brisbane, Australia. Participants allocated to the intervention group will undertake 12 weeks of FAST and will commence training within 2 weeks of the baseline assessments. Participants in the control group will receive no training and will be allowed to continue with usual daily activities. Participants in the control group will be offered a 12-week FAST training programme following completion of the 3-month follow-up assessments. The experimental design and outcome measures are reported in figure 1, according to Consort guidelines.[70]

Study intervention: FAST

The intervention group will undertake 75 min of FAST, 3 times per week, for 12 weeks, totalling 36 sessions (total FAST dosage=45 h). The FAST programme will target the MG, LG, SOL and TA muscles as they are the most commonly impacted muscles in spastic-type CP and play a primary role in body weight support and forward propulsion during the stance phase of walking, and toe clearance during the swing phase of walking.[71 72] Functional anaerobic training has been included in this study to address the multifactorial nature of motor impairments seen in CP, as well as incorporating context-specific training relatable to the outcomes being assessed (eg, anaerobic power and mobility).

Training programme design

Participants may train individually or in small groups (<6) to allow strict supervision by two experienced trainers with tertiary qualifications in the field of exercise science. A 5 min warm-up and cool-down of the lower

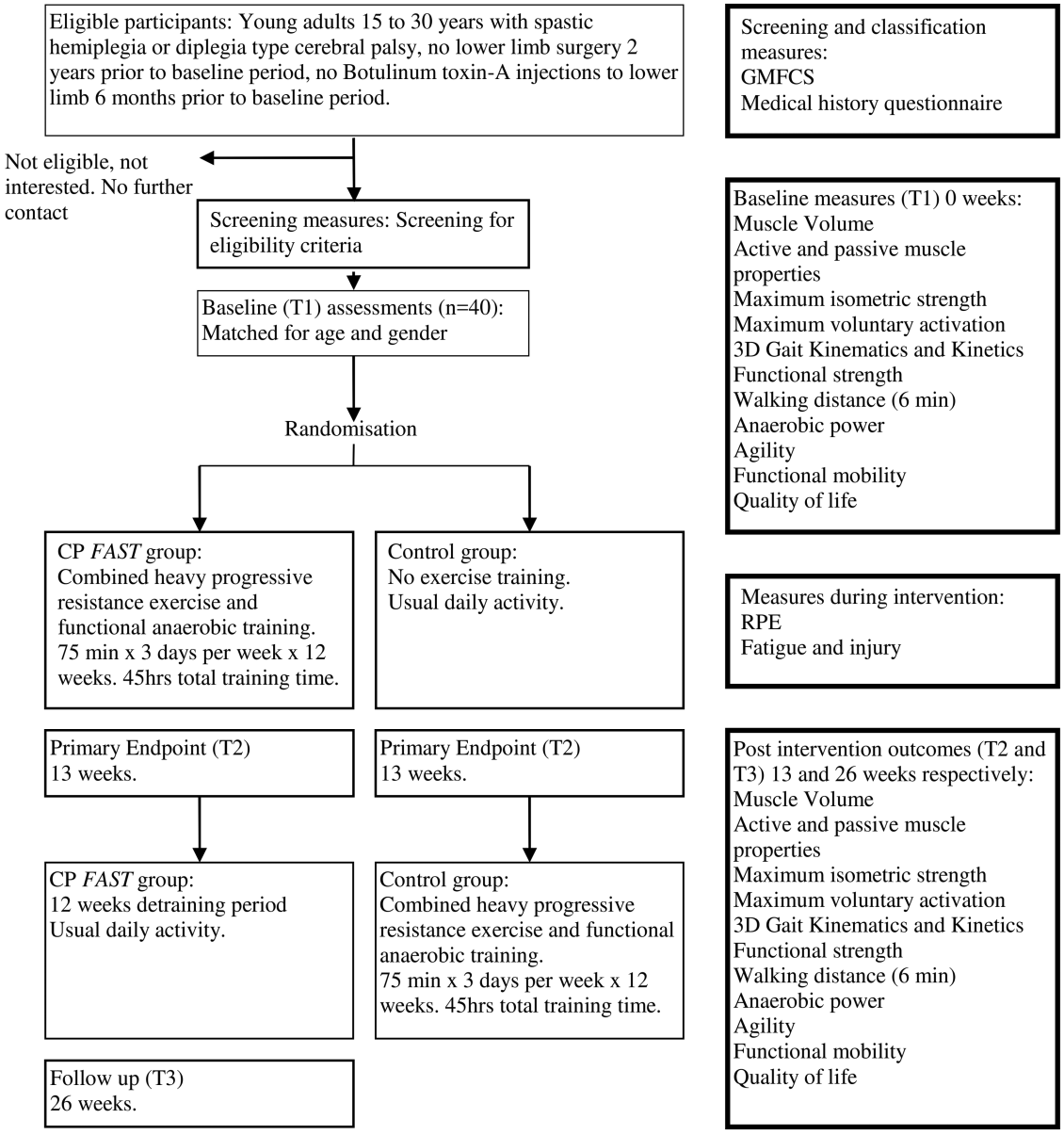

Figure 1 Study flow diagram of intervention and outcome measures (3D, three-dimensional; CP, cerebral palsy; FAST, functional anaerobic and strength training; GMFCS, Gross Motor Function Classification System; RPE, rating of perceived exertion).

limb muscles using a stationary bicycle or treadmill will be performed by all participants at the beginning and end of each session, respectively. The heavy resistance training will be performed first in each session, followed by the functional anaerobic training component. Each participant will be familiarised with the different exercise stations and taught correct technique prior to commencement of the training programme.

The heavy resistance training component of each session will consist of five resistance exercise stations (figure 2). Each participant will commence on an individual station and progress through the circuit until they have completed all five stations. Participants will commence at a random station each week to prevent staleness of the training programme and to randomise any neuromuscular effects of training order. The resistance exercises selected in this study are as follows: seated bent knee calf raise, leg press, seated straight knee calf press, tibialis anterior raise, and standing calf raise. A full description of each exercise is presented in table 1 below.

The functional anaerobic training component will consist of 2–3 (dependent on training period) functional anaerobic exercises per session focusing on power, agility, coordination and speed of movement, adapted from Verschuren *et al*[66] The exercises are designed to improve anaerobic capacity and mobility in a task-specific context related to everyday activities, such as stair climbing, bending, changing direction and stepping over obstacles. A detailed description of each functional anaerobic exercise is presented in table 2.

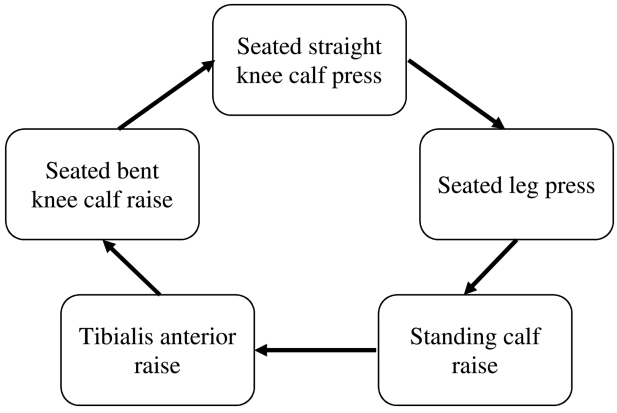

Figure 2 Flow chart outlining the resistance exercise training circuit. Starting exercise station for each session may vary between training sessions. Exercise order will be preserved.

PRT volume and intensity

A high training volume and moderate load will follow the principles of PRT for healthy young adults[73] to achieve the primary training goal of increasing muscle size.[74] The training programme will be periodised, comprise multiple sets, focusing on the 6–12 repetition maximum (RM) range, and take place 3 times per week (at least 24 h relative rest between training sessions) in order to enhance muscle hypertrophy.[75] Training weeks 1–4 are made up of the highest training volume at a moderate load (3 sets of 12 RM) to maximise the neural adaptations that primarily occur during the early stages of a resistance training programme.[76] The training programme will progress by decreasing the number of repetitions per set, completed at a higher load, from weeks 5 to 12. Table 3 details the progression of training load and volume over the 12-week intervention.

Four exercises (seated bent knee calf raise, seated straight knee calf press, standing calf raise, and tibialis anterior raise) will be trained unilaterally on left and right legs. The leg press exercise will be trained as a bilateral movement. This will allow the left and right gastrocnemii, SOL and TA muscles to be trained in isolation, and minimises any compensatory movement strategies employed by the participants to accomplish the exercise. The multijoint leg press exercise was included to provide a greater training stimulus to the larger muscles (quadriceps, hamstrings, gluteals) of the lower limb.

Commercially available weighted pulley systems will be used as the resistance for the leg press and seated straight knee calf press with a weight range 7–250 kg. A custom built training device will be attached to a weighted pulley with a weight range 0.25–50 kg, to be used as the resistance for the tibialis anterior raise. A dumbbell, barbell, or weight vest will be used as the resistance for the standing calf raise and seated bent knee calf raise. Custom weights will be used to allow 0.25 kg increments to be made to all loads.

Participants who are unable to complete 12 RM of the prescribed exercises using the lowest weight (seated exercises) or body weight (standing calf raise) will start training using elastic stretch resistance bands. Once participants can complete 12 RM using the resistance bands, they will progress to a heavier resistance band, or change to the weight-loaded exercise. Hip and knee position will be kept the same regardless of the type of load used.

Functional anaerobic training volume and intensity

The functional anaerobic exercises will be performed at maximal intensity comprising multiple all-out efforts lasting between 20 and 30 s. To satisfy the definition of anaerobic exercise, a maximal effort must be made such that the participant is exhausted at the end of each exercise period.[65] Participants will be instructed to complete as many repetitions as possible in the time allowed, and the trainers will provide verbal encouragement to promote maximal effort. Each session in training weeks 1–4 will comprise 3×20 s maximum exercise bouts of two functional anaerobic exercises. The functional anaerobic training programme will progress over the 12-week period by: (1) adding additional exercises, (2) increasing the repetitions performed, (3) increasing the duration of exercise bouts, and (4) decreasing recovery time. Table 4 details the progression of training volume and intensity over the 12-week intervention.

Individual progression

Initial 12 RM load will be determined in the first week of training for each participant by experienced trainers. Individual progression of load will be monitored in every training session to determine the need for progression. Load may be added to an exercise during a session or prior to the start of a new session if the participant can complete more than the required number of repetitions in all sets of that exercise (ie, the participant is not exercising to fatigue).

Monitoring and adverse events

Correct technique will be strictly monitored at all exercise stations, and individual feedback, instruction and demonstration will be provided by the trainers. Participants will report a rating of perceived exertion on a Borg scale (6–20) at the completion of every training session prior to the cool-down phase.[77] Each participant will complete a training diary in conjunction with the trainer throughout the intervention duration to document their progress, report injuries and fatigue levels, and provide intrinsic motivation to progress their training intensity. A short debriefing session will occur at the completion of the training session to discuss participants' general well-being, motivation and any concerns they may have regarding the training programme. Any missed sessions by participants will be recorded by the trainers. A missed session may be made up for on a separate day during the same training week.

Table 1 Description of strength training exercises to be performed in FAST CP programme

	Seated calf raise	Tibialis anterior raise	Seated leg press	Standing calf raise	Seated straight knee calf press
Muscle(s) targeted	Primary: soleus Secondary: gastrocnemii	Tibialis anterior	Gluteals, quadriceps, hamstrings, triceps surae	Primary: gastrocnemii Secondary: soleus	Primary: gastrocnemii Secondary: soleus
Initial participant positioning	Seated with hips flexed at 90°, knees flexed at 90°, feet flat on the floor approximately 30 cm apart. Dumbbell held on training leg, above the knee. Non-training leg resting with foot flat on the floor	Seated with hips flexed at 90°, knee flexed at 70°, training foot secured in foot plate. Non-training leg resting with foot flat on the base of training device	Seated with hips flexed at 70°, knees flexed at 70°, feet flat on the foot plate approximately 30 cm apart, toes pointing slightly outwards	Standing upright on a 20 cm step, holding a hand rail if required. Place dumbbell in hand on training leg side, heels hanging approximately 10 cm off the step. Non-training leg resting in the air above step	Seated with hips flexed at 70°, training leg knee at 0°, foot flat on the footplate with the heel hanging approximately 10 cm below the footplate. Non-training leg resting with foot flat on the floor
Instructions to participant	*Hold the dumbbell on your knee and keep your toes on the floor, slowly raise your heel up towards the sky until you can't go any further. Slowly lower your heel down to the floor*	*Slowly lift the front of your foot up, keeping your knee bent and heel on the footplate until you can't go any further. Lower your foot back down again slowly*	*Slowly push the footplate forward, keeping your knees slightly bent, and then bring it back towards you slowly*	*Keep your knee straight and toes on the step, slowly raise your heel towards the sky until you can't go any further. Slowly lower your heel down again until it hangs slightly below the step*	*Slowly push the footplate forward with the front of your foot, keeping your knee straight, and then bring it back towards you slowly*
Movement description	1 repetition: lift the weight by raising the heel up using the ball of the foot until the ankle is in maximum plantar flexion before lowering the heel to return to the original position	1 repetition: Lift the weight by dorsiflexing the foot, keeping the heel on the footplate, until the ankle is maximally dorsiflexed before lowering the forefoot to return to the original position	1 repetition: Extend both knees equally to push the footplate forward. Do not lock the knees in full extension before flexing the knees to return to the original position Keep the back flat against the support pad for the duration of the movement	1 repetition: Raise the heel up using the ball of the foot until the ankle is in maximum plantar flexion before lowering the heel to return to the original position	1 repetition: Use the ball of the foot to plantar flex, pushing the footplate forward before dorsiflexing the ankle to return to the original position Keep the back flat against the support pad for the duration of the movement
Unilateral or bilateral training	Unilateral	Unilateral	Bilateral	Unilateral	Unilateral

CP, cerebral palsy; FAST, functional anaerobic and strength training.

Table 2 Description of functional anaerobic exercises included in FAST programme adapted from Verschuren *et al*[66]

Exercise	Equipment	Description	Targeted fitness component
Step-ups	Step or block	Step up with right leg over the block followed by the left. Turn around and step back over the block with left leg first. Count the number of repetitions completed	Strength, power, coordination
Beanbag run	4 mats, 12 beanbags	Place 4 mats in a row, 1.5 m apart. Place 4 beanbags on each of the first 3 mats. Move a beanbag from mat 1 to 2, 2 to 3, and 3 to 4. Run back to the start and repeat. Count the number of beanbags moved	Power, agility, coordination (bending, turning, getting up from the floor)
Lateral step-ups	Step or block	Step up sideways with right leg first over the block. Step back over the block with left leg first. Count the number of repetitions completed	Strength, power (stair climbing, avoiding obstacles)
5 m sprint	2 strips of tape	Place tape 5 m apart. Sprint as fast as possible between lines of tape. Count the number of sprints completed	Agility, speed
Obstacle course	1 hoop, beanbags, step, hurdle, basket	Take a beanbag from the hoop, over the step, under the hurdle and into the basket. Repeat and count number of repetitions completed	Power, agility, speed, coordination (bending, turning, getting up from the floor)
Shuttle sprint	5 lines of tape placed 1.5 m apart	Sprint to line 1, return to start. Sprint to line 2, return to start, continue. Count the number of lines touched	Power, agility, speed, coordination
Up and down stairs	3 stairs (17.5 cm step height)	Move up and down 3 stairs as quickly as possible. Count number of repetitions completed	Strength, power (stair climbing)
Agility run	Bean bag, cones, basket	Zig-zag between 5 cones placed 1.5 m apart (in and out), and return to the start line. Count number of repetitions completed	Power, agility, speed, coordination
4 cone run	4 cones of different colours	Start in the centre of a 2 m×2 m square. Trainer calls a colour to run to, touch the cone, and back to the centre. Trainer then calls another colour. Count the number of cones touched	Power, agility, speed, coordination

FAST, functional anaerobic and strength training.

Participant motivation will be enhanced by providing a visual display of personal best results for each exercise within the training environment. Individuals will be encouraged to improve their personal best performances in each session which will be displayed in relative terms using a change score in performance rather than an absolute result to avoid any negative perceptions associated with underperforming or competing against their peers.

Any injuries or adverse outcomes attributable to the intervention or testing protocol will be documented and reported, and individuals referred to their treating clinician. The presence of a trainer at all exercise sessions will allow close monitoring of the occurrence of injuries or adverse events during training and in response to training. The training diaries completed by the participants will also provide valuable information about short and long-term training experiences. Participants will report any leg pain, lower leg stiffness and level of leg fatigue prior to each training session using a visual analogue scale (0–100 mm). Annual auditing of trial conduct will be completed by study investigators.

Outcome measures

Measures will be taken at baseline (pretraining, T1), immediately following training (post-training, T2), and 12 weeks post-training (retention, T3). Data collection for each assessment time point will be scheduled within a 2-week period. Measures of height, weight, leg length, tibia and fibula length, and maximum calf circumference will be taken at each assessment.

Primary outcomes

There will be a primary outcome measure for the volume (mL) of the MG, LG, SOL and TA muscles, and the neuromuscular properties of the MG muscle.

Muscle volume

MRI will be used to measure muscle volume of the MG, LG, SOL and TA muscles. MRI is considered to be the gold standard of muscle volume measurement in vivo,[78 79] and has been validated against cadaveric values (r=0.99, SEE=3.9 cm^2).[78] Participants will lay supine on the MRI gantry with the knee fully extended and the ankle held in the anatomically neutral position (or maximum dorsiflexion if anatomically neutral is unattainable). Axial plane MRI of the lower leg will be acquired using a Siemens MAGNETOM Verio 3.0 T MRI scanner (Erlangen, Germany) with 2×6 channel body matrix array combined with 24 channel spine coil; two-point gradient echo Dixon images will be acquired in

Table 3 Training progression of resistance exercises to be performed in the FAST CP programme

Week	Speed of movement (s)	Load	Sets	Repetitions	Rest (s)
1–2	Concentric: 2 Eccentric: 2	60% 12 RM	3	12	90
3–4	Concentric: 2 Eccentric: 2	80% 12 RM	3	12	90
5–6	Concentric: 1 Eccentric: 2	100% 10 RM	3	8	90
7–8	Concentric: 1 Eccentric: 2	100% 8 RM	3	8	90
9–10	Concentric: X Eccentric: 2	100% 6 RM	4	6	120
11–12	Concentric: X Eccentric: 2	100% 6 RM	4	6	120

Amount of weight that can be moved through the available range of motion a designated number of times to fatigue. Load will be adjusted in 0.25 kg increments to maintain defined repetition number.
CP, cerebral palsy; FAST, functional anaerobic and strength training; RM, repetition maximum; X explosive concentric movement.

two-dimensional (2D) with TR/TE=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 MG, LG, SOL and TA will be manually segmented by defining a piecewise linear boundary in all corresponding axial plane images using Stradwin (V.4.2, Mechanical Engineering, Cambridge University, UK) reconstruction software. Surface rendering for each muscle and muscle volume (mL) calculations will be performed using the measurement modules within Stradwin. This method has high test–retest reliability measuring MG muscle volumes (ICC=0.99).[80]

Neuromuscular properties

Participant setup and instrumentation: Participants will be instructed to refrain from any strenuous physical activity in the 48 h prior to data collection to minimise possible transient changes in the neuromuscular properties of the muscle. Participants will be assessed at the same time of day to avoid possible diurnal variation in the follow-up neuromuscular measures. All neuromuscular measurements will be made on the MG muscle of the impacted leg, with the knee in full extension (0° extension), and repeated with the knee in 90° flexion.

Full details of the participant setup have been reported previously.[17 23] Briefly, participants will lay prone on an adjustable plinth with their foot secured to a footplate of a Biodex isokinetic dynamometer (System 3, Biodex Medical Systems, Shirley, New York, USA), so that the axis of the dynamometer will be aligned with the ankle joint centre via a custom adjustable foot strap designed to minimise heel lift. The knee will be secured to the plinth using a padded strap to prevent any change in knee angle during the measurements. Prior to any testing, the limits of ankle range of motion (ROM) will be established by applying a manual torque to the footplate and recording the corresponding ankle angle (maximum plantar flexion and dorsiflexion).

A custom LabView programme (V.12.0f3, National Instruments) will be used to control the dynamometer and acquire ankle joint torque, angle and velocity via a USB data acquisition device (NI USB-6259 BNC, National Instruments) at a sampling rate of 1000 Hz. Ultrasound images will be recorded at 80 Hz using a PC-based ultrasound scanner with a 96 element beamformer and a 7 MHz linear probe with 60 mm field of view (LV7.5/65/64D, Telemed Echo Blaster 64 EXT-1T, Vilnius, Lithuania). Electromyographic (EMG) data will be recorded at 1000 Hz from differential surface electrodes placed over the muscle bellies of the MG, LG, SOL and TA using a four-channel NeuroLog EMG system (Digitimer, Welwyn Garden City, UK). Dynamometer, EMG and ultrasound data will be synchronised via a 3 V square wave generated by the ultrasound scanner, which will trigger the recording of data in the LabView software.

An ultrasound transducer will be fixed to the skin using elastic wrap above the MG muscle belly in the same orientation of the muscle fascicles to measure fascicle length and pennation angle changes.[81] Muscle fascicle length will be defined as the straight line distance between the superficial and the deep muscular fascia parallel to the lines of collagenous tissue visible on the ultrasound image. Changes in muscle fascicle length and pennation angle during passive and active lengthening will be automatically tracked using an optical flow tracking algorithm.[82 83] This method of measuring changes in muscle fascicle length has been shown to be accurate and reliable during controlled contractions (CMD 0.98).[83]

Passive mechanical properties: Passive ankle joint torque will be assessed initially in all participants by rotating the foot throughout three cycles of their full ROM at 10°/s. A third-order polynomial will be fitted to the average of three cycles in each participant.[17] A gravity correction will be applied to all torque measurements to account for the gravitational torque acting on the foot and

Table 4 Individual training session design and progression of functional anaerobic exercises

Week	Session	Exercises	Repetitions	Duration (s)	Intensity	Rest (s)
1	1	Step-ups; beanbag walk	3	20	Maximum	100
	2	Lateral step-ups; 5 m sprint	3	20	Maximum	100
	3	Up and down stairs; shuttle sprint	3	20	Maximum	100
2	1	Step-ups; obstacle course	3	20	Maximum	100
	2	Step-ups sideways; agility run	3	20	Maximum	100
	3	Up and down stairs; 4 cone run	3	20	Maximum	100
3	1	Step-ups; beanbag walk	3	20	Maximum	100
	2	Lateral step-ups; 5 m sprint	3	20	Maximum	100
	3	Up and down stairs; shuttle sprint	3	20	Maximum	100
4	1	Step-ups; obstacle course	3	20	Maximum	100
	2	Step-ups sideways; agility run	3	20	Maximum	100
	3	Up and down stairs; 4 cone run	3	20	Maximum	100
5	1	Step-ups; beanbag walk	4	25	Maximum	100
	2	Lateral step-ups; 5 m sprint	4	25	Maximum	100
	3	Up and down stairs; shuttle sprint	4	25	Maximum	100
6	1	Step-ups; obstacle course	4	25	Maximum	100
	2	Step-ups sideways; agility run	4	25	Maximum	100
	3	Up and down stairs; 4 cone run	4	25	Maximum	100
7	1	Step-ups; beanbag walk	4	25	Maximum	100
	2	Lateral step-ups; 5 m sprint	4	25	Maximum	100
	3	Up and down stairs; shuttle sprint	4	25	Maximum	100
8	1	Step-ups; obstacle course	4	25	Maximum	100
	2	Step-ups sideways; agility run	4	25	Maximum	100
	3	Up and down stairs; 4 cone run	4	25	Maximum	100
9	1	Step-ups; beanbag walk, obstacle course	4	30	Maximum	90
	2	Lateral step-ups; 5 m sprint, agility run	4	30	Maximum	90
	3	Up and down stairs; shuttle sprint, 4 cone run	4	30	Maximum	90
10	1	Step-ups; obstacle course, 5 m sprint	5	30	Maximum	90
	2	Step-ups sideways; agility run, shuttle sprint	5	30	Maximum	90
	3	Up and down stairs; 4 cone run, beanbag walk	5	30	Maximum	90
11	1	Step-ups; beanbag walk, obstacle course	5	30	Maximum	90
	2	Lateral step-ups; 5 m sprint, agility run	5	30	Maximum	90
	3	Up and down stairs; shuttle sprint, 4 cone run	5	30	Maximum	90
12	1	Step-ups; obstacle course, 5 m sprint	5	30	Maximum	90
	2	Step-ups sideways; agility run, shuttle sprint	5	30	Maximum	90
	3	Up and down stairs; 4 cone run, beanbag walk	5	30	Maximum	90

footplate. Briefly, a geometric fit of the gravitational moment will be performed on the torque signal.[17] The gravitational moment will be modelled using a generalised sinusoid equation in the region where passive moments are lowest.[84] Slack angle (degrees), peak ankle torque (Nm), ankle stiffness (Nm/degree), and change in ankle angle (degrees) will all be measured at the ankle joint level. Muscle fascicle slack length (mm), change in MG fascicle length (mm), and MG fascicle strain (%) will all be measured at the MG fascicle level. MG physiological cross-sectional area (PCSA) will, in turn, be computed from the ratio of MG muscle volume to MG fascicle length.[85] Detailed explanations for the above measures can be found in Barber *et al*.[17] The level of spasticity will be assessed by passively dorsiflexing the ankle joint through full ROM at a fast velocity (150°/s) using an isokinetic dynamometer while recording EMG data simultaneously from the MG, LG and SOL muscles. The ROM in the ankle joint will be assessed using the isokinetic dynamometry protocol described above. A consistent torque will be applied to the footplate pretraining and post-training to measure any change in ROM following the intervention.

Active mechanical properties: Participants will perform maximum voluntary isometric contractions (MVIC) of the plantar flexors at five ankle angles corresponding to 5%, 25%, 50%, 75% and 95% of the range between maximum plantar flexion and maximum dorsiflexion. An MVIC of the dorsiflexors will also be performed at 50% ROM. Each participant will perform two MVICs at each angle, lasting 4 s each in duration, with a rest period of 2 min between trials. The trial that produces maximum torque will be used for subsequent analysis. Active torque-angle and torque-fascicle length curves will be adjusted for the effect of gravity, and the passive torque measured at the same fascicle lengths will be removed to calculate active torque.[23] Torque will be normalised to PCSA in each participant.

Neural properties: Tibial nerve stimulation will be used to evoke contractions of the triceps surae muscles via a constant current stimulator (DS7AH, Digitimer, Hertfordshire, UK) controlled via a Labview custom user interface. Participants will be prepared by shaving, abrading and cleaning the skin in the popliteal fossa. One Ag–AgCl electrode will be placed on the skin surface proximal to the popliteal crease to deliver the current (24 mm, Tyco Healthcare, Hampshire, UK). A moveable stimulating probe held at various points at the back of the knee distal to the popliteal crease will be used to find the maximum M-wave response of the MG. While the individual relaxes, a double pulse stimulation (stimulation interval of 10 ms) at a constant voltage will be applied and the M-wave response will be monitored following each stimulation. The second skin electrode will then be placed on the area where the largest twitch force is elicited. A single-stimulus square-wave pulse with a width of 0.5 ms (400 V with a current of 20–150 mA) will then be incrementally increased until the twitch amplitude and M-wave plateau. The current will then be increased by 25% to ensure supra-maximal stimulation of the intramuscular nerve branches, and this value will be used in all subsequent supra-maximal twitch trials.

The level of voluntary activation in the triceps surae muscles will be evaluated using the interpolated twitch technique.[86] During the MVICs at neutral ankle angle a supra-maximal electrical stimulus will be delivered (1) during the MVIC torque plateau (peak interpolated twitch torque) and (2) within 2 s following relaxation (peak potentiated evoked twitch torque). Maximum voluntary activation will be determined at neutral ankle angle in all participants using the ratio of peak interpolated twitch torque to peak potentiated evoked peak torque, expressed as a percentage.[86] This method of estimating maximum voluntary activation level is reliable (ICC 0.96–0.99)[86] and has been used to evaluate the level of voluntary activation in different populations[87] as well as to determine any changes in voluntary activation following interventions such as resistance training.[88] Tibialis anterior co-contraction will be assessed using the ratio of mean root mean square EMG amplitude in the active plantar flexor versus dorsiflexor MVICs at the same angle (expressed as a percentage).[89]

Secondary outcomes

Intramuscular fat content

MRI will be used to measure the muscle and the intramuscular fat content of the MG, LG, SOL and TA muscles. Participant setup in the MRI gantry and image acquisition will be identical to that described above. Separate water and fat images will be calculated within the MRI scanner software (syngo MR B19) using the known chemical shift between the water and fat signal components. The borders of the MG, LG, SOL and TA will be manually segmented on the Dixon water images using Osirix[90] (V.6.0.2, Pixmeo SARL, Geneva, Switzerland) to create regions of interest. Intramuscular fat content will be calculated using a ratio of the water and fat signal intensities within the region of interest in each muscle. Measures of intramuscular fat content using this method have been shown to be reproducible within 0.33% in young adults with bilateral CP,[22] with a high intertester coefficient of variation of 1.43%.[91]

Isometric muscle strength

Isometric muscle strength of the plantar flexor and dorsiflexor muscles will be measured with a Biodex isokinetic dynamometer using the protocol and patient setup described above. The maximum peak ankle plantar flexion and dorsiflexion torque obtained from two MVICs at each joint angle will be used for the analysis.

Anaerobic power

Anaerobic power output of the participants will be assessed using the Muscle Power Sprint Test[92] (MPST). Following a warm-up of 5–10 min (cycle ergometer), participants will be required to complete six 15 m runs as quickly as possible with 10 s rest between sprints. Power output can be calculated as the product of body mass and distance,[2] divided by time.[3 92] Participants will be familiarised with the distance and rest time of the test by walking a practice trial. The test will be performed indoors on a straight, flat, non-slippery surface, and sprint times will be recorded using timing gates. The MPST has been validated against the Wingate Anaerobic cycling Test,[93] and has excellent test–retest reliability (ICC 0.98) in children and adolescents with CP.[92]

Agility

The 10×5 m sprint test is a simple and inexpensive measurement tool that will be used to assess an individual's ability to change direction rapidly without losing balance.[92] Participants will be asked to perform 10 5 m sprints continuously between two sets of cones on an indoor, non-slippery surface. Total time to complete the 10 sprints will be recorded using timing gates. This test has high test–retest reliability (ICC 0.97) in children and adolescents with CP.[92]

Functional strength

A 30 s RM test will be used as a functional strength assessment involving components of balance, speed, endurance and muscular strength.[94] Participants will complete as many repetitions as possible in 30 s of the following exercises: (1) lateral step up (performed unilaterally), (2) sit to stand (performed bilaterally) and (3) stand from half kneel (performed unilaterally); 180 s rest will be given between each exercise. The total number of repetitions performed in 30 s for each exercise will be recorded, summed and used in the analysis. This form of functional strength testing has high intertester reliability (ICC 0.91–0.96),[94] and coefficient of variation ranging from 10.9% to 39.9%.[94]

Walking ability

The 6-minute walk test (6-MWT) will be used to assess the maximum distance participants can walk during a 6 min period. Participants will be verbally instructed to walk non-stop around a 30 m indoor, flat, non-slippery circular track for 6 min as quickly as possible (without running). A familiarisation of the test will occur on a separate occasion prior to the assessment. An examiner will follow the participant during the test for safety purposes. The 6-MWT will be videoed to calculate total distance walked (m) and fastest walking speed (m/s). The 6-MWT has excellent test–retest reliability (ICC 0.98)[95 96] in children with CP.

A timed stairs test will assess the time taken for participants to go up and down a five-step set of stairs.[53] The test requires participants to walk up five stairs as quickly as possible (without running), using the handrails if necessary, then turn around on a platform and walk down the stairs as quickly as possible. The test will be videoed to calculate the time (s) taken to complete the test successfully. Separate times will be calculated for the up and down components of the test.

Preferred walking speed (m/s), cadence (steps/min), step length (m), 3D gait kinematics and kinetics will be computed after the participants walk on a force instrument treadmill (AMTI, Arlington, Texas, USA). 3D motion capture reflective markers will be attached to the pelvis, and upper and lower limbs, and position recorded at 200 Hz using an eight-camera, 3D motion capture system (Qualysis, Gothenburg, Sweden). To ensure participants are comfortable using the treadmill, they will be made aware of the safety stop buttons and the handrails. The participants will initially walk at a slow pace while holding the handrails and the speed will be increased slowly until a comfortable walking speed is achieved. When comfortable using the treadmill, the participant will be asked to walk without holding the handrail. Participants will then be required to determine their self-selected walking pace by increasing/decreasing the treadmill at 0.2 km/h increments each 30–60 s until they report that the speed is most comfortable without holding the hand rails. Data will be collected from participants walking at a self-selected speed on flat, an uphill (7%) and downhill gradients (−7%). Ten complete strides will be collected from each leg and the average of five complete strides will be used in the analysis for each participant.

In vivo muscle mechanics during walking

Two-dimensional B-mode ultrasound will be used to examine MG muscle function during treadmill walking by attaching a flat ultrasound transducer (LV7.5/65/64D, Telemed Echo Blaster 64 EXT-1T, Vilnius, Lithuania) to the surface of the skin above the MG muscle, and recording muscle fascicle length changes as described previously.[30] Muscle fascicle behaviour during walking will be analysed using the semiautomatic process described earlier which has been shown to be highly repeatable (CMC 0.88).[82] The average of five complete strides will be used in the analysis for each participant to ensure the overall reliability of muscle fascicle length data.[97] Surface EMG will also be collected from MG, LG, SOL and TA muscles to assess muscle activation and timing during gait (Digitimer Ltd, Welwyn Garden City, UK).

Participation

The Assessment of Life Habits (Life-H 3.0)[98] questionnaire (general long form) will be administered to assess an individual's perception of participation related to daily activities, and social roles across 12 domains (nutrition, fitness, personal care, communication, housing, mobility, responsibilities, interpersonal relationships, community life, recreation, education and employment). Adequate to excellent internal consistency (α 0.73–0.90) and test–retest reliability (ICC 0.73) has been reported for this questionnaire.[99] Six domains will be evaluated in this study including fitness, mobility, recreation, community life, education and employment. These areas were identified as they potentially reflect the difficulties for young adults with spastic-type CP that may be impacted by the intervention.

Masking

Masking of the participant from the intervention is not possible due to the nature of the study. Neuromuscular data will be quantitatively analysed and masked to group allocation. The physical performance measurements will be performed by the same researchers who will also be providing the training intervention due to practical limitations. However, any bias will be overcome by the objective and quantifiable nature of the outcome measures.

Statistical analyses

Generalised estimating equations for longitudinal analysis[100] will be used to evaluate differences in continuous data between groups for the two postbaseline assessments on an intention-to-treat basis. This method takes into account the dependency of repeated measures in the same participant and any missing data. To evaluate the effectiveness of the intervention, the interaction term of group and time (group×time) will be assessed. Statistical significance will be accepted at $p<0.05$ and the statistical analysis will be performed using SPSS V.20 (SPSS, Chicago, Illinois, USA).

ETHICS AND DISSEMINATION

Ethical approval and trial registration

Full ethical approval has been granted by the Medical Research Ethics Committee of The University of Queensland (2014000066), and the Children's Health Queensland Hospital and Health Service Human Research Ethics Committee (HREC/15/QRCH/30). The trial has been registered with the Australian and New Zealand Clinical Trials Registry (ACTRN12614001217695).

Any substantive protocol amendments will be submitted formally to the Ethics Committees of The University of Queensland and Children's Health Queensland, and not implemented until approved. The registered trial details will also be updated to reflect any approved amendments to the protocol. Participant information and consent forms will be provided by the researcher for all participants involved in the trial. These documents have been amended accordingly in order to provide separate information sheets and consent form which are suitable for children and teenagers. Participants will be given the opportunity to discuss their involvement in the project and ask questions. Informed, written consent will be obtained from all participants over the age of 18 years before entering the trial. Parents or guardians will provide informed, written consent for participants younger than 18 years, and assent will be obtained from participants (if younger than 18 years) before entering the trial.

Data storage and dissemination of findings

Individual data will be monitored by study investigators on completion of testing and during the intervention. No data monitoring committee has been established as the study is not a drug trial, and any adverse events will be identified by study investigators during testing and training. Participant information will be stored in locked filing cabinets at the study site. All data, reports and administration forms will be identified by a coded identification number to maintain participant confidentiality. The final data set will only be accessed by study investigators. Trial findings will be disseminated by publications in peer-reviewed journals, conferences and local research organisations' newsletters and publications. Results will be disseminated regardless of the magnitude or direction of effect. Any decision to describe interim results, stop or terminate the trial will be made by study investigators.

DISCUSSION

This paper presents the study protocol for a RCT investigating the efficacy of a combined FAST programme on skeletal muscle properties and muscle function in adolescents and young adults with spastic-type CP. Critical aspects of the training study are presented in detail regarding the training frequency, volume, duration, intensity and individual progression. The type and technique of each exercise included in the training programme has been standardised and described.

Previous RCTs of strength training interventions in individuals with CP have assessed their effectiveness using performance outcome measures such as strength, walking ability and gross motor function, with conflicting results.[48–50 53 66] To the best of our knowledge, no RCTs have measured the effects of resistance training on lower limb skeletal muscle properties and in vivo muscle function under controlled movements and during walking in this population. Furthermore, it is hypothesised that the addition of functional anaerobic training will enhance the transfer of strength gains to functional performance. Understanding the neuromuscular adaptations following combined FAST in individuals with CP might influence the prescription of exercise training in this population and help guide future conservative treatment decision-making.

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Contributors JGG, GAL, RNB and LAB defined the original study protocol, and JGG led the modification of the study protocol to the present study design and format. JGG, GAL, RNB and LAB developed the training programme design. JGG, GAL, RNB, and LAB are responsible for all ethics applications and the ethical reporting of the study. JGG, GAL, RNB and LAB are responsible for recruitment, data collection and implementation of the study. JGG, LAB and GAL will take lead roles on preparation of publications on the neuromechanics outcomes of the study and JGG, LAB and RNB will take lead roles on the clinical outcomes publications from the study. LAB, GAL and RNB will supervise JGG (PhD student) during the trial. All authors have read and approved the final manuscript. All investigators (JGG, GAL, RNB and LAB) will have the ultimate authority over all study activities.

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