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Determining the most effective exercise for gluteal muscle activation in children with cerebral palsy using surface electromyography

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ABSTRACT

Background: Reduced lumbo-pelvic postural control is a common feature of gait in children with Cerebral Palsy (CP). These features are commonly attributed to insufficiency of the hip musculature as well as underlying bony geometry. Exercises aimed at strengthening the hip muscles are frequently prescribed in children with Cerebral Palsy (CP). There is a lack of evidence indicating the most effective exercises in targeting gluteal muscle activation in this population.

Research question: To determine the most effective exercise for gluteal muscle activation in children with CP.

Methods: This was a cross-sectional study of children with CP. Surface EMG data from the gluteus medius (GMed) and maximus (GMax) on the more involved limb were recorded as participants completed 6 commonly prescribed gluteal strengthening exercises. EMG was assessed for peak activation, normalised to functional reference values.

Results: Data from ten children (5 males, 5 females; mean +- SD age, 13+-3 years) were included for final analysis. The single leg bridge and step up were the most effective exercises for gluteal muscle activation. Differences in activation were found to be statistically significant using Friedman's rank test (GMax p = 0.0001, GMed p = 0.0023).

Significance: This study is the first to show clear differences in activation across gluteal strengthening exercises in a CP population. Exercises which involve weight bearing through a single limb appear most effective in activating the target muscles i.e the single leg bridge and the step up. Exercises involving double limb support or open-chain movements were less effective. The results of this study indicate that careful exercise selection is required to achieve targeted muscle activation in a paediatric CP population. The results of this study will provide guidance for exercise prescription for gluteal strengthening in this population and will inform future research studies on the effectiveness hip muscle strengthening programmes in CP.

1. Introduction

Insufficiencies in hip extensor and abductor muscle function are common features seen in children with cerebral palsy (CP), contributing to altered patterns of movement about the lumbar spine, pelvic and hip regions including excessive trunk lean and pelvic movement [1–3]. Such patterns lead to alterations in force attenuation, particularly in reducing the hip abductor moment during single limb support in gait. The functional effect of such compensations include reduced control in single limb stance, altered loading patterns at the hip joint and negative aesthetic impact on gait patterns [4–8]. In particular negative impacts on participation are a concern [7,9].

The aetiology of hip related movement compensations is multifactorial. Weakness, impaired motor control, spasticity and altered joint and bony morphology are common features in CP [10]. Interventions aimed at addressing these issues include spasticity management as well as orthopaedic surgery about the pelvis and femur [2,10–14]. However, physiotherapy based intervention including gait retraining and muscle strengthening are commonly prescribed in these children as part of routine, as well as post-operative management [7,15]. In particular, strengthening exercises targeting the gluteal musculature are prescribed in attempting to address compensatory movement patterns, and in doing so, maximise walking function and promote independence and participation.

The research base for strength training in CP is growing. However systematic reviews of this research have often reached conflicting and inconclusive conclusions due to heterogeneity of methods and outcomes, as well as small sample sizes [16]. There is limited evidence to

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indicate improvements in gait and gross motor function following strength training in individuals with CP [17–19]. Van Vulpen et al [20] have also shown benefits in terms of participation following muscle power training via parental report of goal attainment. There are extensive guidelines available in relation to strength training in typically developing adolescents and children [21–23]. Based on these guidelines, and in acknowledging the particular challenges posed in a CP population, Verschuren et al [24] have suggested a number of strengthening principles which should be considered when designing research protocols measuring strengthening in children and adolescents with CP. Although acknowledging that the optimal strengthening protocols have yet to be determined in this population, these authors highlight the risk that movement compensation, increased fatigue and reduced motor control may impact on the effectiveness of strengthening exercises in a paediatric CP population. They suggest single-joint training, of sufficient intensity, over a prolonged period (> 12 weeks) with sufficient incorporated rest periods may be optimal when designing training protocols. They also highlight the potential for biofeedback to enhance training outcomes in this population.

A key aspect of successful strengthening is to ensure the specificity of muscle group activation [21–23]. Surface electromyography (EMG) allows for direct, real-time, objective measurement of muscle activation during functional tasks. This allows for quantification of successful activation of a targeted muscle. The aim of this study is to explore EMG activation levels in the gluteus medius and maximus muscles during commonly prescribed muscle strengthening exercises, in a group of children and adolescents with CP and identified hip and pelvic control deficits in gait. The purpose of this study is to inform exercise selection in this population.

2. Materials and methods

2.1. Subjects

This is an observational cross sectional study of eleven children with cerebral palsy who were recruited via convenience sampling. Subject characteristics are outlined in Table 1. Prior ethical approval was obtained from the Royal College of Surgeons in Ireland and the study was further approved by our institutional ethics review board. Informed parental consent and participant assent was obtained prior to formal enrolment in the study.

2.2. Inclusion/Exclusion criteria

All subjects had a diagnosis of bilateral or unilateral CP. Subjects were eligible to take part if gluteal muscle strengthening was identified as a treatment goal by their physiotherapist due to poor lumbo-pelvic-hip control being identified as a problem in gait. Subjects were between the ages of 7 and 17. All subjects were ambulant (GMFCS level 1 and 2). Subjects were excluded if they had received botulinum toxin injection or had undergone lower limb surgery within 6 months of the study enrolment so as to avoid confounding results secondary to iatrogenic weakness.

Table 1
Subject characteristics.

Characteristic	n = 11 **Mean (SD)**
Age (years/months)	13y5m (3y2m)
	Percentage (%) (n)
Gender (F/M)	54.5 (6) / 46.5 (5)
More effected limb (R/L)	54.5 (6) / 46.5 (5)
Gross motor function classification scale (GMFCS):	63.6 (7)
1	
2	36.4 (4)
Diagnosis:	45.45 (5)
Diplegia	
Left Hemiplegia	45.45 (5)
Right Hemiplegia	9 (1)

Table 2
Description of selected exercises targeting the gluteal musculature.

Exercise	Description	
Clam	*Start:* Subject side lying. Knees and ankles together. Knee flexed to 90°. Pelvis perpendicular to surface of bed *Action:* Subject maximally elevate uppermost knee while keep ankles together. External stabilization of pelvis provided if required.	
Lunge	*Start:* Subject in high kneeling (test limb in front). Both knees flexed to 90°. Fixed external support (plinth) provided for stability *Action:* Subject elevates to maximum height while maintaining stance and returns to start position. Instructed to use upper limbs for balance only.	
Squat	*Start:* Subject stands facing bed, feet approximately shoulder width apart. *Action:* Subject lowers buttocks towards floor while maintaining upright trunk and attempting to keep heels on floor. Instructed to use upper limbs in contact with plinth for balance only.	
Step-up	*Start:* Foot of test limb place on step/bench set to 50% of the subject knee height from the floor. *Action:* Subject lifts contralateral limb on to bench/step and lowers contralateral limb to floor. Test limb remains on bench throughout. Instructed to use upper limbs in contact with plinth for balance only.	
Single leg bridge	*Start:* Lying in supine with knee of test limb flexed to 90°. Contralateral hip flexed and knee extended so both thighs are parallel but not in contact. *Action:* Subject lifts pelvis to maximum height and returns, with control, to start position. No pelvic rotation permitted. (Note: where subjects were unable to perform this technique they were allowed to lift pelvis with two feet in contact and then extend contralateral knee).	
Prone hip knee extension	*Start:* Subject kneels on bench, trunk fully supported by plinth with hips and knees in 90° flexion. *Action:* Subject fully extends test hip while simultaneously extending the knee and returns to start position. No pelvic/trunk rotation permitted.	

2.3. Exercise selection

We elected to limit our analysis to six commonly prescribed exercises targeting the gluteal musculature in children with CP in order to minimise subject fatigue and compliance issues. One author (MJ) chaired a focus group with > 10 senior physiotherapy staff in a specialist centre for the treatment and management of physical disability in Ireland. Following approximately a 1 h discussion, the focus group selected the list of exercises outlined in Table 2 for further analysis based on current use and professional preference.

2.4. Data collection

Subjects attended a gait and movement analysis laboratory on one occasion for testing. Equipment was placed on the subject by an experienced physiotherapist (CD or AM) specialised in the area of gait and movement analysis with relevant doctoral level qualifications, and more than 10 years clinical experience. EMG electrodes were placed on the hemiplegic limb or, in the case of a bilateral presentation, the more affected limb as identified by their treating physiotherapist. Following skin preparation, bipolar pre-amplified silver-silver chloride electrodes were placed over the mid-belly of the gluteus medius and maximus as per SENIAM guidelines [25]. A ground electrode was placed over the greater trochanter. EMG data were captured using the Noraxon Telemyo system (amplification factor 1000, 1500 Hz capture frequency). Data were collected throughout each movement repetition and the entire dataset was included for analysis.

Concurrent measurement of limb movement was conducted using the Codamotion system (Charnwood Dynamics Ltd, Leicestershire, UK). Infra-red emitting diodes were placed over the 5th metatarsal head, lateral calcaneus, lateral malleolus, lateral femoral epicondyle, greater trochanter (on top of the ground electrode), anterior superior iliac spine and posterior superior iliac spine of the test limb. 3D kinematic data was not collected and the limb position was used only to confirm start and end points of each exercise. EMG and movement data were collected simultaneously.

Subjects performed two additional exercises for the purpose of EMG normalisation. A single repetition prone hip extension and side lying hip abduction, both performed with an extended knee, were completed without resistance in order to obtain reference EMG values for the gluteus maximus and gluteus medius respectively. Subjects performed the exercises outlined in Table 2 in a random order as determined by the drawing of lots. For each exercise, the subject was instructed in technique and a trial repetition completed. Following any corrections to technique, the subject performed four repetitions during which EMG and movement data were collected continuously.

2.5. Data analysis

Data was analysed offline using a custom written Matlab programme (Version 2016b, The Mathworks Inc. Natick, MA, USA). Movement data was used to segment the datasets into individual repetitions across each exercise. The marker(s) with the maximum change in position for each exercise were selected to determine start and end points for each repetition. Raw EMG data was extracted for both the gluteus medius and maximus for the full duration of each repetition, for each exercise, across all subjects. Data adversely affected by motion artefact was omitted from final analysis. EMG data was band pass filtered between 10 and 500hz to remove non EMG artefact. We also applied a notch filter about 50hz to remove any power line interference. The filtered data was full wave rectified and smoothed using the Root Mean Squared (RMS) approach. A non-overlapping 200hz window was employed in this approach. RMS signal for the six test exercises was normalised using the peak RMS signal from the prone hip extension and side lying hip abduction exercises for the gluteus maximus and medius respectively. For each subject, the maximum normalised EMG signal was calculated for each repetition of each exercise. The average maximum signal across all repetitions was calculated for each exercise for each subject. Given the non-parametric distribution of these normalised maxima, the rank order of the median group data was examined using a Freidman Rank test. Power calculations were conducted on the results

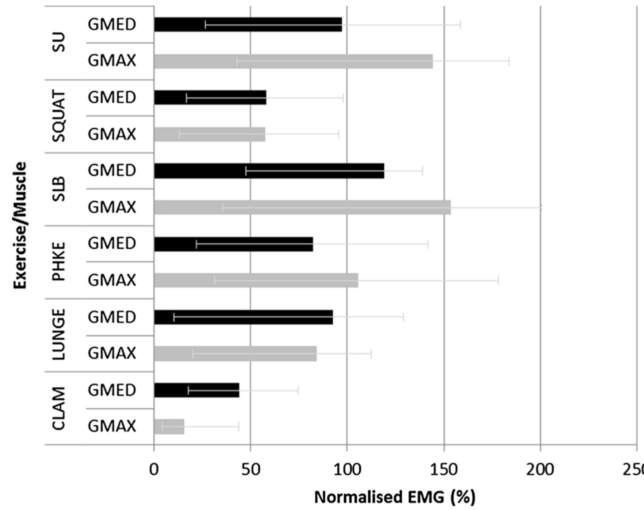

Fig. 1. Median peak and interquartile range EMG levels for the gluteus medius (black) and maximus (grey) normalised EMG across all exercises. SLB = single leg bridge, SU = step up, PHKE = prone hip knee extension, GMED = gluteus medius, GMAX = gluteus maximus.

obtained to ensure sufficient beta values based on the ability to detect a 20% difference in EMG activation.

3. Results

Data from one subject was omitted owing to the absence of acceptable EMG data. Therefore 10 subjects were included for final analysis. A power analysis using the collected dataset indicated a beta value of 0.8 based on the ability to detect a 20% change in EMG activation

There were clear differences in EMG activation across the six exercises. This finding is confirmed by the Freidman Rank test for gluteus maximus ($p = 0.0001$) and gluteus medius ($p = 0.0023$) activation across all six exercises. A graphical summary of the results is provided in Fig. 1.

The results indicate that both the 'Single Leg Bridge' (gluteus maximus median EMG 153.7%, Inter-quartile range (IRQ) 118.2, 200.8%; gluteus medius median EMG 119.3% IQR 72.0, 38.9%) and 'Step-Up' (gluteus maximus median EMG 144.6%, IQR 101.8–183.8%; gluteus medius median EMG 97.2%, IQR 70.6–158.7%) are most effective at activating the gluteus maximus and medius. The 'Clam' appears least effective at activating these muscles when considering EMG amplitude (gluteus maximus median EMG 15.7%, IQR 11.6–43.8; gluteus medius median EMG 44.2%, IQR 26.6–74.4%). The reader is directed to Figure 2 (available as supplementary data) for the graphical representation of normalised EMG amplitude across all repetitions and subjects for the full duration of each exercise. In particular, we highlight the expected inter-subject variability in duration and amplitude of contraction as being a feature of this dataset.

4. Discussion

This is the first study to quantify EMG amplitude across a range of hip strengthening exercises in a paediatric CP population. The 'Single Leg Bridge' and 'Step-Up' are the most effective exercises at activating the gluteus medius and minimus of the six exercises considered within this paper. These exercises are executed while weight bearing on a single-limb. The other weight bearing exercises examined during this project were the 'Squat' and the 'Lunge'. However, these exercises are performed while weight bearing on both legs and therefore may allow for compensatory use of the less effected limb, thus reducing the levels of activation in the target muscles. The 'Clam' and 'Prone Hip Knee Extension' are non-weight bearing and appear less effective at activating the target muscles perhaps due to reduced load intensity.

The principles of muscle strengthening are well established in literature relating to typically developing children and adolescents [21–23]. Key features of successful strengthening protocols include individualisation of programmes; progressive overload; specificity in terms of muscle group, muscle action, energy systems used as well as velocity of contraction; delivery of sufficient exercise volume and load intensity to reach training goals, sufficient frequency of loading; provision of adequate rest periods for recovery; selection of appropriate form of resistance; and the design of appropriate training variation and periodisation to maximise muscle adaptation [21–23]. In a CP population, it is recommended that protocols consider the potential for compensatory movement to offload target muscles and that complexity of tasks be matched to individual ability [24].

Muscle strengthening has become increasingly central in the ongoing clinical care of individuals with CP. When considering strengthening protocols in a CP population, one must consider the implication of the injury to the central nervous system which underlies the motor impairment. CP is a heterogeneous condition [26–28]. If only considering the singular aspect of muscle function, a child with CP may present with a range of difficulties including neurogenic and non-neurogenic muscle weakness, motor control and coordination deficits, general coordination deficits, spasticity, myotendinous contracture and altered bony geometry [10,27,28]. Some or all of these issues may be present, in varying degrees in an individual with CP, making the design of strengthening protocols challenging in this population. In particular, insuring specificity in terms of muscle group activation as well as sufficient intensity of loading are key aspects of a potentially successful strengthening regime.

The gluteus medius and maximus act, alongside other muscles, to extend and abduct the hip with the anterior fibres of gluteus medius also involved in internal hip rotation. The moment arm of these muscles alters within different ranges of the hip joint [29]. Futhermore, in CP, the bony morphology may be altered about the hip joint which will have an effect on the forces generated by the hip extensors and abductors [30,31]. Our invesitgation did not extend to the quntification of forces about the hip during the exercises examined. Direct force measurement is not possible at the hip joint, not least due to the complex lines of action of the muscles acting across the joint [32]. Furthermore the potentially altered bony geometry and neuromuscular implications of a CP diagnosis add to the complexity of such measures in our study population. Current developements in computer based modelling of muscle actions in CP are underway and may provide enhanced insight into the force generating capacity of these muscle during various strengthening exercises at an individual level.

This study has highlighted, in agreement with the theoretical constructs of Verschuren et al [24], that children with CP appear to employ compensatory strategies to offload target muscles during bilateral loading. The ‘Single Leg Bridge’ and ‘Step-Up’ are single limb loading exercises, offering gluteal muscle specific demands, without the availability of compensatory offloading to the contralateral limb. Therefore this study has confirmed appropriate specificity in terms of muscle activation using both these exercises, fulfilling one aspect of a successful strengthening protocol. This study was limited to an exploration of EMG amplitude during various exercises targeting the gluteal musculature. We did not seek to examine whether the selected exercises were sufficient to induce actual functional strength gains or resultant alterations in function and participation. In any future research which sought to explore functional strength changes, the specificity of action should also be considered in terms of contraction type (eccentric, concentric, isometric), the range at which the muscle is loaded and the velocity of the contraction. The load intensity in terms of force generation, duration of contraction and number of sets/repetitions also should be considered in terms of goal orientated exercise selection.

As children with CP have known impairments in achieving maximal voluntary muscle activation [33], we avoided using a maximum voluntary isometric contraction to normalise our EMG signal. However, we do acknowledge that our analysis was limited to an investigation of EMG amplitude. This was a valid method in the context of identifying exercises which maximally activated the target muscle. Nevertheless, an analysis of muscle activation ratios or activation frequency may have yielded further relevant data in terms of activation quality and motor-coordination. Furthermore, the gluteal muscles are large. We acknowledge the limitations of placing a single sensing pair of electrodes over the gluteal muscle bellies. Surface EMG provides an insight into muscle activity within the detection range of sensors placed on the skin over selected muscles. The signals collected are not immune to interference and impaired quality. Falla et al [34,35] present a detailed review of the physiological and non-physiological phenomena which can influence the surface EMG signal. We elected to use normalised signals to reduce the effect of inter-participant volume conductor influence on signal composition. Additionally, electrode placement was checked via manual assessment to ensure central placement over target muscle to reduce risk of crosstalk. We also filtered or data to reduce the influence of non-myoelectric signal. Nevertheless inter-subject variability in muscle volume and architecture, distribution of, and behaviour of motor-units within sensor ranges, and the number of motor units recruited may have led to some variability across our cohort.

Previous research has indicated that there are three functional subdivisions in both the gluteus maximus [36] and medius [37–39], with different parts of the muscle activated during different functional tasks. We did not measure the independent activation of these subdivisions within our cohort and therefore certain areas outside the sensing range of our electrode may have been more or less recruited during certain exercises. In addition, while the location of the innovation zone appears reasonably predictable in the gluteus maximus, there is a high level of inter-person variability in its location in the gluteus medius [40,41] which may have also impacted the amplitude recorded.

During gait, within-session EMG variability in children is approximately twice the published value for adults [42,43]. Therefore it was unsurprising that individual motor performance across the exercises varied between our participants as demonstrated in Figure 2 (supplementary data). We elected to use a robust approach to our analysis (Freidman rank test), and in spite of the individual differences, overall group performance did highlight clear differences across the selected exercises. Nevertheless, there is no single generic exercise programme that can address the highly variable presentations, impairments and goals of children with CP. Even children with similar physical presentations will vary widely in their chosen participation, their environmental circumstances, their families’ abilities to support their goals and myriad other factors as considered by the International Classification of Functioning, Disability and Health [44] which are too numerous to mention here. On the other hand, a bespoke programme for an individual with CP is very much an in individual decision, driven by the consideration of these individual factors within the therapist-client-family interaction. Our research question was motivated by the clinical dilemmas of therapists in paediatric neuro-rehabilitation who reported uncertainty in the prescription of gluteal exercises, and we sought to provide additional information that might help in this regard. Locally in our service, therapists have used the information gleaned from this study in targeting their exercise prescription, and we hope that future studies will investigate the effects of this in achieving goals pertaining to strengthening and muscle recruitment.

For practical reasons, we limited of analysis to six exercises chosen by expert consensus. This was not an exhaustive list of exercises for gluteal strengthening but rather the six most commonly prescribed gluteal strengthening exercises by therapists within our service. It is certainly possible that other exercises may have induced high activation levels. Nevertheless, our conclusions remain valid within the limits of the exercises examined. Owing to the impact on motion capture marker visibility in some of the exercise, we did not seek to explore kinematic or kinetic variables within our data. Future studies could examine the internal forces generated during strengthening exercises with the application of musculoskeletal modelling and kinetic measurement. Our sampling was via convenience approach and certainly was biased towards a population where gluteal muscle strengthening was an identified treatment goal. However, this population is one for which successful activation of the target muscles is an important individual treatment goal.

5. Conclusion

Exercises which involve weight bearing through a single limb appear most effective at activation target muscles in a CP population. Specifically the 'Single leg bridge' and 'Step-up' are most effective when attempting to activate the gluteus maximus and medius muscles in individuals where hip strengthening is a key treatment target. This study provides key information for further research examining strengthening protocols in CP. Offloading of target muscles through compensation appears to be a significant limiting factor in this population. Ensuring specificity in terms of muscle recruitment is a key first step in designing a successful strengthening programmes and biofeedback using surface EMG may provide the clinician with appropriate guidance.

Conflict of interest statement

Aside from grant funding acknowledged, the authors have no conflict of interest.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.gaitpost.2019.03.013.

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