# Electrical stimulation of gluteus maximus in children with cerebral palsy: effects on gait characteristics and muscle strength

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**The purpose of this study was to determine whether electrical stimulation of the gluteus maximus would improve hip extensor strength, decrease excessive passive and dynamic internal hip rotation, and improve gross motor function in children with cerebral palsy (CP). Twenty-two ambulant children (15 females, 7 males, mean age 8 years 6 months, SD 2 years 9 months, aged 5 to 14 years) with diplegic (*n*=14), hemiplegic (*n*=7), and quadriplegic (*n*=1) CP participated in this study. All were randomly assigned to either the stimulation or control group. The stimulation group (*n*=11) received electrical stimulation of the gluteus maximus of the most affected legs for 1 hour a day, 6 days a week for a period of 8 weeks. Electrodes were applied proximally and distally over the gluteus maximus, with the active electrode initially positioned over the motor points. The control group (*n*=11) did not receive any extra treatment. Measurements of hip extensor strength, gait analysis, passive limits of hip rotation, and section E of the Gross Motor Function Measure were made before and after treatment for both groups. Subjectively, 7 of the 11 parents thought that the treatment made a difference to their child. However, no statistically or clinically significant improvement was found in the stimulation group when compared with the control group.**

Electrical stimulation as a treatment option for cerebral palsy (CP) has been proposed after several studies in recent years (Carmick 1993, Pape 1993, Hazlewood et al. 1994, Steinbock et al. 1997). However, it has been applied in different ways, and, therefore, it is important to distinguish between the various types. First, the stimulation can be applied functionally: stimulation is triggered to assist in a functional activity (Gracanin 1984, Carmick 1993). A second way is to apply the stimulation at a low intensity, below contraction level, for several hours during the night (Pape et al. 1993, Steinbok et al. 1997, Sommerfelt et al. 2001). Finally, electrical stimulation can be applied therapeutically for shorter durations and at an intensity sufficient to cause contraction of the muscle. There are a few studies which have demonstrated that this latter form of electrical stimulation might have a place in the treatment of CP.

Dubowitz et al. (1988) applied electrical stimulation to the tibialis anterior of two children with hemiplegia while they were active. They reported an increase in maximum voluntary contraction during ankle dorsiflexion, and a subjective improvement in motor performance and gait.

In a trial using a randomized matched-control design in 10 children with hemiplegic CP in each group, Hazlewood et al. (1994) applied this type of electrical stimulation to the anterior tibial muscles for 1 hour a day, 6 days a week for a duration of 6 weeks. They reported statistically significant increases in both the active and passive range of movement of ankle dorsiflexion and in the muscle strength of the anterior tibial muscles, although they found little change to the gait pattern.

Wright and Granat (2000) applied electrical stimulation to the wrist extensor muscles of eight children with CP for 30 minutes daily for 6 weeks. Their study design included a baseline, treatment and follow-up period. A significant improvement in hand function and active wrist extension was found after the treatment period and these improvements were maintained until the end of the 6-week follow-up period.

In a recent study using a randomized control design, Park et al. (2001) described the effects of electrical stimulation applied to the abdomen and posterior back muscles in young children (aged 8 to 16 months) while sitting. After 6 weeks of electrical stimulation therapy, changes in the kyphotic angle and the Gross Motor Function Measure (GMFM) score for sitting were significantly higher in the stimulation group (*n*=14) than in the control group (*n*=12).

## STUDY RATIONALE

It is commonly accepted that muscle strength in children with CP is reduced. In a study investigating the muscle strength of children without disabilities and children with CP, Wiley and Damiano (1998) concluded that the strength of the gluteus maximus is particularly reduced in comparison with other lower limb muscles in children with CP.

The aim of this study, therefore, was to investigate whether electrical stimulation of the gluteus maximus would improve muscle strength, gait characteristics, and motor function of children with diplegic and hemiplegic CP. Further, because the gluteus maximus is also an important external rotator of the hip, it was proposed that electrical stimulation of this muscle would shift the rotation of the hip towards more external rotation both during gait and on passive examination.

The design of the study was that of a prospective, controlled, comparative pretest/posttest, single-blind study.

## Method

### PARTICIPANTS

Twenty-two children (15 females, 7 males) with CP were recruited from those who had been referred for gait analysis, and from lists of children matching inclusion criteria supplied by physiotherapists in the Lothian, Fife, and Borders area. The inclusion criteria were as follows: ambulant children with CP aged 5 to 15 years old, with no previous surgery to the hips and without severe dystonia.

Each child was matched as closely as possible with another child for age, strength of the gluteus maximus, and internal hip rotation in gait, derived from the pretreatment tests. The children of each pair were then randomly allocated to either the stimulation group or the control group. The control group received no extra treatment and all children in the study continued with their normal physiotherapy and home exercise programme.

Types of CP and ages of the children are listed in Table I. The ages of the children ranged from 5 to 14 years old. All children were independent walkers. The research protocol was approved by the Lothian Research Ethics Committee and the parents gave written permission before their child's participation in the study.

### APPLICATION OF ELECTRICAL STIMULATION

Surface stimulation was applied with the NeuroTrac2™ stimulator (Verity Medical Ltd, Chilbolton, Hampshire, UK) to the most affected leg. Adhesive electrodes were applied proximally and distally over the gluteus maximus, with the active electrode initially positioned over the motor points (Scott 1965). However, during the first 2 weeks of the stimulation the optimal position for each child was found by moving the electrodes around until a maximum contraction with the least discomfort was obtained.

Parents were asked to apply the stimulation 1 hour a day, 6 days a week, for 8 weeks. An experienced physiotherapist instructed the parents where and how to apply the electrical stimulation and visited the family on a weekly basis for 8 weeks to monitor the progress of the treatment. The children were allowed to use the stimulator in any position they found comfortable, such as while lying prone, kneeling, sitting on a soft seat, or walking, as long as it was indoors. The unit clipped easily onto a waist band or could be placed in a bag or rucksack.

The NeuroTrac2™ stimulator produced an asymmetrical rectangular biphasic waveform. The stimulation parameters chosen (Table II) are similar to those used in comparable applications (Bertoti 2000). To improve the comfort of the stimulation, a ramp time of 0.8 seconds at the start and the end of the stimulation period was included. The on-off duty cycle of 5 to 15 seconds served to reduce fatigue in the stimulated muscle.

The first 2 weeks were used to familiarize the child with the sensation and to condition the muscle. In the first week, the stimulation frequency and pulse width were 10Hz and 75μs respectively for the full 60 minutes. In the second week, the stimulation was split in two segments of 30 minutes each. In the first segment, the frequency and pulse width were 30Hz and 100μs respectively, while during the second segment the frequency and pulse width were decreased to 10Hz and 75μs. The intensity (amplitude) of the stimulation was slowly built up during these 2 weeks. For the remainder of

**Table I: Characteristics of children who took part in study**

| *Matched pair* | *Treatment group* | | *Control group* | |
|---|---|---|---|---|
| | *Age, y:m* | *Type of cerebral palsy* | *Age, y:m* | *Type of cerebral palsy* |
| 1 | 5:4 | Diplegic | 7:10 | Diplegic |
| 2 | 7:10 | Diplegic | 5:0 | Diplegic |
| 3 | 8:0 | Diplegic | 10:5 | Diplegic |
| 4 | 7:4 | Quadregic | 6:0 | Diplegic |
| 5 | 7:4 | R hemiplegic | 4:7 | L hemiplegic |
| 6 | 14:5 | Diplegic | 14:4 | Diplegic |
| 7 | 6:6 | R hemiplegic | 9:2 | L hemiplegic |
| 8 | 10:5 | R hemiplegic | 8:10 | Diplegic |
| 9 | 6:10 | L hemiplegic | 5:0 | Diplegic |
| 10 | 9:8 | Diplegic | 10:2 | R hemiplegic |
| 11 | 11:9 | Diplegic | 9:1 | Diplegic |
| Mean (SD) | 8:6 (2:10) | | 8:2 (2:11) | |

**Table II: Stimulation parameters**

| *Parameters* | *Week 1* | *Week 2, segment 1* | *Week 2, segment 2* | *Weeks 3–8* |
|---|---|---|---|---|
| Stimulation frequency (Hz) | 10 | 30 | 10 | 30 |
| Pulse width (μs) | 75 | 100 | 75 | 100 |
| On:off ratio (s) | 5:10 | 5:15 | 5:10 | 5:15 |
| Ramp (s) | 0.8 | 0.8 | 0.8 | 0.8 |
| Duration (min) | 60 | 30 | 30 | 60 |

the period the frequency and pulse width were maintained at 30Hz and 100µs for the full hour.

Compliance could be checked on the stimulator, which could display the time for which the unit had been in use. However, the unit did not display this information if the full hour of stimulation was split into, for example, two 30 minute sessions. For this reason, the parents were also asked to keep a diary of stimulator usage.

Because of practical limitations, the 22 children participated in the study in three blocks. The first block (seven children) began the study in April 2001, the second block (eight children) in June 2001, and the third block (seven children) in September 2001.

### MEASUREMENTS

All children attended two measurement sessions an average of 10 weeks apart (range 8 to 12 weeks). During this period the children in the stimulation group received electrical stimulation. There was an average of 7 days (range 3 to 14) between the last day of stimulation and the second measurement session. The experimenters who performed the assessments were blind as to who had received the electrical stimulation treatment.

The following measurements were taken for all participants before and after the treatment period: three-dimensional gait analysis, gluteus maximus strength, passive range of movement of the hips, and section E (walking, running and jumping) of the GMFM.

### *Gait analysis*

Three-dimensional gait analysis was undertaken with a six-camera Vicon 370 motion analysis system (Oxford Metrics, Oxford, UK) and one Kistler force plate (Kistler Instrumente AG, Winterthur, Switzerland).

Two marker sets were used concurrently (Fig. 1). The first was the marker set required for data processing with the Vicon® Clinical Manager (VCM) software. The VCM marker set was used to derive the joint angles, moments, and stride parameters. Second, the marker set described by Cappozzo et al. (1995), which is thought to produce more accurate kinematic data (Cappozzo et al. 1996) was used to derive hip rotation. Joint moments were normalized to body height and weight (Hof 1996).

At the Anderson Gait Analysis Laboratory, regular testing of clinicians' placement of markers on participants without disabilities is performed. These quality assurance tests for the effect of marker placement on hip rotation in gait, revealed coefficients of repeatability (Bland and Altman 1986) of less than 6.3°.

Because the measurement of transverse plane rotation angles is prone to errors (Kadaba et al. 1990), peak internal hip rotation during gait was also estimated from close-up video recordings. Estimation of the hip rotation to the nearest 5° was facilitated by rotation indicator blocks attached to the thighs and pelvis (Hillman et al. 1998).

### *Muscle strength*

The strength of the gluteus maximus was measured with the Myometer (MIE Medical Research Ltd., Leeds, UK) using the test position described by Kendall et al. (1993). The child lay prone with the hips flexed over the edge of the plinth, and was instructed to extend the hip, while keeping the knee flexed (Fig. 2). The examiner held the contralateral leg. The MIE myometer consists of two straps on either side of a force transducer. One strap was placed around the thigh 5cm proximal to the knee joint; the other was attached to a fixed point, which was either the plinth or a 200N weight. Verbal encouragement

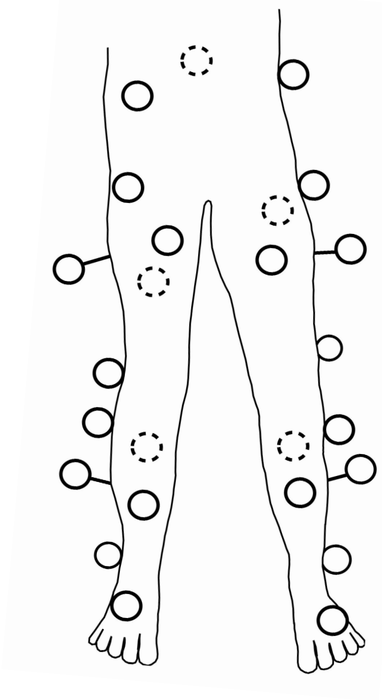

**Figure 1:** *Marker set during three-dimensional gait analysis. Markers were attached to anterior superior iliac spines, midway between posterior superior iliac spines, lateral epicondyles, lateral mallcoli, between second and third metatarsal heads, and heels (not depicted) of feet. Four markers were also attached to each thigh and shank segment. Dotted circles are posterior markers.*

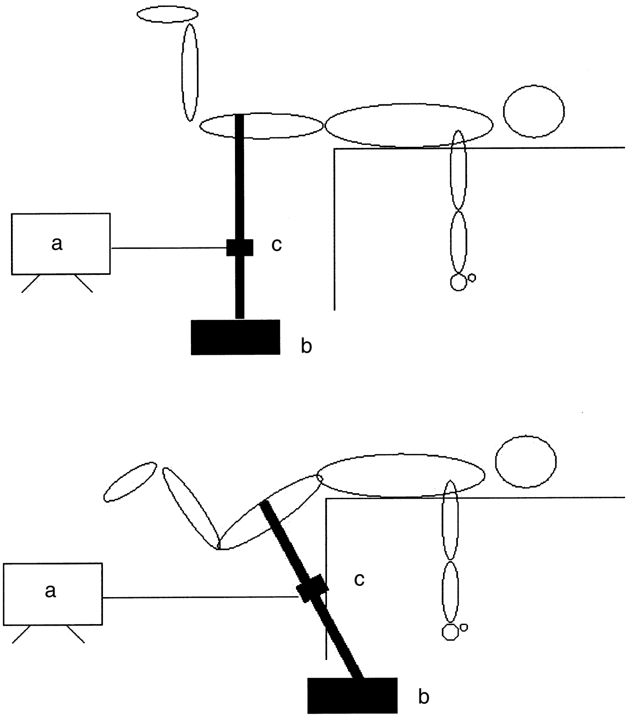

**Figure 2:** *Testing of gluteus maximus strength with hip in neutral (top) and with hip 45° flexed (bottom) using MIE Myometer. (a) display monitor; (b) 200N weight or fixed point of plinth; (c) force transducer.*

was given. Because it was expected that not all children would be able to exert a force with the hip in neutral position, strength was first measured with the hip in 45° of flexion. For both positions, the tests were repeated three times, and the average of the three measurements was used for analysis. The resulting force values were divided by body mass. The coefficient of repeatability (Bland and Altman 1986) of two measurements taken a week apart, derived from 11 children with CP, was 1.12N/kg.

### *Passive range of motion*

The limits of passive internal and external rotation of the hips were measured in prone, with the hips in extension, using a manual goniometer to record the angle between the shank and the vertical.

The midpoint between the limits of passive internal and external rotation was calculated by taking the sum of the limits, external rotation being defined as negative, and dividing this sum by two. This midpoint was found to correlate better with rotation in gait than other passive measures of hip rotation (Kerr et al. 2003). Passive hip extension was measured with the method described by Staheli (1977).

The coefficients of the intra-observer repeatability (Bland and Altman 1986) of measurements taken a week apart were 12.4° for both internal and external rotation, and 10.2° for hip extension.

### *Gross Motor Function Measure*

Motor function was assessed by using dimension E (walking, running and jumping) of the GMFM (Russell et al. 1989).

### *Parent questionnaire*

At the end of the study, the parents whose children were in the stimulation group were given a questionnaire to obtain their views on the use of the electrical stimulator. The questionnaire consisted of 11 mainly multiple choice questions regarding the ease and practicalities of using the stimulator, whether the children liked using the stimulator, their activities while using it, and whether they thought the stimulation treatment made a difference to their child.

### STATISTICAL ANALYSIS

For both the experimental and control groups, only the data for the most affected leg were included for statistical analysis. The differences between the measurements taken at the first and second assessment of the stimulation and control groups were compared by using paired *t*-tests. A difference was accepted as statistically significant at $p<0.05$.

## Results

All children completed the trials. Of the 11 children who received the stimulation, nine obtained a strong contraction of the gluteus maximus. Partial contraction of the muscle was achieved in all cases. Contraction was assessed both visually and by palpation. Additionally, in 5 of the 11 children, the limb could be seen to roll into external rotation. However, a move into extension of the limb against gravity was not achieved.

The stimulator and the diaries kept by the parents showed that all children complied with the stimulation regime, except for one child whose compliance was variable.

### PARENT QUESTIONNAIRE

The questionnaires showed that no problems were encountered using the stimulator, and the majority of the parents thought it was easy to use. Of the 11 children who used the stimulator, four quite liked it, five did not mind, one just tolerated it, and two children disliked using the stimulator. The reasons given for disliking using the stimulator were 'not liking the sensation' (one child) and the fact that it 'interfered with his normal activities' (second child). Most children

**Table III: Mean (SD) of the differences between measurements before and after treatment for stimulation and control group**

| *Variable* | *Stimulation group* | | | *Control group* | | | *p* |
|---|---|---|---|---|---|---|---|
| | *Pretest* | *Posttest* | *Difference (95% CI)* | *Pretest* | *Posttest* | *Difference (95% CI)* | |
| GMFM (% of maximum score on section E) | 80.6 (13.6) | 82.7 (13.7) | 2.1 (–4.6 to 8.8) | 80.6 (14.8) | 82.2 (14.1) | 1.6 (–4.3 to 7.5) | 0.85 |
| Strength (N/kg) | 2.4 (1.3) | 2.7 (1.3) | 0.3 (–1.2 to 1.8) | 1.7 (0.7) | 2.5 (0.9) | 0.8 (–1.2 to 2.8) | 0.22 |
| Max. internal rotation in gait (degrees; Vicon) | 9.4 (11.1) | 9.4 (9.5) | 0.0 (–19.8 to 19.9) | 12.7 (11.2) | 14.3 (10.7) | 1.6 (–13.9 to 17.1) | 0.94 |
| Max. internal rotation in gait (degrees; video) | 9.5 (10.8) | 10.0 (8.1) | 0.5 (–18.9 to 19.9) | 12.3 (5.6) | 15.9 (7.0) | 3.6 (–8.9 to 16.1) | 0.39 |
| Midpoint passive internal and external rotation | 20.9 (7.4) | 18.0 (7.2) | –2.9 (–16.6 to 10.8) | 19.9 (5.3) | 17.1 (5.6) | –2.7 (–11.7 to 6.3) | 0.78 |
| Max. hip extension in gait (degrees) | 1.8 (7.1) | 0.8 (8.4) | –1.0 (–15.1 to 13.1) | –2.2 (7.3) | –2.0 (7.9) | 0.2 (–10.4 to 10.8) | 0.71 |
| Max. hip extension (passive; degrees) | 7.8 (7.6) | 8.3 (8.2) | 0.5 (–11.7 to 12.7) | 4.7 (4.6) | 7.6 (4.1) | 2.6 (–8.6 to 13.8) | 0.74 |
| 10×max. hip flexion moment (dimensionless) | 0.64 (0.30) | 0.70 (0.43) | 0.06 (–0.6 to 0.7) | 0.68 (0.28) | 0.64 (0.19) | –0.04 (–0.5 to 0.4) | 0.48 |
| Stride length (m) | 1.14 (0.15) | 1.11 (0.14) | –0.03 (–0.2 to 0.1) | 1.13 (0.14) | 1.11 (0.13) | –0.02 (–0.2 to 0.2) | 0.79 |
| Speed (metres/s) | 0.96 (0.23) | 0.97 (9.23) | 0.01 (–0.2 to 0.2) | 0.94 (0.18) | 0.94 (0.25) | 0.00 (–0.2 to 0.2) | 0.86 |

*p* values shown were derived from a paired Student's *t*-test for differences between pretest and posttest measurements. An increase in passive and dynamic hip extension and hip moment and a decrease in internal rotation in gait and passive midpoint of rotation signify an improvement. CI, confidence interval; GMFM, Gross Motor Function Measure.

watched TV while using the stimulator. Children also played computer games or did their homework.

Seven parents thought that the treatment made a difference to their child, two were not sure, and two did not think the treatment made any difference.

### EFFECTS OF ELECTRICAL STIMULATION

Means and standard deviations of the measurements before and after the treatment period, the difference between the two measurements with their 95% confidence intervals, and *p* value from the *t*-test are given in Table III.

### *Muscle strength*

Only five children were able to exert a force against resistance with the hip in a neutral position for both legs; therefore, only the results of the strength tests with the hip in 45° of flexion were used for further analysis.

Muscle strength measured with the Myometer increased in both groups, the increase in the control group being slightly, but not significantly, higher than in the stimulation group.

### *Gait analysis*

Peak hip rotation in gait at the first measurement session ranged from 5° of external rotation to 36° of internal rotation over the whole participant population. At the second measurement session, peak internal rotation of the hip in gait was unchanged in the stimulation group and very slightly increased in the control group. Children in the stimulation group showed a slight decrease in peak hip extension in gait after the electrical stimulation treatment, although the control group did not. However, the above differences were not statistically significant.

For both groups, the stride parameters showed a small decrease in stride length, whereas the speed was similar in both sessions.

### *Passive range of motion*

The average limit of internal rotation decreased slightly, and the average limit of external rotation increased slightly in both groups. Passive hip extension had increased slightly but not significantly more at the second session in the control group than in the stimulation group.

### *Gross Motor Function Measure*

There was an increase in score on section E (walking, running and jumping) of the GMFM for both the stimulation and the control groups. This increase was slightly higher for the stimulation group, but there was no statistically significant difference between the two groups.

## Discussion

In this study, electrical stimulation of the gluteus maximus of children with CP for a period of 8 weeks did not result in any significant improvement in muscle strength, gait characteristics, or motor function compared with the control group. This is contrary to the findings of studies that reported an improvement after applying a similar type of electrical stimulation to children with CP (Dubowitz et al. 1988, Hazlewood et al. 1994, Wright and Granat 2000, Park et al. 2001).

The outcome of studies investigating the effects of other types of electrical stimulation, such as low-intensity stimulation, have varied. A positive effect on motor function after night-time low-intensity stimulation was reported by Pape et al. (1993) and Steinbok et al. (1997). However, recent studies by Sommerfelt et al. (2001) and Dali et al. (2002) failed to find a significant effect on motor function with low-intensity electrical stimulation for children with CP.

There are several possible explanations of why the electrical stimulation as applied in this study did not have any significant effect on any of the measurements taken.

First, it is possible that a wider pulse width, as used in some other studies (Karmel-Ross et al. 1992, Steinbok et al. 1997, Sommerfelt et al. 2001), would have made it easier to trigger a stronger contraction of the gluteus maximus. However, in a pilot study undertaken before the start of this study, it was found that a pulse width of more than 100μs resulted in a more uncomfortable contraction.

Second, the gluteus maximus is a more difficult muscle to stimulate than, for example, the tibialis anterior, because of its greater mass and its covering of adipose tissue. Therefore, it was more difficult to trigger a muscle contraction without discomfort and sufficient to elicit movement of the limb. For some children it took longer than the build-up period of 14 days to achieve a full contraction.

Third, electrical stimulation has the potential not only to increase the strength of the agonist but also, by causing motion of the joint, to stretch and thus increase the length of the antagonistic structures. The stimulation applied in this study resulted in a movement of the hip into external rotation in some cases, but did not result in extension of the hip.

This lack of movement of the hip during stimulation in the current study might explain the difference between the current study and that by Hazlewood et al. (1994), who reported an improved range of motion dorsiflexion of the ankle after stimulation of the anterior tibial muscles. In that study, the stimulation was sufficient to cause the ankle to move through its entire range of dorsiflexion.

Fourth, even when a good contraction was achieved, the resulting movement of the thigh might not have been 'functional' enough. It has been suggested (Comeaux et al. 1997) that electrical stimulation might be more successful when the movement achieved by stimulation is functional, for example, when triggered in gait (Gracanin 1984, Carmick 1993), or when it is similar to the movement in gait. The external rotation of the hip achieved in lying or sitting as triggered by the stimulation in this study is considerably different from the function of the gluteus maximus in gait.

Other factors that might be important indicators for the selection of patients for electrical stimulation are age, ambulatory status, and/or initial muscle strength. It might be that younger children will benefit more from electrical stimulation treatment. Interestingly, in this study it was one of the youngest children in the trial, a 6-year-old, who showed the most improvement after the electrical stimulation treatment. After treatment, she scored 5 points more on the GMFM, had increased muscle strength, decreased internal hip rotation in gait, and increased passive range of external rotation of the hip. Carmick (1993) also reported that younger children respond more rapidly to electrical stimulation. She suggested that abnormal movement strategies are not as habitual in the younger child and changes in muscle characteristics had not yet occurred, making a treatment effect easier to obtain. Children in the studies by Pape et al. (1993) and Park et al. (2001), in which electrical stimulation resulted in improvements, were also considerably younger (all less than 5 years old) than those in the current study (5 to 14 years old).

Steinbok et al. (1997) found that the improvement in GMFM score after electrical stimulation was greater for non-ambulant children than ambulant children. For other patient groups it has also been suggested that the more severely weakened the muscle is, the greater is the benefit of strengthening with electrical stimulation (Delitto et al. 1988).

Finally, it is possible that the lack of significant differences in the current study was caused by reduced statistical power. Power calculations performed before starting the study revealed that 15 participants in each group would be necessary for a power of 80% (with $\alpha=0.05$). However, it was not possible to recruit more than 11 participants for each group. Future studies are, therefore, required with a greater number of participants to confirm or refute the results of this study.

## Conclusion

Electrical stimulation of the gluteus maximus applied with the regime used in the present study did not result in any significant statistical or clinical improvement in hip extensor strength, gait characteristics, passive limits of hip rotation, or gross motor function.

Further research is required to determine whether the application of electrical stimulation in a more functional way would lead to better results in terms of gait characteristics and gross motor function in children with CP.

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