Electrical stimulation in cerebral palsy: a review of effects on strength and motor function

Annotation

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Interest in the area of cerebral palsy (CP) and electrical stimulation continues to grow because it has potential as a passive, non-invasive, home-based therapy, which is claimed to result in gains in strength and motor function.[1,2,3,4] If proved effective it might provide an alternative to resistive exercise techniques for children with poor selective muscle control, or indeed it might improve treatment compliance in those children who find exercise programmes difficult. Unfortunately, early reports on the efficacy of this intervention are undermined by poor methodology. A lack of consensus on optimal treatment parameters and variation in the physical abilities of the participants further confound interpretation of the literature.

Essentially, two variations of electrical stimulation are used in muscle strengthening in children with CP: neuromuscular electrical stimulation (NMES) and threshold electrical stimulation (TES). Under the Clinical Electrophysiology Section of the American Physical Therapy Association classification, both types of stimulation are classified as alternating current.[5] NMES is the application of an electrical current of sufficient intensity to elicit muscle contraction. To elicit a contraction, two electrodes are placed on the skin overlying the target musculature. Contraction occurs through the stimulation of the intramuscular branches of the nerve supplying the muscle. Two strengthening mechanisms are proposed: first, the overload principle, resulting in greater muscle strength by increasing the cross-sectional area of the muscle, and second, selective recruitment of type II fibres (fast twitch, large diameter fibres), causing improved synaptic efficiency of the muscle.[6] Stimulation can be provided regardless of the nature of the activity that the patient is participating in. However, when applied in a task-specific manner, in which a muscle is stimulated when it should be contracting during a functional activity, the stimulation is referred to as functional electrical stimulation (FES). In this review FES will be taken to fall under the heading NMES. Dubowitz et al.[7] published the first report on the use of NMES for muscle strengthening in children with CP. Since then several studies of varying methodological rigour and quality have been published.

Alternatively, TES has been described as a low-level, subcontraction electrical stimulus applied at home during sleep.[8] Pape et al., who first published its potential use,[9] subsequently proposed that increased blood flow during a time of heightened trophic hormone secretion could result in increased muscle bulk.[8] Since then, several conflicting reports on its efficacy have been published.

The following review seeks to examine the quality and results of the research, specifically addressing the efficacy of electrical stimulation in strengthening or improving the motor function of children with CP. The stimulation types and parameters employed will also be discussed.

Method

A search was conducted for articles, written in English, on the use of electrical stimulation to strengthen muscles or improve motor function in children with CP. The MEDLINE (1966 to October 2003), CINAHL (1982 to October 2003), AMED (1985 to October 2003), and PEDro (1966 to October 2003) databases

See last page for list of abbreviations.

were searched with the terms 'electrical stimulation' and 'cerebral palsy'. Further literature was obtained by exploring the reference lists of papers identified in this search. Articles were excluded if they were letters, review articles, commentaries or abstracts, if electrical stimulation was not the primary intervention, if the participants were not diagnosed with CP, or if the intervention was not primarily used to improve strength or motor performance. An exception was made for Dubowitz et al.[7] (as it was the first reported case of the use of electrical stimulation for strengthening that used objective outcome measures), in which a case series is described in a letter. This yielded a total of 18 articles: six randomized controlled trials, four uncontrolled/cohort studies, and eight case studies. Twelve of these studies looked at NMES intervention and six at the effects of TES.

The research methods employed to investigate the

Table I: AACPDM levels of evidence (Butler and Darrah)[13]

Level	*Non-empirical*	*Group research*	*Outcomes research*	*Single-participant research*
I	–	Randomized controlled trial. All or none case series	–	*N*-of-1 randomized controlled trial
II	–	Non-randomized controlled trial. Prospective cohort study with concurrent control group	Analytic survey	ABABA design. Alternating treatments Multiple baseline across participants
III	–	Case-control study. Cohort study with historical control group	–	ABA design
IV	–	Before and after case series without control group	–	AB design
V	Descriptive case series/case reports. Anecdotes. Expert opinion. Theories based on physiology, bench, or animal research. Common sense/first principles	–	–	–

Table II: Empirical research (levels I and II)

Authors	*Level/quality*	*Study design*	*Type of CP*	*Age range*	*Intervention (n)*	*Control (n)*
van der Linden et al.[17]	I/S	Matched-groups RCT	Hemiplegia (*n*=7) diplegia (*n*=14) quadriplegia (*n*=1)	5–15y	NMES (and usual physiotherapy) (*n*=11)	Usual physiotherapy (*n*=11)
Steinbok et al.[18]	I/S	RCT	Diplegia (previous SPR)	4y 4mo–10y 4mo	TES (and usual physiotherapy) (*n*=22)	Usual physiotherapy (*n*=22)
Hazlewood et al.[1]	I/M	Matched-groups RCT	Hemiplegia	5–12y	NMES (and usual physiotherapy) (*n*=10)	Usual physiotherapy (*n*=10)
Park et al.[16]	I/W	RCT	Diplegia	8–16mo	NMES (and 6wk intensive physiotherapy) (*n*=14)	6wk intensive physiotherapy (*n*=12)
Sommerfelt et al.[19]	I/W	Crossover RCT	Diplegia	5–12y	TES (and 15–30min daily stretching programme and usual physiotherapy) (*n*=12)	15–30min daily stretching programme and usual physiotherapy. Own control
Dali et al.[20]	I/W	RCT	Hemiplegia (*n*=25) diplegia (*n*=32)	5–18y	TES (and usual physiotherapy) (*n*=36)	Placebo stimulator (10min active TES, then switched off) and usual physiotherapy (*n*=21)

CT, computed tomography; GMFM, gross motor function measure; Level, level of evidence; LL, lower limb; MMT, manual muscle testing; NMES, neuromuscular electrical stimulation; PCI, physiological cost index; PDMS, Peabody Developmental Motor Scales; RCT, randomized controlled trial; Quality, methodological rigour (S, M, W, strong, moderate, or weak); ROM, range of movement; SPR, selective posterior lumbosacral rhizotomy; TES, threshold electrical stimulation; ↑, increased; ↓, decreased.

effects of electrical stimulation in children with CP vary widely, so it was necessary to evaluate the strength of the studies to determine the degree of confidence that one can place in their findings. The American Academy for Cerebral Palsy and Developmental Medicine (AACPDM) adapted the work of Sackett[10] to produce a grading system that permitted the inclusion of less rigorous study design types[11] (see Table I). This was deemed necessary within the field of developmental medicine because of the prevalence of smaller group studies and case reports. This adapted grading system is the method used by the Treatment Outcomes Committee in their evidence reports.[12,13,14,15]

The AACPDM further rated studies as strong (S), moderate (M) or weak (W), depending on the methodological quality of the study and how rigorously the study design had been followed.[11] Thus a randomized controlled trial with some methodological flaws (such as inappropriate choice of outcome measures and statistical methods, or no masking of assessors) would have a rating of level I/W, whereas a single-participant ABA design that was performed well would have a rating of level III/S. Level V studies are not rated for quality because they do not provide empirical research.

Three assessors independently reviewed each of the 18 articles using the criteria of the AACPDM classification of levels of evidence of internal validity.[11] Total agreement on the level of evidence occurred in 15 of 18 articles. The remaining 3 of 18 studies were discussed further in a group and a consensus on the appropriate level was reached. The quality ratings assigned to each study were also scored independently by each assessor and finalized by group discussion.

Results

EMPIRICAL RESEARCH (LEVELS I AND II)

Table II summarizes the design, methods and results of the six studies classified as level I evidence. By definition, these were all randomized controlled trials, three of which looked at the effects of NMES[1,16,17] and three examined TES.[18,19,20] None of the reviewed studies were level II evidence. The studies varied somewhat in terms of participant characteristics and study design. Participant numbers varied from 12[19] to 57,[20] with participants ranging in age from 8 months to 15 years and having diagnoses of hemiplegia, diplegia, or quadriplegia. Park et al.[16] looked at a much younger patient population (8 to 16 months) than the other authors and provided in-patient treatment. Generally, the muscles of the lower limb were stimulated, with treatment being given at home. Three studies varied the classic randomized controlled trial design: two by matching participants[1,17] and one by the use of a crossover design.[19]

Two level I NMES studies showed statistically significant improvements.[1,16] The study by Hazlewood et al.[1] employed NMES treatment on the anterior tibial musculature for 1 hour daily for 35 days, evaluating the effectiveness of the treatment by gait analysis and measuring range of movement and muscle strength. Statistically significant improvements were noted in passive and active ankle range of movement and in muscle strength. The Park et al. study[16] was the only one to stimulate the abdominal and posterior back muscles. Again, statistically significant improvements were observed at the level of impairment (decreased kyphotic angle and Cobb's angle) and at the level of activity limitation (improved

Muscles stimulated	*Outcome measures*	*Results*
Gluteus maximus	Gait analysis, muscle strength, ROM, GMFM, parent questionnaire	*ns* (all measures)
Abdominals, gluteus maximus, gluteus medius, quadriceps, tibialis anterior	GMFM, seated postural control measure, MMT, muscle tone, ROM, PCI	↑ GMFM score ($p=0.001$) other measures, *ns*
Tibialis anterior	ROM, MMT, gait analysis	↑ passive ankle ROM ($p=0.05$) ↑ active ankle ROM ($p=0.03$) ↑ strength ($p=0.02$)
Abdomen and posterior back muscles	Radiographic measurement of kyphotic, Cobb's and lumbosacral angle. GMFM sitting score	↓ kyphotic angle ($p<0.05$) ↑ GMFM sitting score ($p<0.05$) ↓ Cobb's angle (*ns*)
Quadriceps, tibialis anterior	Video evaluation of gait and LL function, MMT, PDMS	*ns* (all measures)
Quadriceps, tibialis anterior	Quantitative motor function tests, ROM, Ashworth scale (spasticity), muscle bulk via CT	*ns* (all measures)

Gross Motor Function Measure sitting score). It is noteworthy that the most recent, and most internally valid, of the NMES studies failed to demonstrate any statistically or clinically significant improvements with treatment.[17] In this study the hip extensors were stimulated for 1 hour per day, 6 days per week for 8 weeks. Outcome measures included three-dimensional gait analysis, myometer measurement of muscle strength, goniometric measurement of passive range of movement, and the Gross Motor Function Measure. The power of this study was reduced by an inability to recruit adequate participant numbers as defined by their pre-study estimation of sample size.

Only one of the three studies of TES supported its use,[18] demonstrating statistically significant functional changes.

Table III: Empirical research (levels III and IV)

Authors	*Level/quality*	*Study design*	*Type of CP*	*Age range*	*Intervention (n)*	*Control (n)*
Wright and Granat[4]	III/W	ABA	Hemiplegia	–	NMES ($n=8$)	No control group
Atwater et al.[21]	IV/W	Before and after case series with no control	Diplegia ($n=3$) hemiplegia ($n=7$)	5–15y	EMG-triggered NMES (and whole-body exercise programme) ($n=10$)	No control group
Pape et al.[23]	IV/W	Before and after case series with no control	Diplegia ($n=3$) hemiplegia ($n=3$)	37–58mo	TES (and usual physiotherapy) ($n=6$)	Own control
Comeaux et al.[22]	IV/W	Before and after case series with no control	Diplegia ($n=10$) hemiplegia ($n=4$)	4–14y	NMES (and 15min daily therapy programme: gait activities) ($n=14$)	No control group

EMG, electromyography; Level, level of evidence; NMES, neuromuscular electrical stimulation; PDMS, Peabody Developmental Motor Scales; Quality, methodological rigour (S, M, W, strong, moderate, or weak); ROM, range of movement; TES, threshold electrical stimulation; UL, upper limb; ↑, increased.

Table IV: Non-empirical studies (level V)

Authors	*Level*	*Type of CP*	*Age*	*Intervention (n)*
Dubowitz et al.[7]	V	Hemiplegia	3y 5mo, 3y 8mo	NMES ($n=2$)
Pape et al.[9]	V	Diplegia	13y	TES (and usual physiotherapy) ($n=1$)
Carmick[24]	V	Hemiplegia	1y7mo, 6y8mo, 10y	NMES (and task-orientated physiotherapy) ($n=3$)
Carmick[25]	V	Hemiplegia	1y 7mo, 6y 8mo	NMES (and task-orientated physiotherapy) ($n=2$)
Carmick[26]	V	Diplegia ($n=2$) quadriplegia ($n=1$) ataxia ($n=1$)	34mo, 53mo, 56mo, 33mo	NMES (and task-orientated physiotherapy) ($n=4$)
Carmick[3]	V	Hemiplegia	7y 8mo	NMES (and usual physiotherapy ± dorsal wrist splint) ($n=1$)
Beck[2]	V	Diplegia	9y	TES and daytime stimulation (and usual physiotherapy) ($n=1$)
Bertoti et al.[27]	V	Diplegia	6 y	NMES (intramuscular) ($n=2$)

ADL, activities of daily living; Level, level of evidence; MMT, manual muscle testing; NMES, neuromuscular electrical stimulation; obs, observational; PCI, physiological cost index; Quality, methodological rigour (S, M, W, strong, moderate, or weak); ROM, range of movement; TES, threshold electrical stimulation; UL, upper limb; ↑, increased; ↓, decreased.

The studies by Sommerfelt et al.[19] and Dali et al.[20] found no effect of TES after 1 year of treatment. The three TES studies employed similar stimulation parameters; however, two major differences existed between the TES studies that demonstrated no statistically significant change and the study by Steinbok et al.[18] First, Steinbok et al. recruited only children with spastic diplegia who had previously undergone selective dorsal rhizotomy and, second, Steinbok et al. stimulated a greater overall number of muscles.

EMPIRICAL RESEARCH (LEVELS III AND IV)

Table III summarizes the empirical research classified as level III or IV evidence. Of the four studies in these categories, three investigated NMES[4,21,22] and one examined TES.[23]

Muscles stimulated	*Outcome measures*	*Results*
Wrist extensors	Hand function, active ROM, wrist extension moment	↑ hand function (p=0.031–0.054) ↑ active ROM (p=0.037)
Wrist extensors or ankle dorsiflexors	Gait videography and pedogaphs, UL videography, goniometry, PDMS	*ns* (all measures)
Tibialis anterior ± quadriceps	Gross motor section of PDMS	↑ PDMS total gross motor (p=0.0139) locomotor (p=0.0079) and receipt/ propulsion (p=0.0018) scores
Gastrocnemius ± tibialis anterior	Gait videos	↑ dorsiflexion during gait (p=0.001)

Muscles stimulated	*Outcome measures*	*Results*
Tibialis anterior, extensor digitorum	Strength, fatigue, motor function	↑ strength, ↓ fatigue, ↑ gait, ↑ motor performance
Quadriceps, tibialis anterior	Standardized gait testing	↓ use of assistive devices for ambulation
Tibialis anterior, triceps surae, ±medial hamstrings	PCI, pedogaphs, gait videos, active and passive ROM	↓ PCI, ↑ active and passive ROM, improved gait parameters
Triceps, anterior deltoid, elbow and wrist extensors, finger flexors and extensors, thumb abductors and extensors	Ability to creep, ability to use both hands together, functional use of UL (all obs), ROM, grasp and release	↑ passive ROM thumb and hand, ↑ active ROM wrist, improved awareness and spontaneous use of UL, ↓ neglect of UL, improved grasp and release and gross motor function
Gluteus maximus, triceps surae, ±tibialis anterior, lateral hamstrings, external obliques	Gait (obs), ROM, MMT, foot alignment, motor function	↑ ROM, ↑ leg strength, improved balance, leg function, posture, foot alignment, motor function, ↓ falls and improved gait parameters
Finger flexors/extensors, wrist extensors	Strength, Mowery's functional hand classification	Improved hand function, ↑ shoulder strength
Erector spinae, gluteus maximus, rectus femoris, oblique abdominals, vastus lateralis, vastus medialis, tibialis anterior, gastrocnemius	Function, posture, gait (descriptive), MMT, ROM, walking speed and distance	↑ tibialis anterior muscle strength, ↑ ROM, ↑ distance ambulated, ↑ ADL function and improved gait parameters
Gluteus medius, gluteus maximus, vastus lateralis, vastus medialus, gastrocnemius, tibialis anterior	Gait analysis with pedograph paper, ROM, gross motor function	Improved gait parameters and gross motor performance, ↑ ROM

Only one paper was classified as level III;[4] the remaining three studies presented level IV evidence.[21,22,23] Again, the studies varied in terms of participant characteristics and study design. Participant numbers were generally smaller than those of the level I studies, with Comeaux et al.[22] presenting the largest sample size of 14. Pape et al.,[23] who reported the smallest cohort (n=6), also had one of the youngest groups studied, ranging in age from 37 to 58 months. The study by Atwater et al.[21] differed slightly from the others in that electromyography-triggered NMES was employed (i.e. the child was asked to contract the muscle and the EMG trace was recorded. NMES was activated when the child contracted their muscle to 40% of the recorded EMG trace). Various muscle groups were targeted, including the wrist extensors,[4,21] ankle dorsiflexors,[21] and lower limb musculature.[22,23] The study by Comeaux et al.[22] failed to isolate the effects of electrical stimulation because participants also completed 15 minutes of gait activities daily.

The study by Pape et al.[23] demonstrated improvements in gross motor abilities during two phases of TES treatment (each lasting 6 months). These improvements were not maintained during a withdrawal phase. Although inconclusive findings were reported by Atwater et al.[21] on the use of NMES, Wright and Granat[4] described improvements in active wrist extension and hand function, and Comeaux et al.[22] reported improved dorsiflexion at heel strike.

NON-EMPIRICAL STUDIES (LEVEL V)

These studies are summarized in Table IV. Dubowitz[7] published the first report on the use of NMES for strengthening in children with CP. This was followed 2 years later by the first case report of TES with a patient with CP.[9] Only one other study described the use of TES,[2] in which a male aged 9 years underwent daytime and night-time electrical stimulation in an attempt to improve gait and functional abilities. Carmick documents the effects of task-orientated NMES with a series of children of different ages and types of CP, targeting both the upper and lower limbs.[3,24,25,26] Carmick observed that the stimulation of spastic muscles in the upper[3] and the lower[26] limbs did not result in an increase in spasticity. The

Table V: Stimulation parameters

Author	*Stimulation type*	*Waveform*	*Frequency (Hz)*	*Pulse duration*	*On:off (s)*	*Ramp up/down (s)*
Dubowitz et al.[7]	NMES	–	40	250μs	–	–
Atwater et al.[21]	NMES	Asymmetric biphasic	20–100	0.3 or 1.0ms	–	–
Carmick[24]	NMES	–	5–7 ↑ to 30–35	300μs	10:25 ↑ to 15:15 or operator control	8 ↓ to 2, 0.5 with gait (ramp up)
Carmick[25]	NMES	–	5–7 ↑ to 30–35	–	10:25 ↑ to 15:15 or operator control	8 ↓ to 2, 0.5 with gait (ramp up)
Hazlewood et al.[1]	NMES	Asymmetric biphasic	30	100μs	7:15	2 (ramp up)
Carmick[26]	NMES	Asymmetric	–	–	–	–
Carmick[3]	NMES	–	7 ↑ to 10 ↑ to 35	300μs	15:15 or operator control	0.5–1 (ramp up)
Comeaux et al.[22]	NMES	–	32	–	Operator control	0.5 (ramp up)
Bertoti et al.[27]	NMES	Asymmetric biphasic	–	1–200μs (ramped)	1:2.5 (ratio)	–
Wright and Granat[4]	NMES	Cyclic	30	300μs	10:10	1 (ramp up) 1 (ramp down)
Park et al.[16]	NMES	–	35	250μs	10:12	–
Pape et al.[9]	TES	–	–	–	–	–
Pape et al.[23]	TES	Alternating coupled	35–45	300μs	1:1 (ratio)	2 (ramp up)
Beck[2]	TES	–	Day: 40	–	7:3 (greater than 2:1 ratio)	Postural muscles: 1–2 (ramp up); fast twitch fibres: 0
Beck[2]	TES	TES	Night: 35	–	12:12	2 (ramp up)
Steinbok et al.[18]	TES	–	35	300μs	8:8	2 (ramp up)
Sommerfelt et al.[19]	TES	–	40	300μs	–	–
Dali et al.[20]	TES	–	35	–	–	–
van der Linden et al.[17]	NMES	Asymmetric biphasic rectangular	10 ↑ to 30	75μs ↑ to 100μs	5:15	0.8 (up) 0.8 (down)

NMES, neuromuscular electrical stimulation; Ramp up/down, time taken to reach desired current intensity/return to zero; ROM, range of movement; Rx, treatment; TES, threshold electrical stimulation.

case report by Bertoti et al.[27] differs from all the other reported applications of electrical stimulation in that the electrodes were sited intramuscularly. Stimulation was triggered either by the parent/therapist or by a switch inserted in the participant's shoe. Treatment ceased when clinically measurable gains were maintained without the use of stimulation.

All the case reports described positive gains with the use of electrical stimulation: the most frequently reported were improvements in functional activities,[2,3,25,26,27] range of movement,[2,24,25,26,27] strength,[3,7,8,26] and gait parameters.[2,7,9,24,26,27]

TREATMENT PARAMETERS

Most authors employed similar parameters, as shown in Table V. Parameters were well defined by all except a few authors.[9,20,26] Frequencies were generally in the range 30 to 45Hz, pulse durations 100 to 300μs, and the time taken to reach the desired intensity (ramp up) ranged from 0.5 to 2 seconds. Some variation existed in the contraction/relaxation times for the activation of the muscles (on:off times). The TES on:off times were generally equal; however, with NMES some authors used equal times[3,4] and others ensured that the 'off' time was at least double the 'on' time.[1,17,27] The intensity of stimulation and duration of treatment depended on whether TES or NMES was employed, with TES tending to be applied for a minimum of 30 hours per week for 6 to 17 months. NMES was most commonly applied for 15 to 20 minutes per week in a task-orientated therapy setting,[3,24,25] or for up to 1 hour daily for 2 months when applied at home.[17]

OUTCOME MEASURES

The AACPDM framework also describes the level of evidence of a study in terms of the categories described by the International Classification of Functioning, Disability and Health (ICF).[28] The present review has not taken such an approach because it sought to discern the efficacy of an intervention as opposed to defining the level at which that intervention might or might not have taken effect. However, it is important to note that most of the electrical stimulation studies measured both impairment (indicating the problems in body structures or functions) and activity limitations (the difficulties that an individual might

Intensity (mA)	*Session duration*	*Session frequency*	*Total Rx time (h/wk×mo)*
Elicit effective dorsiflexion	1h	3/day, daily	21h/wk×2mo
0–90	20min	3/week	1h/wk×2mo
Tolerance (no higher than 50% machine maximum)	15–20min	For 10 sessions, or 1/week for longer periods	0.25–0.33h/wk×11mo
Tolerance (no higher than 50% machine maximum)	15–20min	For 10 sessions, or 1/week for longer periods	0.25–0.33h/wk×6mo
Dorsiflexion short of passive ROM	1h	Daily	7h/wk×1mo
–	–	For 8 sessions or more	–
Tolerance	15min	With therapy for 26 mo	0.25h/wk×26mo
Visible contraction	15min	3/week	0.75h/wk×1mo
20	15min	2/day, 5/week	2.5h/wk×7–10mo
10–40, maximum ROM without discomfort	30min	Daily	3.5h/wk×1.5mo
25–30	30min	Daily	3h/wk×1.5mo
–	–	Daily	–
Less than 10	9h	Daily	63h/wk×6mo
No motor response elicited	9h	3/week	2.25h/wk×17mo
At first reported sensation	0.75h	Daily	63h/wk×17mo
Less than 10	8–12h	6/week	48–72h/wk×12mo
Less than 10	At least 5h/night	6/week	At least 30h/wk×12mo
1–5	At least 6h/night	6/week	At least 36h/wk×12mo
Patient tolerance	1h	6/week	6h/wk×2mo

experience in the execution of a task).[28] It is noteworthy that none of the studies reviewed used a standardized health-related quality-of-life measure to determine whether the intervention under investigation reduced participation restrictions (the problems experienced in life situations)[28] or indeed whether compliance with the treatment protocol actually increased the participation restrictions experienced.

Discussion

Eighteen articles were identified for review in this paper. Of the 12 studies investigating the efficacy of NMES, one reported no improvement with treatment,[17] one reported inconclusive findings,[21] and the remaining 10 all described improvements in function and/or strength. In five of these studies statistical significance was reported.[1,4,16,17,22] It is noteworthy that the level I NMES studies[1,16,17] reported fewer positive outcomes than the uncontrolled studies and case reports.

Of the six TES studies, two reported statistically significant improvements,[18,23] two reported no statistically significant effects,[19,20] and the remaining two case reports described improvements.[2,9] Interestingly, the level I/W TES studies that reported no statistically significant effects with electrical stimulation[19,20] both documented a perceived positive effect of treatment as reported by parents/carers. It is also noteworthy that the participants in the study by Steinbok et al.[18] differed significantly from the participants of all the other studies in that they had previously undergone selective dorsal rhizotomy.

The scarcity of well-controlled trials makes it difficult to support definitively or discard the use of electrical stimulation in the paediatric CP population. The research is dominated by case studies and uncontrolled studies with small numbers of participants, which are thought to provide less powerful evidence than the criterion standard randomized controlled trial.[29,30] Only Steinbok et al.[18] and van der Linden et al.[17] reported pre-study estimation of sample size and power analysis. Most studies recruited either children with hemiplegia or diplegia, effectively reducing their available participant numbers and the potential for generalization of results. Dali et al.[20] acknowledged recruiting participants with hemiplegia and those with diplegia to achieve a larger sample size, and van der Linden et al.[17] reported that it was impossible for them to recruit adequate numbers of participants. No other authors reported difficulties with recruitment or strategies for ensuring adequate sample size. Poor reporting, particularly in terms of randomization procedures, detail of the intervention, type of analysis, and interpretation and generalization of the results, was more common in the studies classified as levels III, IV and V. Many of the case studies advocated the use of electrical stimulation as a useful adjunct to established physiotherapy treatment[2,9,24,25] but failed to acknowledge any potential biases in their work.

Difficulties arose when trying to compare studies owing to variations in stimulation parameters. Clarity in the reporting of stimulation parameters is essential because of their potential influence on study results and in facilitating replication and thus validation of study findings. No authors cited specific guidelines with regard to their choice of parameters. Existing guidelines differ on optimal settings, with Low and Reed[31] suggesting 50 to 100Hz for strengthening and Carmick[3] advocating 30 to 35Hz to ensure that sustained contraction is achieved. Interestingly, Balogun et al.[32] showed no significant difference in strength gains produced at 20, 45, and 80Hz in normal quadriceps musculature with the use of an NMES regimen.

Many of the studies would have benefited from the use of valid and reliable outcome measures. Improvements in strength and function were frequently documented, but the measurement tools and procedures used were not. This review has shown that it is necessary for therapists to use validated functional outcome measures when measuring functional change. However, accurate measurement of the components of functional tasks (e.g. range of movement and strength) is also invaluable because it can provide information on the causes of the problems experienced, and the mechanisms by which treatments might affect them. Quality of life, in terms of the impact of both the underlying condition and the proposed intervention on the child and family, should also be evaluated.

The issue of accurate measurement affects a key question when evaluating any treatment: how much change has to occur before it is considered clinically significant? Only Atwater et al.[21] and Steinbok et al.[18] defined clinical significance for their outcome measures. Several authors reported parent/carer perceptions of treatment effects that were not always supported by the study results.[4,17,19,20]

In conclusion it seems that there is more evidence to support the use of NMES than TES. However, the findings of the studies must be interpreted with caution because they generally had insufficient statistical power to provide conclusive evidence for or against these modalities. Further studies employing more rigorous study designs and follow-up, larger sample sizes, and homogeneous patient groups are required for the unequivocal support of the use of electrical stimulation. The age and type of patient most likely to benefit from this intervention and optimal treatment parameters are as yet unknown.

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List of abbreviations

ICF	International Classification of Functioning, Disability and Health
FES	Functional electrical stimulation
NMES	Neuromuscular electrical stimulation
S,M,W	Strong, moderate, or weak methodological quality/ conduct of trial
TES	Threshold electrical stimulation