The Effect of Therapeutic Electrical Stimulation in Children with Diplegic Cerebral Palsy as Measured by Gait Analysis

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Abstract

The present work was designed as a controlled longitudinal study to test the hypothesis that therapeutic electrical stimulation (TES) to the lower limb muscles of children with cerebral palsy (CP) can improve the quality of gait of these children. Diplegic CP was selected for this study, so that one leg served as the study leg and the other as a control. Four diplegic CP children (mean age 7.7 ± 2 years) took part. TES was delivered to the quadriceps and dorsiflexors of the right legs in 20 minutes sessions, 4 times a week for a total period of six to ten weeks. Gait assessment was made on a 3 m walkway, fitted with parallel bars. Stride length, knee and ankle range and average stride velocity were measured and compared before and after TES treatment and between the stimulated and the unstimulated legs. Results indicated that although the effect of electrical stimulation varied from one subject to the other, an overall improvement in gait quality occurred as reflected by the positive changes in the following walking variables. Stride length and Stride velocity improved in three out of the four subjects, although some of the changes were not statistically significant. Range of knee motion generally improved in all four subjects. Also the ankle range of motion improved in three subjects. Of particular interest was the surprising lack of preferential effect of TES on the stimulated (Rt) leg as compared to the other (Lt) leg.

Key words: diplegic cerebral palsy, therapeutic electrical stimulation, gait analysis.

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Children with cerebral palsy (CP) suffer from a wide range of motor disturbances [1]. Spasticity due to damage in the central nervous system is the most common neurological presentation. More than 50% of children with CP suffer bilateral type spasticity [2] and out of these diplegia is the most common type.

Rehabilitation of CP children involves the application of different therapeutic modalities [1, 3-5] the most frequently in use being: (a) physiotherapy, aimed to encourage development of normal motor system patterns that should positively influence functions of standing and walking ;(b) manual therapy, to prevent muscle and tendon contracture and to improve the range of motion of the joints; (c) local intraspinal or systematic administration of anti-spastic drugs; (d) orthoses for the adequate positioning of joints and for preservation of the range of motion; and (e) surgery for releasing and lengthening of tendons. The effectiveness associated with physiotherapy, the most commonly applied treatment has been challenged [6].

A relatively new method implemented in the treatment of children with CP makes use of therapeutic electrical stimulation (TES). The literature provides results from studies that evaluate the influence of TES on muscle strength, spasticity, motor functions, and gait (e.g. [7, 8]). The results of these studies were inconclusive and lack a consensus. Nevertheless, reports pointed to the existence of some benefits from TES, such as increase in muscle strength, decrease in spasticity and improvement in motor function and quality of gait [9, 10]. Only few studies investigated the influence of TES on gait of CP children, generally making use of subjective tools for gait evaluation [11, 12]. Based on observational gait analysis or clinical evaluation, an improvement in the gait pattern and range of motion of the joints was reported [9]. In some cases, no control group was used [8], and the stimulus characteristics were not described [14].

Observational gait analysis requires an experienced examiner and is based on subjective impression only. The alternative method is gait analysis, in which evaluation is performed by objective, quantitative measurements. Analyzing the gait of children affected by CP is a complex task since cooperation of these subjects is very limited and their gait pattern is highly irregular. A relatively simple and inexpensive method for gait analysis is by means of videography [15]. Video gait analysis has the advantage of allowing the subject to walk freely while the evaluations, either observational or quantitative, can be accomplished off-line. Usage of this tool to compare gait before and after a given therapy, may facilitate the effective evaluation of the changes in gait following intervention. More specifically, speed of gait, stride length and range of motion of the lower limbs joints are known to be compromised by an increased muscle tone and weakness in the lower limbs in diplegic children. These quantities can be measured by videography and provide information unobtainable by simple clinical observations.

The present work was designed as a prospective, controlled longitudinal study. It was hypothesized that TES to the lower limb muscles of children with diplegic cerebral palsy would decrease muscle spasticity and as a result improve the quality of gait.

Diplegic CP was selected for this study since both legs are involved and therefore one leg can serve as the "study leg" whereas the other serves as a "control leg". This within-subject design accounts for a variety of variables, including gross neurological status, individual participant characteristics such as sex, age, cognitive level and motivation, degree of intervention, and fatigue.

Methods

Subjects

Four CP children, out of 60 children attendants of a school for special education, were selected for the present study. The children's ages, two girls and two boys, were between four years and eight months and nine years and six months (mean age 7.7 ± 2 years).

Criteria for inclusion in this study were: (a) spastic diplegia defined as spasticity in the muscles of the lower limbs with only mild involvement of the upper limbs [1]; (b) ability to self-ambulate with a supporting aid; (c) cognitive level and emotional state facilitating understanding and cooperation of the participant. (d) parents' consent, as required by the ethical committee's guidelines of the Israel Ministry of Health.

All children went through a meticulous neurological and functional evaluation by an experienced pediatrician and a physical therapist in order to determine their competence to participate in the study.

Table 1 presents the description of the subjects. All the subjects used a posterior walker for ambulation and had physiotheray, occupational therapy and, language intervention program. Two of the subjects had right and two left hand preference. In three of the subjects the right leg was somewhat more spastic than the left one. The specific characteristics were as follows:

Subject 1- managed to walk with hand support without his walker. She could climb and go downstairs using the rail. She needed help dressing up but was independent in her other daily living activities.
Subject 2- needed aid in getting up from and returning to the sitting position. He was independent in his other daily living activities, other than dressing up.
Subjects 3 and 4- had the same motor and living activity as subject 2, subject 4 also used below-knee splints.

Table 1. Characteristics of the subjects taking part in the study.

	Subjects			
	1	2	3	4
Age (ys.ms)	8.3	9.6	4.8	8.2
Sex	F	M	F	M
Pregnancy	viral disease	28 wks	35 wks (polyhydroamnion)	N
Birth	N	2^{nd} twin	N	vacuum extraction
Birthweight (gm)	3130	1200	1574	3200
N.N.P.	N	complicated	complicated	asphyxia, correction of cardiac malformation
Cognitive status	mild MR	borderline	mild MR	low normal
Emotional status	anxiety	N	anxiety	N
Surgery	-	+	-	-

NNP- neonatal period, MR- mental retardation, N-normal, Surgery-achiles tendon release.

TES treatment

Electrical stimulation was delivered by means of self-adherent surface electrodes (Encore plus), using a programmable electrical stimulator, providing monophasic rectangular pulse trains [16]. Electrodes were attached over the belly of the right rectus femoris and tibialis anterior muscles. The quadriceps and the dorsiflexors were selected due to their dominance in establishing a normal and efficient gait: the first group supports body weight during the stance phase, and the second dorsi flexes the ankle joint during the swing phase and prevents dragging of the foot. The left side was not treated by TES.

Therapy included a sequence of six to ten weeks of therapeutic electrical stimulation (TES) delivered 4 times each week in 20 minutes sessions. The parameters selected for the electrical stimulation were as follow: frequency 20Hz, pulse-width 0.25 msec, and intensity was individually adjusted for each subject. The minimal intensity was 8 mA and was carefully increased up to the subject's tolerance of stimulus. The actual intensity of the stimulus used was below the level necessary to evoke muscle contraction for each subject and was below 14 mA for all the subjects.

Gait analysis

Gait assessment was made before and after TES treatment on a 3 m walkway, fitted with parallel bars. Each subject initially walked from right to left and, following a 45-60 seconds break for turning, walked from left to right. The subject walked several times in each direction until at least ten strides were recorded on each leg. Thus, each walking session included two sets of measurements, in which the left and right sides were respectively exposed for monitoring.

Observational assessment

The observational assessment was performed by two pediatricians from the same videotapes that were used for quantitative assessment. The pediatricians were unaware of the sequence of the tests, i.e., before or after treatment. The following characteristics were evaluated: (a) Proper leg rising; (b) Whole-body stability; (c) Head alignment; (d) Head movements.

Quantitative assessment

The following kinematic parameters were obtained by videography: (a) Stride length was the length measured between the time of heel elevation to the time of the following foot contact of the same leg; (b) Knee range of motion, calculated from maximal extension prior to stance to maximal flexion (in degrees) during swing; (c) Ankle range of motion, calculated from maximal plantar flexion following toe off to maximal dorsi flexion prior to heel strike; (d) Average stride duration (seconds) and stride velocity, (cm/sec). The data were obtained for each exposed leg, in accordance with the direction of walking, as described above.

The above gait parameters were compared before and after TES treatment and between the stimulated and the unstimulated leg.

Equipment

Gait was monitored in the sagittal plane by a NV-M3000EN Panasonic video camera (50 frames/s), positioned perpendicularly to the direction of motion. Five hemispherical markers of 2 cm diameter were used. The markers were attached in the sagittal plane to the greater femoral trochanter (represent the hip), the lateral condyle of femur (represent the knee), the lateral malleolus (represent the ankle), below the lateral malleolus and opposite to the head of the fifth metatarsal (the last two represent the foot). The video tapes were analyzed off-line by means of a computer program. Calibration of the camera and data processing were accomplished by Ariel Performance Analysis System (Ariel Dynamics Inc., San Diego) software.

The procedure included sampling the video frames into the computer as digital data by means of an Ariel frame grabber. The horizontal and vertical positions of each reflective marker were tracked from each frame by using the Ariel built-in data acquisition program for automatic digitization. Following calibration, the absolute coordinates were calculated and low-pass with a zero-phase lag, bi-directional, fourth-order Butterworth filter at a cut-off frequency of 10 Hz. was employed. A "stick diagram" of the lower limb facilitated measurement of the above-mentioned gait parameters. The operator who performed the gait analysis was blinded to which leg was treated

Statistical analysis

From the SAS program package, the general linear model was employed to compare the differences between pre- and post treatment data of the Rt (stimulated) and Lt (not stimulated) leg. This model accounts for repeated measures. A significant inter-subject variance is expected. In order to standardize the data, and initial values, the measurements were divided by the median of the results obtained in the pretest for each parameter. Level of significance was established at $p < 0.05$.

Results

Results of the observational gait analysis are summarized in Table 2. A general tendency of improvement in all the observed parameters is noted.

Kinematic data of stride length and stride velocity for both legs, before and following TES treatment, are summarized in Table 3. Following TES, the stride length increased in all the subjects except for subject 1. The increase in the stride length was found statistically significant in the left leg of subject 2, right leg of

Table 2. Observational gait analysis before and after TES treatment. Scale for scoring each parameter was from 0 to 2 (the higher score indicates improvement). B - before treatment. A - after treatment.

	Leg Raising				Whole-body stability				Head Alignment				Head Movements			
Subject	Lt. leg		Rt. leg		Lt. leg		Rt. leg		Lt. leg		Rt. Leg		Lt. leg		Rt. Leg	
	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A
1st	0	1	0	1	0	1	0	0	0	1	0	0	0	1	0	0
2nd	1	1	0	1	0	0	0	0	1	2	1	2	1	1	-	-
3rd	1	0	1	0	0	0	1	0	0	0	0	0	0	0	0	1
4th	0	1	0	1	0	0	0	1	1	2	1	2	1	1	1	2
Sum	2	3	1	3	0	1	1	1	2	5	2	4	2	3	1	3

Table 3. Summary of kinematic data, including stride length and stride velocity.

		Stride length (cm)			Stride velocity (cm/sec)		
Subject		Before TES	After TES	P<	Before TES	After TES	P<
1st	Rt.	60.9 ± 15.1	57.4 ±15.6	ns	26.9 ± 9.5	30.4 ± 8.9	ns
	Lt.	54.5 ± 11.0	49.6 ± 9.9	ns	18.8 ± 6.3	16.2 ± 3.3	ns
2nd	Rt.	15.7 ± 5.6	22.9 ± 10.0	ns	7.0 ± 3.0	9.0 ± 5.6	ns
	Lt.	11.9 ± 4.7	23.6 ± 6.8	.01	8.6 ± 3.2	12.7 ± 6.4	ns
3rd	Rt.	13.0 ± 4.0	17.1 ± 4.9	.05	5.6 ± 1.9	3.2 ± 1.1	.01
	Lt.	12.1 ± 4.0	14.9 ± 4.4	ns	3.4 ± 1.6	3.4 ± 1.3	ns
4th	Rt.	19.1 ± 7.0	35.2 ± 8.7	.01	16.4 ± 6.0	19.8 ± 5.0	ns
	Lt.	14.0 ± 4.1	26.3 ± 8.1	.01	11.0 ± 3.5	18.9 ± 6.8	ns

subject 3 and in both legs of subject 4. The average stride velocity also increased in subjects 2 and 4 and in the right leg of subject 1. The improvement was statistically significantly only in the left leg of subject 4.

Tables 4 and 5 summarize the range of knee and ankle motion during gait, before and after TES. Maximal angles of knee extension (prior to foot contact) and knee flexion (at the swing phase) indicate a large variability. Nevertheless, the range of knee motion during gait improved in all the subjects and in all legs, except for the right legs of subjects 1 and 2. These increases in range were not statistically significant, except for right leg of subject 3. The variability of results was also large in the plantar and dorsi flexion angles of the ankle joint. The range of ankle motion increased in both legs in subjects 1, 3 and 4, but significantly only in the left leg of subject 4. Analysis comparing the relative change after TES between the treated and untreated leg was performed. This analysis showed a significant improvement for the treated leg only in knee range and maximal knee angle for subject 3. A relative improvement was seen for the untreated leg in stride velocity and maximum knee angle for subject 4 and stride length for subject 2. The other parameters in all subjects did not show a significant difference in the relative change after treatment between the treated and untreated leg.

Discussion

The development of motor skill, such as gait, in children suffering from spastic diplegia is delayed. Quality of gait of these children is poor, mainly due to spasticity and muscle weakness of the lower limbs. Review of the literature regarding therapeutic modalities applied for children with CP provides evidence for the possible benefits of TES [7, 9, 10].

The present study, aimed at longitudinally evaluating the gait of four children with CP affected by spastic diplegia who were treated with TES. The physical therapist gained the children's confidence and they were cooperative and welcomed the TES treatment. The muscles selected for electrical stimulation were the rectus femoris and tibialis anterior. These muscles are easy to identify and both are very important in the process of normal gait. The rectus femoris, flexes the hip joint and extends the knee together with the vastii femoris to support body weight during stance phase. The tibialis anterior, the main ankle dorsi flexors, prevents drop foot and provides a clear off at the beginning of swing phase. It was hypothesized that, since TES decreases spasticity, the children's gait might improve following the treatment because of the expected increase in the range of motion of the knee and ankle joints.

Table 4. Knee range of motion.

		Knee angle (deg)					
		Rt. Leg			Lt. Leg		
Subject		Before TES	After TES	P<	Before TES	After TES	P<
1st	Max.	156.6 ± 12.5	155.6 ± 19.8	ns	160.8 ± 5.5	155.3 ± 4.6	.01
	Min.	114.0 ± 3.7	116.0 ± 11.9	ns	121.6 ± 2.9	111.9 ± 2.0	.01
	Range	42.6 ± 10.8	39.6 ± 9.4	ns	39.2 ± 6.4	43.4± 4.7	ns
2nd	Max.	165.7 ± 4.2	164.2 ± 4.7	ns	154.5 ± 9.6	145.0 ± 2.2	ns
	Min.	117.3 ± 1.8	122.0 ± 1.6	.01	128.7 ± 6.0	113.9 ± 8.8	.01
	Range	48.4 ± 4.0	42.0 ± 5.4	.05	26.0 ± 7.0	31.2 ± 14.6	ns
3rd	Max.	132.8 ± 6.1	146.9 ± 4.3	.01	8.2 ± 13.9	46.7 ± 10.6	ns
	Min.	116.0 ± 5.0	116.7 ± 3.3	ns	58.7 ± 8.2	70.1 ± 2.0	ns
	Range	16.7 ± 6.3	30.2 ± 6.5	.01	20.5 ± 9.2	23.4 ± 10.8	ns
4th	Max.	135.3 ± 5.9	131.5 ± 4.6	ns	118.0 ± 5.5	124.3 ± 4.1	.01
	Min.	121.0 ± 4.5	115.1 ± 7.6	.05	75.1 ± 3.1	113.8 ± 5.0	.05
	Range	14.2 ± 5.9	16.4 ± 7.0	ns	9.1 ± 3.9	10.5 ± 5.7	ns

Max. = maximum knee angle, corresponds to maximum extension of the knee prior to foot contact. Min. = minimum knee angle, corresponds to flexion of the knee.

Results indicated that the effect of electrical stimulation varied from one subject to the other. Nevertheless, an overall improvement in gait quality occurred as reflected by the positive changes in both the observed and measured walking variables. Stride length and stride velocity improved in three out of the four subjects while only some of the changes were significant. Range of knee motion improved in all four subjects, in both legs (except for two legs). Also the ankle range of motion improved in 3 subjects, but only for one leg was the improvement significant.

The gait pattern of the four subjects was characterized by a tendency to walk with flexed knees while the range of motion in the knees and ankles was very limited. The obtained results in this study, aimed at evaluating the influence of TES on the gait of children with CP, are highly encouraging. In the future, it is planned to increase the group of the subjects and the treatment period in order to reach more conclusive information.

The main limitation of our study is threefold. Despite the complicated logistics involving longitudinal measurements on children with CP and the large volume of the obtained data, the expected statistical power is limited due to the rather small number of participants. The

Table 5. Ankle range of motion (PF = plantar flexion; DF = dorsi flexion).

		Ankle angle (deg)					
		Rt. Leg			Lt. Leg		
Subject		Before FES	After FES	P<	Before FES	After FES	P<
1st	PF	2.1 ± 7.0	2.5 ± 3.5	ns	19.0 ± 2.4	26.2 ± 2.6	ns
	DF	39.5 ± 6.7	44.1 ± 5.8	ns	11.4 ± 3.3	12.4 ± 6.2	ns
	Range	32.0 ± 10.0	40.2 ± 6.6	ns	29.5 ± 5.7	35.9 ± 8.6	ns
2nd	PF	8.3 ± 6.5	9.7 ± 3.3	ns	5.6 ± 2.3	13.7 ± 3.3	.05
	DF	5.9 ± 5.9	10.0 ± 3.9	ns	12.8 ± 3.9	4.1 ± 3.3	.05
	Range	16.7 ± 5.8	14.0 ± 8.4	ns	17.5 ± 4.6	15.0 ± 5.4	ns
3rd	PF	3.9 ± 9.9	0.8 ± 4.7	ns	1.6 ± 5.5	1.0 ± 6.4	ns
	DF	26.6 ± 10.3	22.2 ± 11.6	ns	30.8 ± 6.9	23.6 ± 7.6	ns
	Range	21.4 ± 7.8	19.7 ± 8.9	ns	26.0 ± 7.0	23.5 ± 4.7	ns
4th	PF	16.9 ± 4.1	1.5 ± 4.2	ns	20.9 ± 5.8	20.8 ± 7.8	ns
	DF	5.5 ± 2.7	6.1 ± 7.7	.05	3.6 ± 12.0	22.8 ± 9.9	.05
	Range	11.4 ± 4.5	17.3 ± 7.8	ns	24.0 ± 8.2	41.3 ± 9.8	.05

right leg was the more compromised in three of four subjects and therefore randomization of the legs to “study” or “control” assignment could not be accommodated. Naturally, a larger sample size with a different distribution of neurological asymmetry between legs is desirable. It is also conceivable that a more intensive TES intervention would have resulted in a more significant change related to gait. This, however, would require a higher degree of cooperation from the children and therapists.

A number of factors contribute to the large variability in the results. First, it should be noted that the gait of diplegic children with CP is considerably slow and disrupted, with numerous stops. This causes irregularities within the gait cycles, making these cycles largely variable. Another factor was that the data collected on the left and the right legs came from separate walking bouts, limiting the comparison between the sides. For instance, in regular steady-state gait, stride length should come out to be the same if measured on the left and right legs. This was not the case under the conditions of this study.

Of particular interest is the surprising lack of preferential effect of TES on the stimulated (Rt) leg as compared to the other (Lt) leg. Although we cannot account for this phenomenon, the possibility of a general (rather than unilateral) locomotor outcome due to TES is not inconceivable. The existence of such an effect might mask the specific effect of TES on the stimulated leg. Further studies should expand our observations by extending the period of intervention and addressing the possible reciprocal effect exerted by the stimulus to the less compromised, non-stimulated, leg via the more compromised stimulated leg.

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