Correction of Gait Abnormalities in Cerebral Palsy Children using Functional Electrical Stimulation

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Abstract

This study aimed to assess the orthotic effect of FES on the gait of CP children. Core FES strategies, based on common CP gait deviations, were developed and tailored for each subject. A single case experimental design was employed [ABAB] allowing the effects of the withdrawal and reinstatement of FES to be assessed. Gait analysis was performed in each phase of the study. Outcome measures were pre-defined for each child and targets for clinical significance were set for these outcome measures. Comparisons were performed between these targets and actual outcomes. Eight subjects completed the study. Consistent improvements were recorded for four subjects. Results for one subject were mixed. There was little or no change in the remaining three subjects.

1. Introduction

A variety of approaches exist for treating the impairments and disabilities associated with cerebral palsy. Interventions established as common clinical practice in the treatment of cerebral palsied children may be broadly grouped into three categories, physiotherapy, orthotic devices, and surgical intervention. While the individual objectives of these interventions may differ, their overall aim is the same, that is to improve the functional ability of the child. The primary effect of CP is impaired muscle function. Functional Electrical Stimulation (FES) works at the level of impairment and offers several potential benefits, principally, controlled activation of muscles when required.

1.1. Previous Work

To date, there have been relatively few reports of the use of FES to correct gait abnormalities in CP children. Case reports indicate that this is a promising technique [1]. However, these have lacked objective data to corroborate the perceived improvements. Other investigators have quantified certain gait parameters, reporting statistically significant improvements when FES was applied [2], [3]. Both of these studies concentrated solely on addressing the issue of inadequate ankle dorsiflexion and the latter failed to make use of reliable gait analysis techniques. Comeaux et al [3] concluded that there was much scope for further investigation into the orthotic effect of FES in CP children. Lane [4] employed gait analysis to plan FES intervention, as well as an outcome measure to assess the efficacy of FES. Two subjects were tested, both of whom received FES to the ankle dorsiflexors during the swing phase of gait. Positive outcomes were observed for these subjects demonstrating the need for a detailed evaluation of the use of gait analysis in planning an FES intervention for the CP child.

The aim of this study was to determine the effectiveness of individualised FES gait strategies for the CP child. Gait analysis techniques were used for planning and evaluating these strategies.

2. Experimental Method

Children aged between seven and seventeen years with a diagnosis of diplegic or hemiplegic spastic cerebral palsy were considered eligible for the study. Eight subjects were recruited (five males aged 8 years 11 months to 17 years 6 months, and three females aged 12 years 11 months to 13
years 10 months).

A single case experimental design was employed, with each subject acting as their own control. All subjects initially underwent a baseline gait analysis to identify and quantify gait deviations. At this stage outcome measures were defined for each child and targets for improvement were set for these outcome measures.

Appropriate FES strategies were then selected from the core strategies. The selected FES strategies were tested and refined in an iterative manner to determine the most effective intervention for each subject. Two final test sessions were performed to assess efficacy and repeatability of the FES intervention. For a final test session an ABAB [withdrawal – reinstatement] experimental design was employed. Comparisons were performed between the target values and actual outcomes achieved. Replication of this sequence during the second test session on a separate day enabled repeatability to be assessed.

A finite state control algorithm allowed a range of FES strategies to be developed and implemented on a PC. This interfaced to a multi-channel stimulator. Foot switches provided control inputs to determine the stimulation timing. The following FES strategies were tested; bilateral ankle dorsiflexion in swing (subjects A, B, G & H), unilateral ankle dorsiflexion in swing (subject F), unilateral knee extension and ankle dorsiflexion in swing (subjects D & E) and unilateral knee extension and ankle plantar flexion in stance (subject C).

Data collected included 3D kinematics and kinetics, temporal and spatial gait parameters and foot contact patterns. The outcome measures defined included temporal–spatial variables, mode of initial contact and summary variables of the kinematic data (e.g. minimum dorsiflexion in swing phase). These outcomes were then compared to the previously defined targets for improvement.

3. Results

Figure 1 demonstrates the change in dorsiflexion during the entire gait cycle with the chosen FES strategy for Subject F. Figure 2 shows the change in foot contact pattern for the same subject. The intervention produced a reduction in frequency of forefoot contacts and an increase in the frequency of heel strikes. Knee flexion data for a subject C, who received FES to knee extensors and plantar flexors in stance, is shown in figure 3. There was a small consistent improvement in mid stance however the targets for improvement were not met.

![Left Ankle Dorsiflexion](image1)

**Figure 1** Averaged left ankle dorsiflexion for Subject F. A1 = no FES; B1 = with FES; A2 = FES withdrawn; B2 = FES reinstated. N = 10.

![Subject F - Left Foot Initial Contact](image2)

**Figure 2** Mode of initial contact for the left foot for Subject F. HS = heel strike; FL = flat foot; FF = fore foot.

![Right Knee Flexion](image3)

**Figure 3** Averaged right knee flexion for Subject C. A1 = no FES; B1 = with FES; A2 = FES withdrawn; B2 = FES reinstated. N=10

Table 1 gives an overview of effectiveness of the individual FES strategies for each subject. The efficacy of
the strategy for each subject was categorised according to the comparison of the actual and target outcomes.

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Table 1 Summary of effectiveness of individualized FES strategies for all subjects. I+ = targets consistently met or exceeded; I = improvement but targets not consistently met; NC = no change; W = worse.

4. Discussion

There were very clear benefits to some subjects from this approach of applying an individualised FES gait strategy. This single case experimental design served to highlight the heterogeneity of the subject group. The study design allowed for a range of FES strategies to be thoroughly tested using outcome measures and targets for improvement pre-defined individually for each child. Quantitative gait analysis techniques proved useful in developing the FES strategies and defining the targets for improvement in the outcome measures.

Despite apparent similarities between some of the subjects, their outcomes were very different. Numerous factors may have contributed to the equivocal outcomes for three subjects, including spasticity of the antagonist muscles limiting range of motion. Tolerance was an issue in the case of one subject only. A carry over to the stance phase was observed in some subjects who received stimulation to the dorsiflexors during swing phase. This represented a further potential benefit of orthotic FES intervention.

Further investigations will concentrate on attempts to improve outcome in those subjects for whom the efficacy of FES may be limited by restricted range of movement. One approach would be to combine FES with botulinum toxin (Botox) injections to reduce the effects of spasticity, specifically of the plantarflexors. Work has already begun to establish the effects of FES-Botox combination therapy.

5. Conclusions

Gait analysis was used successfully to quantify gait deviations in CP children and develop appropriate FES strategies, outcome measures and targets for improvement to address these deviations. Employing a single case experimental design allowed for a range of FES protocols targeting a variety of muscle groups to be tested and the individual outcomes to be thoroughly assessed.

The study determined that FES could have positive effects on the gait of children with CP. The equivocal results in the case of three of the subjects indicate that further work is warranted in order to address the factors that limited the outcomes of some subjects.

Acknowledgments

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References


