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Enhancement of Two Motor Functions of the Lower Extremity in a Child With Spastic Quadriplegia

CLAIRE ANNE LASKAS, SHEILA L. MULLEN, DAVID L. NELSON, and MARNEE WILLSON-BROYLES

This single-subject experimental design examined the immediate effects of four neurodevelopmental treatment (NDT) activities on two dependent variables: dorsiflexor muscle activity during an equilibrium response and frequency of heel contact during movement to a standing position. The subject was a 2.5-year-old boy with spastic quadriplegia. During the seven days of Baseline 1 Phase, the nine days of Treatment Phase, and the seven days of Baseline 2 Phase, dorsiflexor muscle activity was examined using an EMG instrument with surface electrodes. Frequency of heel contact was recorded as the number of times in seven trials that the child came to a standing position with his heel contacting the floor. Conditions were identical across all three phases except that four NDT activities were introduced during the Treatment Phase and were withdrawn during the Baseline 2 Phase. The results demonstrated that these NDT activities increased dorsiflexor muscle activity during a posterior equilibrium reaction and increased the frequency of heel contact when the child came to a standing position. This study contributes to the growing body of literature in NDT.

Key Words: Cerebral palsy, Child development, Neurophysiology, Physical therapy.
remain. Although children within developmental age groups were randomly assigned to treatment and control groups, the heterogeneity of the sample studied made the formation of groups not entirely equal. Also, the broad range of measurements used were not always appropriate for all of the children.

Another deterrent to examining treatment effectiveness in children with cerebral palsy is the ethical concern of withholding a treatment intervention from a group of children for the formation of a comparison group. To cope with this problem, investigators have compared the effects of a neurophysiologically-based treatment program that included NDT techniques with the effects of more traditional programs. Schezer et al found greater improvement in motor status, home management, and social maturation in 14 children who received a neurophysiologically-based treatment program than in 8 children of a control group who received a program of passive range-of-motion exercises. Although assignment to groups in this study was random, the groups were not entirely equally matched. The authors suggested that the degree of motor involvement and mental development may have affected the results. Carlson found that 6 children who received a facilitation program involving techniques derived from the methods of the Bobaths, Rood, and Ayres showed greater gains in gross motor development than did a comparison group of children receiving a program of fine motor, adaptive, and self-care skills. Although these two studies demonstrated the effectiveness of treatment, the specific effects of NDT cannot be determined because combinations of treatment techniques were used.

One approach to further research is to continue to study the overall effectiveness of NDT through the use of randomly assigned treatment and control groups. An additional approach to the study of NDT involves the investigation of the immediate effects of a replicable set of NDT techniques geared to the individual needs of a specific subject. Duration of effects and the ability to generalize the results are more limited in this second approach. A series of studies, however, may build on each other so that the effects of the many types of NDT activities can be investigated in terms of their effects on subjects' responses. If the results of single-subject experiments are to be generalized, these experiments must be replicated over a number of subjects with various therapists.

Using a single-subject experimental design, Ray et al found techniques that facilitated mouth closure, including jaw control, to be effective in decreasing the drooling of a child with cerebral palsy. Mullen used a single-subject experimental design to examine the effects of particular NDT activities on a child with spastic diplegia. Dorsiflexor muscle activity during a posterior equilibrium reaction was examined using a biofeedback instrument before and after a treatment with four NDT activities. The results of this study showed a general increase in muscle activity during the treatment phase of the experiment compared with the baseline phases. Because of a problem of instrument reliability and the consequent inaccurate measurement of muscle activity on one day, this study could not definitively document the treatment's immediate effectiveness.

Our study replicated Mullen's study in part and advanced the research design used. We used both a physiological measurement and a behavioral measurement to document the effects of the NDT activities.

We examined the immediate change in dorsiflexor muscle activity during a posterior equilibrium reaction using the Cyborg J53 biofeedback instrument. Equilibrium reactions are adjustments of the head, trunk, and extremities in response to displacement of the body or supporting surface. During a posterior equilibrium reaction, part of the normal response is dorsiflexion of the foot. In a child with spastic quadriplegia, this response often does not occur. Rather, the ankles plantar flex apparently as a result of the persistent influence of the positive support reaction.

The behavioral measurement involved direct observation and recording of the number of times the child's heel contacted the floor during movement to a standing position. Because of the persistent influence of the positive support reaction, the child with spastic cerebral palsy typically stands on his toes. A foot positioned with the heel contacting the floor is the pattern a child with a normal motor system assumes during movement to a standing position.

**METHOD**

**Subject**

After his parents had given informed consent, a 2.5-year-old boy under the care of the Cerebral Palsy Clinic of Children's Hospital Medical Center of Boston became the subject for this study. He was selected because of his age, diagnosis, and motor functions. He had a diagnosis of cerebral palsy manifested by mild spastic quadriplegia with the characteristics of increased muscle tone in both lower extremities, brisk tendon reflexes, and clonus. He did not use any orthoses, and he had not undergone any orthopedic surgical procedure. At the time of the study, he was pulling to a standing position and cruising but using an abnormal extensor pattern of the legs with plantar flexion of the feet. Trunk control was sufficient for maintaining sitting balance in a small chair with back support, but he required arm support to maintain a sitting position on the floor. Although he had obvious upper extremity motor involvement, the subject was able to bring his hands to midline to manipulate and transfer even small objects. Considered to have normal intelligence, he was at age level in terms of receptive language but was somewhat delayed in speech.

**Apparatus**

The Cyborg® J53 EMG biofeedback instrument was used to monitor dorsiflexor muscle activity. This instrument has bandpass filters of 100 to 250 Hz, input impedance greater than 50 MΩ, and input noise of .7 µV RMS. A Litebar® visual display shows EMG activity in microvolts as a discrete series of red lights with three sensitivity scales and a possible range of .7 to 1,000 µV. For this study, we chose the range of 4 to 100 µV. Cyborg's® Quick-Stick® 801-006 flexible sensors were used. The first active electrode was placed 2 cm below and 1 cm lateral to the tibial tubercle of the left leg. The second was placed 0.5 cm below the first (electrode centers were 3.0 cm apart). The ground electrode was placed over the patella. Relatively consistent electrode placement was maintained from day to day by skin markings (Fig. 1).
Procedure

We conducted the study daily in the child’s home in the morning for 23 sessions. An A-B-A withdrawal single-subject experimental design was used. The first seven sessions served as Baseline 1 Phase, the next nine sessions as Treatment Phase, and the final seven sessions as Baseline 2 Phase. For the duration of the experiment, the child received routine physical therapy services once a week in addition to what he experienced in the study. In the course of the day, these therapy sessions always followed the sessions conducted by the principal investigator (C.A.L.) and were consistent throughout the Baseline and Treatment Phases of the experiment. Because this study was concerned with the immediate effects of treatment only and any differences between Baseline and Treatment Phases could not be because of procedures that were consistent across all three conditions, we did not consider that the routine therapy confounded the results of this study.

At the beginning of each session, the electrodes were positioned, and the measurements of dorsiflexor muscle activity during three posterior equilibrium reactions were recorded. The child stood in a supported standing position with his feet 6 in (15.2 cm) apart (measured between the medial malleoli). To produce the equilibrium reaction, the principal investigator knelt behind the child with her hands positioned on the child’s hips and pulled the subject rapidly backwards. A wooden stand was placed 9 in (about 23 cm) behind the subject’s heels to maintain the distance of the posterior displacement. The child was displaced posteriorly in 1.8 seconds (timing was maintained by a metronome). The largest display of EMG activity during the equilibrium reaction was then recorded. This procedure was done three times, and the mean of these recordings was considered the daily initial score. After the recording of the initial daily score, the wires were disconnected from the electrodes, but the electrodes remained in place.

During the seven sessions of each Baseline Phase, the child was next allowed 20 minutes of free play with toys. Free play principally involved manipulative activities, such as building with blocks, but also involved some gross motor activities, such as pushing a truck while crawling. After free play, the electrode wires were reconnected, and three more recordings of dorsiflexor muscle activity produced the daily final score.

The principal investigator then placed the child in a small toddler chair for measurement of the second dependent variable (heel contact when coming to a standing position). He was positioned with his hips and knees at a 90-degree angle of flexion. His feet were positioned 6 in apart (measured between the medial malleoli) and 6 in in front of the base of the chair (measured from the heels to the chair). He was encouraged to move to a standing position by a play activity of reaching for a toy. To ensure safety, the principal investigator placed her hands lightly on the child’s pelvis, but she made no attempt to assist the child in the movement to the standing position. The position of the foot in the upright standing position was recorded as toe contact only or toe and heel contact, for seven consecutive trials.

After the seven sessions of Baseline 1, the Treatment Phase began and continued for nine sessions. During the 20-minute period after the initial daily score was obtained, the child received a program of four NDT activities as described by Mullen. Although these techniques may also be advocated by other neurophysiological theories, they were designed using a NDT framework. The treatment consisted of the following four activities: 1) approximately five minutes of rhythmical rolling from a supine to a prone position with the therapist’s hands placed on the child’s hips, 2) approximately five minutes of anterior-posterior displacement on a beach ball in a sitting position with the therapist’s hands placed on the child’s pelvis, 3) approximately five minutes of lateral displacement while straddling a bolster in the sitting position with the therapist’s hands placed on the child’s pelvis, and 4) approximately five minutes of movement from sitting to standing while straddling a bolster with lateral and anterior-posterior displacement with the therapist’s hands placed on the child’s pelvis.

All other procedures, including the daily final score and the subsequent seven trials of coming to a standing position, were the same in the Treatment Phase as in the Baseline 1 Phase. During the final seven sessions of the experiment, Baseline 2 repeated the procedures of Baseline 1.

In the EMG study, the day-to-day changes in electrode placement can provide unreliable measurement. Therefore, in this study, the dependent variable was the difference between the initial daily scores and the final daily scores. We believe this daily difference score provided a more reliable method for making day-to-day comparisons across Baseline and Treatment Phases. The other dependent variable, heel contact in movement to a standing position, was recorded each session as the number of times out of seven attempts that the
child reached the standing position with his heel contacting the floor.

To ensure interobserver reliability, recordings of dorsiflexor muscle activity and foot position in movement to a standing position were independently made by the principal investigator and a trained observer. A physical therapist served as observer for 14 days of the Baseline 1 and Treatment Phases, and an occupational therapist served as observer for 8 days of the Treatment and Baseline 2 Phases. On the last day of Baseline 2, only the principal investigator made recordings. Interobserver reliability of dorsiflexor muscle activity was calculated by dividing the number of daily initial and daily final trials in which agreement was perfect (129) by the total number of trials observed by two observers (132). The percentage of agreement was 98 percent. Interobserver reliability of heel contact was also calculated by dividing the total number of agreements (153) by the total number of trials observed by both parties (154), for an overall percentage of agreement of 99 percent.

Criteria for Discarding Trials

To avoid the difficulties of poor subject cooperation, we established criteria before the initiation of the experiment, which allowed for days when the child was sick or uncooperative. The criteria for terminating or not conducting a session were 1) the child's sickness, 2) the child's irritability or uncooperativeness, 3) displacement of the electrodes at any time during the session, and 4) malfunctions in the instrument.

On the fifth day of the Treatment Phase of the experiment, the session had to be terminated during the initial recordings because the child was sick and uncooperative. No session was scheduled for the tenth day because of the child's previously scheduled medical appointments. Hence, the 23 sessions were conducted over a 25-day period.

During the third day of Baseline 1, the child's spontaneous, playful activities began to influence and confound the recording of dorsiflexor muscle activity. Therefore, to avoid the invalid measurement of muscle activity, we established these criteria for inappropriate trials: 1) the child lifted his foot off the ground, 2) the child sat down, or 3) the child pulled or threw an object during the posterior equilibrium reaction. Both observers had to agree that one of these criteria was met before a trial was discarded. On each day, trials continued until three valid measurements were obtained for the initial and final recordings. During the 14 sessions of the Baseline Phases of the experiment, 15 trials were discarded, and during the nine days of the Treatment Phase of the experiment, 10 trials were discarded. No measurements of heel contact had to be discarded.

Data Analysis

As is conventional for single-subject experimental designs, the results of this study are depicted graphically. Statistical analysis is usually not done in single-subject experimental design. Because of the variability in recorded muscle activity, however, binomial statistics as described by Kazdin were computed on this dependent variable. Kazdin's simple statistical test determines change across phases in single-case experiments. After using the split-middle technique to calculate the celeration line of the Baseline, the number of Treatment measures above the Baseline's celeration line is counted.

RESULTS

Figure 2 suggests differences between Baseline and Treatment Phases. The daily changes in muscle activity after the 20 minutes of NDT treatment appear greater than the daily changes after the 20 minutes of free play. We found, however, much variability from session to session. One strategy suggested by Hersen and Barlow is the use of statistics when variability is high. In this study, all nine measures of treatment were above the celeration line of Baseline 1. The probability of this occurring by chance is .5^9 (p = .002). Similarly, all seven measures of Baseline 2 are below the celeration line of the Treatment Phase (p = .008). These binomial statistics confirm the visual impression of Figure 1 that the Treatment measures are greater than the Baseline measures. During the Treatment Phase, the average of the initial daily scores of dorsiflexor muscle activity before treatment was 37.7 µV, and the average of the daily scores after treatment was 54.0 µV.
(an average daily increase of 16.3 µV). An interesting feature is the average daily decrease of 14.0 µV from the initial to the final scores during the Baseline 1 and 2 Phases. This finding may indicate that play decreased subsequent dorsiflexor muscle activity.

Analysis of Figure 3 reveals a dramatic change in heel contact between Baseline 1 and the Treatment Phase. The heel never contacted the floor during movement to a standing position in any trial in Baseline 1. During the Treatment Phase, however, the heel contacted the floor seven out of seven times on each day. The hypothesis that these NDT activities would increase the number of times the heel contacted the floor during movement to a standing position is accepted.

**DISCUSSION**

Neurodevelopmental treatment techniques provide a child with cerebral palsy more functionally useful patterns of movement because they inhibit abnormal muscle tone and abnormal reflex activity and facilitate normal movement patterns. This study demonstrated immediate changes in dorsiflexor muscle activity during a posterior equilibrium reaction after a program of four NDT activities. These changes in muscle activity reflected a more normal and functional movement pattern. In addition, these four NDT activities produced a directly observable improvement in the position of this child's foot in movement to a standing position. He was able to come consistently to the standing position with his heel contacting the floor. We noted that during Baseline 2, heel contact with the floor gradually decreased. This decrease may indicate a mild carry-over effect.

The results of this study depend on the validity of the measurements. Electromyographic feedback has been proposed as a valid reflection of muscle activity. The discrete Litebar display of the Cyborg J53 biofeedback instrument permitted objective and reliable recording of changes in muscle activity by two independent observers. The flexible sensors used with this instrument maintained consistent contact with the child's skin throughout each day of the experiment. The portability of this instrument and the noninvasive characteristics of these procedures made this instrument suitable for clinical research. Because the recording of EMG activity by biofeedback instruments varies from day to day with minor changes in electrode placement and skin resistance, only posttreatment scores of muscle activity would not have been valid. In this study, we computed the average difference in muscle activity between initial and final scores within each day of the experiment and maintained relatively consistent electrode placement across days.

Measurement of muscle activity also can be altered by the physiological and psychological state of the child. An attempt was made to control these factors by establishing criteria for the termination and elimination of a session. Early in the study, we also observed that the child's play activities were influencing the recording of dorsiflexor muscle activity. Because this added variable could have produced invalid measurements, criteria had to be established for the elimination of these trials. Future researchers should consider factors such as these when they design a study.

To establish clinical significance and to document the effects of these treatment procedures further, we included a related behavioral measurement in this study. The results of the measurement of heel contact clearly demonstrated the effectiveness of the treatment program. The behavioral measurement actually proved to be more stable (reliable) on a day-to-day basis than the physiological measurement. In practice, this measurement was less subject to alteration by the activities of the child. The behavioral measurement was a clinically significant measurement because it described a specific improvement in a motor behavior that can benefit this child in the achievement of a stable walking pattern. Observation and documentation of this improvement also provided encouragement to the child's mother.

Changes in other motor behaviors of the child were also informally observed to improve after treatment. Less toe clamping and less pronation of the foot were noted in standing. Also, this child's observable response to the posterior equilibrium reaction changed. During Baseline and initial Treatment sessions, his forefoot did not leave the ground in response to the posterior displacement. During the final treatment sessions, however, we noted the child's foot dorsiflexed with the forefoot leaving the ground during the equilibrium response. Future studies could examine and document changes in these behaviors. Because present evaluation tools are frequently not sensitive enough to discern the subtle changes in motor behavior that result from treatment, defining specific motor behaviors and establishing criteria for measuring changes in these behaviors can offer therapists clinically useful indicators of progress.
To provide the opportunity for replication of these procedures, we used a limited number of particular treatment activities to examine their influence on specific motor functions of the lower extremity. As opposed to an actual NDT program, we had no opportunity to adapt these procedures to the varying needs of the total child. Despite this rigid treatment method, this study demonstrated changes in the child's foot position and dorsiflexor muscle activity. Future studies need to examine the effects of additional methods of the NDT approach. In addition, other aspects of motor behavior under different treatment conditions should also be studied in single-subject experimental designs and in group designs. Furthermore, the long-term effects of NDT should be documented.

The major limitation of this study was a lack of control for the possibility of experimenter bias. The principal investigator, who was aware of her hypotheses, may have unintentionally administered the procedures for the equilibrium reaction or the movement to standing in a biased way. Also, the measurements of the dependent variables may have been influenced by the observers' knowledge of the hypotheses. We would have preferred to administer the stimuli and measure the results in a blind way, but this was not possible for practical and financial reasons. The presence of a trained therapist observer for each session and the adherence to preestablished procedural criteria, however, protected against the possibility of experimenter bias.

Another issue of concern is the variability of the EMG recordings. Under ideal conditions, the Baseline and Treatment Phases of a study should continue until a pattern of stability or consistent trend is evident in the data. The length of time this study could continue, however, was limited. Fortunately, the treatment was robust enough to demonstrate changes from the Baselines despite the high variability.

CONCLUSION

Clinical practice using NDT techniques has advanced much more rapidly than systematic research of this approach. Documentation of the effectiveness of NDT is difficult, but single-subject experimental design provides a way to begin such documentation without ignoring individual differences among children. A progression of single-case experiments might provide valuable information concerning the relationships between many of the NDT techniques and their various behavioral and physiological effects.

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