Sensory Feedback for Head Control in Cerebral Palsy

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Five school-aged children with cerebral palsy were given an auditory feedback signal when their heads tilted past a predetermined angle. After three to seven individual sessions, all of the children were able to work in the classroom on regular school activities while using the sensory feedback to monitor and alter head position. Over a period of nine weeks, all children improved their stabilizing skills of the head and neck when responding to the performance information. Three of the children were successful at self-monitoring for up to one hour while maintaining the head within the required zone at least 80 percent of the time. Inability of the other two children to do so was probably related to poorer motor control and possibly to a lack of independent work skills.

Key Words: Biofeedback, Motor skills, Cerebral palsy.

One common problem for the child having moderately or severely disabling cerebral palsy is the inability to control adequately the position of his head and trunk. Although he may be able to maintain a precarious static sitting balance, movement of his arms and hands can disturb this balance. Conversely, movement of the head is frequently associated with abnormal upper extremity displacement, interfering with hand function. Both reactions are serious postural problems for a child in play, educational, or, later, vocational settings.

Establishing exercise programs specifically for neck and trunk stability has been difficult. Very young children do not have the language abilities to respond to direct commands and have extremely short attention spans for repeated activities, even when elicited through postural responses. Older children are primarily concerned with what they see as more functional activities involving the hands or legs. Current treatment techniques promote the facilitation of automatic movements and emphasize the instruction of parents and teachers in exercises and in advantageous positioning of the child's body to generate improved control and function.1-3 Even so, the time spent in therapeutic activity is minimal in relation to the amount of time the child spends in inappropriate postural and movement patterns during the rest of the day. Frequently, skills achieved in the presence of the therapist are not practiced again until the next therapy session, which may be several days later. Under such conditions, the necessary repetition of precise, near-peak performance required for the development of coordinated movement is unlikely to be achieved by the cerebral palsied child.4

The possibility of using knowledge of muscular activity and body movements as precise and repetitive sensorimotor performance information has greatly expanded with the development of biomonitoring technology. Known variously as sensory feedback therapy,5 augmented sensory feedback,6,7 and biofeedback,8-11 this type of performance information has been used to redirect aberrant movements with the intent of developing long-term functional improvement of neuromuscular control.

Sensory feedback is a response-oriented technique through which objective performance information related to a specific motor task is presented to provide...
Two types of auditory feedback have been commonly used in systems designed for application to neuromuscular rehabilitation. Performance information can be given using an auditory signal that changes in proportion to the amount of activity produced, thus acting as ongoing guidance for the movement or activity.\textsuperscript{8-10, 12} Proportional performance information most closely matches the cybernetic concept of feedback.\textsuperscript{12} A second type of auditory feedback operates on a nonproportional basis. A desired area of movement or activity is described and excursions past the predetermined boundary elicit a single continuous tone indicative of a change of performance.\textsuperscript{10, 11, 14, 15} The signal can be arranged to indicate either success or failure. A related form of performance information based on a nonproportional switching arrangement uses response-contingency systems, in which a desirable event such as the operation of a television set occurs as long as the required activity occurs.\textsuperscript{11, 12, 14}

Within the past eight years, attempts have been made to apply the concepts of sensory feedback systems to the child with cerebral palsy to improve sensorimotor control of the head. Harris and associates used an electronic device to promote control of head movement.\textsuperscript{12} These investigators used electromechanical potentiometers placed in a large helmet to detect head movement and to provide a proportional auditory signal intended to guide the head into an upright position. The device could also be connected to a movie projector, which operated only when the child was performing in the desired manner ("response contingency"). Improvement in motor control while the device was worn was reported in nine children with athetoid cerebral palsy. Carry-over into functional activity for some children was implied by the investigators. Self-monitoring away from the investigators was not reported.

Ball and associates described automated reinforcement of head posture in two children with cerebral palsy who were also mentally retarded.\textsuperscript{14} A mercury switch was attached to an earphone and to a transistor radio. When the head was held upright, the child could listen to the program. The use of the radio as a contingency response reportedly improved ability to orient the head while reinforcement occurred.

A portable Head Position Trainer was tested by Wooldridge and Russell during both individual training and self-monitoring sessions involving 12 children (3-10 years old) with spastic, athetoid, and mixed types of cerebral palsy.\textsuperscript{11} The Head Position Trainer consisted of a group of mercury switches set to provide an angular threshold above which the child had to hold the head in order to turn off a nonproportional auditory tone. The system could be linked to various electrical toys or audiovisual aids that operated when the head was in the desired position. All children responded to the biofeedback program, and three children reportedly demonstrated carry-over of functional improvement. The investigators concluded that the Head Position Trainer was an effective sensory aid for the cerebral palsied child in the development of head control and position awareness.

In all of the previous investigations, the selected children responded to the sensory feedback provided during a variety of training regimens. However, response-contingency incentive devices had been used in some manner in each of the programs. When the child was expected to attend to other auditory or visual information in the classroom, response-contingency systems using television or toys were not appropriate.

Normally, little conscious attention is given to postural activity. However, for a child who has cerebral palsy, postural activity is frequently a conscious effort. Inasmuch as postural skills provide the background for other functional activities, it seems desirable to have the child practice control during daily activities in which other motor behavior is also required. Therefore, in this investigation, only an auditory tone was provided as an indicator of head-position performance. The purpose of the study was to assess the ability of the school-aged cerebral palsied child to self-monitor and correct head position in functional situations encountered in the classroom.

**METHOD**

**Subjects**

The children studied were located in the greater Philadelphia area at Widener Memorial School for the orthopedically handicapped. Criteria for selection required the child to have quadriparetic cerebral palsy, to be 6 to 12 years old, to demonstrate a lack of head and trunk control in the sitting position and during arm movements, and to have the ability to hear the audio feedback signal, see visual stimuli, and make corrective head movements on command. Five girls were selected to participate in the study.

Following selection based on the above listed criteria, evaluations were completed to record the child's method of communication, her gross motor skills, and...
Fig. 1. Head Position Monitor. Helmet has accelerometer and earphones; control unit regulates feedback and collects data.

an estimate of body image and right-left awareness. Gross motor skills were recorded using the Milani-Comparetti scale as adapted by the Ontario Crippled Childrens Centre.*

Device Description

The Head Position Monitor was designed to measure the deviations of the head in relation to the vertical and to provide a nonproportional auditory feedback when the head movement exceeded a pre-selected angular threshold in any direction (Fig. 1). The sensing element was a miniature piezo-resistive accelerometer mounted on the top of the head in a polyethylene helmet (172 g, or 6.1 oz). The helmet served to hold the earphones through which the child heard the auditory signal and to locate the transducer so that deviations away from the gravitational vertical in any direction were transformed to angular deflections. The auditory feedback, which was similar to the signal heard on an emergency vehicle, occurred when the head exceeded the angular threshold selected for each child. Two cables connected the transducer to a control unit and the control unit to the earphones. These cables were clipped together and went from the helmet, behind the child, to the control unit that was suspended from the back of the child’s wheelchair.

Procedure

Initial training with feedback. Each child was introduced to the auditory feedback in individual sessions out of the classroom. The angular threshold was arbitrarily set at 25 degrees from the vertical for the children who did not use head supports and at 35 degrees for the children who used a support. When the child practiced with the feedback or when performance was monitored, the head rest was removed. The auditory feedback signal was demonstrated during passive movement of the child’s head. Then the child was asked to start and stop the auditory signal by actively moving. When the signal could be terminated repeatedly on command, each child was asked to stabilize the head and to keep the feedback signal silent for one-minute trials. A stopwatch was used and verbal encouragement was given to remind the child of the task. Performance graphs were drawn for each trial and shown to the child. When the child could spend 90 percent of five consecutive trials in the desired zone, either the angular zone was reduced to 25 degrees or, if already at that point, the trials were lengthened to five minutes. During the five minutes, the child worked on identifying word or number flash cards that were held at eye level. One to three trials of five minutes each were completed daily, interspersing head-upright activities, such as the flash cards, with other exercises requiring hand, arm, or eye movement. Initial training out of the classroom terminated when the child could spend 80 percent of the time within the 25-degree zone during these practice sessions.

Classroom monitoring. To establish a base-line performance, each child wore the Head Position Monitor in the classroom for three sessions of 30 minutes with no feedback. Children then started to use the auditory feedback daily in the classroom for five-minute sessions, which gradually increased in length. At first the therapist continued to work with the child, providing reminders and encouragement in the new situation. When the child could work for 10 minutes, the therapist attempted to withdraw and allowed the child to self-monitor, gradually increasing the amount of time the Head Position Monitor was worn. Performance graphs were drawn for each session and posted in the classroom.

Training sessions were given daily for nine weeks and then a removal of feedback procedure commenced. Each child received one session with no feedback followed by multiple dual sessions in which audio feedback was given in one part of the session and removed in the other part of the session. These dual sessions were manipulated so that two children received audio feedback first, followed by no feedback; two children had the procedure reversed; and one child had the sequence alternated from day to day. The dual sessions were followed by one to three measurement sessions with no feedback, a period of 10 days when the feedback device was not worn, and

* Ontario Crippled Childrens Centre, 350 Rumsey Rd, Toronto, Ontario, Canada, M4G 1R8.
one final measurement session in which no auditory feedback was given.

Data Analysis

Objective data consisted of three measurements accumulated on the control unit:
1. Total time of the training session
2. Time spent within the desired angular zone
3. Number of crossings into the desired zone
Inasmuch as training sessions were not of equal length, the time spent within the desired zone was converted into a percentage to allow for intrasubject comparison as training progressed.

Percent time in zone

\[ \text{Percent time in zone} = \frac{\text{Time in desired zone}}{\text{Total time of training session}} \times 100 \]

To display daily performance, this measure was recorded on a graph kept in each child's classroom.

The results were evaluated on a single-subject-design basis.16

RESULTS

Description of Subjects

Relevant characteristics, gross motor estimates, and quantity of feedback training for each child are outlined in the Table.

Response to Training

Four to seven individual sessions were spent on the introductory training phase. Four children were returned to the classroom, operating the Head Position Monitor at a 25-degree angular threshold. Static upright posture was not the prime goal; therefore, no attempt was made to reduce the angular threshold beyond 25 degrees. The fifth child (DF) had very little success at the 25-degree threshold during the initial training period and therefore was measured and trained at a 35-degree angular threshold.

During three no-feedback sessions in the classroom, the median performance value for each child was between 4 and 48 percent time in zone (Fig. 2). Over a period of nine weeks, four children each had 38 feedback sessions and one child had 33 sessions. Time of each session increased from five minutes on an individual basis, depending upon performance. The average daily session length for each child is shown in the Table. Under classroom-feedback conditions, all children increased their ability to maintain the head within the required threshold. Median values were between 62 and 92 percent time in zone, representing increases of 24 to 62 percent time in zone (Fig. 2). The post-no-feedback performance in Figure 2 represents only one session at the very end of the program following 10 days of no feedback and no monitoring. Performances decayed without the feedback to values of 22 to 73 percent time in zone.

TABLE

<table>
<thead>
<tr>
<th>Subject</th>
<th>Diagnosis</th>
<th>Chronological Age (yr)</th>
<th>Gross Motor Age (mo)</th>
<th>Communication</th>
<th>Total Feedback (hr)</th>
<th>Feedback (min/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AH</td>
<td>Spastic</td>
<td>10.1</td>
<td>3-6 Head rest</td>
<td>Verbal</td>
<td>26.2</td>
<td>1.2</td>
</tr>
<tr>
<td>DF</td>
<td>Athetoid</td>
<td>8.1</td>
<td>3-4</td>
<td>Nonverbal</td>
<td>16.6</td>
<td>10.1</td>
</tr>
<tr>
<td>DM</td>
<td>Spastic</td>
<td>10.1</td>
<td>3-4</td>
<td>Nonverbal</td>
<td>11.0</td>
<td>17.4</td>
</tr>
<tr>
<td>KD</td>
<td>Athetoid</td>
<td>8.2</td>
<td>5-9</td>
<td>Nonverbal</td>
<td>18.3</td>
<td>28.9</td>
</tr>
<tr>
<td>BB</td>
<td>Spastic</td>
<td>11.5</td>
<td>4-7 Head rest</td>
<td>Nonverbal Classwork typed</td>
<td>18.7</td>
<td>34.0</td>
</tr>
</tbody>
</table>

Fig. 2. Median performance and range for feedback and pre- and post-no-feedback sessions. Angular threshold set at 25 degrees for all children except DF (35 degrees).
Fig. 3. Median performance and range for dual sessions. Effect of feedback on performance for KD was significant at $p < .05$; for all others, $p < .01$.

Data from the dual sessions were analyzed separately from the other classroom-monitoring sessions. No matter what condition was presented first, all children demonstrated improved performance under feedback conditions (Fig. 3). These paired scores were subjected to the Wilcoxon Signed Rank test and proved to be significant at the $p < .05$ level for one child and at the $p < .01$ level for four children.

Ability to Self-Monitor

Consistent self-monitoring ability was demonstrated by three children (AH, KB, BB), who were able to work independently for at least 25 minutes at a time while retaining performance levels in excess of 80 percent time in zone. Two of these children could work for one hour while maintaining the same performance level. The third child could not be scheduled for one hour of classroom time uninterrupted by special classes or therapies. However, she was able to self-monitor twice daily for sessions of 25 minutes each. The daily record of performance illustrated in Figure 4 represents one of these children and shows relatively consistent behavior, although activities changed daily.

Two of the five children were unsuccessful at self-monitoring. These children (DF, DM) could only work for 15 to 20 minutes at a time using the auditory feedback. Both had poorer motor skills (Table), primarily differentiated from the other children by a lower level of upper extremity skills. These two children could not operate learning systems equipment independently and had no independent method of communication. These factors limited the work that could be accomplished without a teacher or aide to place educational material or interpret responses. The variable performance of these children is represented by Figure 5.

DISCUSSION

The results of this study support the evidence of previous investigators of the abilities of selected children to maintain the head in a more central and upright posture while receiving sensory feedback information related to performance. In this investigation, only the auditory signal was used as performance information, because the purpose was to determine if the child would attempt to self-monitor during the dynamic and functional activities required in the classroom. The auditory feedback signaled an error. Instrumentation silence was equated with successful performance. Inasmuch as the characteristics of the auditory signal were not dependent upon the magnitude of error, the system differed from the continual, proportional feedback used by Harris and associates and was more closely related to the non-proportional information used by Wooldridge and Russell. However, unlike the previous investigations, response-contingency incentive devices were not used in the training program.

Although all children improved while using the feedback, only three achieved self-monitoring. For the initial classroom sessions, the therapist remained with the child and encouraged continued response. However, the ultimate goal was for the child to self-monitor and to retain a high in-zone performance rate without interference from the investigator. The three children who achieved this level all had enough hand skills either to use a pencil grossly or to use a typewriter and were able to work independently on
class work. Two of these children were verbal and one was nonverbal.

The two children unsuccessful at self-monitoring had no independent method of communication, could not operate any learning system equipment, and always worked with an aide either individually or in a group. Responses to class work were given by eye signals. These two children rarely responded to the auditory feedback for more than 15 to 20 minutes despite nine weeks of sensory feedback. Both of them continued to need verbal reminders to respond. Possibly the lack of persistent response was related to behavioral factors combined with the somewhat poorer motor skills. These two children had little experience in working on a task independently and successfully; they had not developed independent work habits. Perhaps this type of child would benefit initially from the response-contingency systems used by previous investigators.

The long-term aspects of physical and mental fatigue were not directly addressed in this investigation. The ability of certain children to self-monitor leads to the suggestion that sensory feedback could be used within functional activities on a long-term basis. This situation would allow specific therapy to be provided under the direction of a therapist, but would not require the therapist's presence at all times. In any such program, the feedback device should be capable of indicating quantitative performance at the end of each session as well as providing the auditory feedback. This information is extremely important for determining the duration, angular threshold, and activity of each subsequent session.

The fact that feedback information is available does not automatically ensure that it is used. Both Annett and Harris and associates have discussed the need for the activity to be related to meaningful function initially in order to promote continued practice. The ability to maintain the head in a stable and erect manner did not seem to be of importance to any of the children. In fact, the presentation of the feedback required the child to divide her attention and to increase the level of awareness to attend to postural stability as well as to ongoing activity. If the effort to maintain the head upright is greater than the perceived value of doing so, continued practice will probably not occur. Further exploration is required to determine the deficits incurred by the inability to control the movements of the head.

The measurement of generalization of improved performance has remained a difficult problem, inasmuch as the Head Position Monitor must be worn to record performance. During the dual sessions, when recording was carried out sequentially, all five children demonstrated significantly improved performance during practice with the auditory feedback, as opposed to wearing the feedback device but receiving no performance information. This finding would indicate that, by the later stages of the training program at least, performance was regulated by the feedback and not by the presence of the equipment. Thus, the Head Position Monitor could be used to measure carry-over without affecting performance. The decrease in performance when the auditory feedback was removed indicated to us that postural awareness remained under volitional control and had not progressed to an automatic state during the nine weeks of daily training. Whether automatic postural control activity can be developed remains undetermined. Factors that determine eventual success may be related to length and frequency of training and to the relationship of the training to functional activities when upright head posture is perceived by the child to be a definite advantage or requirement.

CONCLUSION

Sensory feedback techniques appear to offer a unique opportunity to provide immediate, consistent, and continual objective-performance information related to specific motor skills. In this selected group of children, performance was greatly improved when the sensory feedback was supplied. Children capable of self-monitoring were those who could also work independently on classroom assignments. However, changes in motor control, although marked, were temporary, and a transition from volitional to automatic postural control was not observed during this investigation. Further studies are required to document long-term functional improvement.

The development of objective measuring tools such as the Head Position Monitor provides the opportunity to assess performance in a functional environment. The use of such devices can help in evaluating
the results of other methods of treatment as well as sensory feedback techniques.

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REFERENCES
