Biofeedback Treatment for Cerebral Palsy in Children and Adolescents: A Review

Robert James

This article reviews the role of augmented biofeedback as a treatment aid for selected neuromuscular problems in children and adolescents with cerebral palsy. Neuromuscular dysfunction often prevents those inflicted with cerebral palsy from performing even simple tasks of daily activity. Research has evaluated the role of augmented biofeedback in reducing this neuromuscular dysfunction. Augmented feedback, on the whole, has been successful in improving head and neck posture, reducing hypertonicity, and improving weight-bearing during gait, hand-eye coordination, sitting posture, and drooling. However, most studies have shown that the carry-over without feedback was limited. Moreover, the generalization to real-life situations often was not demonstrated. The sample size in most studies was very small. Future research should address the adequate number of training sessions needed to produce an improvement and consider the mode and type of feedback appropriate for a given subject. Augmented biofeedback appears to have important implications in the treatment of those with cerebral palsy.

Biofeedback

Biofeedback has long been viewed as a vital link in the vast number of control mechanisms in the body. The very nature of homeostasis is dependent on biological information being returned, in part, to the control center from which it originates. Such information is used by the controller tissue (e.g., central nervous system) to alter the effector output (e.g., muscle and/or gland).

Over the years a technology of instrumentally augmented biofeedback has evolved. This technique allows a person to monitor a given physiological process and attempt to control it. An example would be having a person observe her heart rate on a special monitoring device and then attempt to speed the heart rate or slow it down. Thus, using biofeedback techniques, one would be able to control a physiological process that was previously considered beyond conscious control. The growth and development of biofeedback technology has been accompanied by excitement, frustration, and wild claims of application.

Advertisements for biofeedback equipment have appeared in popular magazines claiming that its use would cure a broad range of problems. Although many

---

Robert James is with the Department of Exercise Science, University of Massachusetts, Amherst, MA 01003.
of these claims are unfounded, biofeedback does have important applications in selected clinical settings. Clinical uses of biofeedback range from stress reduction to improvement in neuromuscular control. Particularly, biofeedback has been shown to play an important role in the treatment of neuromuscular disorders. In many neuromuscular disorders an individual is limited in the performance of everyday activities because of a lack of gross or fine muscular control. This review will focus on the efficacy of augmented biofeedback to improve motor function in a specific neuromuscular disorder, cerebral palsy.

**Augmented Biofeedback**

Augmented biofeedback is an instrumentally augmented process that provides an individual with information (e.g., visually or auditorily) about the state of the system being monitored. Through a series of trial-and-error mind/body adjustments, an individual attempts to either maintain or change a given physiological state. The typical biofeedback system consists of a transducer or sensor, signal amplifier, signal processor, signal display, and person. Figure 1 illustrates a closed-loop EMG cybernetic biofeedback system used in training the child to control the state of selected forearm striate muscles.

Central to biofeedback technology is the concept of self-control. Self-control can be viewed as the ability to set, maintain, and/or change the levels of activation of body tissue within a particular range and time interval. These levels of activation are expressed in measurable temporal and spatial patterns of behavior (e.g., range of limb motion or levels of striate muscle action potentials). In principle, changing one's physiological state is accompanied by an appropriate mental/emotional change. Conversely, altering the mental/emotional state, consciously or subconsciously, results in a change in the physiological state. Thus, augmented biofeedback strategy recognizes the intimate mind/body link in self-control.

![Figure 1](image)

Figure 1 — (1) child, (2) EMG sensors, (3) differential amplifier, (4) signal processor, (5) visual feedback display, and (6) auditory feedback.
There are several reviews of the efficacy of the technique of augmented biofeedback (14, 20, 22, 29). Yates (29) compiled a volume of over 1,000 clinical and basic research studies dated prior to 1978. In 1978 the Task Force Study Section of the Biofeedback Society of America (26) produced a series of reports ranging from position papers on biofeedback as a research tool to clinical outcomes. Shellenberger and Green (22) made a detailed analysis of conceptualizations about biofeedback training and their ramifications in research. They provided a framework for understanding many conflicting results and conclusions about the efficacy of biofeedback training.

The first review of biofeedback research with a pediatric population was done in 1978 by a section of the Biofeedback Society of America’s task force (7). Six reviews have appeared since (1, 5, 15, 18, 19, 24). Of these, King’s review (15) focused solely on the problem of asthma and Lubar’s review (19) focused on attention deficits and hyperactivity disorders. The other reviews varied in the extent of coverage and detail of these two conditions as well as conditions of brain damage, headache, and neuromuscular dysfunction.

Given the positive implications of the earliest research (7) for the use of augmented biofeedback in the treatment of neuromuscular dysfunction in those with cerebral palsy, a review that expands and updates the available information is warranted. In addition, such a review should build upon the evidence of the clinical efficacy of biofeedback treatment of persons with cerebral palsy as well as offer insight into research questions.

**Neuromuscular Control**

Cerebral palsy is a condition or group of conditions resulting from damage to the neuromuscular and speech mechanisms of the brain. The neuromuscular symptoms range from mild to severe in terms of paralysis, weakness, incoordination, abnormal muscle tone, and fluency in postural adjustment. The treatment of the person with cerebral palsy must be multidisciplinary, addressing the neuromuscular and speech problems as well as the social, psychological, and environmental problems.

A major habilitative focus continues to be on the aberrant neuromuscular systems and its consequences on speech and activities of daily living. Therapeutic procedures include neurectomies of the peripheral nerves, medication to suppress hypertonicity, therapeutic exercise, and stress management procedures (e.g., Jacobson’s progressive relaxation exercise). The rationale for most of the treatments is that once muscle tone is somewhat normalized, then purposeful movement and speech is maximized.

The following sections will review augmented biofeedback studies for head, limb, and striate muscle control, gait training, eye-hand coordination, sitting posture control, and control of drooling. In addition, reducing neuromuscular dysfunction may help maximize the person’s functional improvement in play, educational, and vocational settings (1, 5, 10, 14).

**Head and Limb Control**

Perhaps the most studied area of the use of augmented biofeedback with cerebral palsy is head control. This is not surprising, given the fact that poor head control is one of the most common problems with this population. In addition, this lack
of neuromuscular control is often refractory to traditional physical medicine treatment.

Harris (10) suggested that a defect in the afferent servomechanical feedback control system is a major contributor to muscle imbalance and faulty coordination in persons with cerebral palsy. Harris et al. (11) then developed a series of exoskeletal electronic sensory aids to provide feedback to the child with cerebral palsy. The goal was to assist the child in correcting movement error purported to be associated with his or her own incorrect feedback.

Harris et al. (11) examined the efficacy of a head control device (HCD) and a limb position monitor (LPM) with 18 subjects with athetoid cerebral palsy who ranged from 7 to 18 years of age. Ten of the subjects using the HCD improved head stability. The duration of holding a fixed posture with the head increased from a few seconds to more than 5 minutes. Concomitant normalization of neck muscle tone was also noted (subjective evaluation). Similarly, the nine subjects using the LPM improved arm stability and range of motion. Harris et al. did not give the actual magnitude of change or the statistical tests of significance of improvement for either the HCD or LPM treatments. Therefore, while their findings seem encouraging, the degree of improvement is not known.

Using a mercury-switch device, and working with 12 children (ages 3–10 yrs) who had cerebral palsy, Wooldridge and Russell (28) provided them with precise auditory and visual feedback regarding the position of the head. A child was fitted with the head position "trainer" and directed to maintain head position within adjustable training angles. Movement beyond the training angles resulted in auditory and/or visual feedback to inform the child of the direction of movement error. Additional information of target head position was also provided through on/off switching of a cable-car racetrack, record player, television set, radio, or tape recorder. The alternate form of feedback was employed in order to help motivate individual children. Training feedback schedules also varied to meet the needs of each child, therefore a total group analysis was not attempted. Wooldridge and Russell (28) were encouraged with the results, which showed that children were able to improve head positioning. Moreover, they noted positive changes in self-concept and body awareness in several of the children.

**Transfer to Functional Activities**

Previous applications of augmented feedback training have generally been successful in helping the child with cerebral palsy to regulate head and neck posture (11, 28). However, such control tends to be response contingent, with limited carry-over functional improvement. For example, the gains in head control made with feedback were either lost or minimized when augmented feedback was removed. Moreover, little if any transfer of head control was reported during functional activities such as those encountered in a classroom.

Leiper et al. (17), working with children who had cerebral palsy, investigated the effect of providing them with auditory feedback when head movement exceeded a preselected angle from the vertical. Each of five children between 6 and 12 years of age was first introduced to the auditory feedback in a session outside of the classroom. The head-position monitor consisted of a helmet with an accelerometer and earphones coupled to a control unit used to regulate the feedback and collect data. Classroom monitoring and training began with three baseline sessions of 30 minutes each with no feedback, followed by daily feedback
sessions. The classroom feedback training started with 5-min sessions and gradually increased to 10 minutes. Performance graphs were drawn for each session and were posted in the classroom as a form of delayed feedback or knowledge-of-results feedback (KR). The KR was intended as a motivational aid. Daily feedback training sessions lasted 9 weeks.

Analysis of the data showed that all the children increased their ability to maintain head posture within the required threshold settings during feedback conditions. These results are in agreement with the investigations of Harris et al. (11) and Wooldridge and Russell (28). It should be noted that only three of the five children were able to sustain the control without feedback. Thus, the positive performance changes were temporary and the transition from self-regulation to automatic postural adjustment was not observed. Perhaps a longer training period (overlearning) would result in automaticity of preferred head posture.

Leiper and his colleagues (17) raised an important issue in their discussion as to whether the inability to control head posture was indeed a problem. They contend that the child may not feel the importance of such control. Further, such control may require the child to divide his or her attention between ongoing classroom activities and head posture. For this age group, the demand of awareness and neuromuscular adjustment may create such a sensory overload as to cause internal conflict, with the child choosing to neglect head posture.

Walmsley et al. (27) hypothesized that for children with severe handicaps, the learning of head control would be maximized if music were used as a reinforcement. Five such children under 12 years of age were trained with music feedback over 24 daily 15-min sessions. The training sessions were preceded by pretesting and posttesting sessions without feedback. The biofeedback head-training unit consisted of an adjustable head frame supporting a cluster of mercury switches, control circuitry, timer, and counter. The head trainer was positioned to be activated within a target window of 35°. Taped music as appropriate for a particular child was used as reinforcement and motivation for the upright head posture. A 5° deviation in any direction from the preset training angle was taken to be an acceptable performance error.

The Wilcoxon matched-pairs signed-rank test for differences in performance between pretest and posttest baselines was used to examine the effects of biofeedback on head regulation. A one-tailed test was found significant at the 0.06 level; therefore the researchers concluded that this suggested head control improvement for the group. In reality only three of the five children had improved. However, the comment was made that these results should be treated with caution because the sample size was small and the training period was brief. One must also consider whether the small gains in head control justified the amount of time the children spent training. No information was given concerning the carry-over effect of the biofeedback session.

Catanese and Sandford (4) addressed the efficacy of biofeedback in establishing head position and the transfer of the positive behavior to everyday situations. Four subjects 5 to 17 years of age, with fluctuating muscle tone from hypotonic to hypertonic, were trained using a head-position trainer designed to activate a cassette recorder for auditory feedback (short and long stories, music, and songs) contingent on head position. All four were observed in the classroom for 10 half-hour periods before training. Following the baseline observations, the subjects were randomly assigned to one of two groups. Those in Group 1 received
20 daily sessions using the head-position trainer alone, without social reinforcement such as verbal encouragement. Those in Group 2 received the same treatment for 10 daily sessions, followed by 10 daily sessions with social reinforcement. Social reinforcement was hypothesized to help maintain gains from the feedback treatment.

The results showed that the head-position trainer gave effective feedback information. However, the improvement gained with feedback was not well maintained without the feedback in the classroom situation, whereas the use of social reinforcement produced positive long-term gains in the classroom. This study, although limited by the small sample size, does provide a warning against using only high-tech biofeedback procedures without social reinforcement.

**Muscle Control**

Many of the difficulties that persons with cerebral palsy have in controlling movement stem from abnormal levels of striate muscle activity. Too much (hyper-tonicity) or too little (hypotonicity) muscle activity may be present in varying degrees before, during, or following movement. Conventional treatments for the abnormal levels of muscle activity have met with varying degrees of success. More recently, electromyographic (EMG) augmented biofeedback has been used to treat such conditions.

**Forearm EMG**

The question of the nature and self-regulation of hypertonic musculature was addressed by Harrison (12). Five adults with cerebral palsy were compared with five nonhandicapped, or with themselves after several training strategies including conditions of no EMG feedback, EMG visual feedback, and/or KR of the state of the forearm flexor musculature. The relevance of including this experiment (12) and the following one by Harrison (13), using adults with cerebral palsy in a review of biofeedback in pediatrics, is to suggest other possible models of evaluation and treatment.

Levels of holding tension (e.g., EMG level) and speed of EMG release were used as criterion measures. The first training series consisted of the repeatability of EMG levels with and without EMG feedback, speed of EMG release, ability to grade muscular activity with and without EMG feedback, and amount of extensor muscular activity induced by a given forearm flexor contraction. This first experiment (12) demonstrated that adults with spastic cerebral palsy performed poorly on repeatability of forearm EMG activity compared to neurologically nonhandicapped subjects. However, the ability of the former to grade muscular activity improved following a program of EMG visual biofeedback. An important observation was the exacerbation in forearm extensor activity during the prime activation of the forearm flexor musculature. This suggests that those with spastic cerebral palsy had difficulty in differentiating flexor from extensor activity (reciprocal inhibition).

Harrison’s (13) second series of experiments investigated ways of helping those with spastic cerebral palsy to achieve better neuromuscular control during simple arm movements while using either continuous augmented EMG feedback or knowledge of results. KR consisted of giving the subject postresponse information about the outcome of arm control. When provided with augmented EMG
feedback, the subjects learned to relax more quickly and improved in their ability to maintain specific levels of neuromuscular activity. Normal precision of setting high, low, and intermediate muscular levels was achieved with a KR training paradigm.

Harrison (13) suggested that KR appeared to be superior to concurrent EMG feedback when the task was to produce specified patterns of sequential and simultaneous activity in the biceps and forearm flexor muscle group. Harrison also suggested that KR is a more useful form of feedback for persons with spastic cerebral palsy because it allows them to focus fully on internalizing the appropriate movement engrams and on sensing accurate movement cues. This issue of feedback types (concurrent vs. KR) has not been fully researched in either those with cerebral palsy or other subject populations.

**Frontal EMG**

Finley et al. (8), in an attempt to improve motor and speech performance, were the first to use frontal EMG biofeedback with persons who have athetoid cerebral palsy. It was hypothesized that self-regulation of the frontalis muscle activity would generalize to other somatic musculature, in turn leading to improvements in motor and speech activity by reducing dystonic background neuromuscular noise.

Six subjects between the ages of 14 and 31 were trained with auditory EMG for forehead muscular activity over a 6-week period. Augmented biofeedback consisted of an auditory EMG signal (clicks) and visual meter readings. The research design consisted of pretesting of motor and speech levels, treatment with EMG biofeedback, and posttesting. Frontal forehead EMG feedback training sessions were given twice weekly over a 6-week period. Average frontal pretraining EMG was 28.9 μV p-p, and for posttraining it was 10.0 μV p-p. Trend analysis of EMG acquisition curves showed a significant reduction in frontal tension across all sessions for five of the six subjects.

Parents and subjects reported some improvement in speech and general functions. No objective measures were given for either the speech or motor functions. Finley and associates (8) suggested that the reduced bioelectric activity in the forehead was reflective not only of frontalis control but also of other striate muscles that may have influenced performance. However, they admitted that objective measures were not taken of a generalized transfer effect.

In a follow-up study, Finley et al. (9) studied the effects of electrophysiological behavior modification (EMB) of forehead EMG in children with cerebral palsy. Speech and motor preelectrophysiological EMB was evaluated in four children 6 to 10 years of age, followed next by 6 weeks of frontal EMG EBM training with subsequent rest and retraining periods. Auditory and visual EMG augmented feedback was provided during the training sequences. The children were gradually trained toward low levels of frontal EMG by setting a cumulative voltage threshold. If the child’s EMG voltage fell below threshold at the end of each 60-sec epoch, a reward (toy) was automatically dispensed from an electromechanical device. Frontal EMG decreased significantly over the initial 12 trials. Improvement was noted in speech and motor skills. However, a 6-week follow-up showed increased frontal EMG activity as well as deterioration of speech and motor function. Repeating the EMG EBM training reestablished the low EMG state along with partial recovery of speech and improved motor functions.
Forearm flexion activity was also monitored in order to address the question of generalization of the relaxation of the frontal region to other somatic muscles. Forearm flexor EMG pretraining levels for the group averaged 13.6 µV p-p and 11.5 µV p-p following 12 frontal EMG training sessions. Forearm and frontal EMG correlated significantly both within and across training sessions. Fine hand-motor skills, gross motor skills, and oral muscular function of speech improved significantly (<0.01, Kendall’s W) in each child, with the exception of one child who experienced no change in speech.

Even though this study had a small number of subjects, the results indicate that frontal EMG electrophysiologic behavior modification shows promise as a training technique for children with cerebral palsy with a prominent spastic component. An important observation relevant to forearm flexor activity is that the children initiated purposeful movements of the upper extremities that were not present before treatment. As noted by Finley et al. (9), the operant conditioning techniques used (EMG EBM) differ from general biofeedback training in that secondary reinforcers (e.g., toys) were used contingent upon the child eliciting the correct physiologic response of lower frontal EMG. In traditional biofeedback training, the child’s knowledge that the desired response was elicited is viewed as sufficiently rewarding to establish a repeat of the behavior (lower frontal EMG). The argument was made that combining the operant paradigm with biofeedback maximized self-regulation.

**EMG Case Studies**

Cataldo et al. (3) raised methodological questions concerning the Finley et al. (9) study. It was noted in their critique that the comparison, without supporting objective data of the EMG reinforcement condition with the control condition of no treatment, did not demonstrate statistical significance of EMG feedback in the training procedures. Although the results are still encouraging, the efficacy of using secondary reinforcers with EMG feedback in a muscle control regimen remains to be answered.

Accordingly, Cataldo et al. (3) investigated three cases of cerebral palsy in which a rigorous within-subject experimental analysis was employed to assess the effects of EMG feedback in improving muscle control. The first subject was a 9-year-old boy with severe choreoathetoid cerebral palsy involving the trunk and extremities. The focus of the EMG biofeedback training was on self-regulation of the level of EMG activity and athetoid movement in the biceps muscle of the right arm. Feedback consisted of a light changing from green to yellow to red as a function of the EMG potentials. In addition to the visual feedback, a changing tone proportional to the EMG activity was used.

The research design consisted of an A-B-A reversal of conditions starting with eight feedback training sessions with the goal of reducing the audio signal and changing the visual-feedback-light color to yellow. This change produced lower EMG activity in the biceps muscle. Over the training sessions, the predetermined levels of relaxation were systematically changed so that successively lower levels of muscle activity were required to produce a given feedback signal (behavioral shaping/gradual control). Each session lasted 30 to 60 minutes. The substantial amount of variability noted in the initial trials was not observed in later trials. Involuntary movement was also reduced during volitional forearm movement. However, hospital staff did not notice changes in ward behavior.
The second subject was an 8-year-old boy with choreoathetoid cerebral palsy involving the trunk and extremities. His age-equivalent gross motor functioning ranged from 2 to 7 months and included extreme variability in muscle tone. EMG biofeedback training focused on having the boy increase voluntary muscle activity in the pectoral muscles and decrease muscle activity in selected jaw, neck, and shoulder muscles. The total number of daily trials ranged from 6 to 20 within a 60-min period, depending on the boy’s stamina. The results showed improvement in self-regulation of the target muscle activity along with carry-over control of muscle activity without feedback. However, control of the specific musculature in the upper extremity did not generalize to aid in the improvement of pattern movement of the limb.

The last case involved a 25-year-old man with severe choreoathetoid cerebral palsy; he was in the educable mental retardation range (IQ 62). Emotional stress and excitement greatly increased involuntary movements. EMG biofeedback training focused on voluntary control of the left biceps, left jaw, and frontalis muscles. Visual and auditory biofeedback was used to inform the subject of muscle activity levels. Each of the 14 daily training sessions lasted 60 minutes. Evidence of relaxation in the forehead and jaw muscle groups was noted in both feedback and no-feedback conditions. Anecdotal reports noted generalized relaxation and a better quality of voluntary movement.

While the three case studies by Cataldo and colleagues (3) indicate that feedback enhances muscle control and provides evidence of carry-over of feedback effects to a no-feedback training condition, the degree of improvement is in question. Except for the data presented in graph form, the report is mostly anecdotal. The lack of objective measurement and the low subject number is somewhat surprising, given Cataldo et al.’s initial criticism of the Finley et al. study in 1977 (9).

Ankle Joint Control

The utility of using EMG biofeedback training to improve motor control in spastic cerebral palsy was further documented by Skrotzky et al. (23), who hypothesized that control of contiguous muscles to the ankle joint would improve ankle range of motion. Four subjects with diplegic cerebral palsy, ages 11 to 29 years, were studied to determine the change of active range of motion of the ankle, the time to relax after target muscle contraction, and degree of retention of control. The EMG activity of the gastrocnemius and anterior tibialis muscles was monitored for both feedback purposes. Standard goniometric techniques were used to determine the range of the ankle plantar and dorsal flexion.

The research protocol consisted of a baseline period used to determine ankle range of motion and EMG activity, followed by two training periods and finally a retention period. One leg was randomly designated as the experimental limb and the other was named the control limb. Both auditory and visual feedback were used during the two training periods of isometric and concentric contractions of the target muscles on the experimental side. No feedback was used during the first training period on the control side. However, auditory and visual feedback were used on the control side during the second training period.

Results showed an increase in active range of motion (ROM) of the ankle joint in the experimental limb ranging from 20 to 500%. The ROM of the control limb increased from 33 to 450% over the same time period of 5 training days.
However, only two of the four subjects retained the gains in both limbs following treatment. Skrotzky et al. (23) suggested that the lack of total ROM retention by all subjects may have been due to insufficient duration of the feedback training. Most of the learning in the relaxation time (RTR) patterns of the spastic gastrocnemius of the experimental limb was noted during the first few feedback sessions. No learning was noted in relaxation time without EMG feedback in the control limb during the first training period. Retention of low RTR was only noted in the gastrocnemius of the experimental limb.

**Gait Training**

Children with cerebral palsy present a variety of gait problems such as excessive knee flexion and toe-walking, lack of coordination, hyperextension of the knees, and lack of symmetry in weight-bearing. Such problems can lead to joint damage and excessive energy expenditure.

It is well recognized that gait training techniques to achieve a functionally efficient and smooth pattern are needed in habilitating the child with cerebral palsy. The efficacy of using a limb-load feedback device to assist in self-regulation of weight-bearing during gait was studied by Seeger et al. (21). Four children with hemiplegic cerebral palsy, between 5 and 10 years of age, were trained in weight-bearing biofeedback sessions ranging from 5 to 20 minutes each over a span of 14 to 20 days. The experimental design consisted of a period of pretesting with no feedback, followed by a period of weight-bearing biofeedback and then posttraining evaluation. During the gait training period, auditory feedback was provided whenever a threshold amount of weight was applied to the heel of the affected side. The goal was to equalize weight-bearing of both limbs. The feedback unit consisted of a load-sensitive insole coupled to a control box worn on the belt. Load output was hard-wired to an amplifier and pen recorder. Force measurements were calibrated in newtons and transformed to percentage of body weight.

Results of the feedback training indicated that for each subject the increased weight-bearing over baseline levels was statistically significant, and that the improvement of weight-bearing on the affected side was maintained during a follow-up period. Although only a few subjects were trained, the success of feedback was impressive because previous treatment had not proven successful. Clearly, considering the problem of the lack of symmetry in weight-bearing noted in many children with cerebral palsy, further study is warranted.

**Eye-Hand Coordination**

Many children with cerebral palsy have difficulty with eye-hand coordination in fine motor tasks such as writing and tracing. Feedback from visual, tactile, proprioceptive, and kinesthetic systems provides sufficient information for the neurologically intact and physiologically mature individual to adjust behavior and improve accuracy in such tasks. However, many individuals with cerebral palsy receive inappropriate information feedback from their movements, thus hindering fine motor coordination.

Talbot and Junkala (25) conducted an experiment to determine whether auditorally augmented feedback would enhance the eye-hand coordination tracing tasks of students with cerebral palsy. Fifty-nine students with a mean age of 14 years and 3 months were pretested both for accuracy and speed on the Southern
California Motor Accuracy Test (SCMA) and then randomly assigned to one of three groups. Group 1 traced line drawings while simultaneously receiving auditorally augmented feedback of their accuracy in remaining on the stimulus line. Group 2 performed the same tasks but without augmented feedback. Group 3 served as control with no training. All subjects were posttested after the training period and again 3 months later as a follow-up test.

A special pen was used for the feedback trials. The pen projects a small beam of infrared light through its tip, which then reflects the light back from the white background paper when the pen moves off the black tracing line. The reflected light is picked up by sensors in the pen and is processed to activate both a timer and an audio signal (audio feedback mode). Thus the subject hears a buzzing sound when the stylus strays from the line.

Groups 1 and 2 receive 20 days of pattern tracing. One 10-min session was conducted in the morning and one in the afternoon. Analysis of covariance was used to statistically equate the three groups on the pretest SCMA scores. The first posttest mean group scores showed significant differences on both the accuracy and speed trials. The feedback group was significantly better than the tracing-alone group and the control group on both the accuracy and speed tests. Although these patterns of improvement seemed to be maintained 3 months later, the change was not significant. The decrement in control may simply be that behavior tends to revert to pretreatment levels and that either booster sessions or overlearning of the original task is needed. The feedback procedure in this study holds considerable promise for the improvement of tracing skills for students with cerebral palsy in a classroom setting. Such skill is proposed to serve as a foundation for printing, writing, and drawing.

**Sitting Posture Control**

Lack of trunk control is one of the common and limiting motor deficits exhibited by children with moderate to severe cerebral palsy. Such control is important to motor development leading to functional skills. Although movement therapy is effective in lessening the deficits associated with lack of head and trunk control, a major limitation has been the total lack of limited amount of carry-over of the short-term treatment to the child's everyday life.

Realizing that repetition of correct posture is needed throughout daily activity, Bertoti and Gross (2) evaluated a biofeedback procedure that was purported to motivate young children with cerebral palsy to regulate proper sitting posture. Five children between the ages of 3 and 5 years with spastic diplegia or spastic quadriplegia participated in the study. The feedback training device consisted of a pressure switch mounted in a back support that was connected to a control unit to activate a timer and/or a VCR. The VCR was activated during feedback training by pressure on the head and trunk-back support as the child assumed an upright sitting posture. The film used with feedback was selected by each child prior to training.

The sequence of evaluation consisted of 5 minutes of sitting baseline behavior while viewing the chosen film. The VCR was not activated during this sequence. Next, the child was shown the control features of the pressure switch in order to activate the VCR. A timer recorded the amount of time the pressure switch was activated during the target behavior of an upright midline sitting posture. Feedback training (VCR on/off) consisted of four 5-min trials.
The results showed that the use of the sitting feedback fostered improved sitting posture in selected children during the feedback trials. The average sequence of sitting times for baseline, feedback, baseline, and feedback (A-B-A-B design) were 53.72, 245.12, 97.66, and 262.18 seconds, respectively. Some carryover seemed evident from Baseline 1 (53.72 sec) to Baseline 2 (97.66 sec), as well as a trend (245.12–262.18 sec) showing the influence of feedback. Bertoti and Gross (2) called for further study of such a feedback device with a larger population and longer training time to determine long-term training effects.

The biofeedback positioning device used by Bertoti and Gross may be employed to lengthen the time a child practices correct postural adjustment. In turn, such extended practice may help prevent spinal and respiratory dysfunction often associated with faulty sitting posture of those with cerebral palsy.

**On-Line Reward System**

Finley and his colleagues (6) raised the question of the importance of an on-line reward system combined with EMG feedback as a motivational tool in training children with cerebral palsy to regulate neuromuscular activity. It was assumed that children, unlike most adults training with biofeedback, often need reinforcement that is explicit and immediate in order to sustain long-term performance enhancement. With the adult it is assumed that being aware of the correct behavioral response, provided by information from the feedback, is sufficiently rewarding to increase the chances of repeating the response.

An automated reward system was devised for use with commercially available EMG biofeedback instrumentation. Rewards chosen by a child were automatically dispensed by the device contingent on tonic and/or phasic EMG reductions. Fourteen children with cerebral palsy, between the ages of 4 and 13 years and one 22-year-old who in addition was moderately retarded, were assigned to one of two treatment groups: on-line contingent reinforcement or off-line contingent reinforcement. Baseline frontal and forearm flexor EMGs were first monitored for three 20- to 30-min recordings without feedback. EMG biofeedback training followed the baseline measures. Subjects in the on-line group automatically received their chosen reward from the device contingent on low frontal and forearm flexor muscle EMGs. The most desired rewards were dispensed last. Threshold EMGs were carefully set in order to shape (e.g., train to reach low EMGs in small steps) behavior both between and within trials. The off-line reward subjects received feedback from frontal-forearm flexor sites but did not receive performance based rewards until after each training period.

Different EMG scores from baseline were used in the data analysis. Both the on-line and off-line reward groups showed significant (<0.01) improvement in reducing their EMG levels from baseline values. Significant (<0.01) downward trends were also noted across the 12 training trials for both groups. While both on-line (contingent) reward and off-line (delayed) reward groups showed reduced EMG in the target muscles, the on-line reward group learned faster and to a deeper level of muscle calming. Finley et al. (6) noted that the disadvantage of their reward procedure was the cost of stocking the instrument with toys and other rewards.

**Control for Drooling**

Drooling is a common problem associated with children who have cerebral palsy. Not only is the behavior hygienically undesirable but it also tends to encourage
social rejection. Drooling is an interaction of the pooling of saliva and inefficient swallowing. The control of the behavior involves sequential activation of lips, tongue, palate, jaws, larynx, and respiratory muscles.

Koheil et al. (16) observed that the severity of drooling was related to the degree of head and neck postural abnormality. In their investigation of 12 children with spastic and athetoid cerebral palsy, they found that although the children had the ability to close their mouth, mouth-open posture prevailed. The goal of the training program was to increase self-regulation of selected facial and neck musculature purported to generalize to muscles associated with jaw closure. The infrahyoid and orbicularis oris muscles were monitored for EMG biofeedback training. Upon reaching control of the tone level of the EMG feedback, an analog EMG auditory signal was used. The goal was to increase the sound level. At intervals of 40 seconds an alarm signaled the child to swallow. This interval was adjusted depending on the measured pooling of saliva or drooling. Results showed a significant decrease in drooling behavior.

Retention of the control of drooling was slightly lower 1 month following training with feedback. However, the regression was not significant from the original gains directly after feedback training. Although 1 month is not a long follow-up period, the slight regression suggests that perhaps longer initial periods of training or booster sessions are needed. In any event, given the importance of this control technique for those with cerebral palsy, such treatment is recommended along with continued research.

Discussion and Summary

Although the number of available research articles was not extensive for this review on the use of biofeedback for persons with cerebral palsy, several important inferences can be made. For example, augmented feedback on the whole has been a successful training technique in assisting those with cerebral palsy to regulate head and neck posture (4, 11, 17, 27, 28). However, as noted by Leiper et al. (17), such control tends to be contingent on the presence of augmented feedback.

Catanese and Sanford (4) addressed the carry-over problem by providing a group of their subjects with added social reinforcement following contingent head-position feedback. This reinforcement produced positive long-term gains in the classroom. The limited carry-over may reflect the child’s need to focus on ongoing classroom activities rather than divert his or her attention to head control, thus creating a possible sensory overload. Finally, it may be that longer training periods are needed (overlearning) in order to develop the automatic neuromuscular patterns necessary for preferred head posture.

The studies that addressed the issue of hypertonicity (3, 8, 9, 12, 13, 23) generally supported the use of EMG biofeedback although, again, the carry-over of self-control was either minimal or not reported. The hypothesis was often made that control of selected muscles (forearm flexors or frontalis) would generalize to other somatic areas. In one of the studies by Finley et al. (9), this generalization was found. Forearm EMG correlated significantly with frontal EMG both within and across training sessions.

All of the reported EMG biofeedback training studies used from 3 to 14 subjects. Clearly, while the results are encouraging, more control studies with
more subjects are indicated that would address the issue of the mode of feedback (concurrent vs. delayed) as well as the type of feedback (auditory vs. visual).

Given the importance of developing a functionally efficient and cosmetically smooth gait pattern, the research by Seeger et al. (21) was encouraging. All four children with hemiplegic cerebral palsy were able to improve their weight-bearing during gait, following training with auditory weight-bearing feedback. The load-sensitive insole and control unit provided an opportunity to set target behavior and thus train the child in gradual steps to the desired level of weight bearing. More important, the improvement in weight-bearing was maintained during follow-up evaluations. Studies that have examined the efficacy of biofeedback in control of eye-hand coordination (25), sitting posture (2), and drooling (16) all showed positive results. Again, the carry-over without feedback was limited.

In summary, the reviewed studies demonstrated that biofeedback is effective in supporting self-regulation of several problem areas for children with cerebral palsy. However, the positive findings tend to be contingent on the presence of the augmented feedback and lack total generalization and carry-over value to real-life situations. And, with the exception of the Talbot and Junkala (25) study, the findings should be interpreted with caution because of the small sample sizes studied. Also, studies should be designed with an adequate number of training sessions (train to criteria) as well as the most appropriate mode and type of feedback for a given subject.

References


