ELECTROMYOGRAPHIC FEEDBACK AND NEUROMUSCULAR EDUCATION – A REVIEW

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INTRODUCTION

There are numerous variables which affect the efficiency and effectiveness of motor skill learning and performance. One of the most critical of these is feedback, or knowledge of results. Sage (1971) defines feedback as "the information which an individual receives as a result of some response". Studies of feedback show it to be the strongest, most important variable controlling performance and learning. It has been shown repeatedly that there is no improvement without feedback, progressive improvement with it and deterioration after its withdrawal. Feedback increases the rate of improvement early in practice on a new task, enhances performance on tasks that are overlearned, and makes tasks less fatiguing and more interesting.

Fitts and Posner (1967) divide feedback into two types: intrinsic and augmented. The former arises as a natural consequence of the response of the individual and is not dependent on external supplemental information from the environment. It arises from visual, auditory, proprioceptive, and tactile stimuli which are a consequence of the movement of response. Thus intrinsic feedback comes from sensory stimulation during and after performance. For example, the tennis serve either hits the target or misses in one direction or another; proprioceptive feedback supplies data regarding the body musculature which are associated with varying degrees of deviation from the target, visual feedback provides information about directional deviations, and audible feedback may give indications as to the nature of impact of racket and ball. Skilful responses are virtually impossible without proprioceptive feedback. Movement itself often supplies various kinds of input from the proprioceptors which supply data for processing to influence the temporal and spatial organization of the movement response. With practice, an individual comes to a kinaesthetic awareness, a 'feel', of the sequence and correctness of each component of the movement pattern. Augmented feedback is the provision of special information which is ordinarily not present in a learning task. It is extrinsic to the individual and takes the form of either verbal information by an instructor or an external stimulus, such as a feedback circuit from a machine, which supplements the feedback obtained from the senses. The tennis serve may be practised with only intrinsic feedback or the performer may receive augmented feedback in addition, provided by an instructor who may give specific information about why errors in shot direction occurred or may simply give praise for a good serve. Howell (1956) studied the effect of providing augmented feedback to subjects by showing them force-time graphs on their sprint start after each practice trial. Another group did not receive this information. The first group successfully learned the desired force-time pattern and improved their speed and momentum, the second group made very little improvement.

The principle of "Biofeedback", described by Birk (1973) as:

> the use of monitoring equipment to detect and amplify internal physiologic processes within the body to make this ordinarily unavailable information available to the patient

: is used in neuromuscular education as a means of providing supplemental augmented feedback to intrinsic proprioceptive cues. The subject receives audiovisual electromyographic (EMG) feedback of his own muscle activity incurred during a movement task. (Fig. 1)

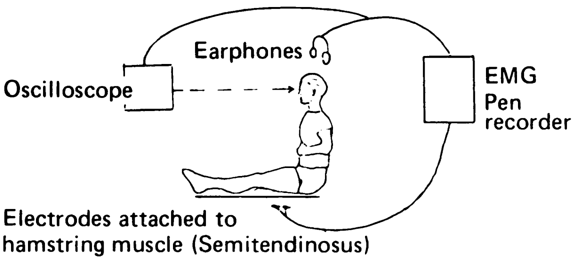

Fig. 1. EMG Feedback apparatus used to monitor audiovisual feedback of Hamstring muscle activity during flexibility exercises.

Feedback may be utilized in the control of ongoing responses (action feedback) or it may be retained in memory store and used in the control of subsequent responses (learning feedback). Augmented feedback may be concurrent or terminal (Holding, 1973). The former is information which is present all the time a person is responding, as in watching a pointer whilst adjusting a control knob, the latter being information which arises as a result of a completed response like the score of a dart throw. If one squeezes a hand dynamometer whilst watching the pointer it is possible to reach an exact pressure, say 30Kg. Having once reached the mark in this way, however, there is no guarantee that one can repeat the same pressure with the pointer hidden. On the other hand one might defer looking at the pointer until after making an attempt at the correct pressure. Seeing the attempt is 2Kg light one might press again a little harder, stop, and look again at the pointer, making repeated attempts to reach the 30Kg mark by successive approximation. It is important to distinguish between changes in immediate action, and performance and changes which give rise to more permanent learning, since quite dramatic manipulations of action feedback may have only temporary effects. The terminal knowledge of results coming after an action is more likely to assist in learning than is concurrent feedback, whose function is rather to regulate the actions during which it occurs (Holding, 1973). Giving concurrent feedback only intermittently to supplement terminal knowledge of results appears to be of probable value in permanent learning (Sage, 1973).

Learning is a modification of behaviour brought about by experience and is measured by changes in performance in the direction of some criterion. In order for the learner to modify his behaviour to achieve the criterion, or goal, he must know whether or not his responses are bringing him closer to the criterion. He needs information about his responses.

EMG Feedback and Relaxation

Clinicians have often observed that instructing a patient to relax a particular muscle group sometimes results in a tensing of the muscles rather than the intended relaxation. Such patients seem unable to discriminate the proprioceptive cues which accompany a state of muscle tension. Nevertheless, numerous workers have reported that individual motor units of human muscle are controllable by the experimental subject and that normal (uninjured) subjects can voluntarily regulate the potential output of motor units with high order gradation when auditory and/or visual feedback training is given (Basmajian, 1974, for a review).

Mathews and Gelder (1969) studied the effects of relaxation training with phobic patients, showing that the EMG activity was altered during relaxation and concluded that relaxation is in some way associated with a controlled decrease in 'arousal level' with retention of consciousness. Paul (1969) compared hypnotic suggestion and brief relaxation training, and showed the superiority of the latter in reducing subjective tension levels and distress. Jacobs and Felton (1969) employed visual feedback of EMG from the trapezius muscle to facilitate relaxation in patients with neck injuries as well as normal persons. Subjects were given ten 15 min trials; the results demonstrated clearly that visual feedback of muscle activity leads to an increase in relaxation of the trapezius muscle. Although patients with neck injuries have more difficulty than the normal person in relaxation when using only proprioceptive and kinaesthetic cues, such subjects gain dramatically in ability to relax when permitted visual EMG feedback. Budzynski et al. (1973) report a significant reduction in muscle contraction headache activity in patients trained in the relaxation of the forehead musculature through EMG feedback. Training consisted of 16 semi-weekly, 20 min feedback sessions augmented by daily home practice. A pseudofeedback control group and a no-treatment control group failed to show significant reductions. In three to six, 20 min feedback sessions chronic headache patients can learn to decrease resting forehead EMG levels by 50-70%. A three-month follow-up questionnaire revealed a greatly decreased medication usage in the experimental group.

Swaan et al. (1974) compared the effectiveness of two rehabilitation methods in the treatment of unwanted activity in the peroneus longus muscle while contracting the quadriceps group. Patients received auditory EMG feedback about activity in the peroneus longus muscle (experimental group) whilst others were treated using conventional physical therapeutic techniques. The data indicated that experimental operant conditioning techniques (Black, 1972) resulted in better inhibition of unwanted muscle activity.

Re-education in Neuromuscular Dysfunction

Treatment of neuromuscular dysfunction involves medical or surgical therapy to reverse underlying disease processes, retraining of the patients' remaining but altered functional capacities and development of external devices or prostheses to substitute for and assist the patients' own efforts. As specific medical or surgical treatment is not yet available for many neuromuscular diseases, the latter two types of treatment are important in the rehabilitation of neuromuscular dysfunction.

Voluntary muscle function depends upon the transmission of nerve impulses from the cortical centres through the upper motor-neurones to reach the anterior horn cells. The axons of these cells, the lower motor-neurones, extend to the group of muscle fibres which they innervate. Under normal conditions this function depends on the activity of two basic structures — the nerve and the muscle. Alteration in either structure results in an impairment of voluntary function. Any disease which affects either upper or lower motor-neurone pathways impedes the nerve impulse and results in muscular weakness or paralysis. Any method which can restore the transmission of neuromuscular impulses is of vital importance in the restoration of voluntary function.

The transmission of nerve impulses may be impaired by numerous factors: (a) inability to initiate nerve impulses, as in sensory aphasia; (b) temporarily impaired function of a proportionate number of nerve cells, as in cerebral thrombosis; (c) temporary blocking of the pathways due to local oedema, as in cellulitis; (d) where anatomical pathways have been re-established but no impulse transmission exists as the cerebral motor engrams have become disorganized, as in sympathetic causalgia – the patient has had severe pain and on recovery has "forgotten" how to transmit impulses to the muscles affected; (e) a similar mechanism in peripheral lesions; (f) substitution – where a group of muscles become paralyzed due to nerve injury and either proximal, adjacent or distal muscle groups take over the function of the paralyzed ones; (g) when a patient has been paralyzed for months and a considerable amount of anterior horn cell destruction has occurred in the spinal cord, the pathways for a certain number of cells are functionally normal but under a state of physiological 'block' – i.e. the patient has lost the ability to transmit impulses – as in anterior poliomyelitis; (h) functional paralysis in which the patient has lost the ability to transmit impulses to an extremity (as opposed to paralysis of true neurogenic origin); (i) excessive neuromuscular transmission of impulses due to local hypertonia, as in tension headaches. (Marinacci, 1972).

The use of EMG feedback for re-education in neuromuscular dysfunction is a relatively simple procedure. In order for a patient to understand the purpose of this technique, he must have audible and/or visual feedback of his own muscle contractions. If the patient is paralyzed and there is no normal function present within the limb, a demonstration of what is expected is shown in the non-affected limb of the patient or demonstrator. Voluntary effort from the patient will determine whether there exists any latent function in the affected limb. If such is found, the feedback guides him to the proper degree of voluntary effort and thus facilitates the transmission of neuromuscular impulses.

There appear to be two specific groups of patients in whom audiovisual EMG feedback has been found to be of considerable value. The first, in whom a considerable amount of latent function is detected. The second, where latent function is minimal in degree.

Almost 15 years have passed since the effective use of EMG in muscle re-education was described by Marinacci and Horande (1960). They reported in considerable detail a method in which EMG was used to develop latent, often unsuspected muscle function in a variety of patients with both upper and lower motor-neurone paralysis. Yet despite the promise of the technique so described, the sporadic literature reports would suggest it has not been widely used. Andrews (1964) states the use of EMG feedback treatment of 20 hemiplegic patients to "help instruct the patient to generate motor unit activity in a non-functioning muscle". The objective of a study by Johnson and Garton (1973) was to develop a practical method of muscle re-education based on the technique of audiovisual facilitation and conditioning. The following means were used: (a) self therapy by the patient to minimize therapist time; (b) development of a simple, inexpensive, portable EMG machine to minimize and eventually eliminate reliance on a highly sensitive and expensive diagnostic EMG unit; (c) limited application to foot dorsiflexion paralysis of more than one year's duration in hemiplegic patients. Three, 30 min training sessions were given in which a needle electrode was inserted into the paralyzed tibialis anterior muscle, and a volitional contraction manifested by EMG. The patient was then familiarized with a portable unit and instructed to carry out re-training for a minimum of two 30 min sessions per day using auditory feedback; results were good. Brudny et al. (1974) report the use of audiovisual feedback displays of integrated EMG output. Nine patients were taught volitional control of their spasmodic torticollis. The patients were selected sequentially and had previously received conventional forms of medical or surgical therapy without success. Five had also received physiotherapy. Therapeutic sessions lasted from 30 mins to one hour, from three to five times weekly, for an average of 10 weeks. During feedback therapy 7 patients could maintain active control of the neck muscles indefinitely, 2 could do so for approx two hours. With treatment terminated 3 maintained control indefinitely, 3 could do so for several hours and 3 could do so for only five mins.

Although a subject may learn muscle control and learn to relax very efficiently, it does not follow necessarily that he is able to sense subtle increases in muscle tension and use his relaxation or gradation skills outside the laboratory setting.

Matthews (1964) points out that muscle spindles are not present in such numbers as to provide conscious perception of limb position. The concept that the tension inducing and maintaining mechanisms in muscle are basically reflex in nature (Eldred, 1967), and are mediated through the spindle afferents and the gamma loop system seems to be accepted generally. However, by no means does muscle function begin and end with the spindle system exclusively. Other afferent receptors are not only active but have central connections as high as the sensory cortex and consciousness, as anyone who has lifted a weight will attest. Rose and Page (1969) report an attempt to determine the influence of conscious discrimination on a quadriceps (knee extension) lift. The results demonstrated that a differential of approx 10% between two loads lifted in succession approaches the threshold of non-discrimination; a differential in excess of 20% approaches invariable discrimination. For the rectus femoris muscle the "incremental unit" – the additional force which accomplishes the maximal rate of increase in muscle strength – is approx 1¼ lbs. This unit differs for different muscles. The inferences made are:

(a) that sensory information from the extremity and clear conscious awareness of muscle contraction is present; (b) that there is ease of differentiating the gross magnitude of weight; (c) the difficult point to resolve in "memory" is the finer gradation of successive weight changes. This would suggest that if incoming signals from afferent mechanisms can be held to a sufficiently low level of change, they do not ascend to higher levels in sufficient amounts to be interpreted consciously nor to result in modulation of response from integration and interaction of such conscious reactions.

Tension perception in patients having pain associated with chronic muscle tension was investigated by Fowler et al. (1974). They report that subjects with chronic neck and shoulder pain were able to reach deep levels of relaxation of painful regions with the use of EMG feedback. However, only a few subjects were able to recognize tension levels of tension build-up outside the laboratory. They seemed to behave "like a boiler factory worker who has worked around noise so long he doesn't hear it anymore". The findings support the conclusions of Jacobson (1967) that people are remarkably unable to judge their muscle tension levels. This would suggest that when EMG feedback is used to facilitate muscle re-education it should be supplemented by training in muscle tension perception.

Booker et al. (1969) studied the treatment of a patient with a lesion in the left peripheral facial nerve whose accessory nerve was partly connected with the peripheral part of the facial nerve. It had not been possible to restore facial symmetry using conventional techniques, but with the employment of EMG feedback symmetry was restored. The basic configuration was a pursuit tracking system in which the patient viewed two spots on an oscilloscope screen. The upper spot was the target that was displaced horizontally by a sine wave, the lower one being the cursor, displaced by the involved muscle EMG. The task was to move the cursor in synchrony with the target. Perfect tracking would result in the cursor being superimposed on the target as it was displaced. Feedback treatment was supplemented by home practice of conventional mirror work.

EMG Feedback and Motor Skill Acquisition

The fact that man can consciously control individual motor units makes possible novel application in motor skill acquisition. Basmajian and Newton (1973) showed that with myoelectric feedback through fine wire electrodes in the lips and buccinator muscles of the cheek, clarinet players can quickly "revise the localized activities in bizarre ways without losing the ability to perform". In addition, Basmajian and White (1973) showed that trumpet and trombone players have different natural patterns, that these vary with proficiency, and that they can be altered with EMG feedback. Payton and Kelley (1972) explored the factors controlling biceps brachii and deltoid during performance of skilled tasks in a way that lends itself to feedback training.

Applications to sports techniques are multiple, particularly in closed skill situations (Whiting, 1969), which lend themselves admirably to EMG feedback techniques. For example, auditory feedback of the quadriceps activity during the golf drive will give an indication of the contribution of the legs to that movement. Concentration on increasing that activity in relation to the timing of the stroke will reinforce verbal cues from a coach. The copying of audible EMG patterns from a skilled performer should enhance acquisition of the motor skill. In activities where a degree of relaxation during performance is desirable, as in putting, audible EMG activity will enable the subject consciously to reduce tension levels in appropriate muscle groups. Similar situations exist in most ballistic skills where forceful agonist contractions, which initiate the movement, are followed by a relaxation phase during mid-stroke. The contribution of individual body segments to a final velocity and the build-up or summation of forces are vital elements in the performance of most throwing and striking activities. The evaluation of a forcible leg drive during shot putt may be manifested by EMG feedback and thereby controlled; the contribution of final wrist and finger movement to shot release may be maximized in similar manner. Flexibility, a feature required in many gymnastic and athletic activities may be indirectly illustrated by the monitoring of antagonist muscle activity (Munrow, 1961). By feedback training of the antagonist in static and dynamic situations, it may be suggested that the flexibility of the trained limb be influenced markedly. It has generally been believed that during the movement of a joint in one direction, muscles that move it in the opposite direction show some degree of antagonism. It has been shown however, that the so-called antagonist relaxes completely except perhaps with one exception, at the end of a whip-like motion of a hinge joint (Basmajian, 1974). The activity of the antagonist during a skilled movement may be a sign of nervous abnormality, as in the spasticity of paraplegia, or, in the case of skilled movements, a sign of ineptitude. The athlete's continued drill to perfect a skilled movement exhibits a large element of progressively more successful repression of undesired contractions. This antagonist activity may be monitored as audiovisual EMG feedback for the discernment of the subject.

OVERVIEW

Biofeedback is now the subject of articles in scientific journals, in the popular press, even in 'Playboy'. An accumulating body of knowledge suggests that Biofeedback represents an effective technique for the shaping of self control over certain autonomic and somatic physiological events. It is now being used as a treatment of insomnia, headache, anxiety, stress, cardiac arrhythma, circulatory disorders, backache, strokes, epilepsy, asthma, myopia, ulcers, reading disabilities, spasticity, high blood pressure, as an aid to motor skill learning, and even as a method of contraception. What has been surprising to most people is the ease with which ordinary patients take to the feedback signals and learn to manipulate them by acquiring more precise control over the muscles requiring training or recruitment.

"There is no limit to the novel applications in research and technology that are possible from the basic knowledge that, given electronic feedbacks, man can control individual motor units with extreme precision".

(Basmajian, 1972)

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