KEY WORDS: Electromyography; feedback; hemiplegia; motor activity; physical therapy

Electromyographic Feedback and Physical Therapy for Neuromuscular Retraining in Hemiplegia

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• Electromyographic feedback was compared with physical therapy for its relative effectiveness in training motor activity in patients with hemiplegia. A cross over design was used, so that each patient served as his own control. Strong reinforcement for attentional direction and for successful response to established criteria was used with both modalities. Electromyography through auditory and visual display was found effective in improving electromyographic activity, but more limited in training effective function as measured by active range of motion. In some cases it was counterproductive. Using an instrumental modality permits attention to only a limited number of motor elements involved in a motion, and is even more limited with respect to the interplay of activation and inhibition of those components. The activity of physical therapy, using tactile, proprioceptive, visual and communicative modalities, has the capacity for attending and drawing attention to many motor elements, as well as to the complexities of activation of some components concomitantly with the inhibition of others during the training process. Electromyographic feedback was felt to be especially useful in its ability to enhance figure-background discrimination and bypass possible areas of sensory obtundation.

Several recent studies have employed electromyographic feedback for neuromuscular reeducation.[1,2] Use of biofeedback input generally is reported to produce good quantitative and functional gains in motor control. Biofeedback is often considered a new therapy. Experimental and anecdotal comparisons of biofeedback to conventional physical therapy have been taken to suggest that biofeedback is, in many instances, a superior and more expedient modality than motor training in physical or occupational therapy.

To clarify the role and relative efficacy of biofeedback, the effects of biofeedback on hemiplegic victims of stroke was studied. Dependent variables were averaged electromyographic activity and range of active motion. Physical therapy was incorporated as a control method to biofeedback. The experimental setting was as rigidly controlled as feasible. Explicit, detailed attention was given to (a) the factors contributing to therapy and (b) the process of motor control reeducation under both biofeedback and physical therapy. It is believed that the factors indigenous to a therapeutic situation, including the instructional methods required for the effective use of stimulus modalities, are essential to any discussion of rehabilitation techniques. Hence the present report emphasizes a careful scrutiny of the specifics of the methods employed in relation to outcomes obtained.

Method

PATIENTS

Nine patients having sustained cerebrovascular accident were chosen from the files of hospitals and other institutions in Minneapolis-St. Paul. The patients were initially screened to meet the following criteria: (1) hemiparesis of the upper extremity with significant room for improvement in one muscle or muscle group; (2) a relatively uncomplicated medical history; (3) a minimum of one year poststroke status; and (4) a workable amount of cooperation, motivation and attention. Patients received neurologic examinations and were given the Minnesota Multiphasic Personality Inventory (MMPI) to eliminate possible pathologic profiles.

Except for one patient whose motor deficiency included an apraxia, hemiparesis was the result of basic sensorimotor impairment. All but three patients had suffered right or left hemisphere cortical damage; the three exceptions had possible bilateral damage or deep infarction. Patients were 1 to 10 years poststroke, 50 to 75 years of age, two women and seven men, two with left hemiparesis and seven with right hemiparesis.

Target muscles were the wrist extensors in seven patients, all of whom trained for greater contraction, and the biceps in two patients, one of whom trained for greater contraction and one for inhibition.

DESIGN

Four baseline measurements on the target muscles and movements were taken over four days of a two-week period (two days in each week). Following baseline, a crossover design was employed. Patients were randomly assigned to two groups with the exception that the two patients with left hemiparesis were

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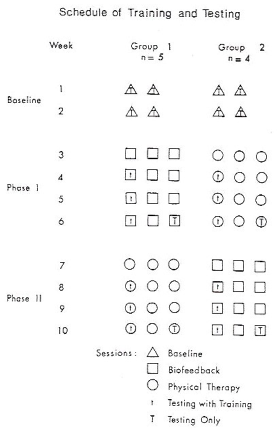

Fig 1—The experimental design.

distributed one to each group. Five patients received four weeks of biofeedback followed by four weeks of physical therapy (group 1), and four patients received training in the opposite order (group 2). Patients were seen at thrice-weekly intervals and measurements identical to those at baseline were taken at the 4th, 7th, 10th, and 12th sessions of the two consecutive four-week periods (fig 1).

MEASURES

Two modes of testing were used. In the first, referred to as "single command," patients were asked to respond to five repetitions of two commands to motion, for example, (1) "raise the wrist", and (2) "let it go." In the second mode, patients were asked to carry on the desired motion repetitively, as rapidly and as forcefully as they could move. This mode is referred to as automatic repetition. Measures were (a) averaged electromyographic response—the peak value of the averaged electromyography of each response, and (b) range of active motion—the difference between the angle of maximum flexion and the angle of maximum extension which is equivalent to the total number of degrees of movement.

EQUIPMENT AND APPROACHES

An electromyograph (Medic Flexline), which recorded the raw electromyographic signal, was connected to a signal averager. This then fed to an oscilloscope screen (American Optical) measuring 19" x 19", to project an averaged electromyographic signal display to the patient. The scope has its own gain settings to magnify the signal above the setting on the electromyograph, thereby allowing more subtle manipulations of signal size. The electromyographic signal was seen as a dot (leaving a trace) which rose and fell with contraction or relaxation of the target muscle. The apparatus also contained a loudspeaker unit which provided a volume-modulated auditory signal, in addition to the visual signal, for biofeedback training. Surface electrodes were used. The skin was marked with dye at each placement site to keep electrode placement consistent over sessions. A goniometer, consisting of a potentiometer connected to two hinged moveable metal strips, was placed over the ulnar axis of the wrist or the lateral epicondyle at the elbow. An ultraviolet paper recorder (Honeywell 2106 Visicorder) was used to record the electromyogram and the angular movement.

During biofeedback training, as well as during testing under both biofeedback and physical therapy training, patients who worked on wrist extension were seated in a slightly padded conventional office chair without arm rests. The chair was positioned on a platform to allow for greater height so that the patient's forearm could rest on an adjustable hospital bedside table which was wheeled next to the patient at a comfortable height. The table was positioned at a standard height and position for each patient and the forearm position on the table was held constant. Of the two patients who worked on the biceps muscle, one patient who required biceps relaxation (patient 5) was seated in the chair alone where his upper extremity was free to relax, and the other patient who required biceps contraction (patient 7) was seated in a wheelchair where his hand rested at his side on the wheelchair seat. (The latter was the only patient who sat in a wheelchair.) During physical therapy training the patients sat in the chair or wheelchair as described above but movement was, of course, not confined to any standardized limb position on the table.

Training Procedures

The procedures for training necessarily embody a number of therapeutic principles, which may vary considerably among different facilities and professionals. For purposes of clarity and specificity, both the physical therapy and biofeedback are described here in considerable detail.

PROCEDURE FOR PHYSICAL THERAPY

Patients were seated and physical therapy using active range of motion, facilitation, resistance, inhibition, etc, was practiced for 30 minutes. Responses were shaped in that patients received immediate positive reinforcement, for example, "good," for any approximations to improved movement. Malfunctional stereotyped patterns had to be broken up in order to establish new repertoires. Therapy for the muscle or muscle group in question required focus of attention on antagonist and other muscles of the forearm and arm, which contributed to impaired motor ability, as well as target muscles. Also, patients were frequently instructed to refer to the practiced movement in the unaffected limb to get the feel for what the correct movement entailed Some patients were told to look in a mirror to eliminate action such as shoulder elevation, internal rotation, or abduction during elbow flexion. Training was highly specific and goals were to shape and trim by instruction and appropriate, correct response, adding and subtracting any undesired features which made movements less "pure," isolated and exact.

Patients' limbs were moved passively at the shoulder, elbow and wrist, and they were told to pay attention to the "feel of it" to feel *where* it was moving and *which* muscles were pulling. There was enhancement of sensation at appropriate muscles and tendons by tactile stimulation concomitant with saying, "Here is the muscle that. . . . .do you feel it?" and telling the patients, "Now pay attention to. . . . ." etc. Movements which could not be initiated by patients, or which had minimal excursion or strength, were assisted by E (experimenter) moving the joints passively through the range (passive range of motion) with the above instructions as well as instructions to "hold" at a position the patients were able to maintain; in addition, the patients were then told to actively contract the agonist ("Don't let it fall, bring it back down with control"), that is, to maintain a voluntary motion of the agonist muscle as much as possible, after passive placement in an antigravity position. This procedure was also followed to provide guidance for the correction of incorrect movements by interspersing such passive movements with patient-initiated attempts, progressively reinforcing for successively correct approximations. Where nonvoluntary antagonist contraction interfered with a desired motion, there was training of voluntary relaxation of the antagonist using the same principles of somesthetic feedback, as were used for activation of a muscle, but attention was directed to relaxation of the antagonist.

Since most patients could move target muscles somewhat, attempts were also made at greater angular excursions and longer holds as feasible. For movements which could not be initiated, or which were initiated poorly, it was stressed that "Even a little bit, this much, is great," demonstrated by E on herself for example, barely extending the wrist (and, as necessary, for example, without wrist supination or without shoulder retraction, elevation, etc). Nonverbal gestures and demonstrations were used as well as verbal ones. For all movements, it was continually stressed "Remember *correct* movement is better than any old kind of motion, etc." The latter stress about correctness of movement was a common constant theme to shape precise, isolated movements, as distinct from stereotyped patterns.

There were three parts to any movement, as feasible. They were instructed as, for example: (1) "raise the wrist," (2) "bring it back down," and (3) "relax it" or "let it go". Concerning (3), most of the time when patients were able to carry out a movement, they were able to carry it out actively contracting the agonist, but very often they would develop a simultaneous contraction of agonist and antagonist muscles which continued for a long period or they would not completely relax the agonist at movement termination. In order to get good target muscle control, it was necessary to give specific instructions to relax or discontinue contraction. In other words, bidirectional ability to contract concentrically and eccentrically—to energize and inhibit—was always stressed so that if the patient were extending the wrist, it was equally strongly stressed to bring the hand down voluntarily, instead of letting it fall, as possible, and then relax, that is, "let it go" when the whole movement was completed.

E repeatedly served as an example of correct movement and had the patients try movements appropriately on unaffected limbs. Demonstrations from E of what the specifics were in a particular movement were done both by facing the patient and moving, as well as by placing the limb in an orientation similar to the patient's and moving with instructions of "See, now you try it." E would also point and touch herself and the patients on the origins and insertions of muscles that were moving and the joints around which movements were taking place. If there were things patients were doing incorrectly, E would call attention to the difference between the incorrect movement and the correct one, pointing out salient features both on herself and the patients.

E also touched the skin over the muscles concerned a great deal to determine muscle tightness or looseness during movements to ascertain how to shape, or what to inhibit, what to increase, etc. For inhibition of excessive tone there was a great deal of explanation and touching. For example, for tight wrist flexors during wrist extension, E would touch and say "Do you *feel* how tight this is?" Then, for example, she would say, "You have to stop making both these (wrist flexors and extensors) muscles tight at the same time if you are to raise the wrist better." E even sometimes explained in very simple terms how muscles on one side did one thing and those on the other the opposite, so that simultaneous excitation would result in, for example, a wrist that would not raise all the way. Tactile stimulation and attempts at passive motion helped patients feel and attend to excessive tone. The moment tone diminished in the problem muscle E said, "That's it, right."

For the individuals with flaccid upper extremities in particular (two patients in this study), facilitation was used which consisted of skin friction or percussion of the muscle to facilitate and reinforce as movement occurred. For other patients with increased tone, facilitation was used only as necessary to assist elicitation of the desired motion. Most patients did not execute it to some degree, and facilitation was used only as a springboard for a more firmly founded repertoire of voluntary control. Antagonist muscles of the target group and, on occasion, other muscles were also facilitated. Movements in muscles other than the target agonist or antagonist were usually initiated by passive range of motion as described above when considered necessary to the performance of a more desirable motion.

Resistance was a good part of physical therapy. It was used mostly on the target muscle group but sometimes on antagonists of that group and occasionally on other muscles. Resistance was never applied to a point where the patients did not feel successful pushing against E. Patients derived great satisfaction and immediate, physically apparent feedback from the sensation of resistance. (On the other hand, for example, while relaxation [inhibition] training is of equal importance, it is difficult to accomplish, and difficult for patients themselves to experience comparable sensory feedback for relaxation as for excitation in physical therapy.) E made certain that patients knew how to practice resistance training themselves for purposes of work at home.

For many patients there was general training of the paretic upper extremity. This involved instructing the patients to go to the opposite, unaffected limb, tense all the muscles "tight, tight, tight, tight," and then "let go," illustrated by E all the while. Patients were then asked to do the same. E then said:

> Do you *feel* the relaxation? Now it is the same *feeling* you want in your other arm because now it is all tight. (They would know it and agree.) So when you go home to practice, do this (again, show me how you do it) and try to get the same relaxation *feeling* in the affected arm (right or left). Also practice (demonstrated) relaxing in both limbs starting with the good one, "feeling heavy, loose," often using multiple descriptive words. "First your neck muscles, then your upper arm muscles, through your elbow, into your lower arm, through your wrist, into your hand, down to your finger tips."

This was said in a monotonous, hypnotic tone and E was simultaneously getting loose and heavy too. Another relaxation method was instructed as follows: "Try letting your arm go as a dead weight." This was tried on the affected and unaffected limb singly and together. To demonstrate, E would say "Okay, feel my arm and move it. There is nothing coming from me." E's limb remained inactive and the only way it would move was if the patient pushed it, after which it would fall.

As patients learned relaxation, those with excessive tone received emphasis to execute movements with the arm first relaxed to facilitate appropriate, smooth, correct motion. The technique was used as part of the total plan of giving resistance, stressing relaxation, and keeping the target muscle improving without losing achievements to date or disturbing coordinated smooth movement.

All methods were used to the extent and at times at which the patient could feel successful. In other words, E was careful not to ask more of the patient than he could do, yet much was required in terms of work and attention to subtle, gradual changes. Physical therapy was dynamic in terms of what was desired and how hard patients were to try. There was constant verbal feedback, touch, stimulation, explanation, example, corrections, praise, and *direction of attention* to immediate particulars. Constant coaching was an essential component of the therapy program.

Also, there was frequent repetition of important particulars to be sure that patients understood E and that E understood the patients. Patients were repeatedly asked to practice movements on their own, to verify that they were going about the movement correctly. When patients would first arrive for a session, E would say, "Okay, show me what you have been doing," or "what we have been practicing," if they did not do homework, to see how well they remembered, executed, or even if they understood the movement pattern in the first place. The patients typically required much repetition.

PROCEDURE FOR BIOFEEDBACK

For the first session, electrodes were connected to the target muscles on both arms. The patients were first told to try movement on the unaffected side to experience the sound and TV display corresponding to movement. Instructions were as follows (using the wrist as an example):

> We are going to begin by showing you how this machine works. First, we will look at your right (or left) arm (normal side) to see what happens. Please move your wrist up and down like this (demonstrated). Now go ahead and move it slowly, and watch how the dot on the screen goes up and down and listen to how the noise gets louder and softer. The dot goes up and down depending on what you are doing with your wrist. When your wrist is relaxed the dot is low. When the dot moves higher, it is because your wrist is moving more. You can make it high or low with your movements. Also listen to the noise. When your wrist is relaxed the noise is quieter. When the noise gets louder it is because your wrist is moving more. You can make it go quiet or loud with your movement.
>
> Now from here we're going to try it with your other hand to see what we can do. Note the difference in the dot and try to make it go higher (or lower). The higher (or lower) you can make the dot go and the louder (or softer) you can make the noise, the better you are doing. You must put your mind to it to try to make the dot high (or low) or it will not move. The noise will also get louder (or softer) as you try to move (or relax). The way you get the dot and sound to work is by raising your wrist (or relaxing your wrist), that is, bringing your wrist up as much as you can (or letting your wrist go as completely as possible).

After several attempts by the patient following the above instructions, additional instructions were given.

> Now, although we are most concerned with your getting the dot to go higher and the noise to get louder, you should always bring your wrist (or elbow) down to the point where the dot is just a smooth flat line and the noise is absolutely quiet. Do not start another movement until

you reach this quiet, relaxed point. This is because we want to make the muscle go well in both directions—first to make it work and then to shut it off or relax it.

Patients readily understood how the stimuli corresponded to contraction and relaxation. After one session of limb comparison and acquaintance with the apparatus, only the affected limb was connected and the patients were left alone to train for 30 minutes with occasional visits from E. The visits were to monitor performance and ascertain that movements were being executed as correctly as possible. The training room was daylight dim (shade drawn) and the door was kept slightly ajar so that E could view the patient and the TV during practice.

PROCEDURE COMMON TO BIOFEEDBACK AND PHYSICAL THERAPY

Patients were given a great deal of verbal guidance during both biofeedback and physical therapy. That is, if a patient were elevating the shoulder to contract the biceps or flexing the elbow to extend the wrist, he was continually reminded that the movements in question were not being executed appropriately—that, in fact, many movements were occurring at once, movements were incorrect, or that movements incorporated features which were not part of the training. Thus, there was a great amount of verbal guidance to isolate a single correct response, necessarily a more intrinsic part of physical therapy training than biofeedback due to the constant mutual efforts of both patient and E during physical therapy rather than the intermittent visits from E during biofeedback. Also, E made generalized appraisals of the patient's performances after each session of both biofeedback and physical therapy, noting how the patient was doing, adding careful statements of encouragement as necessary or warranted. Exhortation to greater effort was subdued in order to prevent patients from meeting with too much failure should they not succeed, and also, to avoid excessive generalized stimulation which would contribute to hypertonia. Patients were motivated to work. There were few absenteeisms, and subjective reports of a good deal of practice at home from most patients.

Concentration was also a common theme stressed to both groups by E. Frequent statements were made to the effect to "concentrate now," "you must concentrate," and "put your mind to it."

Results

Pooled group analysis (combining groups 1 and 2) showed no significant difference between biofeedback and physical therapy training for scores on either electromyographic activity (table 1), or active range of motion (table 2). (Patient 5 was excluded from the electromyographic analysis because of constant residual biceps activity in both his affected and unaffected limbs during elbow extension. Patient 7 was excluded from the range of motion analysis because of an apraxia which hindered elbow flexion. He consistently used a gross swing of an adducted shoulder to accomplish flexion.) A similar analysis showed significant learning effects in electromyographic activity and range of motion during both biofeedback and physical therapy as compared against baseline. There was no difference between responses to single commands and automatic repetitive responses.

In regard to electromyographic activity in individual groups (table 3), performance of group 1 (biofeedback, then physical therapy) was better than that of group 2 (physical therapy, then biofeedback). Within group 1 there was a significant learning under biofeedback ($p = 0.03$). Further learning under physical therapy was not measured at significant levels in group 1. For group 2, however, significance was not reached in either comparison (fig 2).

Table 1: Pooled Group Comparisons for Averaged EMG Activity*

	Single command				Automatic repetition		
	Δ	SE	P		Δ	SE	P
Pooled group comparisons (Groups 1 and 2)				Pooled group comparisons (Groups 1 and 2)			
BF vs PT $\bar{x}$=69.1 $\bar{x}$=60.4	8.6	±7.6	0.29	BF vs PT $\bar{x}$=69.2 $\bar{x}$=58.6	10.7	±5.6	0.10
BF vs Baseline $\bar{x}$=69.1 $\bar{x}$=42.5	26.5	±7.8	0.01	BF vs Baseline $\bar{x}$=69.2 $\bar{x}$=43.2	26.0	±7.3	0.01
PT vs Baseline $\bar{x}$=60.4 $\bar{x}$=42.5	17.9	±7.1	0.04	PT vs Baseline $\bar{x}$=58.6 $\bar{x}$=43.2	15.3	±5.9	0.03
Overall treatment (Phases 1 & 2) vs Baseline $\bar{x}$=64.8 $\bar{x}$=42.5	22.3	±6.4	0.01	Overall treatment (Phases 1 & 2) vs Baseline $\bar{x}$=63.9 $\bar{x}$=43.2	20.8	±6.0	0.01

*Computed using mean values in microvolts of averaged EMG activity.

Table 2: Pooled Group Comparisons for Range of Motion*

	Single command				Automatic repetition		
	Δ	SE	P		Δ	SE	P
Pooled group comparisons (Groups 1 and 2)				Pooled group comparisons (Groups 1 and 2)			
BF vs PT $\bar{x}$=38.5 $\bar{x}$=39.8	1.3	±2.3	0.59	BF vs PT $\bar{x}$=36.8 $\bar{x}$=37.5	0.64	±2.2	0.78
BF vs Baseline $\bar{x}$=38.5 $\bar{x}$=27.3	11.2	±2.3	0.002	BF vs Baseline $\bar{x}$=36.8 $\bar{x}$=20.8	16.0	±3.0	0.001
PT vs Baseline $\bar{x}$=39.8 $\bar{x}$=27.3	12.5	±3.3	0.01	PT vs Baseline $\bar{x}$=37.5 $\bar{x}$=20.8	16.7	±4.1	0.005
Overall treatment (Phases 1 & 2) vs Baseline $\bar{x}$=39.2 $\bar{x}$=27.3	11.9	±2.6	0.002	Overall treatment (Phases 1 & 2) vs Baseline $\bar{x}$=37.2 $\bar{x}$=20.8	16.4	±3.4	0.002

*Percentage scores—computed using mean values of the range attained relative to the maximum range possible for a given patient.

Table 4 presents the changes in active range of motion after both training programs. Intragroup analyses showed significant increments under biofeedback and physical therapy for both groups 1 and 2. There was no significant difference between the biofeedback and physical therapy in their effect on improvement of active range of motion (fig 3).

Discussion

Both biofeedback and physical therapy were shown to produce significant increments in range of motion. In general, there were significant increments in electromyographic activity under biofeedback and not under physical therapy. Because of the problem of the indirect or nonemphasis given electromyographic activity under the physical therapy training of this study (see "Results"), electromyographic activity under biofeedback and physical therapy could not be directly compared. Biofeedback, however, was effective in significantly altering electromyographic activity.

There are qualifications pertaining to direct comparisons between electromyographic biofeedback train-

Table 3: Intragroup Comparisons for Averaged EMG Activity*

	Single command				Automatic repetition		
	Δ	SE	P		Δ	SE	P
Intragroup comparisons: Group 1 (BF then PT)				Intragroup comparisons: Group 1 (BF then PT)			
BF vs PT $\bar{x}$=59.6 $\bar{x}$=57.3	2.3	±6.4	0.74	BF vs PT $\bar{x}$=58.5 $\bar{x}$=55.4	3.1	±6.8	0.68
(Phase 1) BF vs Baseline $\bar{x}$=59.6 $\bar{x}$=36.2	23.4	±6.0	0.03	(Phase 1) BF vs Baseline $\bar{x}$=58.5 $\bar{x}$=37.2	21.3	±3.4	0.01
(Phase 2) PT vs Baseline $\bar{x}$=57.3 $\bar{x}$=36.2	21.1	±9.0	0.10	(Phase 2) PT vs Baseline $\bar{x}$=55.4 $\bar{x}$=37.2	18.2	±7.8	0.10
Intragroup comparisons: Group 2 (PT then BF)				Intragroup comparisons: Group 2 (PT then BF)			
BF vs PT $\bar{x}$=78.5 $\bar{x}$=63.6	14.9	±14.3	0.37	BF vs PT $\bar{x}$=80.0 $\bar{x}$=61.7	18.3	±7.9	0.10
(Phase 1) PT vs Baseline $\bar{x}$=63.6 $\bar{x}$=49.0	14.6	±12.3	0.31	(Phase 1) PT vs Baseline $\bar{x}$=61.7 $\bar{x}$=49.3	12.4	±9.8	0.29
(Phase 2) BF vs Baseline $\bar{x}$=78.5 $\bar{x}$=49.0	29.6	±15.5	0.15	(Phase 2) BF vs Baseline $\bar{x}$=80.0 $\bar{x}$=49.3	30.7	±14.8	0.13

*Computed using mean values in microvolts of averaged EMG activity.

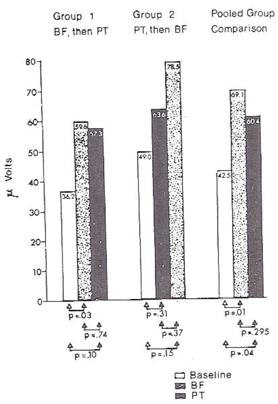

Fig 2—Average change in EMG activity in each group and in each phase.

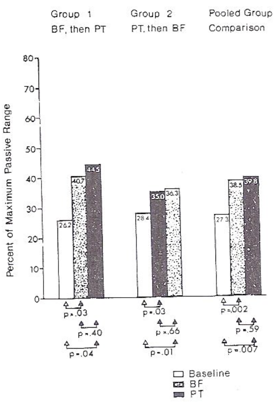

Fig 3—Average change in active range of motion in each group in each phase.

ing and physical therapy in general, even if other assessment measures were used. During biofeedback training, each person in either group was consistently trained to effect an electromyographic increment. Hence, biofeedback training consisted of a relatively unidirectional procedure and goal, specifically that of increased electromyographic activity for each patient. During physical therapy, however, patients were taught the qualitatively more appropriate or kinesiologically correct type of activity at a given therapeutic juncture. This could have been, eg, excitation or inhibition of other limb muscles. Hence, physical therapy was not, in terms of procedure, sensitive to a singular goal of increased electromyographic activity as was biofeedback. In fact, three patients received a great deal of relaxation training during

Table 4: Intragroup Comparisons for Range of Motion*

	Single command		
	Δ	SE	P
Intragroup comparisons: Group 1 (BF then PT)			
BF vs PT $\bar{x}$=40.7 $\bar{x}$=44.5	3.8	4.0	0.40
(Phase 1) BF vs Baseline $\bar{x}$=40.7 $\bar{x}$=26.2	14.4	4.0	0.03
(Phase 2) PT vs Baseline $\bar{x}$=44.5 $\bar{x}$=26.2	18.3	5.0	0.04
Intragroup comparisons: Group 2 (PT then BF)			
BF vs PT $\bar{x}$=35.0 $\bar{x}$=36.3	1.2	2.4	0.66
(Phase 1) PT vs Baseline $\bar{x}$=35.0 $\bar{x}$=28.4	6.7	1.7	0.03
(Phase 2) BF vs Baseline $\bar{x}$=36.3 $\bar{x}$=28.4	7.9	1.5	0.01

	Automatic repetition		
	Δ	SE	P
Intragroup comparisons: Group 1 (BF then PT)			
BF vs PT $\bar{x}$=39.7 $\bar{x}$=41.8	2.1	4.2	0.65
(Phase 1) BF vs Baseline $\bar{x}$=39.7 $\bar{x}$=17.2	22.6	2.7	0.003
(Phase 1) PT vs Baseline $\bar{x}$=41.8 $\bar{x}$=17.2	24.6	5.6	0.02
Intragroup comparisons: Group 2 (PT then BF)			
BF vs PT $\bar{x}$=33.1 $\bar{x}$=33.9	0.80	1.8	0.68
(Phase 1) PT vs Baseline $\bar{x}$=33.1 $\bar{x}$=24.4	8.7	2.3	0.03
(Phase 2) BF vs Baseline $\bar{x}$=33.9 $\bar{x}$=24.4	9.5	2.3	0.02

*Percentage scores—computed using mean values of the range attained relative to the maximum range possible for a given patient.

physical therapy and therefore made no increments in electromyographic activity while three patients received strong resistance training, with no general relaxation, and attained opposite results. Thus, biofeedback and functionally oriented physical therapy are not strictly comparable with regard to their effect on electromyographic activity. It can, however, be concluded that biofeedback did increase that which it specifically conditioned—electromyographic activity somewhat more than did physical therapy.

In this paper, the procedure section of "Methods" was developed as comprehensively as possible to delineate explicitly the means employed in either therapeutic situation of the biofeedback and physical therapy. After careful consideration of common therapeutic features and specific functional outcomes under either regimen, the conclusion here is that biofeedback is not a therapy in and of itself, but rather a feedback modality of therapy. It is sometimes intimated that biofeedback may be designated a therapy as a likely alternate to physical therapy. The generic term of therapy as applied to biofeedback includes several features common to physical therapy. The primary distinguishing features between biofeedback and physical therapy would seem to be the visual and auditory input in biofeedback versus the somesthetic input in physical therapy and the peculiar cognitive features inherent to each mode. The other distinction would be the association of the feedback with an electrical correlate of muscle activity for one, and limb or body movement for the latter.

The above conclusion is based on observations that biofeedback as an isolated treatment affects the circumscribed events of increased or decreased electromyographic activity. Tangential or superordinate processes important to the return of motor control in terms of function are not part of the biofeedback treatment except possibly as corollaries of increased or decreased electrophysiologic output. That is, greater or lesser muscle contraction alone is distinct from many of the variables important to increased function, such as increased range of motion and coordination between postural and translatory motor activity. Reeducation of function is imparted to a patient via a constantly changing program of external and internal events. These events include changing foci of attention, changing instruction and the use of concentration on appropriate sensations. These features are important to both biofeedback and physical therapy, and are essential elements in any learning situation. The fact is, that attention to the therapeutic milieu as a primary example of a circumstance in motor learning was high in the study. This fact probably explains the high degree of overlap in results, since this approach represents a most fundamental common element in both modalities as applied. Any distinction in this or other studies will need to consider these basic components, often ascribed, casually, to "therapist skill." However, they can be defined, and should be, to be able to identify the real factors operative in any study of this kind. To the extent that there was this commonality, within the limits imposed by the modality itself, any differences noted would be differences inherent in the procedures tested here.

The hemiplegic patient with stroke commonly suffers a spastic stereotyped obligatory mass flexion movement pattern. When he is connected to electromyographic feedback equipment, the resulting movement is often the same stereotyped pattern, as typically evidenced in case reports of this study.[3] To effect isolated, specific contraction, a patient must receive multiple supplementary instructions concerning limb positioning, appropriate versus inappropriate response patterns, and immediate apprisal of alterations in a movement pattern at any of the joints of a paretic limb. Otherwise, a patient probably will not use electromyographic feedback effectively.

A patient also typically needs much repetition concerning what he should be doing in either biofeedback or physical therapy. For example, when left alone without guidance to practice using biofeedback, many patients, though they may be altering the electrophysiologic output of a target muscle, will only repeat some gross stereotyped movement pattern which is not functionally appropriate. Consistent instructions on response specifics and focus of attention by the patient, via the therapist, are necessary.

The following cases illustrate how movement problems and supplementary methods besides biofeedback conditioning may be necessary to effect function. Two patients (patients 2 and 3) who had relatively high levels of electromyographic activity and good range of motion at experimental outset, reported that electromyographic increments on biofeedback seemed meaningless. When questioned, they also reported that they could not feel the increments. Subjectively, they were unable to distinguish between an initial effort and an increment of up to 50 to 100% as measured by electromyographic activity. Ideally, these patients had to learn how to use their muscles in a practical way and, for example, experience strength against resistance. During biofeedback, these patients were given verbal assistance in the form of instructions such as to diminish supination patterns or to concentrate on awareness of position. Such goals were functionally germane.

Again, it was found that some patients could develop increments in electromyographic activity via biofeedback but such increments could be counterproductive. For example:

During biofeedback training (phase 1), patient 9 changed her baseline electromyographic recruitment level of 70.8 μv, to 80.0 μv—a gain of 9.3 μv—and increased her range to 44.1°. In physical therapy, she decreased her EMG level again by 4 μv but increased her range to 60° over the baseline level of 41.4°. The change in range in physical therapy and the slight electromyographic decrease were due to comprehensive instructions derived from physical therapy principles aimed at effecting a qualitatively more correct (that is, functional) movement. The latter, for patient 9, was not effected by electromyographic increases (which were associated with an array of detrimental response features) but rather by greater muscle relaxation (less or steady amounts of electromyographic recruitment) to achieve (within the limits of contracture) a greater and smoother range response. Patient 9 made general improvements in function during biofeedback too. The improvements occurred, irrespective of little electromyographic increment, because of the multiple instructions and attention given patient 9's target movement.

This example points to an essential difference between motor evolution conceptualized in terms of sheer electromyographic recruitment versus evolution of range increments which are part and parcel of functional change. By and large biofeedback affects the former, while general physical therapeutic methods affect the latter.

One important aspect of therapeutic change in either physical therapy or biofeedback was patient motivation guided by experimenter feedback which informed the patient of the quality of his progress and kept his motivation high. Another was response-specificity requirements (see "Method") with appropriate instructional feedback whereby patients were given *immediate* verbal apprisal, with enhancement of sensation, by attention, at instants of improved motor control. As rehabilitation is a learning process, the most expeditious and fruitful approach is to help the patient build a new motor repertoire by instructing highly specific, well-defined, though sometimes microscopic approximations to movement with positive feedback or honest, directive appraisal of the inappropriate quality of stereotyped responses. The latter serves to make the patient aware of what he is doing incorrectly. The patient, of course, also must be simultaneously instructed in the desirable response specifics and the means to correct movement patterns. Finally, patients must always concentrate on training specifics to the best of their ability, since attention to and awareness of sensory reafference of the improved quality are essential to development of control, and the ultimate ability of motor response.

The complexity of changes required for functional motor control are in part related to input modalities and in part to general therapeutic methods. The latter are:

(a) motivating a patient and keeping his attention focused and sustained
(b) manipulating the therapeutic situation to conduce the proper instructive circumstances
(c) teaching a patient to be aware of target body parts
(d) conditioning a patient to respond to evidence of visual, auditory or haptic effect of motion
(e) manipulating body parts either directly by E or by the patient himself through E's instructions

All of the above factors are understood to fall under the rubric designated as physical therapy. Within this framework, electromyographic biofeedback is seen as a new, provocative and valuable stimulus *modality* which can be utilized within a therapeutic program for certain patient types and specific patient problems.

Biofeedback was found to be a valuable stimulus modality for two patients, 5 and 7, each of whom had individual characteristics for utilizing electromyographic feedback to best advantage.

Patient 7: This man had severe impairment of sensory function and a weak elbow flexion response (his target movement) which was elicitable only by stimulation of the stretch reflex. There was, thus, both minimal motor, and presumably minimal concomitant sensory reafference, associated with the elbow flexion response. He had an inattentiveness to his affected upper extremity precisely because of poor sensation in the limb. With an electrode placed on his biceps and connected to the cathode ray oscillograph during biofeedback (phase 1 for patient 7), he was surprised to see any activity at all, and was, after approximately two weeks, able to increase his electromyographic activity from an initial 11.8 μv average of activity at baseline to an average of 71.2 and 49.0 μv of activity at weeks three and four of biofeedback. He reported feeling his response in conjunction with greater increases in electromyographic recruitment; hence, a cycle of informational, along with some sensory reafference cues, was effectively completing a loop upon which he could build gains. Biofeedback served as a provocative entry modality into his sensorimotor system and furthermore would conceivably have been a continuing invaluable tool to reach some acutely necessary modicum of a physiologic substrate of electromyographic recruitment in any of the muscles of his flaccid limb.

Patient 5: This man had relatively good sensory function. However, his biceps (the target muscles) and other muscles were so spastic and hypertonic that his upper extremity is best described as rigidly set in a flexed elbow position of 45° with a pronated wrist and flexed fingers which, to the touch, had a "hard" feel of hypertonia. This patient was 10 years poststroke and his condition appeared "permanent." Although he had good proprioception, the limb was practically "static" when he tried to move, in that there was little motion around the elbow joint and hence a barely detectable amount of biceps relaxation around which to begin elbow extension. In the face of such a pragmatic problem, biofeedback was an invaluable tool. An electrode on the biceps connected to the cathode ray oscillograph sufficed in a few sessions to cause decreased biceps activity and a passive range of motion of up to 72.5° at test session four of biofeedback versus a mean of 8.6° at baseline. The biceps electromyographic activity never went to complete zero although adjustments were made at appropriate sensitivity levels whereby any progress would be readily apparent to the patient. The training time of four weeks of biofeedback was hardly sufficient for full and facile control over biceps relaxation. Although he still maintained good range of motion during physical therapy, his latency to initiate elbow extension, as well as the actual time taken to achieve maximum elbow extension, which was decreasing during biofeedback, began increasing during physical therapy. In sum, for patient 5, biofeedback was an excellent beginning for biceps relaxation and, most dramatically, for increased range.

For all other patients, biofeedback did not seem, in and of itself, a particularly efficacious modality for *return of function.* The verbal guidance afforded patients during biofeedback, in supplement to the biofeedback modality itself, was an extremely important ingredient in biofeedback training. Though the biofeedback stimulus was rather parenthetical for many patients, biofeedback training was helpful for all patients to the extent that continual verbal guidance during practice with the cathode ray oscillograph for the elimination of undesirable response features or the reinforcement of correct response patterns, effected general functional changes. Case histories[3] seemed to indicate that such functional changes were due to the rigorous verbal demands and continuous, immediate verbal appraisals (positive or negative feedback) given patients while they were using the biofeedback apparatus.

The failure to find clear differences between responses to single commands and automatic repetitiveness suggests that both modalities of training provide equal access to the motor systems involved. The statistical procedures carried out do have limited discriminative ability. There was some trend for biofeedback effectiveness for electromyographic response in automatic repetition test mode to approach criterion levels of statistical significance. This was not demonstrated for automatic repetition measured by change in range of motion. This difference would require further study to achieve more certain conclusions. The other element to consider is that of limbic system[5] involvement in self-generated, internal signalling and sequential activities. Thus, for this group of subjects, automaticity would not be a serious issue, considering their other motor problems.

In conclusion, biofeedback training is a relevant technique. It was not as completely appropriate, as a sole instructional modality, as it might have been when incorporated into an entire system of therapy. Motor control and skill is not gained simply by contracting or relaxing a single muscle to full capacity but by a process of acquiring control of activating and inhibitory mechanisms coordinating the simultaneous interplay of many muscles, as individuals and as groups. To achieve this control, there must be an adequate neural substrate to accomplish learning, plus a therapeutic technique and milieu that enhances learning at the best possible level. Hence, biofeedback was not isolatedly, that is, without verbal instructions of specifics, an automatic cause of therapeutic gains.

In general, biofeedback would seem to be an efficient and effective training modality in specific instances where electromyographic increases or decreases are vital or germane to motor function. Biofeedback was also noted to be an effective incentive to learning by virtue of its technologic and cultural attractiveness to the subject population.

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