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COMPARISON OF ACTUAL AND SIMULATED EMG BIOFEEDBACK IN THE TREATMENT OF HEMIPLEGIC PATIENTS[1]

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INTRODUCTION

Electromyographic (EMG) biofeedback for muscle re-education, as first described by Marinacci and Horande (1) in 1960, has gradually come to be accepted as a useful treatment modality in the rehabilitation of hemiplegic patients. While the use of this technique, termed "myofeedback" by Lee, *et al.* (2), has met with only limited success in decreasing spasticity (3), its effectiveness in increasing the conscious control and force of specific muscle groups has been repeatedly illustrated by investigators using experimental designs ranging from anecdotal case reports (3) and multiple systematic case studies (4) to group outcome studies, both uncontrolled (5) and controlled (6). These investigations all demonstrated the relative effectiveness of myofeedback by comparing it directly to conventional physical therapy. Although not specifically dealt with by any of these studies, it has been generally accepted that the success of this technique depends on accurate feedback of muscle activity that is quantitative, continuous and immediate in nature (7, 8).

More recently, in an attempt to determine the specificity of myofeedback, Lee *et al.* (2) compared the short term effects of true myofeedback to those of an approximated "placebo myofeedback". The latter was described as being "positive noncontingent" feedback. It was, however, a simulation of the patient's own myofeedback created by having the examiner contract a muscle "simultaneously with each attempted contraction by the patient". The resulting electromyographic signal was then substituted for the patient's without his knowledge. By subjecting the patients in the study to true feedback, placebo feedback and no feedback in various orders on three consecutive days and comparing the results, Lee concluded that "the effect of myofeedback (in terms of integral EMG units) is non-specific at least in its short-term application".

Recently, in a controlled study utilizing subjects with "no known neuromuscular dysfunction", Middaugh (9) compared the various effects of: 1) EMG feedback; 2) sensory stimulation; and 3) unassisted practice to a control group

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in improving function of the abductor hallucis muscle. She concluded that EMG feedback was "highly effective when subjects had little initial use of the target muscle" but "may have actually interfered with training" in those subjects who already had considerable use of the target muscle prior to training.

The purpose of this study was to determine the extent to which the success of myofeedback therapy with hemiplegic patients is dependent on actual myofeedback and to what degree, if any, it is due to other as yet undefined elements of the treatment design. The effects of actual myofeedback were compared to those of simulated myofeedback (similar to Lee *et al.*'s (2) placebo myofeedback) and no myofeedback in the treatment of foot drop and shoulder subluxation. This was done utilizing actual patients in a clinical situation, all of whom were simultaneously undergoing conventional physical therapy. The results were assessed in terms of active range of motion and integral EMG activity.

MATERIALS AND METHODS

Subjects

Twenty-four adult subjects, from 19 to 77 years of age (mean, 57.6), with hemiplegia secondary to cerebrovascular accidents (CVA) were selected from in-patients at the Spain Rehabilitation Center (SRC) using the following criteria: 1) a state of health such that the subject was currently undergoing traditional physical therapy; 2) paralysis or paresis of either foot dorsiflexion or shoulder abduction, or both, secondary to CVA; 3) a reasonable pain-free passive range of motion (approximately 50% or more of normal) in the target limb; and 4) the ability to cooperate and understand instructions.

Subject evaluation

Prior to the start of treatment, individual subject disability was determined for all patients participating in the study. Both the anterior tibial muscle and the deltoid muscle, which normally prevent foot drop and shoulder subluxation respectively, were evaluated. The function of these muscles was then described in terms of: 1) passive range of motion (PROM) in degrees; 2) active range of motion (AROM) in degrees; and 3) maximum electrical activity of the muscle contracted alone in millivolts. These same parameters were re-evaluated on the day following the termination of the treatment by an evaluator who was unaware of which treatment modality, if any, the patient received.

Experimental design

Twelve of the twenty-four subjects were randomly assigned to Group I (Actual Myofeedback Group: AMG), while the remaining twelve subjects were assigned to Group II (Simulated Myofeedback Group: SMG). In those cases in which both anterior tibial and deltoid muscles met the required experimental criteria (n = 20), one muscle was selected at random to serve as part of Group III (Control Group: CG). In this way one muscle of each subject was treated with either actual or simulated myofeedback while the other muscle served as a control in those subjects who had two muscles suitable for this study (table 1).

Treatment procedures

Group I (AMG) was treated with the BFT 450 Myotrainer and BFT 251 Meter System (Biofeedback Technology, Inc.[5]) using an adaptation of the procedure outlined by Baker *et al.* (10). In essence, the treatment was as follows:

1) The center of the target muscle was estimated. Points to either side of the approximated center (two centimeters horizontally for the deltoid; four centimeters vertically for the anterior tibial) were cleansed with alcohol and lightly abraded with fine sandpaper to decrease electrical resistance. Electrode gel was applied to two surface electrodes (Beckman[6] silver-silver chloride disk electrodes) which were then taped to the skin at these points. A ground electrode was similarly applied to any convenient point on the same limb. All three points were then marked with indelible ink to aid in session to session consistency.

2) The subject was then urged to attempt to contract the target muscle maximally during a five to ten second period as audio-visual myofeedback was given. Audio feedback was in the form of a constant pitched tone. Visual feedback was in the form of a voltmeter whose scale of deflection could be adjusted to correspond to the range of the patient's responses. Rest periods of sixty to ninety seconds were given between each trial, during which time complete target muscle relaxation (i.e., a low meter reading) was encouraged. Between ten and fifteen trials were attempted during each twenty minute therapy session.

3) With increasing proficiency, the feedback threshold of the trainer was increased so that progressively greater contractions were necessary to produce the same feedback response.

4) As the patient gained increasing control of the target muscle group, simultaneous relaxation of synergistic muscles was stressed.

Group II (SMG) was treated in a manner seemingly identical to Group I (AMG), but without their knowledge subjects in Group II received simulated myofeedback fabricated in the following manner: For every target muscle contraction, or attempted contraction as evidenced by limb movement and/or synergistic muscle activity, "feedback" was given to the subject by use of a concealed switch in conjunction with the previous mentioned myofeedback equipment. This "therapist mediated feedback" reflected solely the therapist's subjective estimate of the subject's efforts and was only partially contingent on actual target muscle activity, as even patients with no target muscle activity on initial or final evaluation were given abundant "feedback" throughout the treatment course.

The muscles included in **Group III (CG)** were evaluated at the beginning

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TABLE 1
Composition of groups I, II, and III

Group	Number of subjects	Mean age years (± S.D.)	Target muscles	Mean duration of hemiparesis days (±S.D.)	Mean pre-treatment duration of physical therapy days (±S.D.)
I (AMG)	12	59.4 (±18.3)	6 deltoid 6 anterior tibial	74.5 (±54.5)	12.6 (±15.6)
II (SMG)	12	55.8 (±19.1)	6 deltoid 6 anterior tibial	79.3 (±57.8)	10.0 (±7.7)
III (CG)	20	54.8 (±18.6)	10 deltoid 10 anterior tibial	60.2 (±42.8)	10.6 (±11.6)

and end of a two week period during which time they underwent no type of myofeedback treatment. During the entire study all subjects were simultaneously receiving conventional physical therapy designed individually for them according to their needs and abilities by the staff at SRC.

RESULTS

When the data gathered at initial evaluation were analyzed statistically using the t-test for independent samples, no difference was found between groups either in terms of AROM or muscle activity. At final evaluation all three groups showed varying increases in muscle function (fig. 1). Using the t-test for paired samples, the mean increases for all three groups were found to be significant ($p < 0.025$). Overall, the results expressed in terms of AROM in degrees correlated highly with those expressed in terms of muscle activity in microvolts ($r = 0.83$).

When the mean changes in muscle function for each group were compared to each other again using the t-test for independent samples (fig. 2), both Group I (AMG) and Group II (SMG) were found to have changes significantly greater than those seen in Group III (CG) ($p < 0.05$). There was no significant difference between Groups I and II.

When the change in muscle activity for both treatment groups was graphed on the basis of duration of hemiparesis (fig. 3A), the correlation coefficient was low ($r = -.12$). When change in muscle activity for both treatment groups was graphed on the basis of age (fig. 3B), a negative correlation approaching statistical significance was observed ($r = -.40$). When, however, the mean change in muscle function of those subjects equal to or less than 60 years of age ($n = 10$) was compared to that of subjects greater than 60 years of age ($n = 14$), no statistically significant difference was found.

Finally, the mean change in muscle activity of target muscles found to have no AROM at initial evaluation was compared to the mean change in muscle activity of target muscles that had a degree of AROM initially. This comparison revealed no statistical differences when AMG and SMG were taken either separately or combined.

When data were evaluated separately for anterior tibial and deltoid muscles, trends similar to the above were clearly evident. However, because of the small numbers involved, these data groups were combined so that valid statistical inferences could be drawn.

DISCUSSION

The statistically significant greater degree of increase in both muscle activity and AROM of those patients who received both standard physical therapy and a myofeedback treatment (AMG and SMG) as compared to those patients who received only physical therapy (CG) suggests that some aspect of the myofeedback design is an effective addendum to more established techniques. The insignificant difference between AMG and SMG suggests that the effectiveness of this treatment is not dependent on the exact feedback of myoelectric signals to the patient but rather on some other aspect of the treatment design, as yet undefined. As observed by Baker *et al.* (10), one of the major therapeutic reinforcements of this treatment, as reported by patients, is the actual visual movement of the limb being worked with. If this is the case, it may explain at least in part why both feedback groups had similar results in as much as most patients in both groups had this visible and accurate feedback available to them during at least a portion of their therapy. In addition, the extra praise and encouragement which all subjects in Groups I and II received during their daily treatment probably played a part in the relatively greater increases in muscle activity seen.

It came as somewhat of a surprise that the younger patients, who seemed subjectively more motivated as well as in better physical condition, did not do significantly better than the older patients. This finding, as well as the relatively low correlation overall between age and final results, suggest that all age groups of patients may potentially benefit from this mode of treatment.

The fact that the correlation between duration of hemiparesis and functional change was very low suggests that there is no ideal period to wait before instigating myofeedback therapy in order to maximize its effectiveness. In practice, these investigators found that early use of myofeedback seemed to act as a great motivational force in those with early return which carried over to all types of therapy. In those cases in which no EMG activity was discovered during the course of the therapy, it served as a means of helping patients adjust to the reality of their present situations. By stressing that later return was a common occurrence these patients were able to accept their condition at their own individual rates.

In contrast to results reported by Middaugh (9), the subjects who had no AROM at initial evaluation did no better after either "feedback" treatment than those who had a degree of AROM initially. This may represent inherent differences between training little used muscles of normal subjects and retraining muscles that have lost function secondarily to CVA.

Although stated as almost inevitable by other investigators (2), none of the patients in Group II (SMG) indicated by words or actions that they were aware that the feedback they received was simulated. This was attributed to two factors inherent in the experimental design. First, no subject experienced more

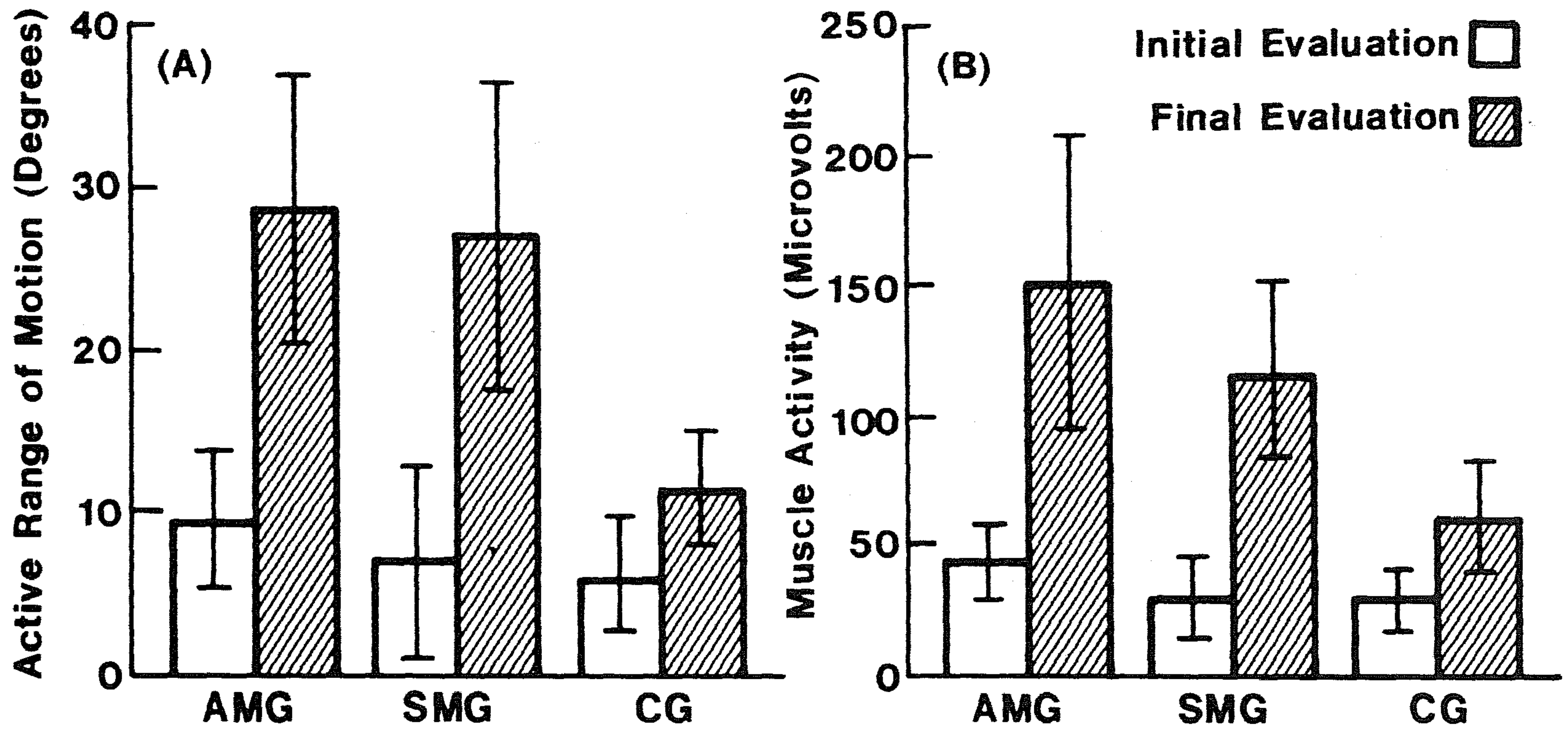

FIG. 1. Mean values for muscle function at initial and final evaluation in terms of (A) muscle activity and (B) active range of motion. Vertical lines represent ±1 standard error. AMG, actual myofeedback group; SMG, simulated myofeedback group; CG, control group.

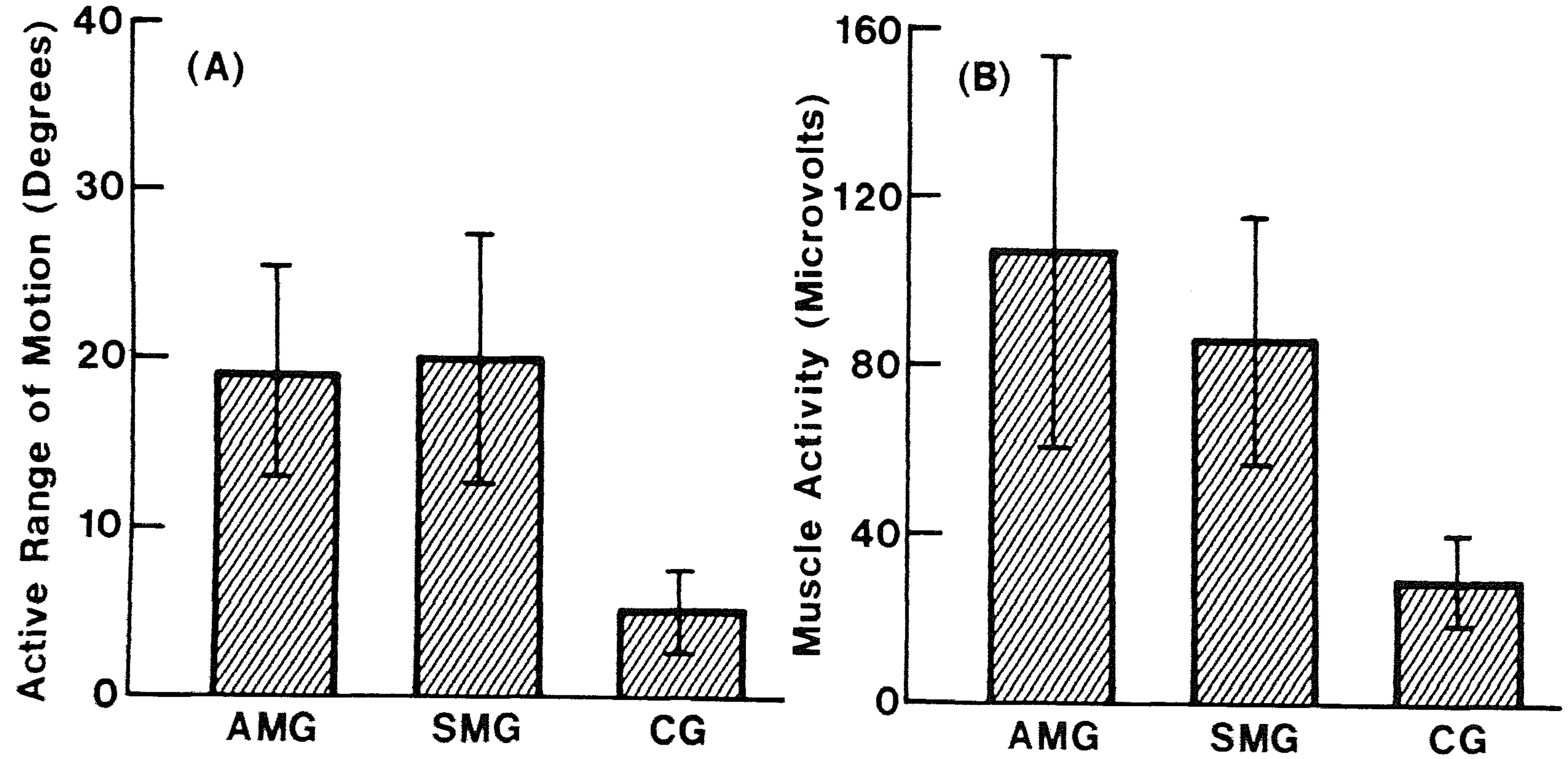

FIG. 2. Mean increases in muscle function from initial to final evaluation in terms of (A) active range of motion and (B) muscle activity. Vertical lines represent ±1 standard error. AMG, actual myofeedback group; SMG, simulated myofeedback group; CG, control group.

than one type of feedback and therefore had nothing to compare it to. Secondly, since hemiplegic patients have an altered degree of control over their affected muscles, they tended to attribute occasional lacks of correlation between the feedback and their efforts to this lack of control.

It should also be pointed out that the simulated myofeedback used in this study is markedly different from noncontingent false biofeedback, termed "placebo biofeedback" by Cohen, *et al.* (11), and "false electromyographic feedback" by Kondo and Canter (12). These feedback modalities consist of prerecorded signals that have no correlation with actual muscle performance except that which is completely coincidental. In contrast, the simulated myofeedback described herein is presumed to correlate crudely but positively with the actual myoelectrographic activity of the target muscle in a way analogous to the way a physical therapist's encouragement correlates with the patient's gross efforts. All effort is rewarded regardless of actual resultant movement, and increasing limb movement is increasingly rewarded appropriately.

In any particular patient, the long term functional improvement of a specific muscle group must be assumed to be a function not only of the type and timing of therapy received, but also of various individual factors including the patient's general physical condition and level of motivation. Inasmuch as these parameters are difficult to quantify and compare in a meaningful statistical way, it is hoped that the immediate objective changes examined positively correlate to some degree with the ultimate treatment outcome.

While the results of this study suggest that myofeedback can be an effective addition to the rehabilitation program of hemiplegic patients of all ages, it also points out the need for a clearer understanding of the mechanisms involved in its success.

SUMMARY

The specificity of EMG biofeedback (myofeedback) was examined by comparing the effects of actual myofeedback, simulated myofeedback and no myofeedback in the treatment of foot drop and shoulder subluxation. A group of twenty-four hemiplegic subjects, who were simultaneously undergoing traditional physical therapy, were randomly assigned to either Group I (Actual Myofeedback Group; AMG) or Group II (Simulated Myofeedback Group; SMG). Those in Group I received ten sessions of actual myofeedback over a two week period. Those in Group II received a similar course of treatment, but without their knowledge were given a simulated myofeedback initiated by the therapist corresponding to the patient's apparent efforts rather than their actual performance or muscle activity. For those subjects in whom both deltoid and anterior tibial muscles met the study criteria, only one muscle was treated as a part of Group I or Group II. The other muscle was assigned to Group III (Control Group; CG) and evaluated before and after a two week period during which it underwent no myofeedback therapy. Upon statistical evaluation, AMG, SMG and CG were all found to have statistically significant increases in

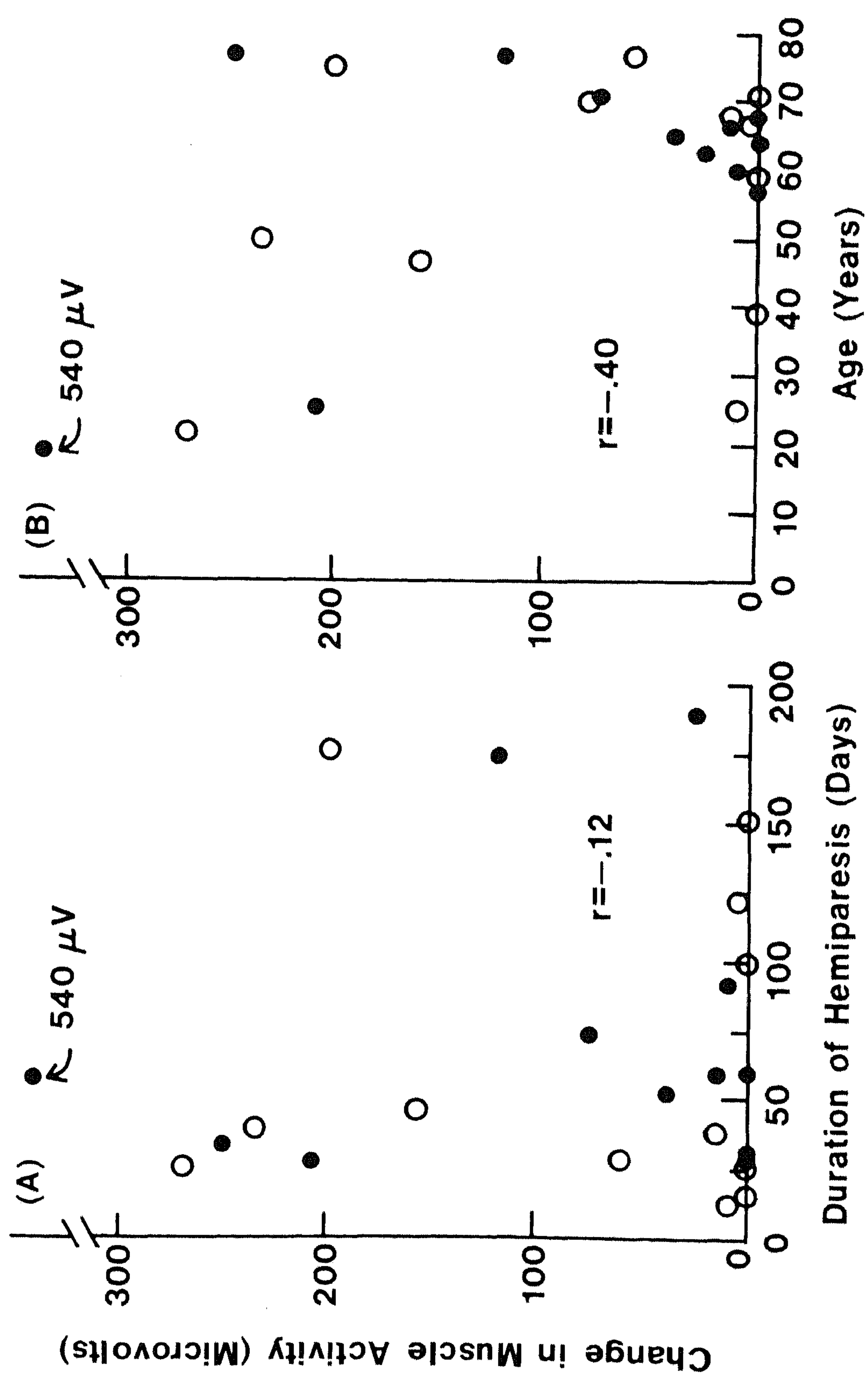

FIG. 3. Graph of change in muscle activity for treatment groups on the basis of (A) duration of hemiparesis and (B) age. (● = AMG, actual myofeedback group; ○ = SMG, simulated myofeedback group.)

muscle function in terms of both mean change in muscle activity measured in microvolts and in mean change in active range of motion measured in degrees. While no significant difference was found between AMG and SMG in either of these parameters, both AMG and SMG were found to have significantly greater increases than CG. It was concluded that although myofeedback appears to be an effective addendum to traditional physical therapy for hemiplegic patients, its success is due to as yet undefined elements of the treatment design.

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