Perceptual and Motor Skills, 1995, 80, 963-977.

ELECTROMYOGRAPHIC EFFECTS OF FATIGUE AND TASK REPETITION ON THE VALIDITY OF ESTIMATES OF STRONG AND WEAK MUSCLES IN APPLIED KINESIOLOGICAL MUSCLE-TESTING PROCEDURES [1]

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Summary.—The study investigated the effects of fatigue and task repetition on the relationship between integrated electromyogram and force output during subjective clinical testing of upper extremity muscles. Muscles were studied under two conditions differing in the nature and duration of constant force production (SHORT-F) and (LONG-F). The findings included a significant relationship between force output and integrated EMG, a significant increase in efficiency of muscle activity with task repetition, and significant difference between Force/integrated EMG ratios for muscles labeled "Strong" and "Weak" in the LONG-F condition. This supports Smith's 1974 notion that practice results in increased muscular efficiency. With fatigue, integrated EMG activity increased strongly and functional (force) output of the muscle remained stable or decreased. Fatigue results in a less efficient muscle process. Muscles subjectively testing "Weak" or "Strong" yield effects significantly different from fatigue.

The electromyographic signal can be considered as an index of motor unit recruitment and accurately reflects the extent to which the muscle is neurologically active. The increase of motor unit recruitment can be a useful tool in assessing the effects of clinical intervention. The neural (re-)activation of a given muscle or groups of muscles can be a primary source of information for the therapist and patient in assessing clinical improvement. The control of a muscle's electrical output by the subject may also be useful in developing a "muscle sense," after which the attention may be shifted towards the training of more functional output, e.g., force, movement.

[1]This study was supported by a grant from the International College of Applied Kinesiology to the first named author. The support and helpful comments of Dr. Marc Rosen is gratefully acknowledged. Requests for reprints may be addressed to Dr G. Leisman, Institute for Biomedical Engineering and Rehabilitation Services, Touro College, Dix Hills, NY 11746.

In theory, a monosynaptic stretch reflex will result in motor facilitation and subsequent muscle contraction. This ability of a muscle to lengthen but to generate enough force to overcome resistance is what is qualified by the examiner and termed "Strong" or "Weak." In the absence of a pathological neurological deficit, clinical inferences are made based upon the results of manual muscle tests. The muscle test in this paradigm is also used posttherapy (treatment) to assess patients' progress during physiological therapeutics (Kendall, Kendall, & Wadsworth, 1978; Walther, 1981). The form of muscle testing instructs subjects to offer maximal isometric resistance to isokinetic forces applied by the examiner in ways described by Kendall, *et al.* (1978). These procedures are commonly employed in Clinical Neurology as a means of subjectively evaluating muscle tone. Here, the examiner in the application of force to the subjects' resistance evaluates the muscle groups being studied as subjectively "weak" or "strong" on a 5-point scale.

In the present study, the effects of "muscle strength," muscle group, and task repetition on integrated EMG and on force was examined. This, we believe, is an important issue to examine as often there is a tendency to use integrated EMG output as an indirect indicator of functional improvement. Although, in general, there is a relationship between the integrated EMG signal and the functional output, e.g., force, movement, tension, timing, there are indications that the relationship between electrical and mechanical output changes over time as a result of fatigue and repetition of the task. Fatigue is a constant (isometric) force condition resulting in a significant increase of the integrated EMG (Moritani & DeVries, 1978; Viitasalo & Komi, 1978; Kasser & Lehr, 1979; Seidel, Bayer, & Bräuer, 1987; Zwarts & Arendt-Nielsen, 1988). Practice also results in increased muscular efficiency (Smith, 1974).

On the other hand, repetition of the task may indicate the opposite effect. The work of DeVries (1968), Metz (1971), and Ludwig (1982) indicate that the acquisition of a motor task leads to a significant decrease in the integrated EMG.

The purpose of the present study was to investigate the relationship between integrated EMG and functional output (force) during muscle testing of different muscle groups. The present study can be considered a methodological investigation of the relationship between the bioelectrical output and a functional output of certain muscles in a clinical situation.

Method

Subjects

The subjects were 30 volunteers, males who ranged in age from 26 to 41 years. None were suffering from any detectable motor or neurological defects. Each subject participated in all conditions which were repeated on two sessions.

Apparatus

A metal harness with a force transducer (Kyowa, 0–50 kg) was placed over each of the muscles studied. The harness guaranteed a good but not complete fixation of the body segment being studied. The EMG measurement commenced when the subject reached the target level. The electrodes were placed according to Delagi and Perotto (1980) and Winter and Yack (1987) and the interelectrode distance was 20 mm center-to-center. To ensure the application of electrodes to the same location across sessions, the electrode position was marked on the skin. Prior to placement the skin was cleansed with alcohol and rubbed with sandpaper. This lowered resistance below 5 KΩ. The EMG signals were preamplified 10 times by small headstages to a Nihon-Khoden amplifier and filtered (bandwidth 25–450 Hz) before data analysis. The raw amplified signal was filtered in this way and full-wave rectified by means of a low-pass third-order Paynter filter, set at a bandwidth of 30 Hz and at an averaging interval of 10 msec. (Gottlieb & Agarwal, 1970). The filtered and rectified signal was, together with the force transducer output, fed into a computer operating Dataq (Dataq Instruments, 1989) signal-processing software, with a sample frequency of 2 kHz. The force and EMG signals were averaged over periods of 250 msec. and stored for later analysis. The output of the force transducer was, together with the reference target, displayed on a storage screen in front of the subject. The EMG signals were not affected by artefacts associated with moving cables.

Procedure

Each of the subjects was placed on an examination table and was tested with surface electrodes. In all subjects, electrolytic solution was applied and the impedance was reduced by cleansing the skin with alcohol and sandpaper. The bipolar surface electrodes (Ag/AgC1, area 0.25 cm^2) were affixed with adhesive tape with a 2-cm center-to-center distance aligned along the muscle fibers according to the landmarks of Winter and Yack (1987) and Delagi and Perotto (1980). Informed consent was obtained from each subject and IRB approval granted.

The muscles chosen for this study included the Latissimus dorsi, Teres minor, Biceps brachii, Triceps, Quadriceps, Deltoid, Rhomboid, Supraspinatus, Pectoralis major, Middle Deltoid (Leisman, Shambaugh, & Ferentz, 1989).

Muscle-testing procedures were employed under double-blind conditions. Here the examiner took the origin and insertion point of the muscle. The limb was then positioned so that the muscle was shortened, i.e., that it approximated its origin and insertion points. The body parts were positioned to isolate best the muscle being tested from its synergists. Tests were then provided by applying pressure in a direction that would then elongate the muscle. These tests were then graded on the ability of the subject to resist the initial application of force, i.e., the ability of the subject to react or adapt to the testing pressure. The subject was instructed to contract the muscle maximally in the vector that "isolated" the muscle. This pressure was resisted by the examiner until the examiner detected no increase in force against his hand. At this point an additional small force was slowly exerted at a tangent to the arc created by the body part being tested. The initial increase of force up to maximum voluntary strength did not exceed 1.5 sec. and the increase of pressure applied by the examiner did not exceed a 1-sec. duration. "Weak" and "Strong" muscles were determined for each of the subjects in twelve upper extremity muscles in this way by a practitioner experienced in the procedures described above. "Strong" muscles were defined as ones which were able to adapt to the additional force and maintain their contraction with no weakening effect. "Weak" muscles were defined as ones which were unable to adapt to the slight increase in pressure, i.e., the muscle suddenly became unable to resist the test pressure.

The electrophysiologic examination was done blind as to whether a given muscle was rated "Weak" or "Strong." Electrophysiologic testing was performed while applying passive resistance to the muscle group being tested using the procedures described below.

The muscles were studied under an isometric condition. Measurements were performed under two conditions differing in terms of the nature and duration of the constant-force production: short (SHORT-F) and long (LONG-F) constant-force production. The effects of fatigue were studied in the long constant-force-production task in which the subjects had to maintain a constant force as long as possible. There were two force levels, one on each of two separate days. Prior to the LONG-F condition, the relationship between force and integrated EMG was studied in the SHORT-F condition to test whether this relationship changed with repetition of the task.

The muscle groups studied are reported in Table 1. The subjects were required to generate with each of the muscles an isometric force against a force transducer. The required force was presented by means of a computer-generated display on a storage oscilloscope. The target force was indicated by the vertical height of a light spot trace moving along a straight horizontal line at a constant speed (1 cm/sec.) from left to right across the screen. Subjects attempted to follow this target with a second light spot which was driven by the output from the force transducer. Hence the tasks were structured as very simple tracking tasks, with the subjects receiving continuous feedback on their performance.

At the beginning of every session, each subject was instructed to contract each of the muscles studied as hard as possible for 3 sec. This was repeated three times and the highest force recorded was taken to represent

TABLE 1
MUSCLES TESTED BY "STRONG"/"WEAK" STATUS AND SEQUENCE TESTED

Name	Strong	Weak
First Muscle Tested		
Latissimus dorsi	8	2
Teres minor	4	4
Quadriceps	2	
Deltoid	6	
Rhomboid	2	
Supraspinatus	2	
Second Muscle Tested		
Teres minor		8
Biceps	2	
Pectoralis Major	4	2
Latissimus dorsi	2	8
Rhomboid	2	
Middle Deltoid	2	
Third Muscle Tested		
Middle Deltoid	2	
Latissimus dorsi	4	
Supraspinatus	4	
Teres minor	2	
Middle Deltoid	8	
Quadriceps	2	
Biceps	4	
Rhomboid	2	
Triceps	2	

the 100% Maximum Voluntary Contraction (100% MVC) for that subject during that session. This percentage of maximum voluntary contraction technique has the important advantage of compensating for variations in strength among subjects.

After a 3-min. rest, each subject was engaged in the SHORT-F condition. In this condition, the subjects repeatedly had to generate a constant force for 5 sec. The level of the force was indicated by the height of the computer-generated target force and displayed on the oscilloscope screen as a horizontal line. In each session, the subject had to work through nine force levels (10, 20, 25, 30, 40, 50, 60, 70, 75% MVC) presented in an ascending or descending order. In this condition, the effect of fatigue was minimized by rests of 50 sec. between 5-sec. contraction periods.

After a further 3-min. rest, the subjects participated in the LONG-F condition, in which they were strongly encouraged to generate the required level as long as possible. The display of the force levels were the same as in the SHORT-F condition. The trial ended when the executed force fell below 90% of the target level. Each subject performed this task at 10, 25, 50, and

75% MVC. Half of the subjects had an ascending order while the other half had a descending order.

Statistical Analysis

A one-way factorial designed analysis of variance with repeated measures was performed with "Strong" vs "Weak" muscles × session × repetition using force output for the integrated EMG as the measured variable.

Results

Maximum Voluntary Contraction (100% MVC)

The mean maximum force across the 30 subjects and across the two experimental sessions was 316.2 N. The maximum force increased slightly over the two sessions. The means for Sessions I and II were 295 N and 329 N. This increase is not statistically significant.

SHORT-F Condition: Relation Between Force Output and Integrated EMG of Agonistic Muscle

The data, pooled for both sessions, show a close relationship between force output and integrated EMG. In Fig. 1, the mean integrated EMG values of the muscles studied are displayed for every force level for muscles reported to be "Weak" and "Strong." The values are averaged for the 30 subjects and over the total 5-sec. period.

Repetition of Task

The SHORT-F task was repeated twice on separate days. The maximum force was not statistically significant between the two sessions and therefore the relation between integrated EMG and force output was not stable between the different sessions. The results of the SHORT-F condition, (with "Strong" vs "Weak" muscles × session × repetition × force output for integrated EMG) show an increase in force output which is significant ($F_{3,81} = 2.81$, $p < .05$), and at the same time the integrated EMG output remains stable. Efficiency, however, can also be expressed as the ratio between force output and integrated EMG output (F/IEMG). Therefore, for each subject and for each of the force levels a ratio was calculated between force output and integrated EMG output. The averaged ratios across the two sessions for subjects with weak vs strong muscles are for Session I/weak muscles 1.39, Session I/strong muscles 1.68, Session I/weak muscles 1.61, and Session II/strong muscles 1.84. A significant increase in the ratios is noted across sessions reflecting an increasing efficiency of muscular activity with repetition of the task. Also, independent of the task repetition, significant differences are noted between F/IEMG ratios for muscles labeled "Strong" or "Weak" ($F_{3,81} = 4.98$, $p < .01$).

LONG-F Condition

Whereas in the SHORT-F condition the effect of fatigue was minimized

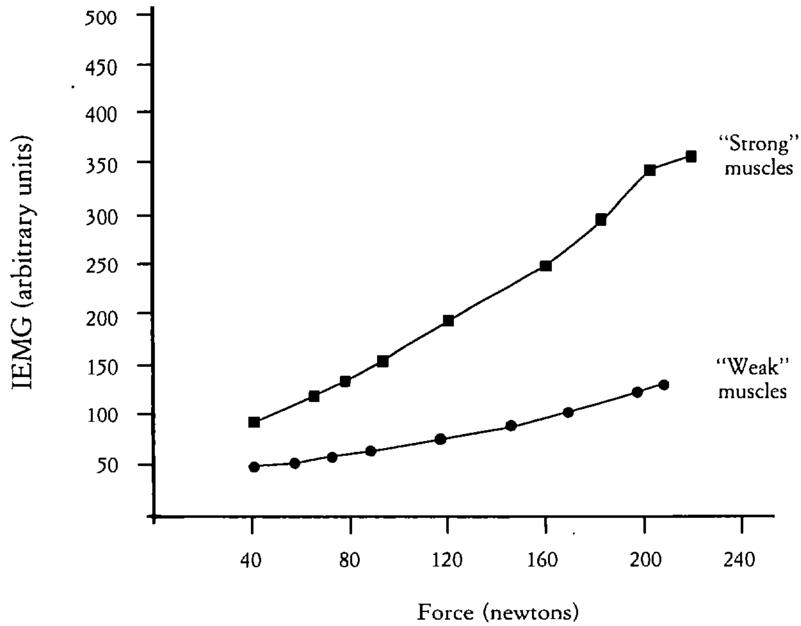

FIG. 1. EMG output averaged across 5-sec. periods and across subjects for "Weak" and "Strong" muscles. The output is given for each of the two experimental sessions and the nine force levels of the SHORT-F condition.

by means of relatively long intertrial rest periods of 3 min., in the LONG-F condition the effect of fatigue on the integrated EMG signal was examined. In this condition the subjects had to maintain a constant isometric force for as long as possible. The over-all mean correlation coefficient between force and the corresponding integrated EMG levels was $r_{ppm} = .94$ (*df*: 58, $p < .001$) for both weak and strong muscles pooled.

Fatigue

The average time that the subject could maintain the desired force level in the LONG-F condition was 21.05 min. for the 10% MVC, 9.04 min. for the 25% MVC, 2.03 min. for the 50% MVC, and 0.53 min. for the 75% MVC tasks for muscles labeled "Strong." Also, in the LONG-F condition, the maintenance of desired force level for muscles labeled "Weak" was 16.03 min. for the 10% MVC, 8.04 min. for the 25% MVC, 1.53 min. for the 50% MVC, and 0.33 min. for the 75% MVC tasks. The effect of this long isometric constant-force task on the integrated EMG for both "Strong" and "Weak" muscles is shown in Fig. 2. The electromyographic activity of the ten muscles studied is plotted against time. The data show a significant and rapid increase of the integrated EMG activity during the contraction period for both "Strong" and "Weak" muscles. The increases are, respectively, 43% in the 10% MVC, 94% in the 25% MVC, 75% in the 50% MVC, and 35% in the 75% MVC conditions for muscles labeled "Strong." For muscles labeled "Weak," the increases were 36% in the 10% MVC, 68% in the 25% MVC, 51% in the 50% MVC, and 22% in the 75% MVC. One could observe this increase after the first 10 sec. of the contraction period. The mean increase from the first 10-sec. to the second 10-sec. period of the contraction time for the four force levels were, respectively, for "Strong" muscles 4% (10% MVC), 7% (25% MVC), 12% (50% MVC), and 35% (75% MVC condition). For "Weak" muscles, the results were 2% (10% MVC), 5% (25% MVC), 9% (50% MVC), and 23% (75% MVC condition).

For each subject in the 10% conditions for both "Strong" and "Weak" muscles combined, the total contraction time was divided into 50 equal steps. Each step corresponded to a specific integrated EMG value. An analysis of variance performed on the averaged integrated EMG values for all subjects, corresponding to the 50 steps, showed a significant increase in electromyographic activity ($F_{49,44}=3.13$, $p<.001$). For each subject in the 25% MVC condition, the total contraction time was divided into 20 steps. Analy-

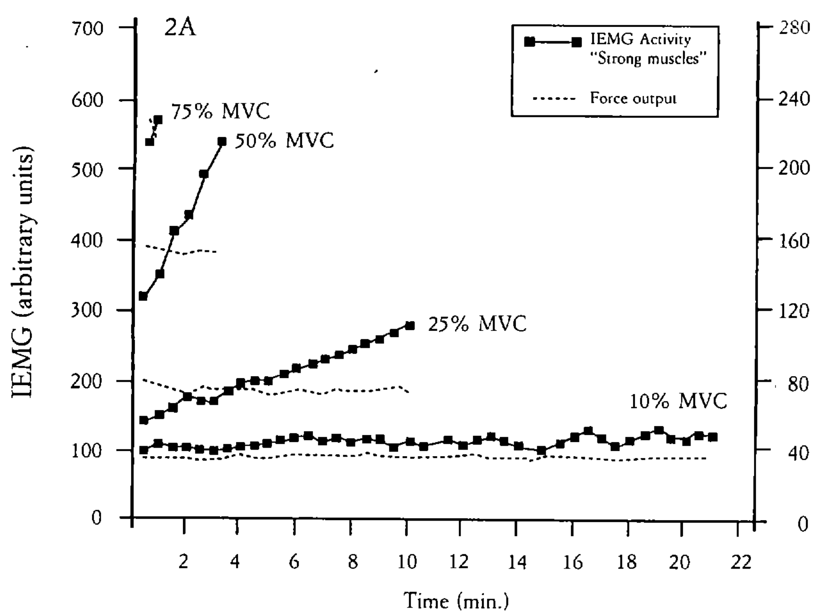

FIG. 2. Mean EMG output of "Strong" and "Weak" muscles during the LONG-F condition for each force. The EMG activity is plotted against the (continued on next page)

sis of variance, performed in the same way as with the 10% MVC condition, showed a significant increase in electromyographic activity ($F_{19,17} = 24.38$, $p < .001$).

The contraction time in the 50% MVC condition was divided into six steps and the integrated EMG activity, averaged across the 30 subjects, was significant ($F_{5,45} = 27.22$, $p < .001$). Although the averaged integrated EMG activity in the 75% MVC condition (two steps) increased, this increase was not significant ($F_{1,29} = 3.65$, $p < .10$).

The reason for the division into equal steps was the following. The integrated EMG activity was averaged over 10-sec. periods. Because the number of 10-sec. periods varied across the 30 subjects, the subject with the fewest periods was taken as the reference. For the four force levels (10% MVC, 25% MVC, 50% MVC, and 75% MVC) these values were, respectively, 50, 20, 6, and 2. Next the contraction time of each other subject was divided in 50, 20, 6, or 2 equal periods. Hence, the data analysis was not based on the fewest number of 10-sec. epochs all the subjects had in common, but the contraction time of each subject was divided in equal parts based on the reference.

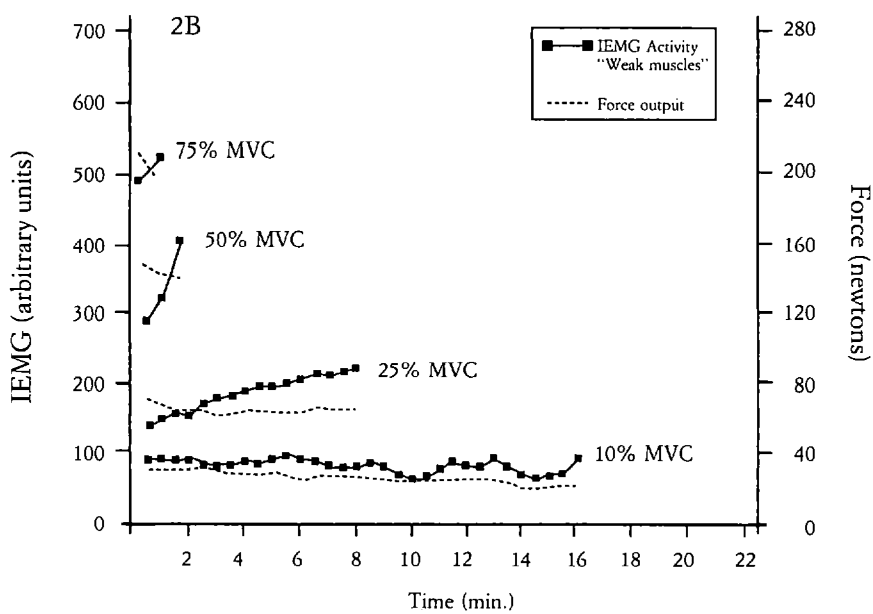

FIG. 2. (Cont'd) contraction time. The dashed lines indicate the average force output of the (A) "Strong" and (B) "Weak" muscles.

During the trials, the subjects were instructed to hold the force output constant. The trial ended when the force output fell below 90% of the target level. As is shown in Fig. 2, the electromyographic output of the muscle increased during the contraction time, whereas the force output of the muscle decreased significantly for the four force levels with all subjects combined [10% MVC ($F_{49,44}=5.83$, $p<.001$), 25% MVC ($F_{19,17}=6.19$, $p<.01$), 50% MVC ($F_{5,45}=8.16$, $p<.01$), and 75% MVC ($F_{1,29}=14.27$, $p<.05$)].

In the SHORT-F condition, the ratio between force output and integrated EMG increased significantly as a function of repetition of the task. In the LONG-F condition, the ratio decreased. The ratios (F/IEMG) averaged across the 30 subjects for the first 10 sec. of the contraction time were compared with the ratios calculated for the last 10 sec. of the contraction time for each of the subjects' "Strong" Latissimus dorsi muscles. The relationships described below held for each of the other muscles tested. This was performed for each force level, The ratio, averaged across force levels and all "Strong" Latissimus dorsi subjects ($n=18$) for the first 10 sec. is 1.18; for the last 10 sec., this ratio is 0.88. The decrease of the F/IEMG ratios is significant ($F_{1,29}=7.52$, $p<.05$). Table 2 shows the ratios for each individual force level. Also, the Pearson correlation coefficient between integrated EMG and force decreased for subjects with "Strong" Latissimus dorsi from the first 10 sec. of the contraction time ($r_{\text{ppm}}=.96$, *df*: 17, $p<.001$) to the last 10-sec. period of the contraction time ($r_{\text{ppm}}=.90$, *df*: 17, $p<.001$). Note that these results are the opposite of the results of the SHORT-F task and they represent a decreasing efficiency of muscle activity.

TABLE 2
FORCE/INTEGRATED EMG RATIO FOR "WEAK" ($n=12$) AND "STRONG" ($n=18$) LATISSIMUS DORSI MUSCLES

MVC (%)	LONG-F Condition:Ratio (Force/EMG)			
	"Strong" Latissimus dorsi		"Weak" Latissimus dorsi	
	First 10 sec.	Last 10 sec.	First 10 sec.	Last 10 sec.
10	0.885	0.534	0.684	0.379
25	1.245	0.994	0.972	0.692
50	1.250	0.899	1.012	0.654
75	1.317	1.127	1.201	1.083
n	18	18	12	12
M	2.27	0.88	0.91	0.59
SD	0.23	0.26	0.21	0.24

The ratios (Force output/Integrated EMG) averaged across the subjects with "Weak" Latissimus dorsi ($n=12$) for the first 10 sec. of the contraction time were also compared with the ratios calculated for the last 10 sec. of the contraction time. The relationships described below, as for the subjects with

"Strong" Latissimus dorsi, held for each of the other muscles tested. This was also performed for each force level. The ratio, averaged across force levels and all "Weak" Latissimus dorsi subjects for the first 10 sec. is 0.91; for the last 10 sec. this ratio is 0.59. The decrease of the F/IEMG ratios is significant ($F_{1,11}=7.52$, $p<.05$). Table 2 shows the ratios for each individual force level. Also, the correlation coefficient between integrated EMG and force is for "Weak" muscle, as with the "Strong" muscle subjects, decreasing from the first 10 sec. of the contraction time ($r_{\mathrm{ppm}}=.94$, *df*: 11, $p<.001$) to the last 10-sec. period of the contraction time ($r_{\mathrm{ppm}}=.87$, *df*: 11, $p<.001$) for "Weak" Latissimus dorsi subjects.

Discussion

The results show an approximately linear relationship between the force output of the muscle and the bioelectrical output (integrated EMG). This is in agreement with the results of earlier studies (Edwards & Lippold, 1956). Milner-Brown and Stein (1975) and Moritani and DeVries (1978) have also shown a linear relationship as have others (Mulder & Hulstijn, 1984). Other authors have reported a curvelinear relationship (Moore, 1967; Komi & Buskirk, 1970) or a relationship in which the integrated EMG varies as the square root of the force (Moore, 1967). The present study, however, was not focussed on the exact physiological or mathematical nature of the relationship between the force output and the surface electromyogram. The only purpose was to evaluate the effects of fatigue and task repetition on this relationship under both normal circumstances and for muscles labeled "Weak" or "Strong" by applied kinesiological muscle-testing methods.

Effect of Fatigue and Task Repetition on the Integrated EMG

Fatigue.—Whereas in the SHORT-F condition the influence of fatigue was minimized by sufficiently long intertrial rest periods, in the LONG-F condition, the effects of fatigue were studied. The results showed that, under the influence of fatigue, the integrated EMG activity increased strongly. At the same time the functional (force) output of the muscle remained stable or even decreased. In terms of efficiency, this means that fatigue characterizes a less efficient muscle process.

Muscle-testing procedures which label muscles as "Weak" or "Strong" subjectively, here under double-blind conditions, yield effects significantly different than fatigue. "Weak" muscles, however, like fatigue are also associated with a less efficient muscle process.

The data indicate an almost immediate increasing effect on the integrated EMG. This is contrary to the intuitive notion of a gradual building-up of fatigue. It is also contrary to the experimental results of Lippold, Redfearn, and Vuco (1960) who stated that at a constant-force isometric tension between 10% MVC and 80% MVC, there is a decrease in integrated EMG activity during the first one or two minutes and after that an increase continues until the endpoint is reached. The reason for this difference could be that Lippold and his colleagues employed different experimental procedures.

Repetition of the task.—The direct relationship between the functional (force) output and the bioelectrical output (integrated EMG) is the implicit use for electromyography in objectifying clinical muscle-testing procedures. The clinician would not use the integrated EMG signal as a diagnostic tool in this case but as an "objective instrument," informing him of the activity of the muscle(s).

In motor learning, including neuromuscular rehabilitation or EMG feedback therapy, the integrated EMG (as a representation of this activity level) can be used as an important index of improvement. The results of the SHORT-F condition, however, showed that the relation between functional (force) and electrical output is not stable but changes under the influence of fatigue and repetition of the task. It may also be assumed that muscles subjectively labeled "Weak" or "Strong" employing muscle-testing techniques from applied kinesiology (Kendall, *et al.*, 1978; Walther, 1981), provide different values than for fatigue or task repetition.

The integrated EMG shows a decrease between sessions; the force output, however, is increased. DeVries (1968) and Metz (1971) described this process in terms of the efficiency of muscular activity. A muscle process is more efficient when the functional output (force) remains constant or increases whereas the electrical output (integrated EMG) decreases. This is what is reflected in the results of the SHORT-F condition. To explain this efficiency effect, Metz (1971) and also Basmajian (1977) found a significant gradual decrease of antagonistic muscle activity during the learning of a motor-tracking task (six repetitions of the task). According to these authors, the acquisition of motor control is for the greater part learning to inhibit the activity of irrelevant muscles. Brooks (1986, p. 32) and others (Mulder & Hulstijn, 1985) as well as our pilot studies did not produce a general significant decrease of the antagonistic activity across multiple sessions of testing. It seems, therefore, that the increase in efficiency during the repetitions of testing is primarily the result of changes in the agonistic muscle activity. DeVries (1968) stated "that as a muscle grows stronger through training, the involved fibers become more effective in producing tension. In this event, either fewer motor units need to be recruited or the same motor units can be fired at slower stimulation frequencies to produce the same level of isometric tension. Both factors are probably operant and both will result in lower integrated electrical activity levels" (p. 18).

It is, however, also possible that the subjects learned to inhibit the activity of the other muscles, that is to say, they learned to perform the task by contracting the muscles of the upper extremities which were studied more selectively instead of simultaneously co-contracting other muscles.

Therapeutic implications.—Although the present report is a description of an experiment in which normal subjects perform a rather artificial task which is not directly related to functional adult human movement, the results indicate some general aspects which could be important for muscle testing and other clinical applications (Leisman, 1988, 1989a, 1989b; Leisman & Vitori, 1990). Firstly, repetition of the task leads to more "efficient" muscle activity, although there is a decrease in electromyographic output, and, secondly, fatigue and muscles adjudged as "Weak" show less "efficient" muscle activity although there is a significant increase in electromyographic output.

The electromyographic signal, therefore, may be used as an objective representation of neuromuscular activity. The signal is not only used as a source of information for the patient and the therapist but may also be used as an important index for improvement of muscle function. During early stages of neuromuscular training, when the therapeutic attention is directed on the increase of motor-unit recruitment, this assumption is without problems. However, the results of the present study show that this assumption has some risks if one tries to relate the electromyographic output directly to the functional output of the muscle(s) being trained, i.e., if the integrated EMG is used as an indirect measure of force. In the SHORT-F condition, for example, an increased efficiency of muscle functioning was reflected by even a slight decrease in integrated EMG activity.

On the other hand, results of the LONG-F condition clearly showed a significant increase in integrated EMG activity as a result of fatigue and also associated with muscles judged to be "Weak." These are interesting results. Note that fatigue plays an important role in neuromuscular therapeutic retraining modalities because therapy sessions are often intensive. The results of the LONG-F condition indicate, however, that an increase in integrated EMG output is not always an objective proof of neuromuscular improvement, i.e., sometimes it is only a reflection of fatigue.

The results of this study, however, do not indicate that electromyographic activity is of no use in neuromuscular retraining modalities or that it should be discarded in favor of force (Leisman, 1989c) or motor information-processing measurements (Leisman, 1988, 1989a, 1989b; Leisman & Vitori, 1990). All of these measurements collectively make a meaningful contribution to the study of muscle function and represent different aspects of muscular activity. The integrated EMG is a valid index of motor unit recruitment and reflects the extent to which the muscle is active. This bioelectrical activity, however, is influenced by factors such as task repetition and fatigue. Therefore, we suggest a careful use of the integrated EMG, especially in situations where the electromyogram is used in functional training as an indirect measure of force or as one of the parameters for evaluation of therapy and rehabilitation. In these cases, care can be taken that fatigue does not confound the results.

The training and rehabilitation of motor function to the point at which fatigue is reached form a basic ingredient of many rehabilitation programs and should not be discarded. If, however, fatigue affects the signal which is one of the main sources of information for patient and therapist, then fatigue would have to be controlled. To control this fatigue effect, it would be desirable to measure progress from the start of one session to the start of another session or to employ test sessions separated from the therapy sessions. Given the fatigue effect, rapid, short (test) trials (5 sec.) interspersed with sufficient rest periods are necessary.

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Accepted March 20, 1995.

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