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ABSTRACT

In this study, the training effects of static and dynamic exercise programs on the firing patterns of 450 single motor units (SMU) in the human tibialis anterior muscle were investigated. In a six week program, the static group (N=5) participated in daily high intensity, short duration, isometric exercises while the dynamic group (N=5) participated three times weekly in low intensity, moderate duration, isotonic exercises. The control group (N=4) did not participate in an exercise program. Pre- and post-test SMU firing patterns were recorded by means of 26 gauge tygon coated monopolar needle electrodes. In order to assess the degree of impersistence or periodicity of motor unit firing, an interspike interval (ISI) longer than 260 milliseconds was defined as a lapse in motor firing. An individual ratio of normal ISIs to lapses for each SMU three minute recording run and the mean ratio for each subject (MLR) were calculated. Significant differences were found between MLR pre- and post-test values for both groups (p less than 0.05). These results indicate that changes in motor unit firing can be produced by specific exercise programs. High intensity, short duration exercises produce more variable than normal firing rates, and low intensity, long duration exercises produce firing rates less variable than normal. (Author/BD)

THE EFFECTS OF EXERCISE ON THE FIRING PATTERNS OF SINGLE MOTOR UNITS

by

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Research on skeletal muscle has indicated that:

1. Muscle fibers undergo dynamic alterations or adaptations in the form of structural, functional, and/or biochemical changes as a result of muscular stress or overloading.
2. Skeletal muscle fibers can be divided into two general groups on the basis of structural, functional, biochemical, and electromyographical analysis.
3. Skeletal muscle fibers and motoneuron together act as a single functional unit, the single motor unit, and are dependent on each other for survival.
4. Electromyographic techniques can be used to record and analyze the intrinsic firing patterns of single motor units and provides a means of classifying same.

The following statement evolved from these findings. If a group of skeletal muscle fibers and a motoneuron do act as a unit then changes should occur simultaneously in both as a result of overloading or exercise, and these alterations should be reflected by changes in the firing patterns of the single motor units. This study was designed to test this premise by measuring the training effects of static and dynamic exercises on the firing patterns of single motor units.

METHODS

450 single motor units were sampled from the Tibialis Anterior of 14 male college students who were trained to isolate and control single motor units. The subjects were randomly assigned to three experimental groups --- control, static, and dynamic. The static group participated in a high resistance, short duration, isometric exercise program, 5-days-a-week, while the dynamic group participated in a low-resistance, medium duration, exercise program, 3-days-a-week for six weeks. The control group did not participate in a directed exercise program and none of the groups were restricted in daily activities.

The chronology of data collection was:

1. Pretest for single motor unit firing patterns.
2. Pretest for strength and endurance.
3. Implementation of the six week exercise treatment program.
4. Posttest for strength.
5. Posttest for single motor unit firing patterns.

The single motor unit firing pattern data were collected and recorded on magnetic tape during a three-minute recording run. During the first minute, a controlled, slow-firing rate was recorded. Medium and fast-firing rates were recorded during the second and third minutes of each run. Figure #1 depicts short segments of each run as recorded on an EMG paper print-out. The instructions for time and rate of firing were conveyed to the subject through the use of three remote controlled lights mounted on the EMG equipment.

The data were analyzed with the aid of a Digital Equipment Corporation PDP-9 computer. Each three-minute run was analyzed for variability in inter-spike intervals. Notice in Figure #2 the variable distance between spikes in this slow firing rate segment. This variability was used as the basic measure for determining if a change had actually occurred in the firing patterns as a result of exercise.

The result of this analysis was converted into interval histograms which delineated the non-lapse, lapse, and pause areas (Figure #3). The limits established for each area resulted from the analysis of three-minute single motor unit runs sampled from the first dorsal interroseous muscle. Subsequent analysis of tibialis anterior single motor units indicated that these are acceptable limits.

Individual lapse ratios (ILR) were then determined by dividing the non-lapse area under the interval histogram by the lapse area. The "Individual Lapse Ratio" of this three-

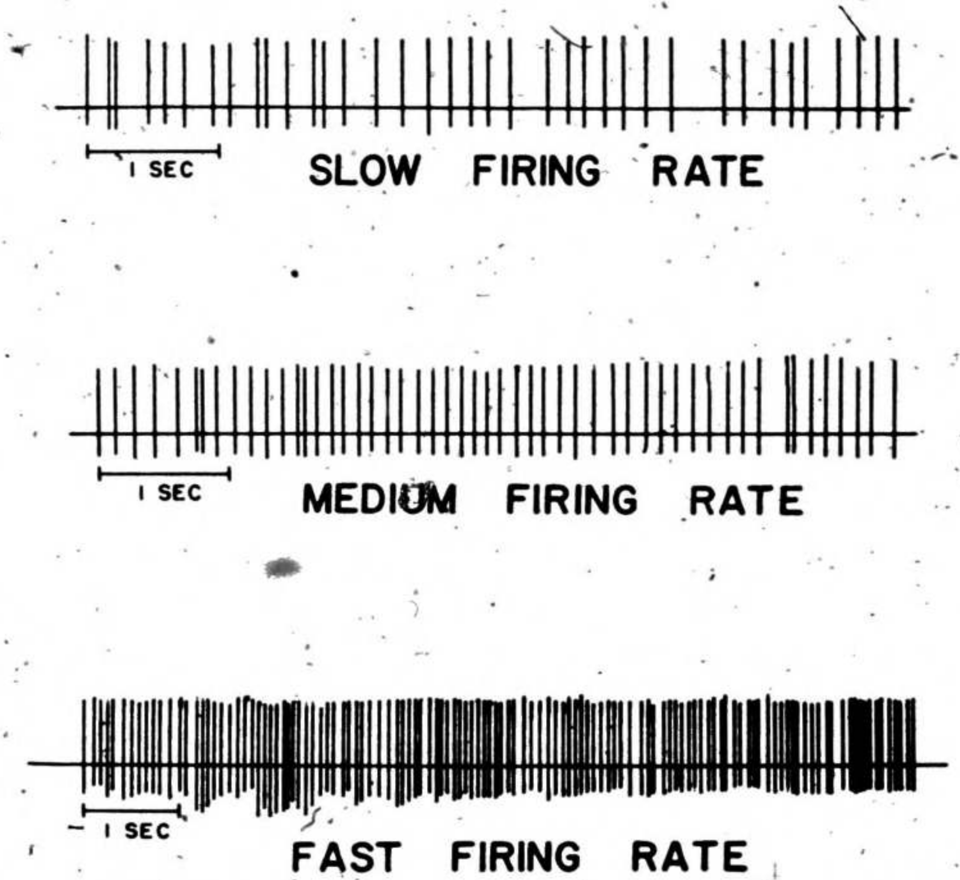

Figure 1. An example of three different rates of firing of a Single Motor Unit as recorded on an EMG paper print-out.

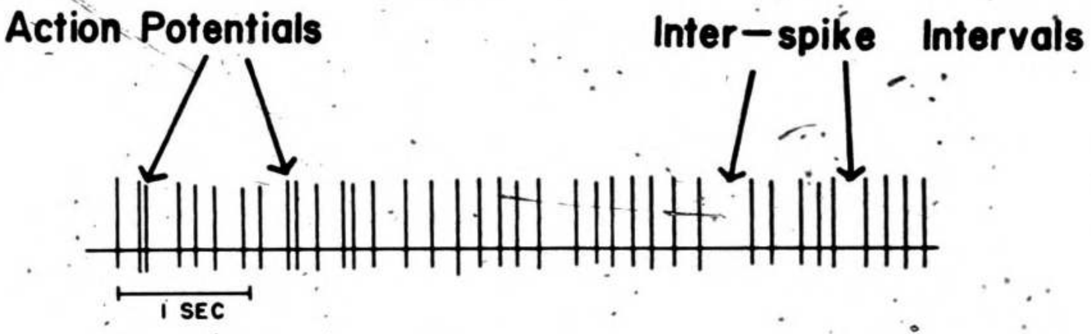

Figure 2. An example of the variable distance between spikes in a slow firing Single Motor Unit.

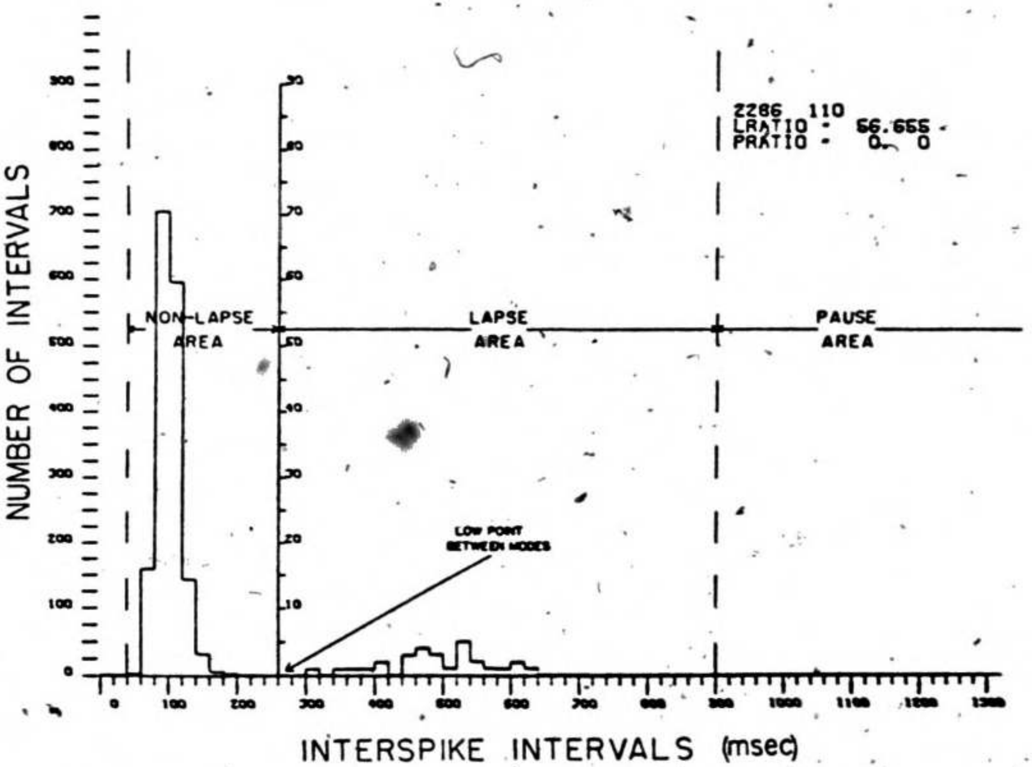

Fig. 3. An example of the computer print out of an interval histogram from one three minute SMU run.

minute single motor unit run was 56.655. Mean lapse ratios for each subject resulted from the analysis of all pretest or posttest single motor unit runs for each individual.

STATISTICAL PROCEDURES

Two different statistical procedures were used to analyze the individual lapse ratio and the mean lapse ratio data. The small number of subjects necessitated the use of non-parametric statistics when analying the mean lapse ratio. Analysis of variance statistical procedures were used to analyze individual lapse ratios.

RESULTS

Table 1 provides the results of the non-parametric analysis. Section A indicates that the difference in mean lapse ratios between the groups was not significant ($p \hat{\approx}$ or > 0.10), and the groups were considered homogenous as a result. Sections B, C, and D indicate the mean lapse ratios of the dynamic and static exercise groups changed significantly between pre- and posttest ($p < 0.05$ and $p < 0.05$, respectively) while no significant change is indicated in the control group ($p > 0.05$).

A parametric statistical analysis of individual lapse ratios produced similar findings. These findings are summarized

Table I
Summary of Non-Parametric Analysis

Mann-Whitney U Test Values for Homogeneity between the Three Pretest Groups

Mean Lapse Ratios (Ranks)

	Control (X) N=7		Static (Y) N-10		Dynamic(Z) N=9	
A	Rank		Rank		Rank	
	X	Y	X	Z	Y	Z
	$\Sigma R()$ 75*	78	$\Sigma R()$ 64**	72	$\Sigma R()$ 95***	95
	$^{*}p \approx 0.10$		$^{**}p > 0.10$		$^{***}p > 0.10$	

Wilcoxon Matched Pairs Signed Ranks Tests for Mean Lapse Ratios between Pretest and Posttest Dynamic Exercise Group Scores

	Ranks R(+)	Ranks R(-)
B	$\Sigma R(+)$ 40	$\Sigma^{*} R(-)$ 5
	N=7	$^{*}p < 0.05$

Wilcoxon Matched Pairs Signed Ranks Tests for Mean Lapse Ratios between Pretest and Posttest Static Exercise Group Scores

	Ranks R(+)	Ranks R(-)
C	$\Sigma^{*} R(+)$ 5	$\Sigma R(-)$ 50
	N=10	$^{*}p < 0.05$

Wilcoxon Matched Pairs Signed Ranks Tests for Mean Lapse Ratios between Pretest and Posttest Control Group Scores

	Ranks R(+)	Ranks R(-)
D	$\Sigma^{*} R(+)$ 7	$\Sigma R(-)$ 21
	N=9	$^{*}p > 0.05$

in Table 2. Between-groups analysis indicated that the groups were homogeneous prior to the treatment program but were significantly different after the treatment program. The within-groups, pre-test to post-test F ratios were not significant for the control and dynamic experimental groups ($p > 0.05$ for both), but was significant for the static experimental group ($p < 0.05$).

DISCUSSION

The primary interest in this research was to determine if the firing patterns of single motor units could provide a means for measuring the dynamic changes that occur in muscle fibers as a result of muscle overloading. Overloading took the form of static and dynamic exercise which emphasized strength and endurance development, respectively. The results indicate that single motor unit activity may reflect changes that occur in the muscle since the high intensity strength exercise program produced significant increases in variability in the inter-spike intervals (ISI) of firing single motor units while the low intensity endurance exercise program produced singificant decreases in variability in the ISIs of firing single motor units.

The differentiation of single motor units on the basis of general motor function was accomplished by Tokizane and

Table II

Summary of Analysis of Variance

Source of Variance	DF	MS	F	p
BETWEEN GROUPS	2	2462.1250	2.594	0.0753
Error	201	946.2825		
WITHIN GROUPS	1	1730.7500	4.375	0.0354
Error	204	413.3193		
GROUPS BY TRIAL	2	1537.7812	3.887	0.0215
Error	201	395.5764		
BETWEEN GROUPS				
PRETEST	2	985.7812	1.280	0.2795
Error	217	770.4231		
POSTTEST	2	3370.9375	5.866	0.0037
Error	217	574.6509		
ANALYSIS BY TRIALS (Within Groups)				
CONTROL GROUP	1	727.6875	0.887	0.6466
Error	47	820.0996		
DYNAMIC GROUP	7	301.1250	1.281	0.2605
Error	73	235.1515		
STATIC GROUP	1	3777.5625	12.859	0.0009
Error	81	293.7654		

Shimazu (1964). Their research was based upon the premise that the single motor unit was a unitary functional unit in which the muscle fibers and motoneuron act as a single unit during voluntary muscle contraction. The unitary concept can be readily seen when viewed in terms of motoneuron and muscle fiber impulses. Tokizane and Shimazu's "law of correspondence between nerve and muscle impulses" indicated that a single impulse which passes along the motoneuron in turn initiates muscle contraction in all the fibers innervated by that neuron. "Thus to each nerve impulse precisely corresponds a muscle reaction; and conversely, every muscle fiber impulse if preceded by a specific nerve impulse . . ." From this, it was concluded that the analysis of single motor unit activity would provide one means of analyzing motor system activity during voluntary muscle contraction.

The classification of single motor units into tonic and phasic types on the basis of variability inter-spike intervals resulted from this analysis of motor activity. Tonic units had more stable inter-spike intervals during low firing frequencies, than phasic single motor units. It was assumed that the tonic single motor units corresponded to Type I fibers while phasic single motor units corresponded to Type II fibers. This relationship has been confirmed by extensive research on the morphological, cytochemical and functional characteristics of muscle fiber, motoneurons and single motor units.

The ability to critically analyze single motor unit activity has in turn provided a possible means for measuring changes that may occur in the components of the single motor unit. One of the first investigations into the effects of exercise and training on single motor unit activity was undertaken by Kawakami (1955). Kawakami used the method first proposed by Tokizane in 1953 to analyze changes in single motor unit activity which resulted from training or exercise. The results of that project indicated that the analysis of single motor unit activity could be used for measuring changes that occur in the single motor unit.

It was, therefore, hypothesized (in the null) on the basis of Kawakami's findings, that dynamic changes occurring in the components of a single motor unit result in comparable changes in single motor unit activity. Thus the dynamic changes which occurred in muscle fibers as a result of exercise (Jeffress & Peter, 1970) could be monitored through changes in single motor unit activity. The results of this study have provided support for this assumption.

The failure of the dynamic exercise group to change significantly may have resulted from an ineffective exercise program; the intensity and/or duration may not have produced sufficient changes in the TA muscle. The functional demands on the muscle may also account for this lack of change; the muscle fibers may be more tonic and less subject to change as a result of dynamic exercises. Another likely source of error was sample size as small samples negate the power of statistical procedures used. A larger sample of subjects and single motor units may have resulted in significant changes between pre and posttest for the dynamic exercise group. A subsequent study using larger samples is necessary in order to substantiate the findings of this research.

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