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Alteration of Motor-Unit Discharge Characteristics in Aged Humans

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The purpose of this study was to determine and compare the discharge characteristics of single motor-unit action potentials (SMUAPs) in young and aged subjects during 5, 10, and 20 percent of maximum voluntary contraction (MVC) of the abductor digiti minimi manus muscle. Three decades of aged subjects ranging from 60 to 90 years of age were compared with a group of 20 to 35 year olds. Specially constructed fine-wire bifilar recording electrodes were used, and SMUAPs were identified by interactive computer processing. Although the results did not reach a statistically significant level, they showed the 70- to 79-year-old age group had the longest mean interspike intervals (ISI) in each of the three percentages of MVC. The prolonged ISI indicate a slow motor-unit discharge rate. In addition, the 70- to 79-year-old group had a statistically significant floating standard deviation, indicating increased variability of discharge, and a significantly different negative floating serial correlation coefficient. All three factors describing motor-unit discharge behavior in the 70- to 79-year-old age group suggest possible substitution of larger motor units for smaller motor units normally active at low tensions.

Key Words: *Action potentials, Aged, Physical therapy.*

The aging process affects all major biological systems in the human body.¹ Although structural and physiological changes have been noted in persons as early as 40 years of age, alterations in movement patterns do not appear until 60 years of age.² For example, handwriting, an unconscious stereotyped movement, becomes halting and distorted in persons over 60 years of age.² Berry and co-workers suggest that alterations in stereotypic movements, such as gait, may be implicated in the in-

creased incidence in falls among the elderly population.³

The effects of aging on skeletal muscles, motor neurons, and spinal cords in animals and human models have been studied. When these studies attempt to relate the neuromuscular aging process to a singular or isolated biologic or physiologic event or series of events, the findings are inconclusive. For example, atrophy of skeletal muscle is noted in the elderly person. Gutman and colleagues have studied muscle models of aged mice and classified the structural characteristics of aged skeletal muscle between that occurring in muscle disease and denervation.⁴ Selective atrophy of the fast-twitch type II muscles has been noted by histochemical, histological, and post-mortem studies of the muscles of aged humans and rats.^{5,6} Campbell et al reported that the number of functioning motor units at the age of 70 is half that at the age of 60 and younger.⁷

When motor neurons are assessed as a separate entity, the changes associated with aging have been manifest in morphometric and physiologic terms. The longest motor axons have spherical swelling, polysynaptic end-plates, and an increase in the innervation ratio.⁸ Pestronk and Drachman reported de-

creased terminal sprouting of motor neurons in aged mouse models.⁹ La Fratta and Canestrari have reported a linear decrease in neural conduction velocity with increasing age.¹⁰

The human spinal cord also has changes associated with aging. Morphometric, post-mortem examinations of spinal cord sections by Scheibel revealed selective loss of small anterior horn cells that subserve the gamma system and small motor units.¹¹ According to Scheibel, this selective loss would tend to support the overt loss of skilled motor performance exhibited in elderly persons.¹¹

The effects of aging on muscle, motor neurons, and spinal cord as separate elements of the functional unit known as the single motor-unit action potential (SMUAP) have been offered. Andreasen and Rosenfalk have studied motor-unit discharge characteristics in healthy humans and in humans with neuromuscular disease.¹² The motor-unit discharge characteristics from aged humans has not been studied.

The normalized tension task of the muscle during SMUAP discharge is another important factor. In the normal physiologic state at low muscle tension levels, small motor units are active.¹² As

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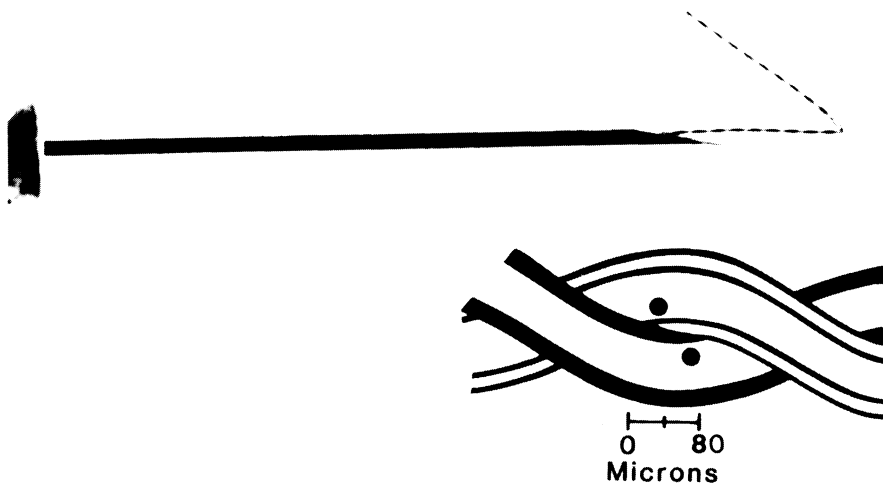


Fig. 1. Schematic of bifilar fine-wire electrodes inserted in needle. Exploded view shows active recording apertures.

tension increases, the SMUAPs discharge faster resulting in a shorter interspike interval (ISI). A further increase in the tension task may activate a slightly larger motor unit that has its own discharge frequency.¹³

The purpose of this study was to compare the discharge characteristics of SMUAPs in young and aged subjects from the right abductor digiti minimi manus (ADM) muscle contracting at 5, 10, and 20 percent of maximum voluntary effort.

Based on the literature review, hypotheses related to three characteristics describing SMUAP discharge behavior were developed. The hypotheses developed stated that the mean ISI, floating standard deviation (FSD), and floating serial correlation coefficients (FRHO) for the ISI would be significantly different ($p < .05$) in three Aged Groups when compared with a Young Group across three percentages of maximum voluntary contraction (MVC).

METHOD

Subjects

All 45 subjects were selected from the University of Iowa, Iowa City, Iowa or the Iowa Veterans Home in Marshalltown, Iowa. Criteria for inclusion in the study were no current or past history of peripheral nerve dysfunction, no current medication known to affect neuronal conduction, and no indication of muscle weakness or sensory deprivation to light touch in the upper right extremity, particularly in the ulnar nerve distribution.

All subjects were informed of the experimental procedure and associated risks and were provided forms for writ-

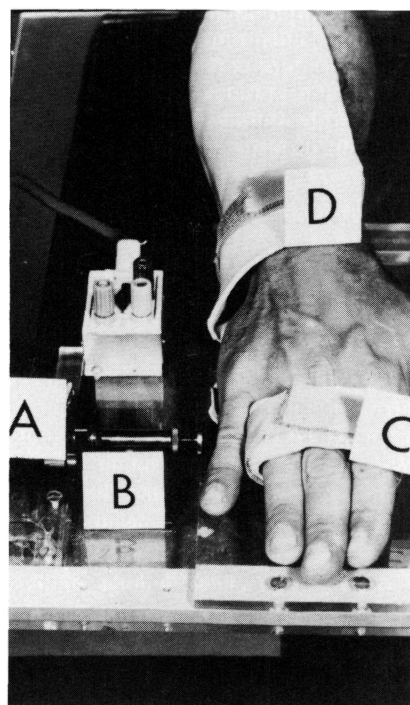


Fig. 2. Apparatus to collect force data: (A) force transducer, (B) orientation of force plate to little finger, (C) restraining device for fingers, and (D) restraining device for forearm.

ten consent. From the 45 participants in this study, four main groups were formed, a Young Group and three Aged Groups. The 13 subjects in the Young Group had a mean age of 29.6 (± 4.2) years. The Aged Group was subdivided into three equal decades beginning at the age of 60 years. The 60 to 69 decade had 13 subjects whose mean age was 65.5 (± 2.2). Nine subjects in the 70 to 79 group had a mean age of 74.8 (± 2.9) years. The last group was composed of 10 subjects who were 80 to 89 years old with a mean age of 83.5 (± 2.8).

INSTRUMENTATION

Active bipolar recording of SMUAPs was obtained by indwelling fine-wire electrodes. The 80 μm wires were braided together at one end for a length of 4 cm (2 in). The braided end was insulated and 5 μm active apertures were prepared by a pulsed laser* (Fig. 1). The fine-wire device was packaged and sterilized.¹⁴

The fine wires were inserted aseptically into the center of the right ADM muscle. The fine wires were connected to a high input impedance probe (Model 7H1P5),[†] which was, in turn, connected to a wide band A-C Pre-amplifier (Model 7P3).[†] The frequency response of the amplifier was set at 3 Hz to 10,000 Hz. The force resulting from isometric contraction of the ADM muscle was obtained by a Satham universal transducing cell.[‡] The output of this force transducer was connected to a DC amplifier (Model 7P122).[†] A restraining device eliminated accessory movements of the forearm and remaining fingers (Fig. 2). The analog force curve, SMUAPs, and verbal comments were simultaneously recorded on an FM instrument recorder.** Frequency response for all channels at 38 cm (15 in) per second was 500 Hz to 64,000 Hz.

Procedure

The average force value of three or four MVCs was calculated for each subject. From the averaged MVC, 5, 10, and 20 percent levels were calculated for each subject. Each percentage of MVC was randomly ordered and held linear for at least 10 seconds. To ensure quality of data, all trials included oscilloscope monitoring^{††} of the SMUAPs and force data. Although two or three trials were completed for each condition, only one trial at each of the three percentages of MVC was chosen for assessment for each subject. Selection was based on the technical quality of the SMUAP data and the subject's ability to maintain the required tension level accurately.

* Precision Aperture, PO Box 10863, Fort Wayne, IN 46854.

† Grass Instruments, 101 Old Colony Ave, Quincy, MA 02169.

** Model 3969A, Hewlett-Packard, 16399 W Bernardo Dr, San Diego, CA 92127.

‡ Gold Cell, Model UC3, Satham Instrument Co, 2230 Satham Blvd, Oxnard, CA 93030.

†† Model 7313, Tektronix, Inc, SW Millikan Way, Beaverton, OR 97005.

Data Analysis

For data analysis, an Interdata 6/17 computer completed analog to digital conversion and transferred all data channels onto a floppy disk. The SMUAP data were fed through a 900 Hz to 3,000 Hz band pass filter and sampled at 5,000 Hz. A second computer program transferred the disk's binary information to an IBM 370 computer and in turn to a VAX digital computer. The interactive VAX library system allowed the waveforms to be displayed on a graphics terminal (Model 1014).^{††} Each 10-second record was then divided into 64 segments, or pages, that represented a 204.8 msec portion of the 10-second record. An interactive analysis program allowed the investigator to mark a visually identified SMUAP with a letter character (Fig. 3). The time was automatically recorded in milliseconds as the identified SMUAP appeared in a series during the 10-second record. The time between successive appearances of the same SMUAP was the ISI. On completing the analysis for a particular subject's record, the ISI data for each SMUAP were stored. In addition, a hard-copy printout was made of the ISIs for each SMUAP. Any ISI beyond the 95 percent confidence level was identified, and that section on the wave form record was reexamined. The long interval usually revealed the synchronous firing of SMUAPs. Subse-

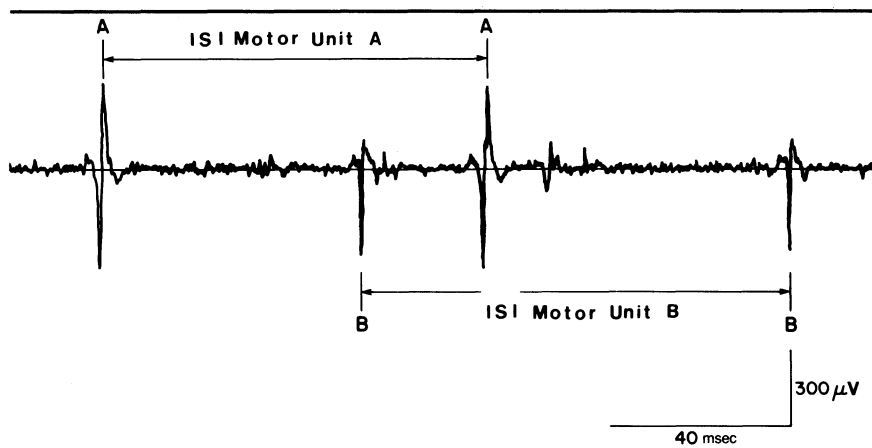


Fig. 3. Sample of single motor-unit action potentials with associated letter characteristics and measurement of interspike intervals (ISI).

quently, the reexamined SMUAP record was corrected, and all subsequent ISIs for that record automatically recalculated.

Single motor-unit action potential discharge behavior was described by examining three statistics of the dependent variable (ISI). The distribution of ISIs was represented by the mean. The variability of the ISI discharge was determined by the FSD.^{12,15} The relationship of successive ISIs was determined by using the FRHO.^{12,15}

A three-factor design analysis of variance (ANOVA) was used to test for statistical significance across the main effects of age and percentages of MVC. Mean values of each of the three descrip-

tors of SMUAP discharge behavior were nested within the appropriate cell. Error terms accounted for between-subject variability.

RESULTS

Data analysis yielded 34,354 total ISIs from 268 identified SMUAPs. The Young Group had 102 SMUAPs identified resulting in 15,210 ISIs. The three Aged Groups had 166 SMUAPs identified, (64, 49, and 53, respectively) yielding 19,144 ISIs from all three percentages of MVC.

Grand mean ISI values and associated standard deviations for each age group at each percentage of MVC appear in Figure 4. The ANOVA for main effects across age groups did not reach the .05 level of significance. The main effect, however, for percentage of MVC was significant ($p < .05$). A *post hoc* Duncan's multiple range test revealed the Young Group to have significantly different, shorter ISIs than the three Aged Groups'. In each percentage of MVC, the 70- to 79-year-old group had the longest mean interval, but the difference did not reach a level of statistical significance.

Grand mean values for FSD for each age group and percentage of MVC appear in Figure 5. The ANOVA demonstrated significant main effects ($p < .05$) between age groups but not significant by percentages of MVC (Tab. 1). *Post hoc* analysis by Duncan's multiple range test revealed the 70- to 79-year-old group to be significantly different ($p < .05$) from both the 60- to 69-year-old group and the Young Group but not from the 80- to 89-year-old group. The 80- to 89-year-old group was not significantly different from the other Aged Groups or the Young Group. The FSD

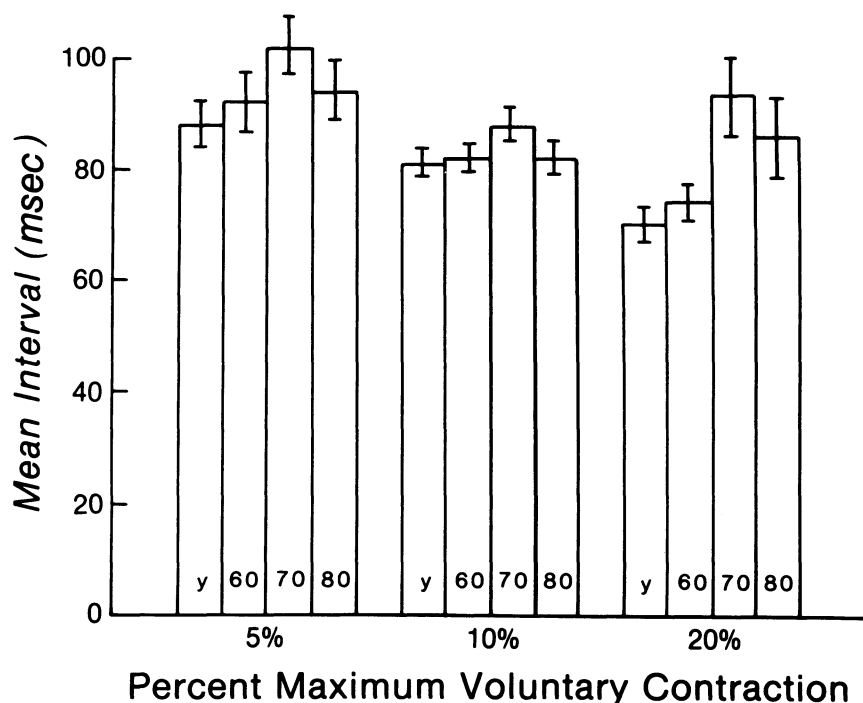


Fig. 4. Bar graph of grand mean and standard deviation for interspike intervals (msec) for each age group at each percentage of maximum voluntary contraction.

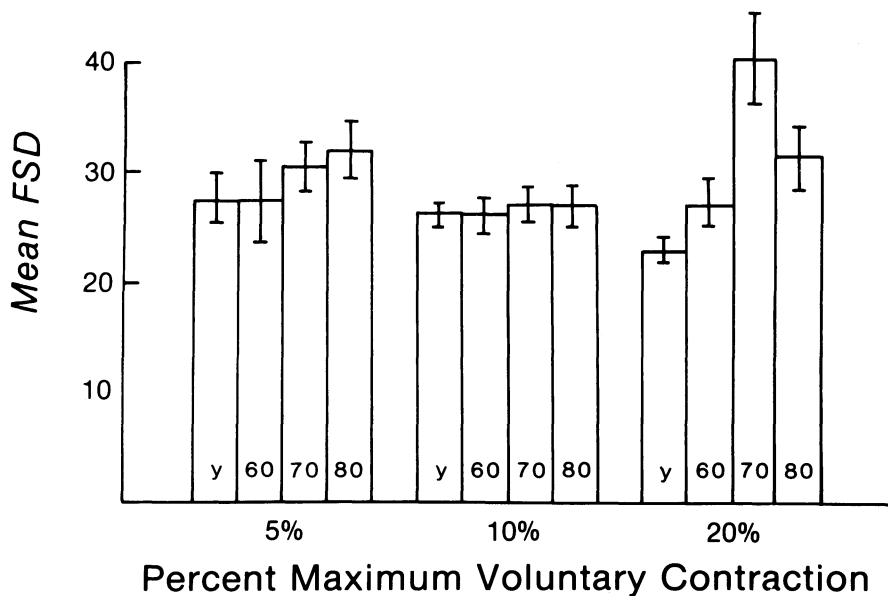


Fig. 5. Bar graph of grand mean floating standard deviation (FSD) in milliseconds and standard error of means for each age group at each percentage of maximum voluntary contraction.

for the 70- to 79-year-old group at 20 percent of MVC was the most variable (Fig. 5) for all percentages of MVC and age groups.

Grand mean values for FRHO appear in Figure 6. Analysis of variance for FRHO revealed significant ($p < .05$) main effects for Aged Groups but not for percentages of MVC (Tab. 2). A *post hoc* Duncan's multiple range test revealed that the 70- to 79-year-old group was significantly ($p < .05$) different from the Young Group but not from the other Aged Groups. The two other Aged Groups were not significantly different from the Young Group. All the obtained FRHOs across ages and percentage of MVCs were negative (Fig. 6). The 70- to 79-year-old group for each percentage of MVC had the largest negative correlation coefficients.

The three hypotheses that stated a significant difference existed in discharge characteristics between the Young Group and three Aged Groups for the three percentages of MVC were not sustained. In fact, the 70- to 79-year-old group for the FSD and FRHO were the only cases where significant levels were reached.

DISCUSSION

In the current study, young subjects performing at the three low tension levels had mean ISI values that ranged from 51 to 144 msec. These ISIs were the same as those found in hand intrinsic muscles by other investigators.^{15,16}

Before this study, ISIs from skeletal muscle motor units had not been as-

Table 1
Analysis of Variance for Floating Standard Deviation

Source	df	SS	MS	F	p
Age group	3	2419.94	806.6	3.05	.0395
Error I	40	10578.99	264.5		
%MVC	2	686.10	343.05	1.81	.1731
Age/%MVC	6	1700.17	283.36	1.49	.1973
Error II	56	10626.98	189.77		

sessed in aged humans. This study examined 268 motor units; other researchers have reported, on the average, less than 100 motor units in studies comparing normal with disease states.^{15,16} In other studies, the SMUAPs were usually obtained for 10 or less subjects, whereas this study included 44 subjects. Clamann indicated that at least 50 intervals are necessary for adequate description of discharge behavior and for statistical tests.¹⁷ This study averaged 149 intervals for the Young Group and 130 intervals for the Aged Group. Based on previous data and suggested criteria, data derived from the current study provide a strong representative view of motor-unit behavior in young and aged humans.

Although a statistical significance level was not reached for the mean ISI across main effects of age, the significantly shorter ISIs for the Young Group as the tension requirements increased are of interest. The 5, 10, and 20 percent of MVC were a sufficient tension gradation and apparently caused a faster discharge of SMUAPs. The 70- to 79-year-old group for all three percentages of MVC illustrated the longest mean ISI of all the groups. Longer ISIs at higher

tension tasks in the 70- to 79-year-old group was a curious finding. Longer ISIs mean a motor unit is discharging slower and the tendency for a long ISI may indicate an irregular discharge of motor units. For example, Freund et al indicate that motor units have a specific tonic threshold tension level at which discharge becomes regular.¹⁸ Milner-Brown and associates have shown a gradual decrease in the ISI as tension requirements increase.¹⁹ At each percentage of MVC, the 70- to 79-year-old group had motor units that did not discharge faster but rather discharged slower than the motor units in the other Aged Groups (Fig. 4). Perhaps motor units in the 70- to 79-year-old group had not reached a tonic threshold for discharge.

The discharge regularity of a single motor unit is directly related to the FSD. An irregular discharge pattern is char-

acterized by inordinately long pauses in SMUAP discharge. The 70- to 79-year-old group had a statistically significant irregular discharge rate compared with the Young Group and the two other Aged Groups (Fig. 5). Single motor units discharging at a subthreshold tension level tend to have an increased irregularity of discharge.¹³ Analysis of the FSD tends to support the long intervals noted by the mean ISI analysis.

The FRHO correlates each pair of motor-unit discharges and establishes the relationship between one SMUAP discharge and the preceding discharge. A negative correlation indicates an alternating pattern of intervals, which are either long to short or short to long. A zero correlation coefficient means no relationship. A positive correlation indicates a direct relationship of intervals of either long to long or short to short.¹²

With the exception of the Young Group at 10 percent of MVC, all FRHOs were statistically significant from zero ($p < .05$). All FRHOs were negative, with mean values ranging from -0.038 to -0.069 in the Young Group (Fig. 6). These results compare favorably with those of Andreassen and

Rosenfalk.¹² Their values were slightly larger, probably because they used a tonic threshold discharge level to study motor-unit discharge rather than a percentage of MVC. Person and Kudina reported computation of 6 out of 13 statistically significant negative serial correlation coefficients in a normal sample at mean ISI of less than 80 msec.²⁰ The 20 percent of MVC in this study had a mean ISI of less than 80 msec for the Young Group and also illustrated statistically significant negative coefficients. Andreassen and Rosenfalk commented that FRHOs tended to increase with advancing age.^{12,15} Lack of sufficient subjects precluded further assessment by them. This study has supported their findings in the 70- to 79-year-old group but not in the other Aged Groups. The FRHO is thought to represent anterior horn cell membrane excitability.²¹ The 70- to 79-year-old group illustrated significant FRHO differences in comparison with the Young Group (Fig. 6). A negative coefficient may be related to discharge characteristics of a large anterior horn cell size or to afferent bombardment on the AHC membrane or both.²²

When the tripartite discharge profile is considered as an entity for each group and percentage of MVC, a disturbance of motor-unit discharge regularity is evident at 20 percent of MVC in the 70- to 79-year-old group and not in the other groups. The discharge profile, con-

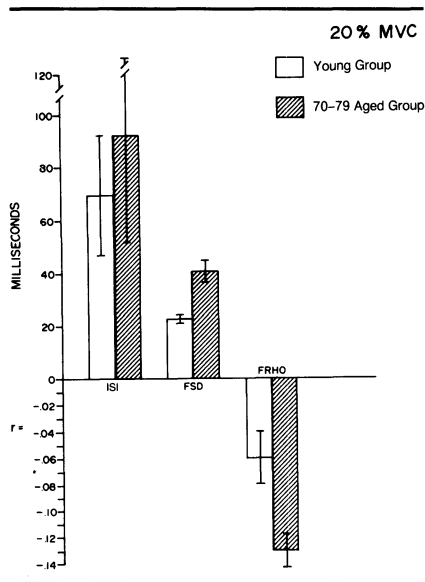


Fig. 7. Bar graph comparing Young Group and 70- to 79-year-old group mean values for the interspike interval (ISI), floating standard deviation (FSD), and serial correlation coefficients (FRHO) at 20 percent of maximum voluntary contraction.

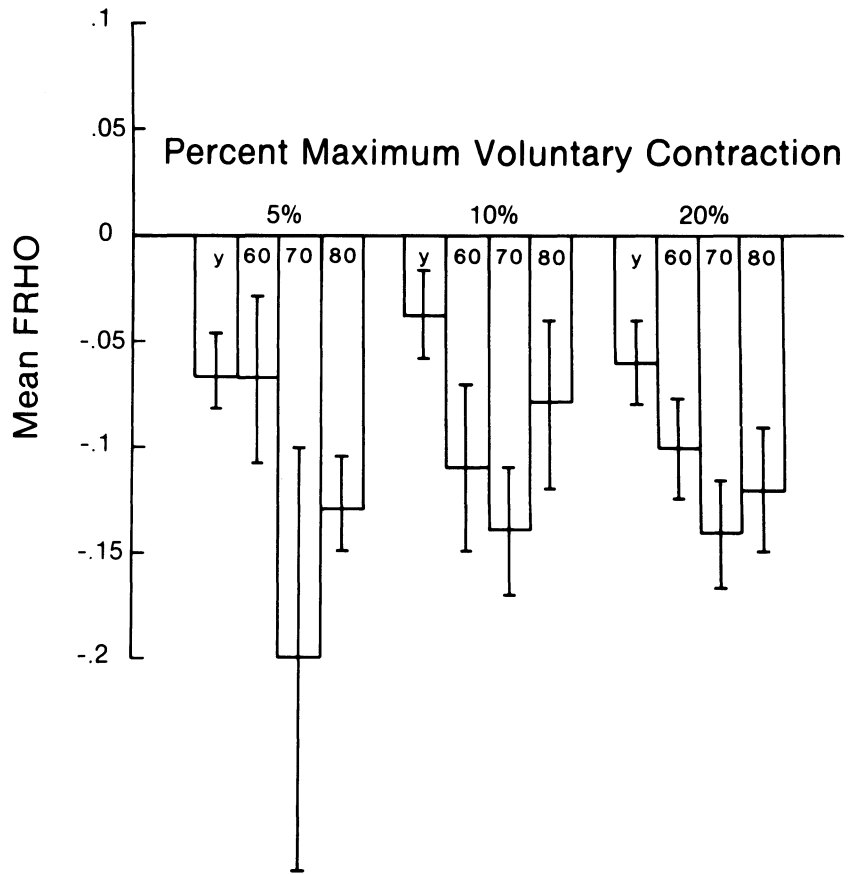


Fig. 6. Bar graph of grand mean floating serial correlation coefficients (FRHO) and standard error of means for each age group at each percentage of maximum voluntary contraction.

Table 2
Analysis of Variance for Floating Serial Correlation Coefficient

Source	df	SS	MS	F	p
Age group	3	0.3662	0.1221	4.01	.014
Error I	40	1.2160	0.0304		
%MVC	2	0.0190	0.0095	0.36	.699
Age/%MVC	6	0.0889	0.0148	0.56	.758
Error II	56	1.4757	0.0264		

sisting of the mean ISI, mean FSD, and mean FRHO, for the Young Group and the 70- to 79-year-old group at 20 percent of MVC is compared in Figure 7. The 70- to 79-year-old group had motor units with longer ISIs, which implies that the motor units were discharging slower. The variability of discharge is greater in that age group than in the Young Group, possibly indicating that the required tension was not great enough to cause a regular tonic discharge of the motor units even though the tension was normalized by percentage of MVC. The larger negative coefficient may indicate that larger anterior horn cells were activated in the 70- to 79-year-old group than in the Young Group. Apparently, the 70- to 79-year-

old group exhibited alteration of existing motor units, which are normally active at low tensions but were not activated, or at least not initially activated in this group. This inaction led to substitution by larger motor units.

Clinical Implication

Activity to prevent or slow down disuse is the underlying theme that pervades texts on aging. In fact, muscle disuse in the elderly person was an important clinical factor brought out by Payton and Poland.¹ Those authors indicated that physical therapy goals should be oriented toward prevention of disuse. This study found that the 70- to 79-year-old group used motor units that were apparently not discharging toni-

cally at low tension levels. We theorized that large motor units were activated during low muscle tension tasks when, in fact, small motor units should have been active. Perhaps, physical therapy management of the otherwise healthy 70- to 79-year-old should include exercises on movement precision at low muscle tension tasks. Also, the use of visual feedback mechanisms during stereotyped tasks may be indicated for purposes of providing a learning experience in precision type movements. Thus, learning how the muscles respond to low-level tasks may help prevent disuse through increased body awareness. The debilitated elderly patient with or without central nervous system deficit may benefit from bilateral activities at low muscle output levels to create and stimulate the awareness of body parts in space.

The disuse syndrome in the elderly person may occur as a self-selected mechanism. For example, improper motor-unit activation may make movement difficult or seemingly uncoordinated. Therefore, further movement may be consciously avoided by the elderly person. Perhaps, the healthy, elderly person can receive a prevention-oriented treatment regimen as Payton and Poland have indicated.¹ In view of the findings of this study, emphasis should be on coordinated movement patterns at low tension levels.

CONCLUSION

This study has discovered alterations in motor-unit discharge characteristics

at low tension tasks for a 70- to 79-year-old group when compared with a Young Group and two other Aged Groups. The motor units in the 70- to 79-year-old group tended to discharge slower with significantly more variation than in the other groups. The negative FRHOs found in the 70- to 79-year-old group are consistent with discharge characteristics found in large anterior horn cells.

REFERENCES

1. Payton OD, Poland JL: Aging process: Implications for clinical practice. *Phys Ther* 63:41-48, 1983
2. Fisher MB, Birren JE: Age and strength. *J Appl Physiol* 31:490-497, 1974
3. Berry G, Fisher R, Lang S: Detrimental incidents, including falls, in an elderly institutional population. *J Am Geriatr Soc* 29:322-324, 1981
4. Gutman E, Hanzlikova V, Jakoubek E: Changes in the neuromuscular system during old age. *Exp Gerontol* 3:141-142, 1968
5. Larsson L, Grimby G, Karlsson J: Muscle strength and speed of movement in relation to age and muscle morphology. *J Appl Physiol* 46:451-456, 1979
6. Tomanga M: Histochemical and ultrastructural changes in senile human skeletal muscle. *J Am Geriatr Soc* 25:125-131, 1977
7. Campbell MJ, McComas AJ, Petito F: Physiological changes in aging muscles. *J Neurol Neurosurg Psychiatry* 37:131-141, 1974
8. Harriman DG, Taverner D, Wolf AL: Ekbom's syndrome and burning paresthesia. A biopsy study by vital staining and electron microscopy of the intramuscular innervation with a note on age changes in motor nerve endings in distal muscles. *Brain* 93:393-406, 1970
9. Pestronk A, Drachman DB: The effect of aging on nerve sprouting. *Trans Am Neurol Assoc* 103:14-18, 1978
10. La Fratta CW, Canestrari RE: A comparison of sensory and motor nerve conduction velocities as related to age. *Arch Phys Med Rehabil* 47:286-290, 1966
11. Scheibel AB: Aging in human motor control systems. In Ordry JM, Brizze K (eds): *Sensory Systems and Communications in the Elderly*. New York, NY, Raven Press, 1979, vol 10, pp 297-310

Larger motor units may be substituting for smaller motor units in the 70- to 79-year-old group.

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12. Andreassen S, Rosenfalk A: Regulation of the firing patterns of single motor units. *J Neurol Neurosurg Psychiatry* 30:897-906, 1980
13. Freund HJ, Budingen HJ, Dietz V: Activity of single motor units from human forearm muscles during voluntary isometric contractions. *J Neurophysiol* 38:933-943, 1975
14. Nelson RM, Soderberg GL: Laser etched bifilar fine wire electrode for skeletal muscle motor unit recording. *Electroencephalogr Clin Neurophysiol* 55:238-239, 1983
15. Rosenfalk A, Andreassen S: Impaired regulation of force and firing pattern of single motor units in patients with spasticity. *J Neurol Neurosurg Psychiatry* 43:907-916, 1980
16. Tanji J, Kato M: Discharges of single motor units at voluntary contraction of abductor digiti minimi muscle in man. *Brain Res* 45:590-593, 1972
17. Clamann HP: Statistical analysis of motor unit firing patterns in human skeletal muscle. *Biophys J* 9:1233-1254, 1969
18. Freund HJ, Wita CW, Sprung C: Discharge properties in functional differentiation of single motor units in man. In Somjen GG (ed): *Neurophysiology Studied in Man*. Amsterdam, The Netherlands, Excerpta Medica, 1972, pp 305-313
19. Milner-Brown HS, Stein RB, Yemm R: The contractile properties of human motor units during voluntary isometric conditions. *J Physiol (London)* 228:285-306, 1973
20. Person RS, Kudina LP: Discharge frequency and discharge pattern of human motor units during voluntary contraction of muscle. *Electroencephalogr Clin Neurophysiol* 32:471-483, 1972
21. Kuffler SW, Nichols JG: *From Neuron to Brain*. Sunderland, MA, Sinauer Associates Inc, 1977, pp 88-132
22. Kernell D: High frequency repetitive firing of cat lumbosacral motor neurons stimulated by long-lasting injected currents. *Acta Physiol Scand* 65:74-86, 1965

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