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## Comparison of skeletal muscle motor unit discharge characteristics in young and aged humans

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### Summary

The purpose of this study was to determine the discharge characteristics of motor unit action potentials. Three decades of aged subjects ranging from 60 to 90 yr of age were compared to a group of 20-35 yr olds. Motor unit behavior was described by the interspike interval (ISI) and expressed statistically as a mean, a floating standard deviation (FSD), and a floating serial correlation (FRHO). The 70- to 79-yr-old group tended to have a slow motor unit discharge rate, an increased variability of discharge (FSD) and a negative serial correlation coefficient (FRHO). All three factors describing motor unit discharge behavior possibly suggest substitution of larger motor units for small motor units normally active at low tensions for the 70-79 age group.

motor units; aging

### Introduction

Evidence indicates that the aging process influences the neuromuscular system. Alterations in stereotypic movements appear in persons as early as 60 yr old (Fisher and Birren, 1947). As the individual ages, psychomotor skills, once automatic and effortless, become conscious tasks requiring visual cues for feedback. For example, handwriting becomes halting and distorted in the elderly person (Birren, 1951). As evidenced by the percentage of accidents that occur at home or in familiar environs, safe performance of activities of daily living is diminished in the elderly person (Shephard, 1978). Senile movement dysfunction apparently increases the elderly person's susceptibility to a familiar environment and makes ordinary activities hazardous.

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Studies are inconclusive in relating the aging process to a specific action or series of events. Views describing the effects of aging on the muscles, motor neurons and spinal cords in animal and human models have been offered. Senile muscle atrophy has been classified as 'functionally denervated' by Gutmann et al. (1968). They categorized the senile muscle atrophy as being between the atrophy noted in neuromuscular disease and denervation. Selective atrophy of the fast twitch type II muscles has been noted by histochemical, histological and postmortem studies of aged human and rat muscles (Tomanga, 1977; Larson et al., 1979). McComas et al. (1971) have shown that motor units decrease in aged humans.

Motor neurons have illustrated alterations associated with aging. Pestronk and Drachman (1978) have shown decreased terminal sprouting of motor neurons in aged murine models. A decrease in conduction velocity of fastest motor and sensory neurons have been reported in aged animal and human models (LaFratta and Canestrari, 1966; Swallow and Griffiths, 1977).

The human spinal cord has shown changes associated with aging. Scheibel (1979) performed postmortem morphometric evaluations of spinal cord sections which revealed selective loss of small anterior horn cells (AHC). Small AHCs subserve the gamma system, and the small motor units. According to Scheibel (1979), the loss of small AHCs tends to support the noted overt loss of skilled motor performance exhibited by elderly persons.

The actual event or series of events operative during the aging process for the neuromuscular system remains uncertain. No studies up to this point have evaluated, in situ, the intact neuromuscular system in aged humans. The discharge of a skeletal muscle motor unit directly reflects concomitant activity of all the components in the intact neuromuscular system. The functional stability of the neuromuscular system can be estimated by studying the discharge characteristics of the single motor unit action potentials (SMUAP) during an isometric tension task.

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

## **Method**

All subjects were selected from the University of Iowa, Iowa City, IA, or the Iowa Veterans Home in Marshalltown, IA. Each subject was thoroughly reviewed by examining the patient's chart, seeking physician comments and performing specific tests to the ulnar motor and sensory distribution.

Criteria for inclusion in the study were: no current or history of peripheral nerve dysfunction, no current usage of medication known to affect neuronal conduction, and no indication of muscle weakness or sensory deprivation to light touch in the right upper extremity, with special attention to ulnar neural distribution.

The young subjects were students at the University. The aged subjects were from a geriatric health care center located in a rural area. The aged subjects were predominantly retired farmers or housewives.

TABLE I

Descriptive statistics for each age group.

Age group	<i>N</i>	Mean	SD
Young	13	29.6	± 4.2
60-69	13	65.5	± 2.2
70-79	9	74.8	± 2.9
80-89	10	83.5	± 2.8

All subjects were informed of the experimental procedure and associated risks, and they provided written consent to participate. From the 44 participants in this study, four main groups were formed, a young group and three aged groups. The data are shown in Table I.

Active bipolar recording of SMUAP was obtained by indwelling fine wire electrodes. The 80  $\mu\text{m}$  wires were braided together at one end at a distance of 4 cm. The braided end was insulated and 5  $\mu\text{m}$  active apertures prepared by a pulsed laser (Fig. 1) (Nelson and Soderberg, 1983). The wires were individually packaged and sterilized. Using aseptic techniques the fine wires were inserted into the center of the ADM.

The fine wires were connected to a high-input impedance probe (Grass, Model 7HIP5). This probe was connected to a wide band A-C Preamplifier (Grass, Model 7P3). The frequency response of the amplifier was set at 3 to 10,000 Hz.

The force resulting from isometric contraction of the ADM muscle was obtained by a Satham universal transducing cell (Gold Cell, Model UC3). The output of this force transducer was connected to a DC amplifier (Grass, Model 7P122). A restraining device eliminated accessory movements of the forearm and remaining fingers (Fig. 2). The analog force curve, SMUAPs, and manually controlled event marker were simultaneously recorded on an FM instrument recorder (Hewlett Packard, Model 3969A). Frequency response for all channels at 15 in. per s was 500 to 64,000 Hz.

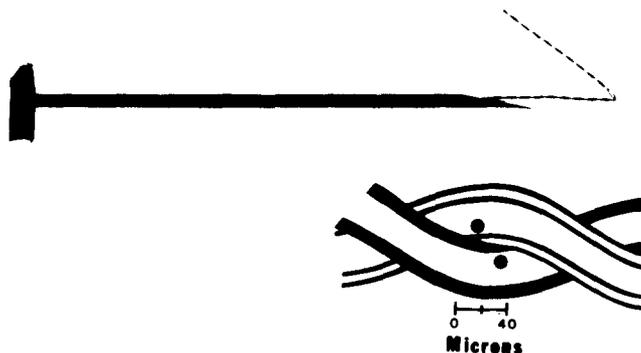


Fig. 1. Schematic of fine wire electrodes inserted in needle. Exploded view shows active apertures.

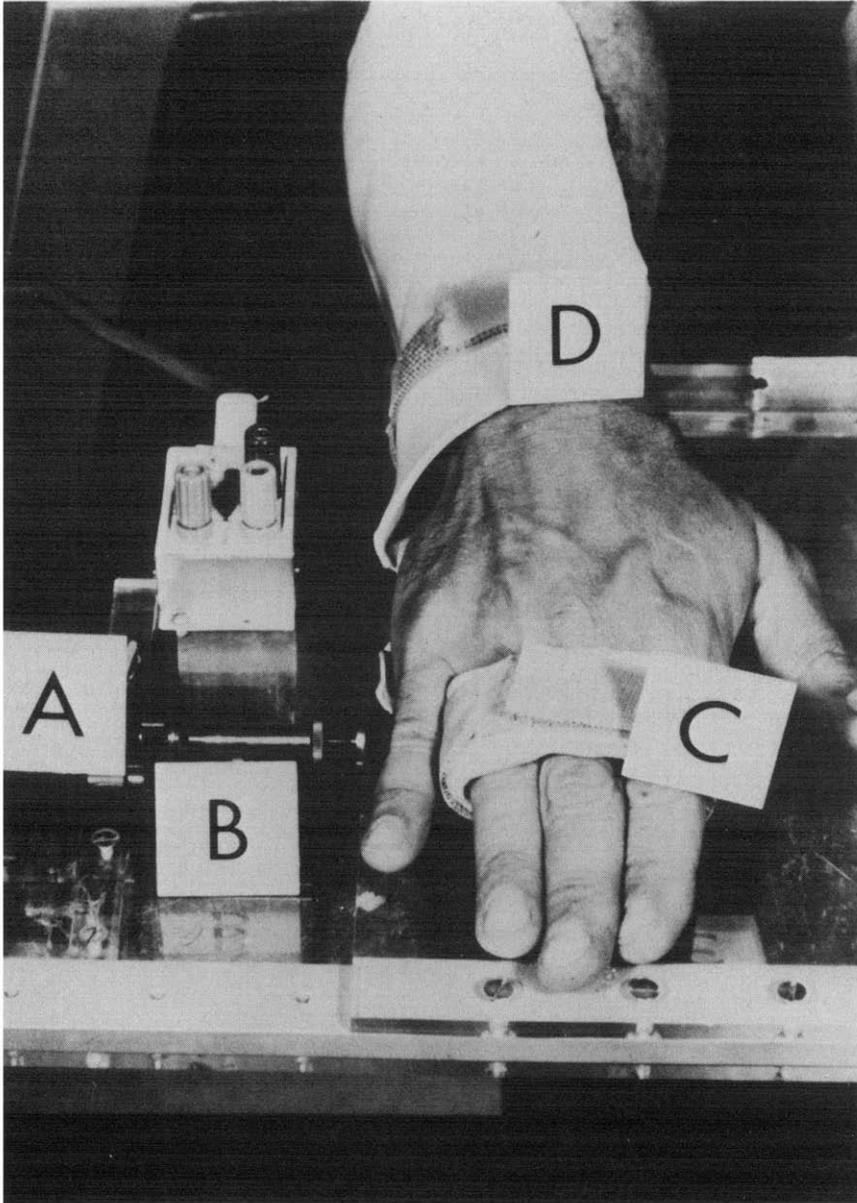


Fig. 2. Apparatus to collect force data. (A) Force transducer; (B) orientation of force plate to little finger; (C) restraining device for fingers; (D) restraining device for forearm.

After suitable orientation to the force trace and relationship to abduction of the little finger the subject was allowed to experiment with the abduction movement. The orientation period lasted approximately 10 min. A 5-min rest period followed

the orientation period. Next, three maximal voluntary contractions (MVC) were obtained. From the MVC force levels, 5, 10 and 20% levels of MVC were calculated.

Each percent MVC was randomly ordered and held linear for at least 10 s. To control for possible fatigue factors, a 3-min rest period followed each 10-s trial at a given percent MVC.

To ensure data quality all trials included oscilloscope (Tektronix, Model 7313) monitoring of the SMUAPs and the force data. Although multiple trials were completed for each percent MVC, only one trial at each of the three percentages of MVC was chosen for each subject. Selection was based on the technical quality of the SMUAP data and the subjects ability to accurately maintain the required tension level.

For data analysis an Interdata 6/17 computer completed analog to digital conversion and transferred all data channels onto a floppy disc. To decrease the possibility of signal aliasing the distant SMUAP data was attenuated by first band passing the data through a 900- to 3000-Hz laboratory manufactured filter. The analog to digital conversion rate was 5000 Hz, more than twice the expected frequency components of the SMUAP data.

A second computer program transferred the disc's binary information to an IBM 370 and in turn to a VAX digital computer. The interactive VAX library system allowed the waveforms to be displayed on a graphics terminal (Tektronix, Model 1014). Each 10-s record was subsequently divided into 64 segments, or pages, that represented a 204.8-ms portion of the 10-s record. An interactive analysis program allowed the investigator to mark a visually identified SMUAP with a letter character (Fig. 3). While the shape of the SMUAP did not change appreciably during the 10-s trial, the amplitude occasionally changed as much as 30%. Intra-rater reliability for SMUAP recognition was  $r = 0.86$  (Nelson, 1981). Automatically recorded was the time, in milliseconds, at which the identified SMUAP appeared seriatim in the 10-s record. The time between successive appearances of the same SMUAP was the interspike interval (ISI). Upon completion of the analysis for a particular subject's record, the ISI data for each SMUAP was stored. In addition, a hard-copy printout was made of the ISIs for each SMUAP.

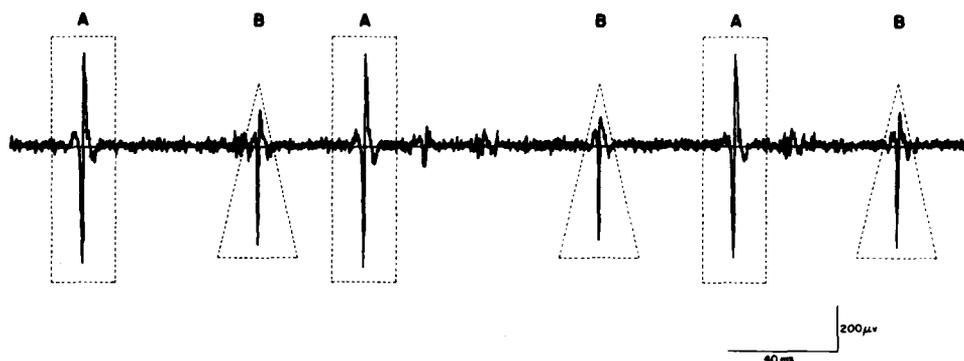


Fig. 3. Sample of single motor unit action potentials with associated letter characteristics.

As a validity check, any ISI determined to be beyond 95% levels for that SMUAP was identified, and that section on the wave form record was re-examined. The long interval usually had one or two synchronously firing SMUAPs. The re-examined SMUAP record was corrected, and all subsequent ISI's for that record automatically recalculated.

Single motor unit discharge behavior was described by examining three statistics of the dependent variable (ISI). The distribution of ISIs was represented by the mean, while the variability of the ISI discharge was determined by the floating standard deviation (FSD). The relationship of successive interspike intervals was determined by using the floating serial correlation coefficient (FRHO) as described by Andreassen and Rosenfalk (1980).

A three-factor design was used to test for statistical significance across the main effects of age and percent MVC. Mean values of each of the three descriptors of single motor unit discharge behavior were nested within the appropriate cell. Error terms accounted for between subject variability.

## Results

Data analysis yielded 34,324 ISIs from 268 identified motor units. The young group had 102 MUAPs identified resulting in 15,210 ISIs. The three aged groups had 166 MUAPs identified (64, 49 and 53, respectively) yielding 19,144 ISIs.

Grand mean ISI values for each age group at each percent MVC are presented in Table II. Grand mean values for FSD and FRHO for each age group at each percent MVC are presented in Tables III and IV, respectively.

The analysis of variance for mean ISIs revealed no significant differences for main effects across age groups.

Analysis of variance for FSD demonstrated significant main effects between age groups (Table V). Post hoc analysis by Duncan's multiple range test revealed the 70-79 age group to be significantly different from both the 60-69 and the young group but not from the 80- to 89-yr-old group. The FSD values tended to become longer (more variable) with age (Table III).

Analysis of variance for FRHO is presented in Table VI. Main effects across age

TABLE II

Descriptive statistics for ISI (ms) for each age group at each percent MVC.

Age group	Percent MVC					
	5		10		20	
	Mean	SD	Mean	SD	Mean	SD
Young	88.0	28.1	81.0	27.5	70.0	23.9
60-69	92.4	30.7	80.2	29.6	74.0	28.4
70-79	103.0	31.1	88.0	30.4	93.0	40.8
80-89	96.0	33.0	82.0	27.6	86.0	34.7

TABLE III

FSD descriptive statistics for each age group at 5, 10 and 20% MVC.

Age group	Percent MVC					
	5		10		20	
	Mean	SD	Mean	SD	Mean	SD
Young	27.4	2.32	26.1	1.21	22.9	1.07
60-69	26.9	2.80	25.2	1.50	27.3	2.24
70-79	30.4	2.15	27.9	1.16	40.5	4.16
80-89	32.2	2.50	26.9	2.18	31.5	2.77

TABLE IV

Floating serial correlation coefficient descriptive statistics for each age group and percent MVC.

Age group	Percent MVC					
	5		10		20	
	Mean	SD	Mean	SD	Mean	SD
Young	-0.069	0.062	-0.038	0.021	-0.062	0.023
60-69	-0.068	0.036	-0.012	0.022	-0.102	0.027
70-79	-0.020	0.056	-0.143	0.034	-0.140	0.029
80-89	-0.130	0.024	-0.183	0.039	-0.121	0.029

TABLE V

Analysis of variance for FSD.

Source	d.f.	SS	MS	F	P
Age group	3	2419.94	806.6	3.05 <sup>a</sup>	0.0395
Error I	40	10578.99	264.5		
$\Delta$ MVC	2	686.10	343.05	1.81	0.1731
Age $\Delta$ MVC	6	1700.17	283.36	1.49	0.1973
Error II	56	10626.98	189.77		

<sup>a</sup> Significant *F* noted between age groups. Post hoc Duncan's test indicated only a significant difference existed between 70-79 age group and young group.

TABLE VI

Analysis of variance for FRHO.

Source	d.f.	SS	MS	F	P
Age group	3	0.3662	0.1221	4.01 <sup>a</sup>	0.014
Error I	40	1.2160	0.0304		
$\Delta$ MVC	2	0.0190	0.0095	0.36	0.699
Age $\Delta$ MVC	6	0.0880	0.148	0.56	0.758
Error II	56	1.4757	0.0264		

<sup>a</sup> Significant *F* noted between age groups. Post hoc Duncan's indicated only a significant difference existed between 70-79 age group and the young group.

groups were significant. A post hoc Duncan's test revealed that the 70–79 age group was significantly different from the young group but not from the other aged groups. The 70–79 age group had an increased negative FRHO (Table IV).

## Discussion

In the current study, young subjects at three low tension levels had mean ISI values that ranged from 51 to 144 ms, which is about the same as found in hand intrinsic muscles by Freund et al. (1975) and Tanji and Kato (1977).

Prior to this study, interspike intervals from skeletal muscle motor units had not been evaluated in aged humans. This study evaluated 268 motor units. Bracchi et al. (1966) and Tanji and Kato (1977) report on the average less than 100 motor units. In other studies the SMUAPs were usually obtained on 10 or less subjects, whereas this study included 44 subjects. Clamann (1969) has indicated at least 50 intervals are necessary for adequate description of discharge behavior and for statistical tests. This study averaged 149 intervals for the young group and 130 intervals for the aged group.

Inspection of mean ISI values reveals that the motor units discharged faster as the percentage of MVC increased (Table II). Sufficient tension gradation apparently caused a faster discharge of SMUAPs and a shift to shorter intervals. At the 20% MVC level for the 70–79 age group the mean interval is longer but still consistent with the other percentages of MVC. The difference in this group was in the standard deviation (Table II). Since the mean ISI main effects test was not significant by analysis of variance across age groups, it was difficult to explain the larger-than-expected variability of discharge without significantly longer mean ISI values.

Tendency for long intervals and larger standard deviation of mean ISI may indicate an irregular discharge of motor units. Freund and co-workers (1975) indicate that motor units have a specific tonic threshold tension level at which discharge becomes regular. It was curious to observe irregularity of discharge at higher tension tasks. Milner-Brown et al. (1973) have shown a gradual increase in motor unit discharge frequency as tension requirements increase. At 20% MVC the 70–79 age group have motor units which were not discharging faster, but rather discharging slower and more irregular than in other aged groups (Table II). Perhaps motor units in the 70–79 age group had not reached a tonic threshold for discharge.

Variability of discharge was described by the FSD. By using a limited number of intervals (19) from which to calculate the FSD exceptionally long intervals had minimal influence on the width of the FSD as shown by Rosenfalk and Andreasson (1980). As noted in Table III the FSD at 20% MVC was the greatest for the 70–79 age group of all three aged groups.

Variability (FSD) of intervals is directly related to the regularity with which a motor unit discharges. By analysis of variance the 70–79 age group had a significantly irregular SMUAP discharge compared to the other two aged groups (Table V). Motor units discharging at subthreshold tend to have an increased irregularity of discharge according to Freund et al. (1972).

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 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.

With the exception of the young group at 10% MVC, all FRHOs were statistically significant from zero ( $P < 0.05$ ). All FRHOs were negative with mean values ranging from  $-0.038$  to  $-0.069$  in the young sample (Table IV). These results compare favorably to those of Andreassen and Rosenfalk (1980). 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 (1972) reported computation of 6 out of 13 statistically significant negative serial correlation coefficients in a normal sample at mean ISI intervals of less than 80 ms. The 20% MVC in this study had a mean ISI of less than 80 ms for the young sample and also illustrated statistically significant negative coefficients. Andreassen and Rosenfalk (1980) have commented that FRHO tended to increase with advancing age. Lack of sufficient subjects precluded further evaluation by them. This study has confirmed their findings in the 70–79 age group but not in other aged groups.

A possible disturbance of motor unit discharge regularity is noted at the 20% MVC in the 70–79 age group when comparisons were made between other aged groups and by young group and not in other aged groups. Alteration of existing motor units in the 70–79 age group, normally active at low tensions, may not have been activated, or at least not initially activated, possibly leading to subsequent substitution by larger motor units in that muscle.

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