QUANTITATIVE ESTIMATION OF SENSITIVITY TO MUSCLE STRETCHES IN THE TONIC MUSCLE SPINDLE DISCHARGES OF CATS

M. Mizote and H. Matsuzaki
Teikyo Heisei University, 2289 Uruido, Ichihara-shi, Chiba, 290-0193, Japan

Abstract- **Joint interval histogram (JIH) and power spectrum density (PSD) of GIa unitary discharges were obtained while muscle of an anesthetized cat was stretched steadily. The PSD curve was approximated three lines in the following frequency band, below 15Hz, 15 to 35Hz and above 35Hz. The gradient between 15 to 35 Hz was steep and corresponds to how much the intrafusal fibers were activated. In a pattern of JIH, Ia discharges distributed wide in general. But, interval was regular and histogram made a group when intrafusal fibers were activated by electric stimulation on the ventral rootlet. In particular conditions, peaks were observed around 50 to 60 Hz in PSD.**
***Keywords* - Joint interval histogram, a power spectrum density, muscle spindle, intrafusal muscle fibers**

I. INTRODUCTION

Mizote has found two types in afferent discharges of a shortened cat muscle by a combination of steady stretch and vibratory stretch. One is a discharge which comes from a dynamic nuclear bag fiber and the other comes from a static nuclear bag fiber or a nuclear chain fiber [1], [2]. But, response pattern of afferent fibers to vibratory stretches is varied as the muscle is extended and the separation in the afferent discharges was impossible because many impulses with several kinds of amplitude were recruited.

We have estimated quantitatively the sensitivity of cat intrafusal muscle fibers to the muscle stretch by the joint interval histogram and by the power spectrum density of inter spike interval of spindle discharges.

II. METHODOLOGY

A. Subjects

Experimental data, which had already been reported [1] and had been recorded on a magnetic tape, were used for analyses of inter spike interval of cats muscle spindle discharges. Cats were anesthetized intraperitoneally and muscles were dissected free of surrounding tissue, while keeping the blood supply intact as much as possible. All other nerves in the hindlimb were cut except the gastrocnemius and soleus nerves. A laminectomy was performed to expose the dorsal and ventral roots between L5 and S1. They were cut at the entry into the spinal cord. The dorsal root was split into fine filaments for the isolation of single primary afferent fiber, which were identified as spindle endings by their behavior during twitch contractions of the muscle elicited by stimulating its nerve. The initial muscle length was determined by the single shock stimulus of ventral root. The muscle tendon through a steel hook was stretched steadily. Muscle was stretched to several mm till spindle discharges kept firing. Inter spike interval of the tonic discharges of muscle spindle was analyzed.

Ventral root L7 was separated into six bundles. Each bundle was used as gamma fusimotor stimulation. Extrafusal muscle fibers were immobilized by gallamine injection, while respiration was kept by a respirator.

Because original recordings of experimental data included responses to the vibratory stimuli or (and) to the electric stimulation of ventral rootlet, discharges during vibrations or during ventral stimulations were ejected for the analyses.

B. Analysis

1) Conversion: Recorded impulses were replayed at a rate of one 8th or one 16th of original recorded tape speed and were converted into digital signal (ADX-98, Canopus) at a sampling frequency of 1kHz. Each peak value of the impulse discharges was detected and was saved as a file in a personal computer.

2) The joint inter-spike interval histogram (JIH): The joint inter-spike interval histogram was obtained as the joint distribution of two successive inter-spike intervals(t_n, t_{n+1})[3].

3) Power spectrum density (PSD): The time interval between nth impulse occurrence and the following (n+1)th impulse was converted into the amplitude at the time of (n+1)th impulse occurrence. The treatments were repeated over all the inter-spike intervals. Adjacent peaks were connected each other by a line till all peaks were connected, and a line graph was produced. The line graph was sampled by sampling frequency of 1kHz for a power spectrum density (PSD) analysis [4],[5].

III. RESULTS

A. The joint inter-spike interval histogram

The pattern of the joint inter-spike interval histograms shows distributions of the tonic discharges to the steady stretch around the short intervals and is scattered wider as the interval is longer, when the muscle is stretched by a steady stretching or by a ramp and hold stretching. In Fig.1, there is not much difference between (1) 3mm stretches and (2) 5mm stretches. But, as shown in Fig.2 left rows, the pattern of JIH is changeable. Three different Ia discharges are compared simultaneously at 10mm steady stretch for about 15sec.

In Fig.3 left rows, the patterns of JIH are varied. Fig.3c shows the joint interval of the histogram is plotted on the regular intervals as if the inter spike interval is synchronized. The histogram shows presence of periodical firings (about 30, 40, 50, 60ms).

Ia discharges are synchronized by a phase of sinusoidal stretches while vibratory stimulation is repeated [1], [2]. But, the discharges had not been driven after the vibratory stimulations. The firing pattern of JIH implies that Ia discharge is effected by oscillation of intrafusal muscle fibers.

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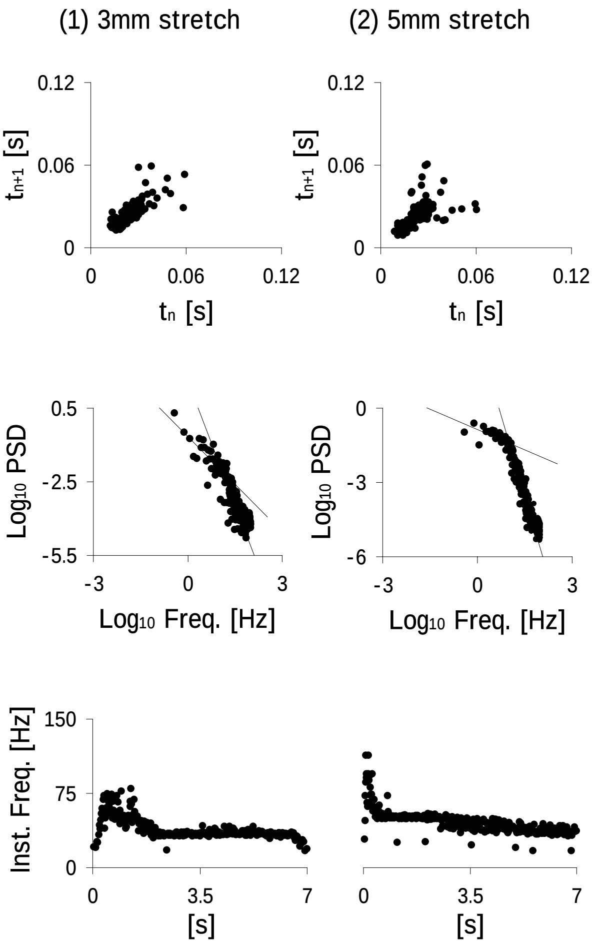

Fig.1, JIH (uppermost), PSD (middle) and instantaneous frequencygram (bottom) of inter-spike interval of Ia are shown when muscle is stretched 3mm(1) and 5mm(2). Thin lines of PSD in the middle of the figure are regression lines between 0 and 35Hz.

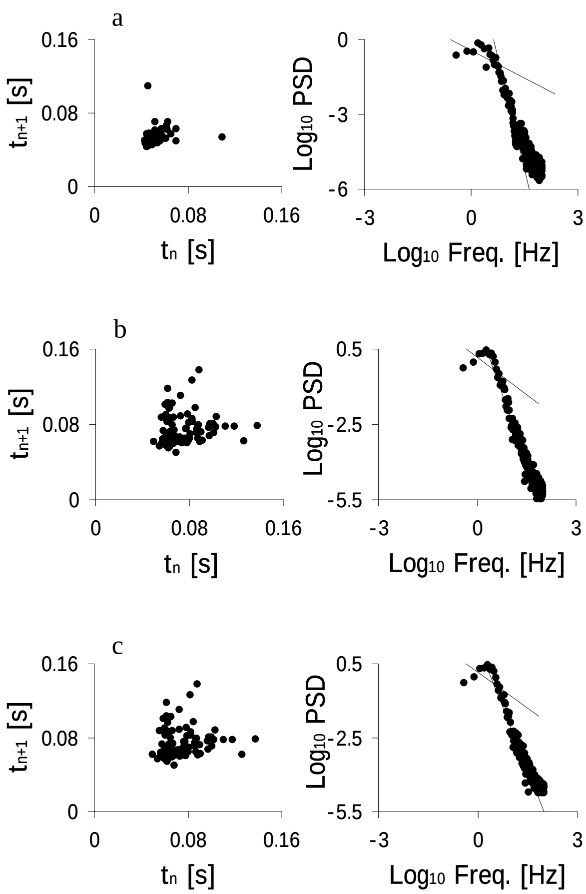

Fig.2; JIH (left) and PSD (right) of the three different Ia discharges are compared simultaneously by the stretch. The sensitivity of muscle spindle is not same.

B. A power spectrum density of inter spike intervals

Inclination of the relation curve between PSD and frequency shows $1/f^n$. The inclination is also approximated by three gradients depending on the frequency band. The gradient of the relation curve is shown in n value. The mean and standard deviation of n value is as follows:

1) Below 15 Hz, n = 0.99±0.38.
2) Between 15 Hz to 35 Hz, n= 2 to 6 (changeable).
3) Above 35Hz, n = 1.8±0.56.

The second gradient between 15Hz and 35Hz in PSD;

PSD is shown in the right rows of all the figures. As the gradient in 5mm stretch is different from the gradient of 3mm stretch (Fig.1), the second gradient of PSD between 15Hz and 35Hz changes when the muscle length changes and when intrafusal fibers are stimulated electrically. It implies the second gradient shows how much intrafusal muscle fibers are activated, probably in the static type of intrafusal muscle fibers like static nuclear chain fibers and a static nuclear bag fiber [9],[10].

We confirm the change of the gradient of PSD by three physiological methods;
1) The muscle stretch by a ramp and hold stretching (Fig.1).
2) Comparison of inter-spike intervals of three Ia fibers, while the muscle is steadily stretched by 10mm from the initial muscle length (Fig2).
3) Separated ventral rootlet to the left gastrocnemius muscle is stimulated by 100Hz electric pulses while the muscle is stretched before and after gallamine injection (Fig.3).

Before ventral root (VR) stimulation, the gradient is about 2 (Fig.3a). But, it is 3 after VR stimulation (Fig.3c). Fig.3b and Fig.3e shows PSD before and after gallamine injection while VR root is stimulated by 100Hz. Then gradient (n) is about 6.

IV. DISCUSSION

Mizote has separated dynamic responses from static responses in the afferent discharges to sinusoidal vibratory stimulus threshold [1],[2]. It was shown that intrafusal muscle fibers were slack or were kinked because muscle was

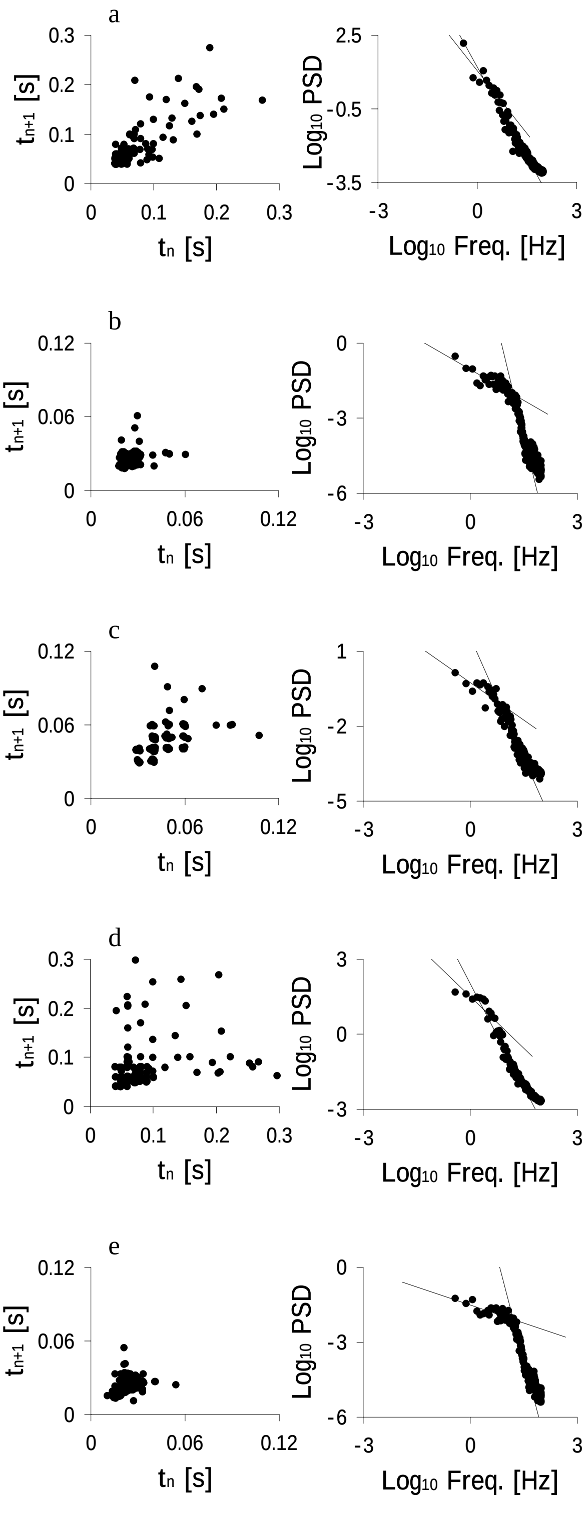

Fig.3; Changes in JIH (left) and PSD (right) of the Ia discharges by VR stimulations or/and with effect of muscle contraction. a; Before VR stimulation, b; During VR stimulation, c; After VR stimulation, rhythmic interval in JIH is observed. d; Before VR stimulation and gallamine injection, e; During VR stimulation after gallamine injection. Peak is observed at 62Hz in PSD.

dissected free of surrounding tissues and was also shortened by an electric shock stimulation to the motor nerve [6],[7].

Steady stretch to the muscle extends intrafusal muscle fibers and vibratory sensitivity to the intrafusal muscle fibers goes up.

In this study, muscle is stretched by 3mm, 5mm or 10 mm from the initial muscle length and unitary afferent discharges also keep firing spontaneously for a while. After contraction of intrafusal muscle fibers by the stimulation, static sensitivity of muscle spindle to the steady stretching is highest. The sensitivity itself does not change even after gallamine injection. It means that the sensitivity of muscle spindle to the static stretch is highest while ventral root is stimulated.

In the power spectrum, the second gradient between 10 to 35 Hz is various corresponding to how large the muscle is stretched and to how much intrafusal fibers are activated.

In the joint interval histogram, spontaneous discharges between vibratory stimuli are distributed at the particular interval time although the vibration already stops. It is implied that intrafusal muscle fibers themselves are oscillated for a while after the vibratory stimulation stops.

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