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Age-related changes of the stretch reflex excitability in human ankle muscles

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ABSTRACT

The purpose of this study was to characterize the effects of aging on the stretch reflex in the ankle muscles, and in particular to compare the effects on the ankle dorsi-flexor (tibialis anterior: TA) and the plantar-flexor (soleus: SOL). Stretch reflex responses were elicited in the TA and SOL at rest and during weak voluntary contractions in 20 elderly and 23 young volunteers. The results indicated that, in the TA muscle, the elderly group had a remarkably larger long-latency reflex (LLR), whereas no aging effect was found in the short latency reflex (SLR). These results were very different from those in the SOL muscle, which showed significant aging effects in the SLR and medium latency reflex (MLR), but not in the LLR. Given the fact that the LLR of the TA stretch reflex includes the cortical pathway, it is probable that the effects of aging on the TA stretch reflex involve alterations not only at the spinal level but also at the cortical level. The present results indicate that the stretch reflexes of each of the ankle antagonistic muscles are affected differently by aging, which might have relevance to the neural properties of each muscle.

1. Introduction

It is well recognized that aging affects the performance of motor tasks, such as the maintenance of posture and balance control (Bohannon et al., 1984; Horak et al., 1989). It is presumed that both the central and peripheral nervous systems contribute to these phenomena, but the precise mechanisms are still unknown (Stelmach et al., 1989). Stretch reflex, a simple neural circuit that responds to the sudden stretch of a muscle, might be also affected by aging.

Some investigations have paid attention to the effect of aging on the spinal reflex modulation of the soleus (SOL) muscle, which is a key muscle for postural control and bipedal walking (Koceja et al., 1995; Angulo-Kinzler et al., 1998; Chalmers and Knutzen, 2002; Kawashima et al., 2004). We previously demonstrated that elderly subjects show augmented short stretch reflex response in the SOL muscle at rest as compared to those in young subjects (Kawashima et al., 2004). It has also been demonstrated that elderly subjects lack the ability to modulate the SOL motoneuronal excitability for instance, Koceja et al. (1995) showed abnormal modulation of the motoneuronal excitability by postural changes.

On the other hand, recent studies have suggested that the stretch reflex of the tibialis anterior (TA), the antagonistic muscle of the SOL muscle, also has an important role in stabilizing the ankle joint during upright standing (Nakazawa et al., 2003), and the early stance phase of walking (Christensen et al., 2001; Nakazawa et al., 2004). However, to the best of our knowledge, only one study has examined the changes of the TA muscle due to aging. Although Nardone et al. (1995) reported that the amplitude of the reflex action obtained in the TA muscle during upright standing did not depend on age; it remains unknown how the stretch reflex function of the TA muscle changes with age, and whether or not the aging process of this muscle is identical to those in other muscles.

It is well known that each of the SOL and TA muscle have different neuronal characteristics, such as different degrees of connection to the motor cortex (Bawa et al., 2002), and different modulation effects on the spinal reflex excitability (Katz et al., 1988). Interestingly, in contrast to the SOL muscle, the TA stretch reflex shows a larger long-latency reflex (LLR) component, which presumably involves the transcortical pathway (Petersen et al., 1998). Given these facts, it is very likely that the aging process of the stretch reflex in the TA muscle is different from that in the SOL muscle.

The purpose of this study was therefore to characterize the effect of aging on the stretch reflex in the ankle muscles, and in particular how they differ between the ankle dorsi-flexor TA and the plantar-flexor SOL.

2. Methods

2.1. Subjects

Twenty healthy elderly volunteers (mean age 68.0 ± 5.9 years, male = 11, female = 9) and twenty-three young healthy volunteers

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(22.4 ± 1.8 years, male = 11, female = 12) with no history of neurological or muscle disorders participated in the present study. The subjects gave their informed consent to participate in this study, which was conducted in accordance with the Declaration of Helsinki and was approved by the Ethics Committee of the National Rehabilitation Center for Persons with Disabilities, Tokorozawa, Japan.

2.2. Procedures

Each subject remained seated comfortably in a chair with the right leg fixed to a footplate connected to a servo-controlled torque motor with a rotary encoder (Senoh Inc., Tokyo, Japan). The axis of rotation of the footplate was aligned with the axis of rotation of the ankle joint. The hip and knee angles were fixed at 40° and 50° flexion positions, respectively (anatomical position was 0°). The electromyographic (EMG) activities in the SOL and TA muscles were recorded using bipolar surface electrodes (Ag/AgCl, diameter 7 mm) placed on the muscle belly at an inter-electrode distance (center to center) of 15 mm. The EMG signals were amplified and band-pass-filtered by a bipolar differential amplifier (AB-621B Nihon Kohden, Tokyo, Japan) with low and high cut-off frequencies between 15 and 1000 Hz, respectively. The EMG, torque and angle signals were digitalized at a sampling rate of 1 kHz (WE7251; Yokogawa Electric Co., Tokyo, Japan) and stored in a computer.

Prior to the stretch reflex tests, the subjects were asked to exert the maximal isometric voluntary contraction for the SOL and the TA muscle in turn in order to determine the maximal EMG level. In this manuscript, the term "MVC" indicates the EMG level during maximal isometric voluntary contraction. The subjects were asked to maintain two contraction levels, i.e., rest (condition REST) and weak voluntary contraction (approximately 10% MVC: condition ACT) in the TA for the TA stretch test and in the SOL for the SOL stretch test. To control the contraction level, the smoothed full-wave rectified EMG and the reference line corresponding to 0% and 10% MVC were displayed on an oscilloscope, and the subjects were asked to keep a rectified EMG at a target level. A quick stretching of the TA or the SOL was given by imposing a quick rotation of the ankle joint at a range from 10° plantar-flexion to 5° dorsi-flexion. The direction of the rotation was plantar-flexion for the TA stretch test and dorsi-flexion for the SOL stretch test. Three different angular velocities, approximately 150 (slow: SL), 250 (moderate: MD), and 350°/sec (fast: FS) were applied five times in random order and at random stimulus intervals (10–15 s). The orders of stretching and contraction levels were randomized.

2.3. Data analysis

The digitized EMG signals were full-wave rectified after subtraction of the DC bias. The mean background EMG activity (BGA) level was then subtracted from the evoked EMG responses. The BGA was calculated during the 100 ms prior to the onset of stretches. In the present study, the incidence of reflex elicitation was calculated to show how often the stretch reflex response appeared in each group and for each contraction level and angular velocity. The number of observed responses was expressed as the ratio to the total number of stretches. The criterion of reflex appearance used for the probability was whether an EMG response reached a level higher than the BGA plus three times its standard deviation (BGA + 3SD). Stretch reflex responses were divided into their short- (SLR), middle- (MLR), and LLR components. The onset and the endpoint of the stretch reflex response were defined in the same manner as the probability of reflex elicitation. In accordance with previous studies (Schieppati and Nardone, 1997; Christensen et al., 2001), the onset of MLR was defined as 20 ms after the onset of SLR and that of LLR was defined in as 20 ms after the onset of MLR. Thus, the duration of SLR and MLR was defined as 20 ms, respectively. The duration of LLR was determined from the above mentioned onset to the endpoint of the stretch reflex response. In the present study, the mean amplitude of the rectified EMG with the BGA value subtracted was used to evaluate the size of each stretch reflex component.

The statistical differences of incidences were tested by the χ^2-test at each muscle contraction level and angular velocity. Statistical differences in each reflex component were tested by two-way analysis of variance (ANOVA, 2×2, muscle contraction level $\times$ group). Scheffé's post-hoc comparisons were used to determine the statistical differences between the REST and ACT conditions and between elderly and young groups. The significance level was set at $P < 0.05$.

3. Results

3.1. Background EMG activity

We confirmed that the level of BGA of the SOL and TA muscles were similar between the elderly and young groups. In the SOL stretch test, the SOL BGA at REST were 0.4 ± 0.07 and 0.4 ± 0.08% MVC for young and elderly, respectively and increased to 9.6 ± 0.59 and 9.9 ± 0.74% MVC at ACT. In the TA stretch test, the TA BGA at REST were 0.4 ± 0.19 and 0.5 ± 0.14% MVC for young and elderly, respectively and increased to 8.6 ± 0.33 and 9.6 ± 0.60% MVC at ACT.

3.2. Probability of reflex elicitation

In the present study, the stretch reflex responses of the TA appeared more frequently in the elderly subjects than in the young subjects. The probability of reflex elicitation in each condition, stretch speed, and muscle is summarized in Table 1. As shown in this table, a stretch reflex response could not be obtained in all subjects. Moreover, the number of responses increased with angular velocity and contraction level. The probability of the TA stretch reflex response in REST was statistically higher in the elderly subjects than in the young subjects at each angular velocity (χ^2-test, $P < 0.05$). On the other hand, the probability of the SOL stretch reflex response in REST tended to be lower in the elderly subjects (χ^2-test, $P < 0.05$). Therefore, we calculated the latency and amplitude of the reflex responses only at the fastest velocity and for subjects who responded to both the REST and ACT conditions in each stretch test.

3.3. Stretch reflex EMG responses

Fig. 1 shows typical waveforms of stretch reflex responses in the TA and the SOL under both postural conditions, REST and ACT, obtained from one subject in each group. As clearly shown in this figure, there was a remarkable difference in the reflex amplitude between the TA and SOL stretch reflex responses. The elderly subjects showed a relatively larger (Fig. 2) and longer response (Table 2) in both REST and ACT in the TA.

3.4. Latency and duration of the stretch reflex EMG responses

The onset of the TA stretch reflex response was earlier in the ACT than in the REST ($F_{(1, 32)} = 15.8$, $P < 0.01$), while no difference was found in latency between the two subject groups (Table 2). In contrast, there was no effect of the contraction level in the SOL stretch reflex response, whereas the effect of group was significant ($F_{(1, 32)} = 23.1$, $P < 0.01$) in this muscle.

An interaction between groups and contraction levels was found in the durations of the TA stretch reflex ($F_{(1, 32)} = 16.0$,