*Original Research*

# Asymmetry of Force Fluctuation During Low Intensity Isometric Contraction in Leg Muscle

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ABSTRACT

*Int J Exerc Sci 3(2) : 68-77, 2010.* The purpose of this study was to investigate the asymmetry of force fluctuation in the leg muscles during isometric knee extension and flexion. Twenty healthy males (21±2 years) performed the maximal voluntary isometric contraction (MVC) in knee extensor and flexor. On the basis of MVC measurement, the subjects performed sustained isometric knee extension and flexion for 15s at levels corresponding to 10%, 20% and 30% MVC. The main findings of this study were: (1) a greater force fluctuation was found in the stronger MVC limb than in the weaker MVC limb at 30% MVC; (2) no difference was found in the force fluctuation between the stronger and weaker MVC limbs at 10% and 20% MVC; and (3) significant positive correlations were found between the target force values and the force fluctuation at each contraction intensity. These results suggest that: (1) asymmetry of force fluctuation increases with load, (2) asymmetry of the force fluctuation is observed at more than 30% MVC intensity; and (3) if the contraction intensity is same relatively loads (% MVC), force fluctuation is increase with absolute load (target force value). Force fluctuation influence the functional ability of an individual in controlling finger or limb movements in daily life. Further, asymmetry of force fluctuation might influence for more than 30% MVC of daily activities.

KEY WORDS: Force fluctuation, asymmetry, isometric contraction, knee extension, knee flexion

## INTRODUCTION

Human movement is brought about by joint torque resulting from muscle force generated by the contraction of multiple muscles. The force generated during voluntary muscle contraction is not constant, but fluctuates. Fluctuations in muscle force during voluntary contractions can produce variability in movement; this fluctuation is referred to as “force fluctuation”. Force fluctuations are often influenced by multiple factors, including force level (10, 26), fatigue (8, 12), and inactivity (26) in young normal individuals. Hence, force fluctuations influence the functional ability of an individual in controlling finger or limb movements in daily life (9, 16, 23). For example, Oshita and Yano have reported the force fluctuation in plantar flexion is significantly correlated to posture stability during single-leg stance in young male (16). Salonikidis et al. have also reported highly skilled individuals present a greater ability to perform steady isometric contraction than less skilled participants (23).

In previous studies on the asymmetry of limb, several researchers have reported physiological differences between the preferred and the non-preferred upper limb. There are several apparent adaptations that result from the repeated use of the preferred hand: (1) a greater number of pyramidal tract fibers innervate the muscles of this hand (30); (2) the preferred hand is usually stronger and more versatile than the non-preferred one (7, 21); and (3) it shows smaller discharge rate variability during isometric contraction (1). Further, Adams et al. reported the significantly greater force fluctuation for the non-preferred compared with the preferred hand during isometric abduction task in index finger at 30% maximal voluntary contraction (MVC) (1). However, Semmler and Nordstrom reported the asymmetry of force fluctuation was not observed during isometric index finger abduction at less than 10% MVC (25). These studies are indicated contraction intensity might influence for the asymmetry of force fluctuation.

In contrast to upper limb, the role of preferred limb is not cleared in lower limb (2). For example, if the person would kick a ball with is preferred limb (2, 3, 19), another limb is often required supporting self body weight. Therefore, it does not understand which limb is stronger. Because, one limb is in daily preferential use, the other limb is daily supporting self-body weight over many years. Although the physiological difference between preferred and non-preferred leg is not often observed (2, 4, 5, 11, 13, 17, 22), the strength or power difference between legs (i.e. ratio of the stronger to the weaker knee extension force) is associated with ageing (18, 20, 27), risks of fall (20, 27) or walking ability (18). However, Sawai et al. reported the intensity of most daily activities (i.e. walking, step, bipedal or one-leg standing, and so on) in lower-limb muscles are not maximal but it is approximately less than 30% MVC (24). If force fluctuations influence the functional ability of an individual in controlling finger or limb movements in daily life, asymmetry of force fluctuation during isometric contraction at less than 30% MVC will be one of the important causative factors for the motion of daily activities. Oshita and Yano reported the asymmetry of force fluctuation was not observed during isometric knee extension at less than 20% MVC (17). However, to our knowledge, the asymmetry of force fluctuation during isometric contraction in the leg muscles at 30% MVC remains unclear. To reveal this fundamental study might provide one of the useful information for improving the daily activities, in the future. Thus, the purpose of this study was to investigate the asymmetry of force fluctuation in the leg muscles during isometric knee extension and flexion at 10–30% MVC.

## METHODS

*Participants*

Data were obtained from twenty healthy males (21±2 years). All subjects reported an absence of current or medical history of neuromuscular disorder. The subjects were informed of the purpose of the present study beforehand and a statement of informed consent was obtained. Further, this study was approved by the Human Ethics Committee of the Graduate School of Human Development and Environment, at Kobe University.

*Setup*
The subjects performed the exercise in a seated position; they were asked to perform a static unilateral knee extension and flexion exercise with each leg, with the hip and knee joint forming an angle of 90° in the flexed position (angle at full extension = 0°). Throughout the experiment, the subject's upper body was firmly held in a chair by a seat belt. The forces of isometric contraction of the knee extensor and flexor muscles were measured by a strain gauge force transducer (LTZ-100KA, Kyowa, Japan) attached to the subject's ankle by a strap, just above the malleolus. The generated force and the target force were displayed as horizontal lines on the monitor of a personal computer (PC) placed in front of the subject to provide visual feedback. All force signals were stored with a sampling frequency of 1 kHz on the hard disk of the PC by using a sensor interface with 24-bit analog-to-digital converter (PCD-300A, Kyowa, Tokyo, Japan).

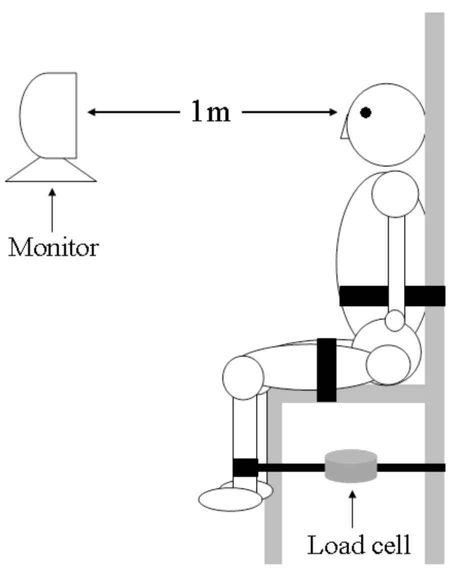


Figure 1. Schematic drawing of the setup used for the steady isometric contraction task.

*Experimental Protocol*
MVC task was performed in knee extension and flexion force exerted by the quadriceps and hamstrings for a period of 5s with encouragement from the investigators. Each subject performed at three trials, with subsequent trials performed if the differences in the peak force of two MVCs were >5%. Subjects were allowed to reject any effort that they did not regard as "maximal." The trial with the highest peak force was chosen for analysis.

On the basis of MVC measurement, the subjects performed sustained isometric knee extension and flexion for 15s at levels corresponding to 10%, 20%, and 30% MVC with visual feedback (steady contraction task). The range chosen of 10-30% is chosen as this is the intensity of most daily activities, such as walking, step, bipedal or one-leg standing, and so on (24). Data were collected for 1 trial at each target, and the order of the target force was randomized across subjects and intensities. There was a rest period of >1 min between trials and subjects were also allowed to rest between trials (up to five minutes) if they wished.

*Datal Analyses*
In the steady-contraction task, the middle approximately 8s (8192 sample) of the contraction was used for further analysis because there was no systematic change in fluctuations within trials. These data were processed by using a waveform analysis software SPCANA (ver 4.71, Japan). After band pass filter (<100 Hz), force fluctuation was expressed as the standard deviation of the force.

In all the data obtained, comparison of the 3 intensities (10%, 20%, and 30% MVC) for changes in the force fluctuation of each

Table 1. Means and standard errors of the force fluctuation during isometric contraction tasks.

| Force fluctuation (N) | | 10% MVC | 20% MVC | 30% MVC |
|---|---|---|---|---|
| Extension | Weaker | 0.420 ± 0.033 | 0.865 ± 0.133 [a] | 1.003 ± 0.092 [a] |
| | Stronger | 0.412 ± 0.030 | 0.790 ± 0.065 [a] | 1.261 ± 0.125 [a, b, *] |
| Flexion | Weaker | 0.404 ± 0.044 | 0.833 ± 0.159 [a] | 0.993 ± 0.145 [a] |
| | Stronger | 0.404 ± 0.047 | 0.756 ± 0.088 [a] | 1.136 ± 0.165 [a, b, *] |

Force fluctuation was expressed as the standard deviation of the force. Alphabets "a" and "b" indicate significant difference compare with 10% and 20% MVC task, respectively ($P < 0.05$). An asterisk "*" indicates significant difference compare with weaker limb ($P < 0.05$).

limb (stronger and weaker limb in MVC) and muscle (knee extensor and flexor) was performed using one-way analysis of variance (ANOVA) with repeated measures of the force fluctuation. When a significant main effect was found, Tukey's post hoc test was used to determine significant differences among the contraction intensity. Comparison among the changes in the force fluctuation for limbs at each contraction intensity was made using a paired *t*-test. Linear regression analysis between the target force value and the force fluctuation was performed. These analyses were performed by using the JSTAT (version 12.5, Japan) software. In these data, the significance was accepted to be at the $P <$ 0.05 levels. Data are presented as the mean ± standard error of the mean (SEM) unless otherwise stated.

**RESULTS**

The results of the maximal voluntary knee extension showed that the right limb was stronger in 13 subjects (619.1 ± 44.67N for stronger vs. 563.2 ± 44.66N for weaker), whereas the results of the maximal voluntary knee flexion exercise showed that it was stronger in 17 subjects (stronger; 419.8 ± 32.50N, weaker; 361.5 ± 32.80N).

Table 1 shows the means ± SEM of force fluctuation during isometric contractions at the target force. Force fluctuation during the steady contraction task increased with the force level for both limbs and both muscles ($P < 0.001$). The results of Tukey's post-hoc test showed that the force fluctuations during 20% and 30% MVC were not different significantly. However, force fluctuations for both these MVC were significantly greater than in the 10% MVC in both the muscles of the stronger limb. In the weaker limb, force fluctuation increased with force level in both the muscles. With respect to the asymmetry in force fluctuation, no significant differences were observed between the muscles of the stronger and the weaker limb during 10% and 20% MVC. However, in the case of both muscles, force fluctuation in the stronger limb was significantly greater than that in the weaker limb during 30% MVC.

Table 2 shows the correlation coefficients between target force values and force fluctuation for each limb. In each task, for both the limbs, force fluctuation showed a significant positive correlation with the target force values. Figure 2 shows the correlation coefficients between target force values and force fluctuation for both limbs.

Table 2. Correlation coefficients between target force values and force fluctuation in each limb.

| | | | RMS of force | | |
|---|---|---|---|---|---|
| | | | 10% MVC | 20% MVC | 30% MVC |
| Target force | Extension | Weaker | 0.605 ** | 0.559 * | 0.818 ** |
| | | Stronger | 0.511 * | 0.767 ** | 0.754 ** |
| | Flexion | Weaker | 0.578 ** | 0.448 * | 0.632 ** |
| | | Stronger | 0.527 * | 0.664 ** | 0.609 ** |

Values are expressed as correlation coefficients. Force fluctuation was expressed as the standard deviation of the force. A sterisks "*" and "**" indicate significantly correlated ($P$ < 0.05 and 0.01, respectively).

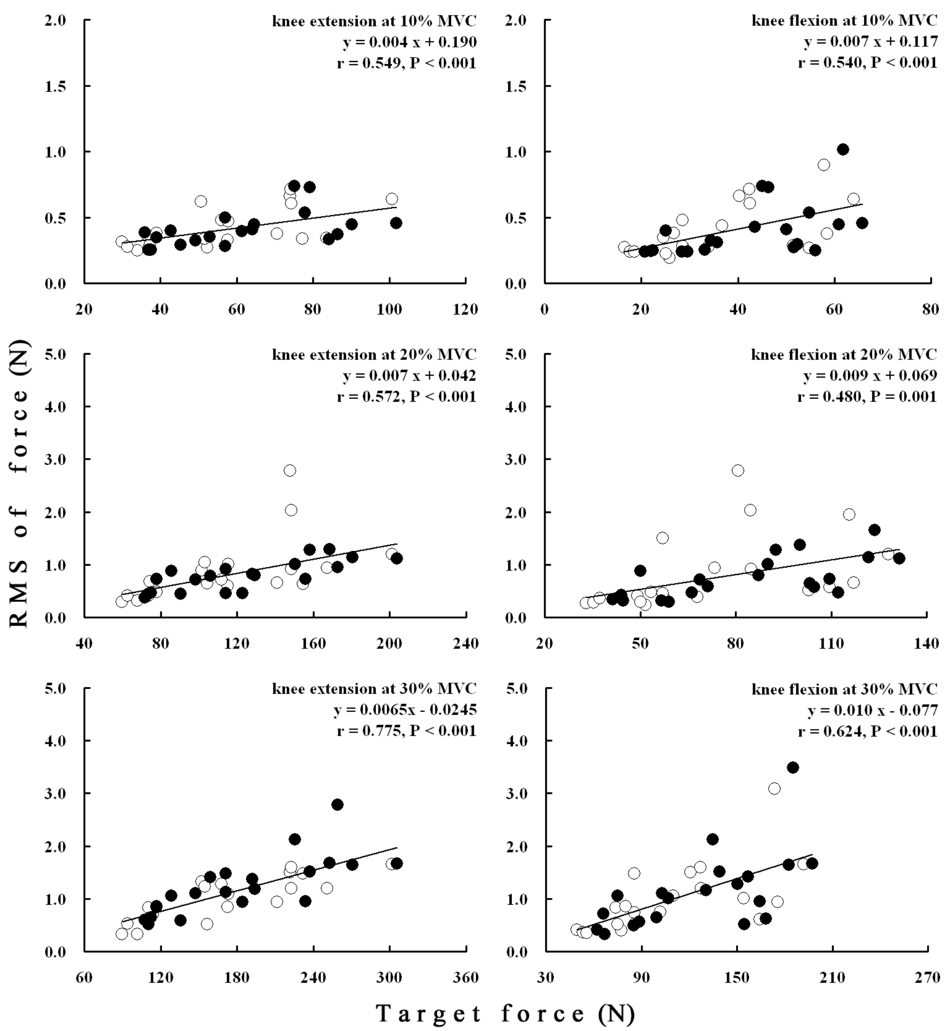


Figure 2. Correlation coefficients between target force values and force fluctuation in both limbs. Force fluctuation was expressed as the standard deviation of the force. Open and closed circles are expressed as "weaker" and "stronger" MVC limb, respectively.

In each task, force fluctuation showed a significant positive correlation with the target force values. Therefore, force fluctuation increase with relatively load (% MVC). However, if the contraction intensity is the same relative load, force fluctuation is increased with absolute load (target force value).

## DISCUSSION

The main findings of this study: (1) a greater force fluctuation was found in the stronger limb than in the weaker limb at 30% MVC; (2) no difference was found in force fluctuation between the stronger and the weaker limbs at 10% and 20% MVC; and (3) significant positive correlations were found between the target force values and the force fluctuation at each contraction intensity.

Several researchers have reported that the force fluctuation increases with increase in the contraction intensity (6, 10 26, 28); this is consistent with the results of this study. Discharge rate variability or contraction property in active muscle is thought to be a major determinant of the increase in force fluctuations with increase in the contraction intensity (14, 15, 19, 29). For example, previous studies have revealed that force fluctuation is positively correlated with the discharge rate variability during isometric contraction (15, 29). Further, Adam et al. have reported force fluctuation was differed between preferred and non-preferred hand, and discharge rate variability was also differed between these hands during isometric abduction in index finger at 30% MVC (1). Although, this study did not measured the discharge rate variability, our results were revealed force fluctuation during isometric knee extension and flexion at 30% MVC was significantly different between the stronger and the weaker limbs; a greater force fluctuation was found in the stronger limb than in the weaker limb. Therefore, asymmetry of force fluctuation at 30% MVC isometric contraction is observed not only in the upper-limb but also the lower-limb.

The asymmetry of force fluctuations in knee extensor and flexor muscles as observed in this study was partially consistent with the results of Adams et al. (1). Their study has indicated greater fluctuation in the non-preferred hand than in the preferred hand, whereas this study indicated greater fluctuation in the stronger limb than in the weaker limb. In the case of the upper limbs, the difference in strength between the preferred and non-preferred hands is usually not significant, but the former is slightly stronger than the latter (1, 25). Further, it is known that discharge rate variability during isometric contraction is greater in the non-preferred hand than in the preferred hand (1). The preferential use of either hand for daily activities is thought to be one of the important factors for these differences in the upper limbs. However, in the case of the lower limbs, the role of the preferred limb remains unclear (2). For example, if a person kicks a ball with his preferred limb (2, 3, 19), the other limb is often required to support his own body weight. Thus, one limb is preferentially used for daily activities, while the other limb plays the role of supporting one's body weight, and this is a practice that develops over many years. Therefore, the person does not understand which limb is stronger—the one that is used preferentially everyday or the one that supports his/her body weight. In this study, significant positive correlations were found between target force values and force fluctuation for each task. Therefore, our results suggest that the force fluctuation increases with absolute load (target force value) by increase discharge rate variability, in the case of the same relative loads (% MVC).

Semmler and Nordstrom have reported that no differences were found in the discharge rate variability or force fluctuation amplitude between the preferred and non-preferred hand during isometric index finger abduction (25). Further, Oshita and Yano also reported that no difference was found in the force fluctuation between the stronger MVC limb and weaker MVC limb during isometric knee extension (17). In the present study, although the force fluctuation was different for the limbs at 30% MVC, no difference was found in the force fluctuation at 10% and 20% MVC. The difference of force fluctuation between 30% MVC task (our study and Adams et al. [1]) and less than 20% MVC (present study, Semmler and Nordstrom [25] and Oshita and Yano [17]) is thought to be due to differences in the intensities of the tasks. Semmler and Nordstrom's study was performed using very low loads (less than 10% MVC) (25). Further, Oshita and Yano utilized low loads (10% and 20% MVC) (17). In the report by Adams et al., the index finger abduction task was performed at a moderate force level (30% MVC), and a significantly greater fluctuation was found for the non-preferred than that for the preferred hand (1). This suggests a potential load-dependent effect of dominance. The reasons for differences in the force fluctuations between 30% MVC and 10% or 20% MVC isometric contraction have not been clarified in present study. In the absence of relevant differences in fluctuation between intensities, the explanation for differences in the force fluctuation between intensities may be differences in the relationship between the force fluctuation and discharge rate variability. It has been reported that although the relationship between force fluctuation and discharge rate variability is significant during low-intensity (approximately 7% MVC) contractions, it is not significant at very-low-intensity (approximately 1% MVC) contractions (25). This report suggests that the asymmetry of force fluctuation at intensities of less than 20% MVC is not due to differences between the contraction intensities and discharge rate properties. On the other hand, discharge rate variability or force fluctuation during isometric contraction increases with increase in the contraction intensity (29). In the case of low-intensity contractions, because the value of discharge rate variability or force fluctuation is too small, the changes in their values may not have been significant. However, because discharge rate variability was not measured in this study, the reasons for the observed differences in force fluctuation could not be clarified. Thus, further studies involving the measurement of discharge rate variability are required to clarify this.

Although physiological differences are not often observed between the preferred and non-preferred leg (2, 4-5, 11, 13, 17, 22), the difference in the strength or power between the legs (i.e. ratio of the stronger to the weaker leg) has been found to be associated with ageing (18, 20, 27), risk of falls (20, 27), or walking ability (18). For example, Skelton et al. have shown that there is a greater asymmetry associated with leg extension power in fallers than in age-matched non-fallers (28). Oshita et al. have shown that asymmetries of both the knee extension and flexion strength are important causative factors for functional decline that affects the walking speed in normal populations with low leg strength (18). However, Sawai et al. reported the intensity of most daily activities (i. e. walking, step, bipedal or one-leg standing, and so on.) in lower-limb muscles are less than approximately 30% MVC (24). Although the intensity of most daily activities are less than 30% MVC for the person with normal or high muscle strength, it will be high intensity for the person with low muscle strength. Force fluctuation can influence the functional ability of an individual in controlling finger or limb movements in daily life. Further, this study indicated asymmetry of force fluctuation is observed at 30% MVC but it is not observed at less than 20% MVC. Therefore, although asymmetry of force fluctuation might not affect the most daily activities for the person with high muscle strength, it might affect the most daily activities for the person with low muscle strength. However, almost subjects on the previous studies about the relationships between asymmetry of leg strength and risk of falls (20, 27) or walking ability (18) are middle or older adults. Force fluctuation is influenced by age; for example, Tracy and Enoka have shown that the force fluctuation during isometric contractions increases with contraction intensity, and that this value is larger in the elderly than in young subjects (28). Therefore, asymmetry of force fluctuation in lower limb might be difference between older adults and present results. However, Salonikidis et al. have also reported in young adults; highly skilled individuals present a greater ability to perform steady isometric contraction than less skilled participants (23). Thus, future examination is required to examine whether asymmetry of force fluctuation in young adults is related to daily activities, such as walking ability, posture stability and so on.

In conclusion, this study was revealed: (1) a greater force fluctuation was found in the stronger limb in MVC than in the weaker limb in MVC at 30% MVC; (2) no difference was found in force fluctuation between the stronger and weaker limbs at 10% and 20% MVC; and (3) significant positive correlations were found between the target force values and the force fluctuation at each contraction intensity. These results suggest that (1) asymmetry of force fluctuation increases with load, (2) asymmetry of the force fluctuation is observed at more than 30% MVC intensity; and (3) if the contraction intensity is same relatively loads (i.e. % MVC), force fluctuation is increase with absolute load (i. e. target force value). Force fluctuation influence the functional ability of an individual in controlling finger and limb movements in daily life. Further, asymmetry of force fluctuation might influence for more than 30% MVC of daily activities.

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