Oxygen Requirement for One- and Two-legged Light Knee Extension Exercises

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Abstract

The purpose of this investigation was to examine if the differential response appears in the oxygen requirement between one- and two-legged light, simple exercises, and if the work load causes the proportional volume of oxygen requirement in those exercises. Six young adults performed one- and two- legged knee-extension exercises in static and dynamic ways, respectively. Oxygen uptake was measured, and the oxygen requirement for the exercise without the resting oxygen uptake was calculated. The sum of the oxygen requirement of the left- and right-legged exercise was significantly more than the two-legged one. A wider variation of oxygen uptake among the subjects was observed in the one-legged exercise than in the two-legged exercise. The findings required us to consider if additional synergistic muscle activities were engaged more than expected during the one-legged extension exercise than in the two-legged exercise.

Key words : oxygen requirement, one- and two legged, knee-extension, static exercise

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INTRODUCTION

The differential cardiorespiratory response to one- and two-legged exercises has been discussed from various research institutions. Ogita et al. (2000) found that the sum of the oxygen uptake ($V_{dot}O_2$) during their left and right one-legged exercise was larger than that in their two-legged exercises and concluded that the differential $V_{dot}O_2$ response between one-legged and two-legged exercise would be attributed not only to the difference in force application through the exercise movement and to the effect of a postural component, but also to the inhibited circulatory response caused by the multiple limb exercise. They also supposed that $V_{dot}O2_{peak}$ and the exercising muscle mass are not in proportion. However, in our experience (Arimoto, et al., 2005) where oxygen requirements for the exercise was compared in one-and two-legged leg press exercises, there was no significant difference between the two as examining oxygen requirement rather than oxygen intake only during exercise was considered to be important when comparing the metabolic demand of muscle activities in one-and two-legged exercise. We supposed that simpler exercises would be better than multiple joints exercises such as the leg-press to clarify the deferential response. The purpose of this investigation was to clarify if the differential response appears in the oxygen requirement between one- and two-legged light, simple exercises, and if the work load causes the proportional volume of oxygen requirement in those exercise to change. For a practical purpose, to clarify the cardiorespiratory responses with knee extension exercise, which is routinely performed for muscular fitness, is worth designing training for the extensors (Muramatsu et. al., 2009), especially for senior citizens.

METHOD

Participants and preparation

Six Japanese college students (18-20 yrs.) participated in this study. All of the subjects were informed of the procedures and signed an informed consent. The six subjects had had a periodical health check by a school physician and all of the subjects had no signs of health problems. Three of them, KG, TK, and MT, have not been involved in sports club activities, but the rest do vigorous sporting activities once or twice a week. This experiment was given approval by the human right committee at Yokohama College of Commerce.

Before the study started, the subjects came to the laboratory two or three times to be introduced to the experimental exercise, and be given basic physical examinations including measurement of calf length (CL), maximal voluntary muscle contraction (MVC), and maximal oxygen uptake ($V_{dot}O_2max$).

Table 1. Characteristics of the subjects

Subj.	Age (yr)	Ht (m)	Wt (kg)	CL (cm)	VO2max (ml/kg/min)	MVC (kg)
KG	20	1.69	54	35.0	35.4	37
TK	20	1.74	56	37.4	39.8	32
MT	20	1.63	55	33.2	36.8	27
KN	19	1.73	60	38.5	46.2	37
KY	18	1.82	72	40.5	54.7	41
SJ	19	1.74	64	35.8	52.9	54
Mean	19.3	1.73	60.2	36.7	44.3	38
SD	0.82	0.064	6.88	2.61	8.22	9.21

Note : calf length, MVC : maximal voluntary muscle contraction.

Their CLs were measured in accordance with Martin et. al. (1991), MVCs were measured by a dynamometer (Tension Meter-D®, TAKEI, Tokyo, Japan). $V_{dot}O_2max$ and other respiratory parameters were measured on a computer-controlled cycle ergometer (Combi 232-C®, Combi, Tokyo, Japan) with a gas monitor system (aero-monitor AE300s AE®, Minato Medical Science, Osaka, Japan). The protocol of the maximal graded exercise test was conducted based on the method by Cariozzo et al. (1983). Their physical characteristics are shown in Table 1.

Exercise protocol and procedure

Every subject performed both one-legged and two-legged knee extension exercises separately in an intermittent static way and in a dynamic way each for four different days, wearing a weight belt around the ankle(s). A weight belt ranging in weight from 4 kg to 7 kg was assigned to the subject so that all subjects would be able to complete the exercise. Although MVCs of the right and left leg are different, the subjects were given only one weight, which would often be used in a daily training setting. The weights assigned were 11 to 18 % of one's higher MVC. In the data analysis, as the representation of each load the subjects were assigned, moment of force (N•m : force of the weight belt [N] × calf length [m]) was used. For the static exercise, the subjects sat in the chair keeping their back on the wall and put their one leg or both legs on the stand so that the maximum distance moved during extension was 10 cm. When they performed the one-legged exercise, the unloaded leg was expected to be down and relaxed. The subject lifted the weight belt up to the maximum distance and sustained it for 5 seconds, brought it back down and took 5-second rest. This procedure was continued for 4 minutes. For the dynamic trial, the subject sat in the same posture as for the static exercise except using no foot stand and lifted the weight belt once every 5 seconds for 4 minutes in accordance a metronome. The one-legged session was conducted in a series taking a 10 minute recovery break. The order of the leg to be exercised was determined randomly. The subject remained sitting at least 20 minutes before being put on the mask and electrodes used to measure cardiorespiratory parameters. The resting data was recorded and then the weight belt was attached, which was taken off immediately after the exercise.

Data analysis

The oxygen requirement was defined as the amount of $V_{dot}O2$ that increased over a resting $V_{dot}O2$ including the recovery phase, which referred to net oxygen requirement (ORT) for each exercise. Each ORT was divided by 4 to express a per-minute value. The Student's t-test was used to determine the significance of the difference of means and the regression coefficients for statistical analysis.

RESULTS and DISCUSSION

First shown are the results from the static exercise session. The means and standard deviations (M±SD) of the altering $V_{dot}O2$ from the resting condition to the end of the session including 4-minute exercise episodes and the following recovery episodes are shown in Figure 1. The M±SD of the peak of %$V_{dot}O2$max and the peak of %HRmax during the exercises were 15.3±4.68% and 46.6±5.22% respectively in the one-legged exercise, and 16.3±3.48% and 45.7% respectively in the two-legged exercise. These close mean values in the two types of exercise directly came from the high value at the last minute in the second session of the one-legged exercise. In fact, MT, one of the subjects who looked very tired, consumed more oxygen in the second session than in the two-legged session, which may have caused additional muscle activity of other muscles rather than only the knee extensor.

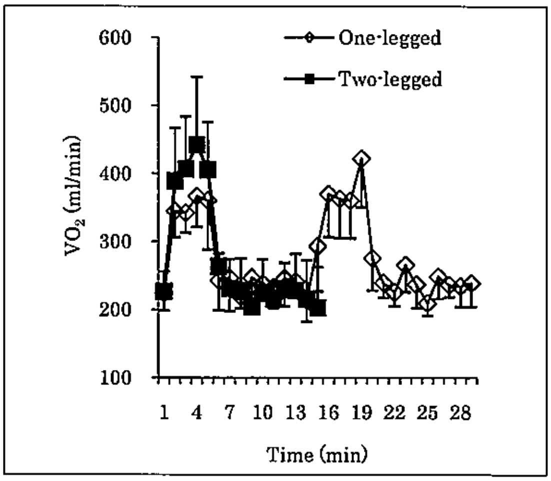

Figure 1—Oxygen uptake (M±SD) during and after knee extension exercise in the intermittent static pattern.

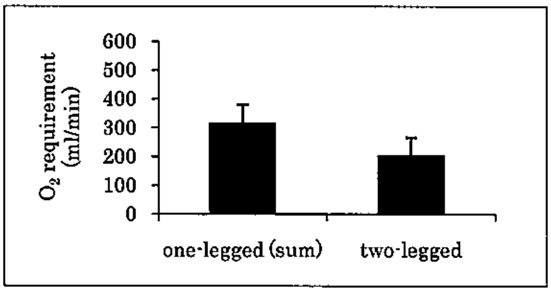

Figure 2—Oxygen requirement (M±SD) of the one-and two-legged knee extension exercise in the intermittent static pattern. ($t_{(5)} = 22.81, P < 0.05$)

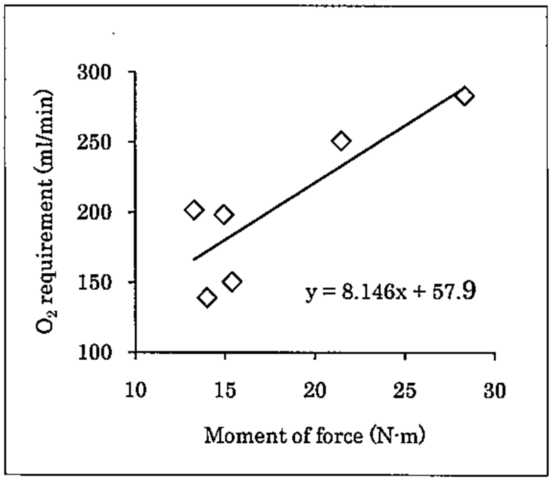

Figure 3—Correlated distribution of moment of force and oxygen requirement ($t_{(4)} = 3.338, P < 0.05$)

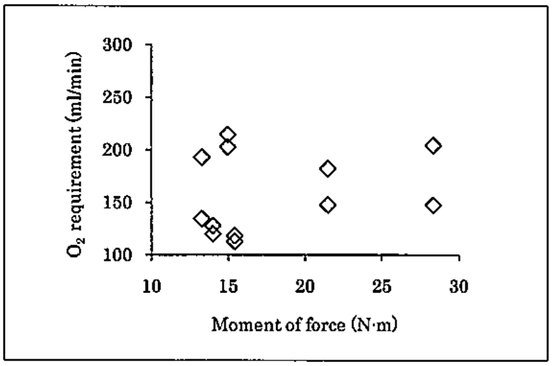

Figure 4—Correlated distribution of Moment of force and oxygen requirement in the one-legged knee extension exercise in the intermittent static pattern.

The ORTs of two one-legged exercises were added to compare with the ORT of the two-legged exercise. As shown in Figure 2, the mean value of the summed ORT of the one-legged exercise was significantly higher than that of the two-legged exercise ($t_{(5)} = 22.81$, $P < 0.05$). The significance still remained even though MT's data had been removed ($t_{(4)} = 7.90$, $P < 0.01$) .

Other than the magnitude of the ORT, another factor we needed to make clear was if the amount of work load proportionally affects the amount of ORT so that we could estimate if these two types of knee extension has the same mechanical efficiency. In this respect, with the relationship between the moment of force and the ORT of the two-legged exercise (Fig. 2), it was clear that the ORTs tend to be in proportion with the moment of force as the regression coefficient was significant ($t_{(4)} = 3.338$, $P < 0.05$). Contrary, between the moment of force and the ORT of the one-legged exercise, there was no significant correlation (Figure 4). The results suggested that there may have been seemingly unnecessary motion other than the working extensor with individual differences among the subjects. Furthermore, this results suggest a possible hypothesis that the one-legged knee extension exercise tends to involve synergistically accompanying muscle activities in the other side of the body, the same are being involved in the two-legged knee extension exercise.

On the dynamic exercises, as previous studies have shown, the mean of the sum of two ORTs resulted from the left and right one-legged exercises were significantly higher than that of the two-legged exercise in this experiment. Fig. 5 shows the alteration of VO2, and Fig. 6 shows the M±SD of each ORT for the one-legged and the two-legged exercise ($t_{(5)} = 3.071$, $P < 0.05$). The regression coefficient between the moment of forces and the ORTs for the two-legged exercise was significant ($t_{(5)} = 3.277$, $P < 0.05$), but no significance was found in the one-legged case as the same as in the static case.

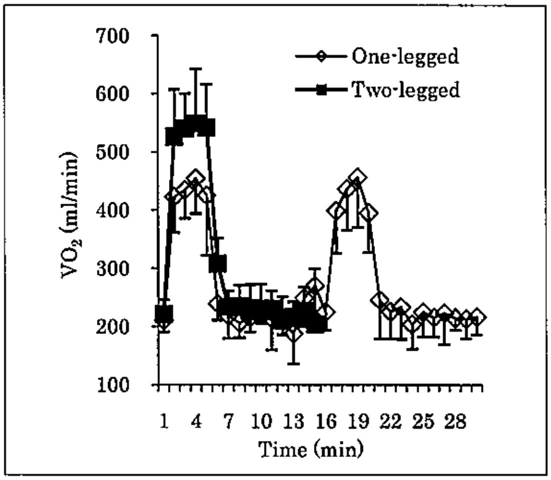

Figure 5—Oxygen uptake (M±SD) during and after knee-extension exercise in the dynamic pattern.

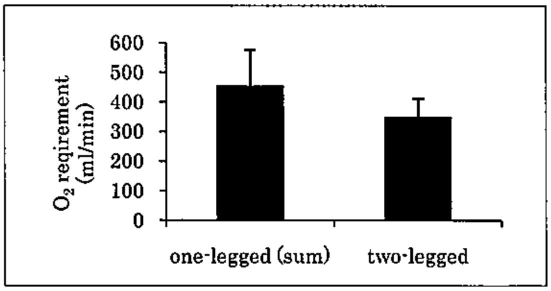

Figure 6—Oxygen requirement (M±SD) of the one- and two-legged knee extension exercise in the dynamic pattern. ($t_{(5)} = 3.071$, $P < 0.05$)

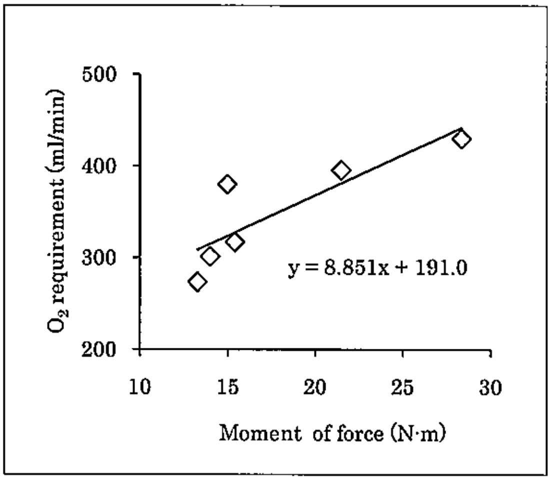

Figure 7—Relationship between oxygen requirement of the two-legged knee extension exercise in the dynamic pattern. ($t_{(5)} = 3.277$, $P < 0.05$)

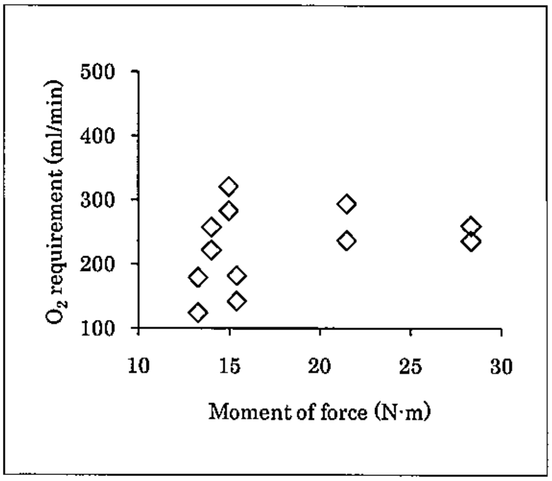

Figure 8—Correlated distribution of Moment of force and oxygen requirement in the one-legged knee extension exercise in the dynamic pattern.

Above all, any different tendency did not appear in the oxygen requirement between the dynamic exercise and the intermittent static exercise adopted here for a special purpose. We used the term 'intermittent static exercise' in our protocol. That was the correct term to use as long as a five-second static muscle effort was repeatedly performed with a five-second interval. However, the cardiorespiratory response to such an intermittent static exercise was reported that there was no significant difference compared with dynamic exercise (Sharkey, 1966).

The intermittent static exercise was used here with an expectation that it would reduce extra muscle activities other than the extensors' activity. However, even in the static exercise, wide variation was seen in the ORT for the one-legged exercise.

CONCLUSION

It was clear that light one-legged knee extension exercises tend to require more energy consumption than the same moment of force of two-legged exercises in an intermittent static mode and in a dynamic mode. It was thought that synergistically accompanying activities of other muscles rather than the extensor affected the oxygen requirement more in the one-legged knee extension exercise. However, further research will be needed and tried in various conditions for conducting exercise, such as work load, duration, or posture.

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