Acute effects of low-load resistance exercise with different rest periods on muscle swelling in healthy young men

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A brief running title: Acute effects of low-loaded resistance training and rest periods

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ABSTRACT

The effects of high-loaded resistance training on muscle strength and muscle mass depend on rest periods between sets. However, whether differences in rest periods during low-loaded resistance exercise (RE) have an influence on improving muscle characteristics remains unclear. Understanding the effects may guide to prescribe low-loaded resistance exercise safely and effectivity. The purpose of this study was to investigate acute effects of low-loaded RE on muscle swelling with different rest periods between sets. A total of 42 young men (age, 22.9±2.4 years; height, 172.1±5.4 cm; body mass, 65.6±6.5 kg) were recruited to participate in the study. They were assigned to one of three groups with different rest periods between sets (20 s, 60 s, or 180 s). A total of 12 sets of 10 repetitions of RE with 30% of one repetition maximum on knee extensor muscles were performed. Muscle thickness of the vastus lateralis was measured using ultrasonography as indicator of muscle swelling every 3 sets. Muscle thickness significantly increased after 3 sets of RE in the 20-s (3.9 ± 3.3%) and 60-s groups (5.9 ± 3.8%) but only after 12 sets in the 180-s group (4.3 ± 3.1%). REs with rest periods shorter than 60 s could result in exercise-induced muscle swelling after fewer sets of RE.

Key words: knee extensors; ultrasound; muscle swelling; rest interval

表題：低強度筋力トレーニングにおける休息時間の違いが運動直後の一過性の筋厚変化に及ぼす影響

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Abstract:

　本研究の目的は，低強度筋力トレーニングにおいてセット間の休息時間が即時的な筋厚変化に及ぼす影響を検証することである．対象は健常若年男性 42 名とし，セット間休息時間の異なる 3 群(20 秒群，60 秒群，180 秒群)に無作為に分類した。30%1RM の低強度での膝伸展筋力トレーニングを 10 回 1 セットとして 12 セット施行した．超音波診断装置を用いて外側広筋の筋厚を運動開始直前と 3 セット，6 セット，9 セット，12 セット終了時に計測した．なお，運動直後の筋厚の増加はトレーニングによる代謝物蓄積による浸透圧変化による一過性の水分貯留の結果である．その結果，20 秒群と 60 秒群は 3 セット終了以降で運動直前に対して有意な筋厚の増加を認めた．一方，180 秒群では 12 セット終了時のみ有意な筋厚の増加を認めた．12 セット終了時の筋厚変化率には 3 群間で有意差はみられなかった．本研究の結果から，低強度筋力トレーニングにおいてセット間休息時間が短いと早期から一過性の筋厚増大が生じることが示唆された．

INTRODUCTION

Resistance exercise (RE) promotes health benefits and is generally prescribed as an intervention to increase muscle mass in patients with neuromuscular diseases, musculoskeletal disease, disuse, and aging.[1] Conventionally, RE with high load, such as 60–80% one repetition maximum (1RM), for >6 weeks has been suggested to generate muscle hypertrophy.[2,3] It has been reported that high-loaded resistance training causes muscle hypertrophy in older adults [4]. However, high-loaded RE is also known to be associated with some risk factors causing orthopedic injury [5] as well as can increase the heart rate and blood pressure excessively [6]. Therefore, especially for frail, older adults or patients, low-loaded RE is often prescribed. Some studies have demonstrated that even low-loaded RE could result in muscle strengthening and change the muscle morphology [7–13].

The effects of RE are influenced by contraction mode, loading volume, repetition velocity, and rest period between sets.[2,14–18] A recent study reported that RE could have similar effects of muscle hypertrophy if the training volume (the accumulation of absolute work) was of the same condition, even when the contraction mode was different (i.e., concentric versus eccentric contractions), as long as total absolute mechanical work was equal.[19] Mitchell, et al.[8] or Ikezoe, et al.[7] reported that even at the low-loaded RE of 30% 1RM, high-repetition resistance training to volitional failure resulted in the same effect on muscle hypertrophy as did resistance training at a high-loaded RE of 80% 1RM. Tanimoto and Ishii[10] reported that when exercises are performed with slow sustained muscular contraction, low-loaded RE of 50% 1RM result in the same effect on muscle hypertrophy as high-intensity RE of 80% 1RM. Thus, even low-loaded RE has been considered to exert the same effects on muscle hypertrophy as high-loaded training by increasing the number of repetitions or performing with sustained muscular contraction.

In addition, rest periods between sets of resistance training, which associate with metabolic stress, have been considered to affect muscle hypertrophy.[16] With regard to the effects of rest periods between sets, Villanueva, et al.[20] reported that high-loaded resistance training for 8 weeks with 60-s rest periods elicited greater improvements in body composition, muscular performance, and functional performance compared to those with 4-min rest periods among older adults. On the other hand, de Salles, et al.[21] showed that high-loaded resistance training with 3- or 5-min rest periods caused greater improvements in muscle strength than training with 1-min rest periods, when resistance training is performed to failure. Since resistance training with longer rest periods might lead to increase in the number of repetitions, i.e., increase in training volume, greater improvements in muscle strength may be explained by the high training volume. In other words, Villanueva, et al.[20] and de Salles, et al.[21] demonstrated that differences were observed in the effects of high-loaded resistance training on muscle strength and muscle mass depending on rest periods between sets. However, whether differences in rest periods during low-loaded RE have an influence on improving muscle characteristics remains unclear.

Several studies using ultrasonography or MRI have reported that muscle thickness or cross-sectional area (CSA) increases immediately after one session of RE.[22–25] The acute effects on muscle thickness and CSA, which itself is not muscle hypertrophy, have been considered to be an important factor to induce muscle hypertrophy.[17,26] The increase in muscle thickness or CSA, that is, muscle swelling following RE, has been recognized to be due to alterations in intra- and extracellular water balance induced by increased vascular permeability.[27] With regard to vascular permeability, RE may cause cellular accumulation of lactate and hydrogen ions, which are induced by degradation of muscle glycogen.[28] The molecular weights of lactate and hydrogen ions are smaller than that of muscle glycogen. Therefore, the high lactate and hydrogen ion concentrations and concomitant increase in intracellular acidosis after exercise[29] may accelerate water uptake in muscle cells according to permeability.[30–32] Increased pressure against the cell membrane causes activation of anabolic protein kinase transduction pathways, which can subsequently promote muscle hypertrophy.[33–35] Fahs[36] has shown that RE without blood flow restriction to failure can generate acute effects on muscle swelling similar to that observed in RE with blood flow restriction. Moreover, same muscle hypertrophy effects between the two RE groups have been observed after a 6-week intervention. These studies suggest that muscle swelling such as an increase in muscle thickness immediately after RE could possibly be associated with muscle hypertrophy after intervention in the future.

The purpose of this study is to assess muscle swelling of the vastus lateralis by knee extension RE, and to see if it is affected by different rest periods after performing 12 sets of 10 repetitions at 30% 1-RM in healthy young men. We hypothesized that muscle swelling occurs after a smaller number of training sets in the group with shorter rest periods, and that exercise with shorter rest periods induces a greater degree of muscle swelling than exercise with longer rest periods.

MATERIAL and METHODS

Subjects

A total of 42 healthy young men who did not have an experience of regular RE participated in this study (age, 22.9±2.4 years; height, 172.1±5.4 cm; body mass, 65.6±6.5 kg; mean ± standard deviation). The participants with a history of neuromuscular disease or musculoskeletal injury involving their lower limbs were excluded. The participants were assigned at random into three experimental groups (n = 14 for each group) with different rest periods between sets: 20 s, 60 s, or 180 s.

A priori analysis of sample size for this study was conducted using G*Power software

(G*Power 3.1, Dusseldorf, Germany). We conducted a pilot study with seven participants to evaluate the effect size for the main variable, which indicated that the effect size was large. According to the large effect size, the power analysis using an effect size of 0.40, an α error of 0.05, and a power of 0.80 revealed that the required sample size was 14 subjects for each group. Because the acute effects of exercise are often attenuated when subsequent bouts of similar exercise are performed (called "repeated bout effect"),[37,38] the acute effect on muscle thickness may be acclimatized after the second or third session of RE. Therefore, we allocated the participants among three groups, and compared the acute effect after the first bout of RE in each group.

All participants were sufficiently informed about the purpose of this study, and signed written consent was obtained prior to the start of the study. The study was approved by Kyoto University Graduate School of Medicine Ethics Committee (E2246) and conducted in accordance with the Declaration of Helsinki.

Resistance Exercise

The participants were assigned to three groups with different rest periods between sets: 60 s as the basic rest period, 20 s as a group with a shorter rest period, or 180 s as a group with a longer rest period.

RE was performed using ankle cuff weights at the distal lower leg, which is usually used as low-loaded resistance exercise. The participants were seated without their feet touching the floor. The RE for knee extensors on the right leg consisting of 12 sets with 10 repetitions was performed with each rest period, based on our previous study [7]. Both concentric and eccentric contractions for 3 s through the entire range of motion of the knee (90°–0°; 0° = full knee extension) and isometric contraction at 0° for 1 s in between concentric and eccentric contraction were performed, based on a previous study[13]. The movement speed was regulated with the aid of a metronome at 60 rpm. The participants were instructed not to accelerate quickly.

RE load was set at 30% of 1RM, based on the value of 1RM measurement. The 1RM was measured by increasing the load every 10 Nm, using the isotonic mode of a dynamometer (Biodex System 4, Biodex Medical Systems, Shirley, NY, USA). The definition of 1RM was the maximum load that the participants could produce against the set load in order to move their leg through a range of motion one time (90°–0°; 0° = full knee extension). The 1RM measurement with 2-min rest between each trial was performed after a warm-up session of 10–20 submaximal contractions. The 1RM measurement was performed more than 3 days prior to the RE not to affect the ultrasound measurements.

Measurements of muscle swelling

Muscle thickness of the vastus lateralis obtained using transverse ultrasound images was used as an indicator of muscle swelling.[36] Muscle thickness was measured using B-mode ultrasound imaging device (LOGIQ e, GE Healthcare UK, Chalfont, UK) with an 8 MHz linear array prove (58 dB gain) before (pre-exercise) and after 3 sets, 6 sets, 9 sets, and 12 sets of RE. The participants were positioned in a sitting position with 90° hip and knee flexion and were instructed to be relaxed without muscle contraction during measurement. The transducer was placed at two-thirds on the line from the anterior spina iliaca superior (ASIS) to the lateral side of the patella without interlapping an electromyography (EMG) sensor (just distal from the sensor). All measurements were performed by the same investigator who has established his own intersession reliability.

Measurement of muscle activity during RE

The muscle activity of the vastus lateralis during RE was recorded via surface EMG (TeleMyo™ 2400T DTS, Noraxon Inc., Scottsdale, Arizona, USA) with 1500 Hz of sampling frequency. Surface EMG electrodes (Blue sensor M-00-S/50, AMBU, Ballerup, Denmark) with a 20 mm center-to-center interelectrode distance were placed at two-thirds on the line from the ASIS to the lateral side of the patella according to the recommendations of the Surface

Electromyography for the Non-Invasive Assessment of Muscles project.[39] The raw EMG signals were processed using a bandpass filter between 20 and 500 Hz. The EMG activity was rectified using a root mean square (RMS) algorithm and was expressed as a percentage of the maximum voluntary isometric contraction (MVIC) for knee extension at 90° knee flexion. The muscle activity was averaged every 3 sets during RE.

Intersession reliability of the measurements

To determine intersession reliabilities of the measurements of muscle thickness for the vastus lateralis, measurement was performed twice in eight healthy young men (age: 22.4±0.9 years). The intraclass correlation coefficient (ICC [1.1]) for the measurements of muscle thickness was 0.986.

Statistical analyses

Statistical analyses were performed using SPSS version 22.0 software (IBM Japan, Inc., Tokyo, Japan). Shapiro-Wilk test was employed the normality of the data. When the normality was not achieved, Friedman test was used to analyze changes in muscle thickness followed by RE every 3 sets in each group. When a significant main effect was observed, Wilcoxon's tests with

Bonferroni correction were performed to determine where the difference occurred relative to pre-exercise. Additionally, effect size (ES) was calculated for each sets compared to pre-exercise. The percentage changes in muscle thickness after 3, 6, 9, and 12 sets of RE were calculated as follows: percent change = (after RE – pre-exercise)/pre-exercise. The differences in the percentage changes in muscle thickness after 3, 6, 9, and 12 sets of RE were assessed between the groups using Kruskal-Wallis test. One-way repeated-measures analysis of variance (ANOVA) was performed to compare time-course of muscle activities during every 3 sets normalized to MVIC in each group. When a significant main effect was observed, Bonferroni post-hoc tests were used to examine differences between sets. Statistical significance was set at an alpha-level of 0.05.

RESULTS

Table 1 shows the participants' baseline characteristics, 1RM, and weights during RE. No differences were observed for their age, height, body mass, 1RM, and weight among the three groups.

Changes in muscle thickness

Table 2 shows the muscle thickness measured before and after every 3 sets of RE in each group. The Friedman tests indicated main effects for time in all groups (all groups; $p<0.01$). In the 20-s and 60-s groups, the post-hoc analysis showed a significant improvement in muscle thickness at 3 sets. In the 180-s group, a significant increase in muscle thickness was observed only after 12 sets of RE.

The percentage change values in muscle thickness after 3, 6, 9, and 12 sets of exercise are shown in Table 2. The Kruskal-Wallis tests revealed that no significant differences were found in the percentage change between the groups in each 3 sets (after 3 sets of exercise; $p = 0.117$, after 6 sets of exercise; $p = 0.068$, after 9 sets of exercise; $p = 0.080$, after 12 sets of exercise; $p = 0.152$).

(Table 2 about here)

Muscle activity during RE

Figure 1 shows the muscle activity (%MVIC) for each of the 3 sets. The ANOVAs indicated main effects for time in the 20-s and 60-s groups. However, no main effect was observed in the 180-s group. The post-hoc test revealed that muscle activity during 10–12 sets was significantly greater than during 1-3, 4–6 and 7–9 setsboth in the 20-s and 60-s groups.

DISCUSSION

This study compared the acute effect of low-loaded RE on muscle swelling among three exercises conditions with the same muscle contraction time and different rest periods. The results revealed that the increase in muscle thickness was observed after 3 sets in groups with 20-s and 60-s rest periods, while in the group with a 180-s rest period, change in muscle thickness was observed only after completing 12 sets of RE. To the best of our knowledge, this is the first study to indicate that low-loaded RE with shorter rest period can generate effects on muscle swelling even after low-repetition RE, which is consistent with the hypothesis of our study. However, no difference was found between the three groups in percent changes in muscle thickness, which is inconsistent with the hypothesis of our study.

A previous study [13] demonstrated that even at the low-load of 30% 1RM, RE for knee extension consisting of 3 sets with 10 repetitions (3 s concentric, 1 s isometric, and 3 s eccentric contractions) and a 60-s rest between sets for 12 weeks in healthy older adults could induce muscle hypertrophy. In addition, our previous study [7] also indicated that even with the low-load of 30% 1RM, 12sets of low-loaded resistance training could generate effects on muscle hypertrophy similar to those of high-load resistance training after 8-week resistance training. Based on these findings, RE consisting of 12 sets with 10 repetitions (3 s concentric, 1 s isometric and 3 s eccentric contraction) was selected in the present study as a protocol that could cause future muscle hypertrophy. Muscle swelling immediately after exercise is a response to metabolic stress to skeletal muscle.[26,40] Several studies have reported that muscle swelling results in an increase in protein synthesis and leads to reinforcement of the ultrastructure.[28,41,42] Because the increase in muscle thickness, i.e. muscle swelling was observed after RE, it is possible that the training protocols in this study might be enough stimulation to induce muscle hypertrophy after chronic RE routine.

In this study, increases in muscle thickness were observed after 3 sets in the 20-s and 60-s groups. However, the increase in muscle thickness in the 180-s group was only observed after 12 sets of RE. The increase in muscle thickness immediately after exercise may be due to alterations in intra- and extracellular water balance induced by increased vascular permeability,[27] which may accelerate water uptake in muscle cells according to permeability.[30–32] Concerning the rest period between sets, Villanueva, et al.[20] reported that resistance training with a shorter rest period caused greater acute effects of hormone secretion than a longer rest period. The greater increase in muscle thickness in our study may also be explained by the influence of the release of metabolites at an earlier stage of RE due to shorter rest periods, even when lower-repetition exercise is performed. As for the percent change in muscle thickness, no significant difference was found among the three groups after 3, 6, 9 and 12 sets of RE. However, the time-course in muscle thickness showed that exercise with 20-s and 60-s rest periods can induce muscle swelling after as few as 3 sets. These results suggest that exercise with shorter rest periods could possibility induce greater metabolic stress.

Over the time-course in muscle activity during exercise, the most significant change in muscle activity was evident at 10–12 setsin the two groups with shorter rest periods, i.e., the 20-s and 60-s groups. Previous studies reported that RE with a shorter rest period between sets could induce greater muscle fatigue than with a longer rest period[43] and that higher numbers of training sets could promote greater muscle activity.[44] Therefore, in this study, we suggest that performing RE with shorter rest period can increase fiber recruitment to sustain a constant torque, which might lead to greater muscle activity.

This study has several limitations. First, we investigated only acute effects on muscle thickness immediately after RE. Further studies are required to clarify differences in the effects of long-term intervention of RE on muscle strength and muscle hypertrophy in relation with rest periods between sets. Another limitation of this study was that it included only healthy men. Although low-loaded resistance training is often prescribed for older adults or patients who cannot perform high-loaded resistance training, it is not yet clear whether low-loaded training in these groups can have the same acute effects as in young adults. Further studies including older adults or patients with muscle weakness are needed to address these questions.

This study investigated the acute effects of the low-loaded, high-repetition RE with varying between-set rest periods on muscle swelling. Our results showed that muscle thickness significantly increased after 3 sets in the 20-s and 60-s groups, nevertheless the percent changes in muscle thickness were not different among three groups. Our findings suggest that low-loaded RE with shorter rest periods could cause exercise-induced muscle swelling even after low-repetition RE.

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CONFLICT of INTERESTS

The authors declare that there is no conflict of interests regarding the publication of this article.

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Figure Legends

Figure 1. Muscle activity averaged over every 3 sets during RE

The values are shown as mean ± standard deviation

20 s = 20 seconds of rest period between sets; 60 s = 60 seconds of rest period between sets;

180 s = 180 seconds of rest period between sets

*$p < 0.05$: significantly different between sets

$^{\#}p < 0.1$: different between sets

Table 1. Characteristics and training loads

	All subjects	Rest period		
		20 s (n=14)	60 s (n=14)	180 s (n=14)
Age (years)	22.9 ± 2.4	22.9 ± 2.5	22.8 ± 2.7	22.9 ± 2.1
Height (cm)	172.1 ± 5.4	170.7 ± 4.8	172.3 ± 5.6	173.3 ± 5.8
Body mass (kg)	65.6 ± 6.5	64.4 ± 6.4	65.3 ± 6.7	67.0 ± 6.5
1 repetition maximum (Nm)	100.0 ± 17.9	100.0 ± 17.5	100.0 ± 18.4	100.0 ± 19.2
Weights during resistance exercise (kg)	8.6 ± 1.4	8.7 ± 1.3	8.6 ± 1.4	8.5 ± 1.6

Values are expressed as mean ± standard deviation

20 s = 20 seconds of rest period between sets; 60 s = 60 seconds of rest period between sets; 180 s = 180 seconds of rest period between sets

Table 2. Changes in muscle thickness immediately after resistance exercise (mm)

	Pre	3 sets	6 sets	9 sets	12 sets
20 s	23.2 ± 0.7	24.1 ± 0.7*	24.1 ± 0.6*	24.4 ± 0.7*	24.3 ± 0.7#
Percent change from Pre (%)		3.9 ± 3.3	4.3 ± 2.7	5.3 ± 5.0	4.9 ± 5.9
(ES)		(0.881)	(0.847)	(0.797)	(0.663)
60 s	23.7 ± 0.8	25 ± 0.8*	25.1 ± 0.9*	25.3 ± 0.9*	25.3 ± 0.8*
Percent change from Pre (%)		5.9 ± 3.8	6.0 ± 2.8	6.7 ± 4.3	6.8 ± 1.7
(ES)		(0.881)	(0.864)	(0.864)	(0.881)
180 s	23.5 ± 1.4	24.2 ± 1.4	24.3 ± 1.5#	24.1 ± 1.5	24.5 ± 1.4*
Percent change from Pre (%)		3.0 ± 4.2	3.5 ± 5.3	2.7 ± 4.2	4.3 ± 3.1
(ES)		(0.596)	(0.663)	(0.562)	(0.814)

Values are expressed as mean ± standard deviation

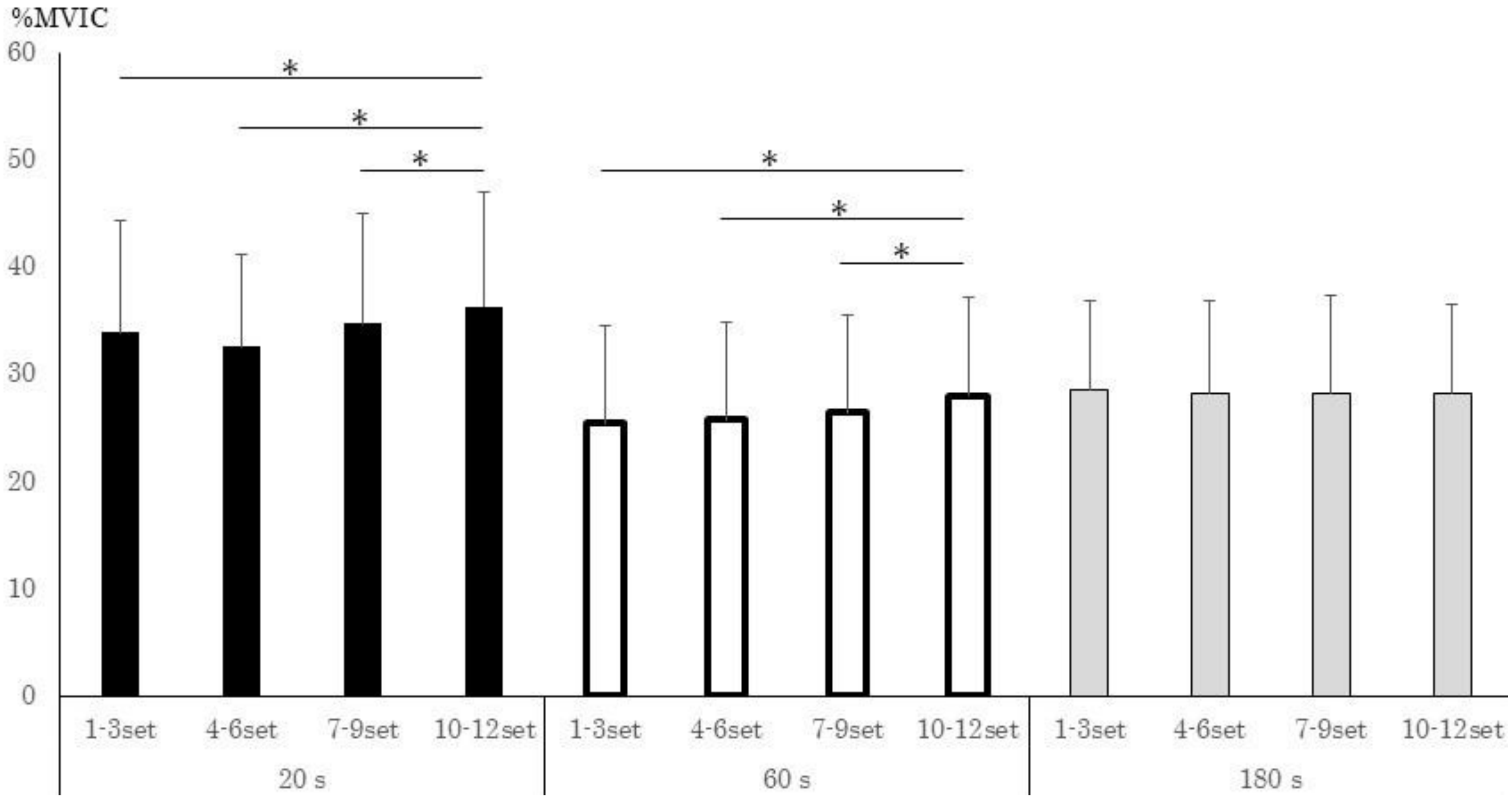
20 s = 20 seconds of rest period between sets; 60 s = 60 seconds of rest period between sets; 180 s = 180 seconds of rest period between sets

Pre = before exercise; 3 sets = after 3 sets of exercise; 6 sets = after 6 sets of exercise; 9 sets = after 9 sets of exercise. 12 sets = after 12 sets of exercise

ES= effect size between Pre and each sets.

*$p < 0.05$: compared with pre

#$p<0.1$: compared with pre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