Sex differences in lifting velocity and blood lactate concentration during resistance exercise using different rest intervals

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Abstract

Purpose: In this study, we examined sex differences in lifting velocity and blood lactate concentration during resistance exercise using different rest intervals (RIs).

Methods: Twenty-two trained men ($n = 11$) and women ($n = 11$) completed different RIs resistance exercise sessions (90s (R90), 150s (R150), and 240s (R240)). All sessions consisted of 3 sets with a 10 repetition at 70% of 1-repetition maximum (1RM). The exercise did parallel squats with free weights. The measurement items are lifting velocity (mean velocity) in each repetition and blood lactate concentration after exercise.

Results: There was a significant interaction between changes in the average velocity of 10 repetition in each set (AV_{10rep}) and sex in each protocol, indicating that AV_{10rep} during squat exercise has decreased in men but not in women in each protocol ($p=0.002 - 0.03$). Blood lactate concentration were significantly higher in men than in women, but there was no interaction.

Conclusion: Our results showed that changes in lifting velocity within a set was not affected by RIs in both men and women, and changes in AV_{10rep} between sets and blood lactate concentration after exercise were affected by RIs only in men, but not in women.

Background

Training variants, such as intensity, volume, lifting velocity, rest intervals, and exercise mode, are manipulated for strength gain and muscle hypertrophy during resistance training. Percentage of the 1 - repetition maximum (1RM) is the most common method used to adjust the intensity of resistance training [1]. However, 1RM is affected by physiological and psychological changes [2]. Recently, velocity-based training has been reported as an effective method for manipulating intensity by several research groups [3, 4]. Lifting velocity during resistance exercise can be used to predict 1RM and may provide greater insight into individual daily readiness compared to %1RM methods [5, 6]. Previous studies have suggested that changes in lifting velocity during resistance exercise is associated with decreased counter movement jumps and increases in blood lactate concentration after resistance exercise [7, 8]. These results have been shown that lifting velocity can predict neuromuscular fatigue and metabolic responses during resistance exercise [8]. However, evidence on lifting velocity during resistance exercise in women is lacking, and further research regarding this matter should be conducted.

Rest intervals may affect lifting velocity during resistance exercise. Long rest intervals allow the recovery of ATP and CP and maintenance of power output during exercise [9]. In contrast, short rest intervals increase metabolic stress more than long rest intervals [10], which is suggested to promote muscle hypertrophy [11]. It has been reported that women recover ATP faster than men during rest intervals [12], and metabolic stress during short rest intervals is lower in women than in men [13]. Additionally, Ratamess et al. suggested that women performed more repetitions during bench press exercise at each rest intervals (1, 2, and 3 min) than men and that women have less fatigability and superior recovery

ability between sets compared with men [14]. Patients have also shown interaction between changes in average velocity and sex only in protocols of 2 min rest intervals, meaning that changes in decline were significantly lower in women than in men. These results may suggest that even short rest intervals may reduce the decline in lifting velocity during exercise in women.

The previous study has reported that women have a slower lifting velocity than men, which could lead to a wide range of load-velocity profiles during resistance exercise [15, 16]. Askow et al. [15] have shown that these sex differences might be affected by differences in strength in men and women. Additionally, there was a greater sex difference in load-velocity profile for lower body squat exercise compared to upper body bench press [17]. Lower body exercises (e.g. squats) shows a faster lifting velocity in a load more than 70% 1RM compared with bench press, and this may be a reason for the aforementioned phenomenon [18-20]. Additionally, since lower body exercises require long rest intervals than upper body exercises [21], the lower body may be more affected by rest intervals and sex differences than the upper body.

We hypothesized that changes in lifting velocity during lower body exercise (squat) in women have a small effect on rest intervals compared with men. The present study was designed to determine sex differences in lifting velocity and blood lactate concentration during resistance exercise using different rest intervals.

Methods

Subjects

Twenty-two trained subjects (11 men; age, 22.6 ± 2.9 yrs; height, 171.3 ± 4.8 cm; weight, 80.8 ± 6.4 kg; body fat, 15.1 ± 3.3 %; 11 women; age, 21.2 ± 1.5 yrs; height, 158.3 ± 5.3 cm; weight, 55.4 ± 4.7 kg; body fat, 23.0 ± 4.3 %) were included. Table 1 shows subject body composition and 1RM of the parallel squat. The training experience of subjects in this study was 4.2 ± 3.2 years. The purpose of this study, measurement methods, and ethical considerations were explained to the subjects both in writing or orally, and the study was conducted after obtaining their consent. The study protocol was approved by Ethics Committee of the Nippon Sport Science University and conducted in accordance with the Declaration of Helsinki.

Exercise Protocol

The study was conducted over four days. In the first session, 1RM measurement was conducted to determine the load of the parallel squat. A barbell (20 kg) was used to check the depth and form of the parallel squat, and after 10 repetitions with 20 kg (rest, 3 min), measurement was conducted with instructions to reach 1RM after about 5 repetitions (rest, 4 min in each interval). Three more days after 1RM measurement were allowed for the experimental protocol. Before the experiment, no exercise was allowed and no muscle pain or fatigue was present. Warm-up was stopped after the day of the experiment (5 repetitions of 20 kg with a rest of at 2 min; 5 repetitions of 50% 1RM with a rest of at 3 min;

2 repetitions of 60% 1RM with a rest of at 4 min). Each protocol consisted of 3 sets of 10 repetitions at 70% 1RM with rest intervals of 90 s (R90), 150 s (R150), and 240 s (R240) in a crossover design. The rest interval between sets was randomly assigned across the three testing days. We measured lifting velocity in each repetition, and blood lactate concentration was measured using Lactate Pro2 (Arkay, Japan) after exercise within 1 min. Body weight and percent body fat were measured using a bioelectrical impedance analysis (model 270; Inbody).

Lifting Velocity

A cable linear velocity transducer (GymAware; Kinetic Performance Technologies, Australia) was used to measure bar velocity. In line with a previous study [22], Several bar velocity outcomes during squat exercise were used as performance variables in the present study. 1) the mean velocity (MV) of the concentric phase during squat exercise; 2) average MV of 10 repetitions in each set (AV_{10rep}); 3) velocity loss (VL) was defined as the change in lifting velocity within a set using the velocity of the first repetition to last repetition; and 4) total velocity loss (TVL) was defined by subtracting the first repetition of the first set and the last repetition of the third set in the protocol.

Statistical analysis

Statistical analysis was performed using the software package SPSS version 25.0 (IBM SPSS, Chicago, IL). Sex differences in body composition and percent body fat, parallel squat 1RM and AV_{10rep} of the set, and TVL were analyzed using the T-test. A repeated measures analysis of variance (set $\times$ sex) was used to examine the interaction of changes in AV_{10rep} between sets and sex in each protocol. Additionally, a repeated measures analysis of covariance (set $\times$ sex) was employed to analyze data AV_{10rep} between sets and sex, thereby removing the effects of squat 1RM strength. A repeated measures analysis of variance (protocol $\times$ sex) was used to examine the interaction of changes in blood lactate concentration and sex. When an interaction was found, the Bonferroni method was used to examine the main effect. A regression analysis was used to examine the correlations between blood lactate concentration and lifting velocity. All measured data are presented as mean $\pm$ standard deviation. A p-value <0.05 was considered statistically significant.

Results

Characteristics in men and women

The results of body composition and 1RM of parallel squat of subjects are shown in Table 1. The results of height, weight, and 1RM of parallel squat were significantly higher in men than in women (height, $p=1.0 \times 10^{-5}$; weight, $p=1.0 \times 10^{-5}$; 1RM of parallel squat, $p=1.0 \times 10^{-8}$). Percent body fat was significantly higher in women than in men ($p=2.0 \times 10^{-4}$)

Changes in lifting velocity

Changes in MV in each protocol (R90, R150, and R240) are shown in Figure 1. Both men and women showed a significant decrease in MV in all sets of all protocols. Additionally, first repetition and last repetition MV in the set, VL compared to the first repetition and last repetition in the set, and TVL compared to the first repetition in the 1 set and the last repetition in the 3 set are shown in Table 2. For both men and women, there was a significant difference between the first and last repetitions in each set. Additionally, men showed a significant decrease in the first and last repetitions in each set in R90. There was no significant difference in the MV of the change within a set between men and women, between sets, or between protocols. Figure 2 show the AV_{10rep} of the overall MV of the set. The AV_{10rep} of each set decreased significantly with each successive set for the R90 and R240 of men (R90, $p=0.002$; R240, $p=0.037$), but there was no difference in R240 between sets and sex. R150 did not cause any significant differences, but there was a tendency ($p=0.264$). For men, AV_{10rep} decreased with each set, yet AV_{10rep} did not decrease for women (R90, 1 set to 2 set; $p=0.005$, 2 set to 3 set; $p=0.008$, 1 set to 3 set; $p=0.001$, R150; 1 set to 2 set; $p=0.0002$, 1 set to 3 set; $p=0.02$). Using 1RM and relative strength (1RM per body weight) as the covariate for AV_{10rep} , there was an interaction in R90 only, but not for R150 and R240 (1RM, R90, interaction, $p=0.02$; set, $p=0.13$; sex, $p=0.64$; R150, interaction, $p=0.10$; set, $p=0.03$; sex, $p=0.95$; R240, interaction, $p=0.22$; set, $p=0.04$; sex, $p=0.89$; 1RM per body weight, R90, interaction, $p=0.001$; set, $p=0.034$; sex, $p=0.03$; R150, interaction, $p=0.53$; set, $p=0.25$; sex, $p=0.12$; R240, interaction, $p=0.64$; set, $p=0.02$; sex, $p=0.16$).

Discussion

In the present study, we examined sex differences in lifting velocity and blood lactate concentration during resistance exercise using different rest intervals. Our results show that interaction between set and sex in AV_{10rep} (R90, $p=0.002$; R240, $p=0.037$). Changes in AV_{10rep} decreased in men but not in women, and a similar tendency was observed in R150 ($p=0.264$, Figure 2). Using 1RM and relative strength (1RM per body weight) as the covariate for AV_{10rep} , there was an interaction in R90 only, but not for R150 and R240. There was no sex difference in changes in MV within a set. There was no interaction between protocol and sex in blood lactate concentrations, but this interaction was lower in women than in men ($p=0.002$, Figure 3).

There was a significant interaction in changes in AV_{10rep} (1set, 2set, and 3set) and sex in each protocol (Figure 2), indicating that AV_{10rep} during squat exercise has decreased in men but not in women in each protocol. In R90 and R150 protocols, there were significant decreases in the AV_{10rep} of each set (1st set to last set) in men but not in women (R90, $p=0.0007$; R150, $p=0.03$; R240, $p=0.09$). Women showed similar changes in AV_{10rep} in all protocols as there was enough time to maintain the AV_{10rep} in R90, R150, and R240. This may be due to sex differences in muscle fiber composition. It has been shown that men have better fast-twitch muscle fiber occupancy than women, yet women have more slow-twitch muscle fiber occupancy than men [23]. Slow-twitch muscle fibers contain higher mitochondria content than fast-twitch muscle fibers, and therefore, have better oxidative capacity and higher endurance [24]. This may influence

the specific characteristics of recovery in energy systems during exercise and fiber type in women [25, 26].

In addition, Ratamess et al. [14] examined sex differences in the change in lifting velocity at different rest intervals (1 min, 2 min, and 3 min) during upper body exercise (bench press, three sets of 10 repetitions at 75% of 1RM). There was a significant decrease in the average velocity for both men and women at all rest intervals. Furthermore, interaction was only observed during 2 min of rest intervals, where the rate of the decrease in average velocity was significantly lower in women than men. The results of the present study have shown an interaction between AV_{10rep} for protocol and sex. Women have shown similar AV_{10rep} between sets, which is similar to previous studies. Ratamess et al. have considered this result to be due to the difference in the influence of muscular endurance between men and women. Previous studies have reported that muscular endurance is higher in women than in men [27] [5], and it is possible that women maintain lifting velocity during exercise more than men. However, previous studies have reported that 1RM affects sex differences in average velocity. In the study of lifting velocity, we also discussed the effect of 1RM on sex differences in lifting velocity at each intensity [15]. It is possible that muscle strength may affect sex differences of lifting velocity during resistance exercise. However, using 1RM and relative strength (1RM per body weight) as the covariate for AV_{10rep} , there was an interaction in R90 only, and AV_{10rep} was found to be significantly lower in men (1RM; $p=0.02$, 1RM per body weight; $p=0.001$) than in women. Our main novel result is that AV_{10rep} was not affected by muscle strength when it comes to short rest intervals. Therefore, there were sex differences in AV_{10rep} changes during short rest intervals. It is also possible that the differences in muscle strength between the upper and lower body may have affected results, as previous studies have reported upper body exercises. Furthermore, in this study, blood lactate concentration was measured, and it was found that the greater the decrease in AV_{10rep} , the higher the blood lactate concentration.

Blood lactate concentration after squat exercise increased in both men and women, and there was no interaction in blood lactate concentration between sex and protocol ($p=0.129$). There was sex difference in blood lactate concentration in each protocol (R90, $p=0.001$; R150, $p=0.011$; R240, $p=0.008$). Furthermore, men had significantly higher blood lactate concentration in R90 than in R240 ($p=0.03$). It has been reported that increases in blood lactate concentration after resistance exercise is dependent on exercise volume [28] and rest intervals [29]. Terada et al. [30] reported that resistance exercise with a high volume protocol resulted in higher blood lactate concentration. Moreover, blood lactate concentrations have been shown to increase more with short rest intervals than with long rest intervals, and a study in men reported higher blood lactate concentrations with 1 min versus 3 min of rest intervals during resistance exercise [29]. A study [13] reported that blood lactate concentrations were significantly higher in men than in women when the exercise protocol was performed with rest intervals of 1 minute. Moreover, blood lactate concentration may be secreted differently depending on muscle mass. Since lactate is secreted more in fast-twitch muscle fibers, it is possible that blood lactate concentration is higher in men with higher muscle mass and strength than in women. In the present study, using muscle mass as the covariate of blood lactate concentration, there was no significant difference in blood lactate

concentrations between intervals (R90, $p=0.537$; R150, $p=0.247$; R240, $p=0.380$). Furthermore, using 1RM as the covariate of blood lactate concentration, there was no significant difference in blood lactate concentrations (R90, $p=0.912$; R150, $p=0.912$; R240, $p=0.397$). Therefore, muscle mass and muscle strength has influenced sex differences in blood lactate concentration in this study. Additionally, women experience no changes in blood lactate concentrations after squat exercise in women among each protocol. There was a similar result of changes in AV_{10rep} between sets. Since blood lactate concentration did not increase in women at the rest intervals used in this study, it is necessary to examine changes at shorter rest intervals.

There was a positive correlation between blood lactate concentration after squat exercise and TVL in all subjects for each protocol (R90, $r=0.462$; R150, $r=0.463$; R240, $r=0.715$). Additionally, R240 with long rest intervals showed the highest relationship between lifting velocity and blood lactate concentration. The previous studies have reported correlations between decreased lifting velocity, blood lactate concentration, and counter movement jump [8, 31]. At all protocols, there was a relationship between TVL and blood lactate concentration, with a similar trend for men and women (men, R90, $r=0.298$; R150, $r=0.649$; R240, $r=0.774$; women, R90, $r=0.637$; R150, $r=0.250$; R240, $r=0.649$). R240 had the strongest relationships, which had the longest rest intervals. From the present study and previous studies, it is suggested that lifting velocity (AV_{10rep} , TVL) may be predictive of blood lactate concentration during longer rest periods.

There was no sex difference in VL within a set in each protocol. Therefore, VL within a set at the same intensity and repetition in long rest interval (R240) is similar to short (R90) and middle (R150) rest intervals in both men and women. Despite the fact that VL has been reported to be responsible for neuromuscular fatigue and blood lactate concentration [8] and that these factors show higher in short rest interval compared with long rest intervals [32], in our study, the first repetition in the final set in R90 was lower than in R240 in men ($p=0.016$) but no in women. The results suggest that the women's MV of first repetition may not be affected by rest intervals between sets. Additionally, the subjects in the present study were trained and had high strength, and it is possible that these factors may have influenced no sex differences in VL within the set.

The limitation of the present study is that subjects have performed squat exercise with free weights. Previous studies using squat have used a Smith machine to perform measurements [33-35]. Free weights and Smith machines have different lifting velocity for squat exercises. In a previous study, the mean velocity of 1RM for men was found to be 0.23 ± 0.05 m/s for free weights and 0.32 ± 0.04 m/s for Smith machine [36] [37]. The difference in lifting velocity between these different exercise styles can be influenced by technique. Consequently, there may be individual differences in velocity loss and fatigue due to lower first repetition. Therefore, lifting velocity or its reduction may be smaller for free weights.

Conclusion

In this study, we examined sex differences in MV and blood lactate concentration during resistance exercise using different rest intervals. Our results have that no sex difference in changes in MV within a set was found. Changes in AV_{10rep} decreased in men but not in women.

Abbreviations

R90: rest intervals of 90 sec; R150: rest intervals of 150 sec; R240: rest intervals of 240 sec; MV: mean velocity; VL: velocity loss; TVL: total velocity loss; AV_{10rep} : the average velocity of 10 repetition in each set; 1RM: 1 - repetition maximum; CPr: creatine phosphate; ATP: adenosine triphosphate

Declarations

Acknowledgements

Not applicable.

Authors' contributions

YM and NK designed the study. YM, MS, HH, TI and TN performed the experiments. YM, MS and HH analyzed the data. YM wrote the first draft of the manuscript with input from all authors. MS, HH, MSS and NK gave significant advice concerning interpretation of the results and critical review of the manuscript. All authors discussed the results and contributed to the final manuscript.

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Availability of data and materials

All data generated or analysed during this study are included in this published article and its supplementary information files

Ethics approval and consent to participate

This study was conducted in accordance with the Declaration of Helsinki. The Ethics Committee of Nippon Sport Science University approved this study, which was performed in accordance with the guidelines for experimental studies involving human participants published by our Institutional Review Board (020-H061). Written or oral, informed consent was obtained from all participants after they were given a complete explanation of the purpose of the study and the experimental procedures.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Tables

Table 1. Characteristics and 1RM in men and women.

	Age (yrs)	Height (cm)	Weight (kg)	Body fat (%)	1RM (kg)
Men (n=11)	22.6 ± 2.9	171.3 ± 4.8 *	80.8 ± 6.4 *	15.1 ± 3.3 *	124.7 ± 16.6 *
Women (n=11)	21.2 ± 1.5	158.3 ± 5.4	55.4 ± 4.7	23.0 ± 4.3	66.3 ± 8.0

Mean ± S.D., RM; repetition maximum, *p<0.05 (vs. women)

Table 2. Mean velocity (MV) of the first to last repetition in the set, velocity loss (VL) in the set, and total velocity loss (TVL) in each protocol.

		Men		Women	
		MV (m/s)	VL (%)	MV (m/s)	VL (%)
R90	1 set-First	0.58 ± 0.10	16.3 ± 11.0	0.52 ± 0.07	18.5 ± 13.2
	Last	0.48 ± 0.09 #		0.43 ± 0.08 #	
	2 set-First	0.55 ± 0.08 †	23.8 ± 8.0	0.53 ± 0.06	21.9 ± 9.0
	Last	0.42 ± 0.07 #§		0.42 ± 0.07 #	
	3 set-First	0.52 ± 0.07 †	24.1 ± 13.3	0.53 ± 0.06	25.8 ± 9.2
	Last	0.39 ± 0.08 #§		0.40 ± 0.06 #	
	TVL	0.19 ± 0.10	24.1±13.3 19.9±12.4	0.13 ± 0.06	25.8±9.2 24.2±8.2
R150	1 set-First	0.56 ± 0.11	19.9 ± 12.4	0.55 ± 0.07	24.2 ± 8.2
	Last	0.44 ± 0.08 #		0.41 ± 0.07 #	
	2 set-First	0.54 ± 0.09	22.9 ± 15.5	0.53 ± 0.07	27.0 ± 7.3
	Last	0.42 ± 0.11 #		0.38 ± 0.06 #	
	3 set-First	0.53 ± 0.09	22.3 ± 15.0	0.53 ± 0.08	24.0 ± 9.5
	Last	0.41 ± 0.10 #		0.40 ± 0.07 #	
	TVL	0.15 ± 0.11		0.14 ± 0.04	18.7±10.9
R240	1 set-First	0.57 ± 0.06	22.3 ± 13.3	0.53 ± 0.06	18.7 ± 10.9
	Last	0.44 ± 0.09 #		0.43 ± 0.06 #	
	2 set-First	0.57 ± 0.06 *	24.1 ± 11.6	0.52 ± 0.05	15.8 ± 10.8
	Last	0.44 ± 0.09 #		0.43 ± 0.06 #	
	3 set-First	0.55 ± 0.07	23.5 ± 10.6	0.55 ± 0.07	23.0 ± 13.6
	Last	0.42 ± 0.09 #		0.42 ± 0.06 #	
	TVL	0.14 ± 0.07		0.11 ± 0.06	

Mean $\pm$ S.D., RM; repetition maximum, MV; mean velocity of concentric phase during squat exercise, TVL; total velocity loss was defined by subtracting the first repetition of the first set and the last repetition of the third set in the protocol, VL; velocity loss was defined as the change in lifting velocity within a set using the velocity of the first repetition to last repetition

* $p < 0.05$ compared to women, # $p < 0.05$ compared to first within set, † $p < 0.05$ compared with 1 set – first rep, § $p < 0.05$ compared with 1 set – last rep.

Figures

Figure 1

Changes in mean velocity (MV) in R90, R150, and R240.

A: R90, B: R150, C: 240.

Figure 2

Average velocity of 10 repetitions in each set (AV_{10rep}) in R90, R150, and R240.

A: R90, B: R150, C: 240.

* $p < 0.05$ compared with 1 set, † $p < 0.05$ compared with 2 set. Interaction was analyzed using a repeated measures analysis of variance (set $\times$ sex). Black shows the result of men, and white shows the result of women.

Figure 3

Blood lactate concentration after each protocol.

* $p < 0.05$ compared with R90.