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Acute Effects of Three Resistance Exercise Programs on Energy Metabolism

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Abstract The knowledge about metabolic effects of different training programs is of huge importance for the regulation of resistance training. Most studies investigated the effect of the variation of a single load character on physiological parameters such as blood lactate and oxygen intake. Therefore, the present study investigates the physiological reactions on practice-oriented resistance exercise programs with different loads and training volumes. 24 male subjects (25.6 ± 5.9 years, 171 ± 4 cm, 74.3 ± 5.3 kg) were randomly assigned into three different resistance training groups (G1 = 30/30/3/60, G2 = 50/20/3/90, G3 = 70/10/4/90; respectively % of one repetition maximum /repetitions /number of sets /rest between sets). Exercises squats, bench press, biceps curl, french press, and rowing were completed in a randomized order. Heart rate (HR), breathing frequency (BF), oxygen uptake ($_{rel}\dot{V}O_2$) and blood lactate (La) were measured at the end of each set. Mean value of all sets in each exercise was used for statistical analysis (ANOVA). Performance was calculated using the relative power index (RPI). There were significant differences in the RPI (ANOVA $p < 0.01$) between the three groups (G1 < G2 < G3). Mean values of all exercises showed a significant difference of the $_{rel}\dot{V}O_2$ between G2 and G3 (ANOVA $p<0.05$), but no differences in other parameters were found (ANOVA $p>0.05$). The $_{rel}\dot{V}O_2$ and HR showed significant differences between the exercises (ANOVA $p<0.05$). Independent of the three training programs, significant differences in HR, RF and $_{rel}\dot{V}O_2$ but not in La were shown between the exercises. In summary, the present study shows, that the physiological effects of the three different strength training programs on $\dot{V}O_2$, HR, La and BF differs very little, despite the strongly differing RPI. The selection of the exercise seems to be especially important for the acute adaptations of $\dot{V}O_2$ and HR, but not for lactate accumulation.

Keywords Resistance training, Strength training, Muscle metabolism, Load characteristics, Blood lactate, Oxygen uptake

1. Introduction

The load characteristics are the main regulation mechanisms of resistance exercise training [1-14]. By varying the load characteristics such as intensity, duration and rest intervals, as well as the speed of movement; the range of motion and order of exercises, the physiological stress of the resistance training can be adjusted individually [13, 14]. Furthermore, involved muscle mass and used training methods influence the energy metabolism [15-17]. Different types of organization, used load characteristics and training materials affect the physiological stress in metabolic, cardiac, neurophysiological and hormonal levels [18, 19]. In addition to the influence of the used weight [20-25], numerous studies have shown the influence of movement speed [6, 8, 20, 26] and length of rest intervals on the physiological stress in resistance training [10, 27, 28]. Most studies have used metabolic parameters such blood lactate (La), oxygen uptake ($\dot{V}O_2$) or ammonium to measure physiological stress. Fröhlich, Klein, Emrich & Schmidtbleicher as well as Rogatzki et al. [29, 30] showed in a comparison of endurance strengths training, hypertrophy training and submaximal strengths training that, a higher number of repetitions led not only to higher lactate concentrations, but also to higher concentration of ammonia in the blood, compared to force training programs with lower repetition numbers and higher loads. This finding indicates a faster reduction in ATP reserves during increased time under tension (TUT) with medium loads. Similar results were found by Abernethy and Wehr [31]. During arm and leg exercises with three sets with 10 repetitions [32] observed, that La increases during the rest intervals within the sets, due to the lactate time delay [23]. Lactate kinetics are considered to be mainly influenced by the TUT [23, 32].

The knowledge about these metabolic effects of different exercise training programs is of huge importance for the regulation of resistance training. Increased La associated with an increased IGF-1 level seems to be potent stimuli for

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effective responses to muscular adaptations [33, 34]. Studies showed that lactate and a metabolic stress-induced reduced pH level plays a decisive role for the adaptation of muscles to exercise stimuli as well as for the hypertrophy [35-37]. Due to the function of lactate as a signal molecule for the process of muscle adaptation, this effect should be considered during resistance training [38]. The metabolic effects of different resistance training programs and the difference between varying exercises are the point of view of current investigations [3, 39-41]. Most studies investigated the effect of variation of a single load character on the physiological parameters and were able to demonstrate their methodological significance for resistance training. For example, Buitrago et al. [3] found differences in the $\dot{V}O_2$ between slow and maximum movement speed. Arazi et al. [20] showed differences in La between high load and low load in a single exercise. These findings, so far, only show the influence of isolated load characters on physiological stress. In practice, however, training programs vary in several load characteristics, such as number of repetitions, movement speed and number of sets depending on the physical load. In addition, several resistance exercises were used. The aim of the present study was the investigation of the physiological stress in practice-oriented resistance training programs with several resistance exercises and different intensities and training volumes.

2. Methods

2.1. Subjects

24 male subjects with an amount of 4.4 ± 1.2 hours training per week (10 strength training/fitness, 8 sports game, 3 endurance, 3 martial arts) were included in the study (25.6 ± 5.9 years, 171 ± 4 cm, 74.3 ± 5.3 kg, BMI 23.2 ± 1.1 kg/m^2). All subjects agreed to participate in the study after oral and written information. The study was approved by the Ethics Committee of Chemnitz University of Technology (V-153-17-TM-NN-Kraft-08092016). The subjects were assigned randomly into three training groups (group 1 = G1: N = 8, 25.5 ± 2.1 years, 180 ± 4 cm, 74.5 ± 4.5 kg, BMI 22.9 ± 0.7 kg/m^2; group 2 = G2: N = 8, 27.5 ± 8.0 years, 177 ± 5 cm, 74.2 ± 7.5 kg, BMI 23.6 ± 1.2 kg/m^2, group 3 = G3: N = 8, 25.9 ± 2.5 years, 178 ± 4 cm, 74.3 ± 3.5 kg, BMI 23.9 ± 1.1 kg/m^2) and completed a resistance training with different training programs (Tab. 1). All participants had experience with resistance training, and were familiar with the applied exercises. During the exercise, the range of motion was standardized and controlled.

2.2. Treatment

Resistance training consisted of exercises for the trunk, the arms and the lower extremities. Exercises squats with 70° knee ankle (SQ), bench press (BP), biceps curl (BC), french press (FP), rowing with weightlifting bar (RO) were completed in a randomized order. Rest between sets and exercises were passed passively in a sitting position (120 to 180 seconds). Before the start of the examination, one repetition maximum (1 RM) was determined for each exercise, with a minimum of two days before training (Tab. 2) [42, 43].

Table 1. Load characteristics of the different resistance exercise programs (G1=Group 1, G2=Group 2, G3=Group 3)

	G1	G2	G3
Load % of 1RM	30	50	70
Repetitions	30	20	10
Sets	3	3	4
Rest interval between sets [s]	60	90	90
Rest interval between exercises [s]	120	120-180	120-180
Set time [s]	42.1±11.4	33.3±8.0	20.2±5.4
Time under tension (TUT) [s]	606.9±88.3	499.1±40.1	405.3±49.8

Table 2. One repetition maximum, mean ± standard deviation (minimum-maximum), *p<0.05 to G3

Group	SQ [kg]	BP [kg]	RO [kg]	BC [kg]	FP [kg]
G1	116.0±14.3 (100-135)	98.0±17.2 (75-115)	91.0±9.6 (80-105)	38.9±5.3 (32.5-47)	40.0±5.3 (33-47)
G2	110.4±13.1 (97.5-135)	87.5±17.1 (65-115)	82.9±16.8 (60-100)	34.1±4.9* (27-42)	38.5±5.6 (27-42.5)
G3	120.7±11.0 (100-135)	98.6±11.4 (85-115)	90.7±9.8 (80-105)	45.0±5.0 (37-52.5)	38.1±8.6 (22-47)

The training programs were based on practice-oriented resistance training programs [44]. Before training, a standardized five minutes warm up on a bike ergometer, with a load of 50 watts, was performed. After a subsequent five minutes resting interval, baseline determination was made for the physiological parameters La, relative oxygen uptake ($_{rel}\dot{V}O_2$), heart rate (HR) and breathing frequency (BF). During the entire training the HR, $_{rel}\dot{V}O_2$ and BF were permanently recorded by automated gas analysis system Metamax 3b (Cortex Biophysik GmbH, Leipzig, Germany). After resting intervals, as well as after each set, capillary blood (20µl) was taken from the earlobe for La determination (EKF Biosen C, EKF Diagnostics, Barleben, Germany). The measurement was done at rest, immediately after each exercise and five minutes after training. To evaluate the HR, BF and $_{rel}\dot{V}O_2$, the mean values of the last ten seconds at the end of each set of the exercises were taken into account. Then the mean values of all sets in each exercise were used for statistical analysis. The performance was calculated by the relative power index (RPI) equation [45].

Equation 1. Relative power index (RPI), w=work (Fg*repetitions*amplitude concentric/eccentric), bm=body mass, h=height, t=exercise time

$$RPI = \frac{w}{bm * h * t}$$

2.3. Statistics

Statistical analysis was performed using SPSS 23.0 software program (IBM, New York, USA). The examination for differences in the anthropometric and physiological data, as well as the frequency of training between the groups was performed by a one way ANOVA. All data were examined for normal distribution by Shapiro-Wilk test and for homogeneity of variances by Levene test. The level of significance was 0.05. For graphical representation Grapher 4.0 (Golden Software Inc., Golden, USA) was used.

3. Results

The average preload values of the $_{rel}\dot{V}O_2$, BF, HR and La were 7.6 ± 4.3 ml/min/kg, 20.6±8.6 1/min, 79.8±26.5 1/min and 1.2±0.4 mmol/l respectively and showed no significant differences between the groups (all $p>0.05$). After the exercises a significant difference of the $_{rel}\dot{V}O_2$ between G2 and G3 ($p<0.05$) but no differences in the other parameters were found ($p>0.05$). The $_{rel}\dot{V}O_2$ and HF showed significant differences between the exercises ($p<0.05$). Significant differences in the $_{rel}\dot{V}O_2$ were found after SQ between G1 and G3 and between G2 and G3 and after FP between G2 and G3 ($p<0.05$) (Fig. 1). HR was significant different after SQ between G2 and G3. BF and La showed no differences between the exercises.

The highest physiological stress and the highest RPI showed the exercise SQ (Tab. 3 and 4). Independent of the three training programs, significant differences in HR, BF and $_{rel}\dot{V}O_2$ were shown between the exercises (Fig. 2 and Tab. 5).

Table 3. Relative Power Index (RPI), *p<0.05 between Groups, #p<0.05 between G1 and G3, +p<0.05 between G2 and G3

	G1	G2	G3
BC	0.849±0.215#	1.087±0.250	1.430±0.419
BP	0.876±0.212#	1.205±0.325	1.337±0.255
SQ	1.023±0.309#	1.072±0.266+	1.518±0.416
RO	0.670±0.106#	0.925±0.271+	1.324±0.383
FP	0.395±0.080#	0.447±0.120+	0.666±0.192
Mean	0.756±0.290*	0.947±0.367*	1.255±0.457*

4. Discussion

The physiological stress in strength training is influenced by different load characteristics [3, 4, 18, 19, 41]. Variations of load, set number, repetition number, rest interval and movement speed are possible factors to control the stress reaction of a training session. In practice, higher loads are usually used in combination with lower repetition numbers. Also set numbers of 3 to 6 sets and rest intervals of 2 to 3 minutes are common [46, 47]. This variation affects several load characteristics within a training program. The aim of the present study was the examination of the physiological stress in practice-oriented resistance training programs. For this purpose, the response of the parameters $_{rel}\dot{V}O_2$, BF, HR and La on three different resistance training programs with the same exercises, but different loads, repetitions, sets and rest intervals was tested in trained subjects. Because the focus of the study was on the load characteristic, the effect of the exercise on the physiological parameters was largely controlled by a randomized exercise order. The three groups can be considered as homogeneous, despite a significant difference of the 1 RM in BC between G2 and G3.

There are different possibilities for the estimation of physiological effects of strength training. Hoppeler [48] describes molecular proteins in strength training, which are particularly relevant for hypertrophy, but therefore a biopsy of the muscle with particular muscular damage is necessary. Like in the present paper, also physiological parameters like La, $\dot{V}O_2$ and HF are described as important variables for estimating the energy metabolism during and after strength training [3, 4, 15, 20, 30, 41, 49-51].

Table 4. Breathing frequency (BF), heart rate (HR), relative oxygen uptake (rel$\dot{V}O_2$) and blood lactate (La) of the exercises dependent of exercise groups, #p<0.05 difference to G1, *p<0.05 difference to G2

	BF [min^{-1}]	HR [min^{-1}]	$_{rel}\dot{V}O_2$ [$ml\ min^{-1}kg^{-1}$]	La [$mmol\ l^{-1}$]
G1	36±12,3	129,8±20,5	14,4±6	7,42±0,98
G2	33,9±12,3	132,3±27,1	16,1±7,3	8,11±1,05
G3	33,4±10	128,5±27,6	12,9±5,3*	7,75±1,27
BC G1	37,3±11,3	139,5±15,3	13,5±3,4	7,65±0,16
BC G2	35,1±12	136,1±22,7	16±4,2	8,56±0,18
BC G3	31,8±11,1	138,5±21,6	13,9±4,7	8,06±0,55
BP G1	35,1±14,2	120,7±17,3	11,8±3,2	8,18±0,86
BP G2	31,3±12	127,6±28,7	12±4,3	7,62±1,03
BP G3	34,3±9,4	125,4±39	11±3,7	7,96±0,96
SQ G1	40,5±10,6	142,5±18,1	22,4±5,4	6,99±1,41
SQ G2	40,9±10,7	142,2±25	23,5±7,9	8,62±1,95
SQ G3	33,7±8,4	129±17,6*	16,1±5,2*#	5,86±1,28
RO G1	35,9±12,4	130,2±19	15,8±4,8	6,31±0,55
RO G2	35,4±12,1	133,7±22,9	18,2±6,1	8,49±0,49
RO G3	36,7±11,6	124,6±33,5	14,4±5,7	8,48±0,98
FP G1	31,9±11,2	117,3±19,6	10,2±4,4	7,97±0,23
FP G2	26,9±10	121,6±29,9	10,4±3,8	7,25±0,47
FP G3	31,7±8,6	122,9±20,7	9,2±4,2	8,41±0,52*

The RPI was significantly higher in G3 training program with a load of 70% of 1RM and 10 repetitions compared to the other programs. Also Buitrago et al. [4] showed a higher concentric power in a program with 70% of 1RM (6 s TUT/repetition) compared with 55% 1RM (10 s TUT/repetition). Although there were significant differences in RPI between the three groups, there were only significant differences in the $_{rel}\dot{V}O_2$ between G2 and G3.

In addition, significant differences in physiological stress between the exercises, independent of the program, were only detected in physiological parameters with a low time constant, such as HR, BF and $_{rel}\dot{V}O_2$. Collins et al. [49] showed that there is a very high correlation between $_{rel}\dot{V}O_2$ and HR even for power loads. Therefore, these two physiological parameters showed comparable reactions after the loads. Brown et al. [52] found a positive moderate to strong correlation between La and subjective stress in the performance of the strength exercises with 8 repetitions of biceps curl and bench press. Due to the stress-induced lactate accumulation, there were barely any differences in the lactate concentrations between the programs and exercises of the present study, although a difference in the subjective stress can be assumed. In contrast the study of Lagally et al. [15] showed a significantly higher La at 90% 1RM compared to 30% and 60% 1RM in a biceps curl exercise program. Another important load characteristic for the lactate accumulation is the movement speed. The variation of load and movement speed in an exercise (leg extension), led to the highest La at a relatively slow movement speed [20]. Adaptation of HR and $_{rel}\dot{V}O_2$ to physical stress is meant to be fast. The exercises SQ and RO were associated with the highest values in the $_{rel}\dot{V}O_2$. Ratemess et al. [41] showed a significantly higher $\dot{V}O_2$ after SQ (large muscle group) compared to BP (low muscle group). Therefore, the quantity of used muscle mass in different exercises as well as the associated movement amplitude in the exercises showed a significant influence on the physiological stress ($\dot{V}O_2$, HR).

Table 5. Breathing frequency (BF), heart rate (HR), relative oxygen uptake ($_{rel}\dot{V}O_2$) and blood lactate (La) of the exercises independent of exercise groups, #p<0.05 difference to BP, *p<0.05 difference to BC, ~p<0.05 difference to SQ, °p<0.05 difference to RO

	BF [min⁻¹]	**HR [min⁻¹]**	**$_{rel}\dot{V}O_2$ [ml min⁻¹kg⁻¹]**	**La [mmol l⁻¹]**
BC	35,0± 11,7	138,1± 19,8	14,4± 4,2	8,09±0,50
BP	33,7± 12,4	124,2± 28,7*	11,6± 3,7*	7,92±0,87
SQ	38,7± 10,6	138,4± 21,6	21,0±7,1*#	7,03±1,81
RO	36,0± 12,1	129,8± 25,1*#	16,2± 5,7*~	7,83±1,24
FP	30,1± 10,4~	120,2± 24,1*~	10,0± 4,1*#~°	7,93±0,64

Further studies confirm these effects on the physiological stress dependent on the used muscle mass during strength exercises [17, 32, 39]. Regarding the rest interval, Ratamess et al. [41] demonstrate a significantly lower $\dot{V}O_2$ in strength training with a pause of 120 seconds versus 180 seconds. In the present study, the rest interval between the exercises was between 120 and 180 seconds and 60 to 90 seconds between sets. Preliminary experiments stated, that shorter rest intervals between exercises led to complications for G2 and G3. Summarizing these two factors seems to be relevant beside the other load characteristics such as load, number of repetition and TUT.

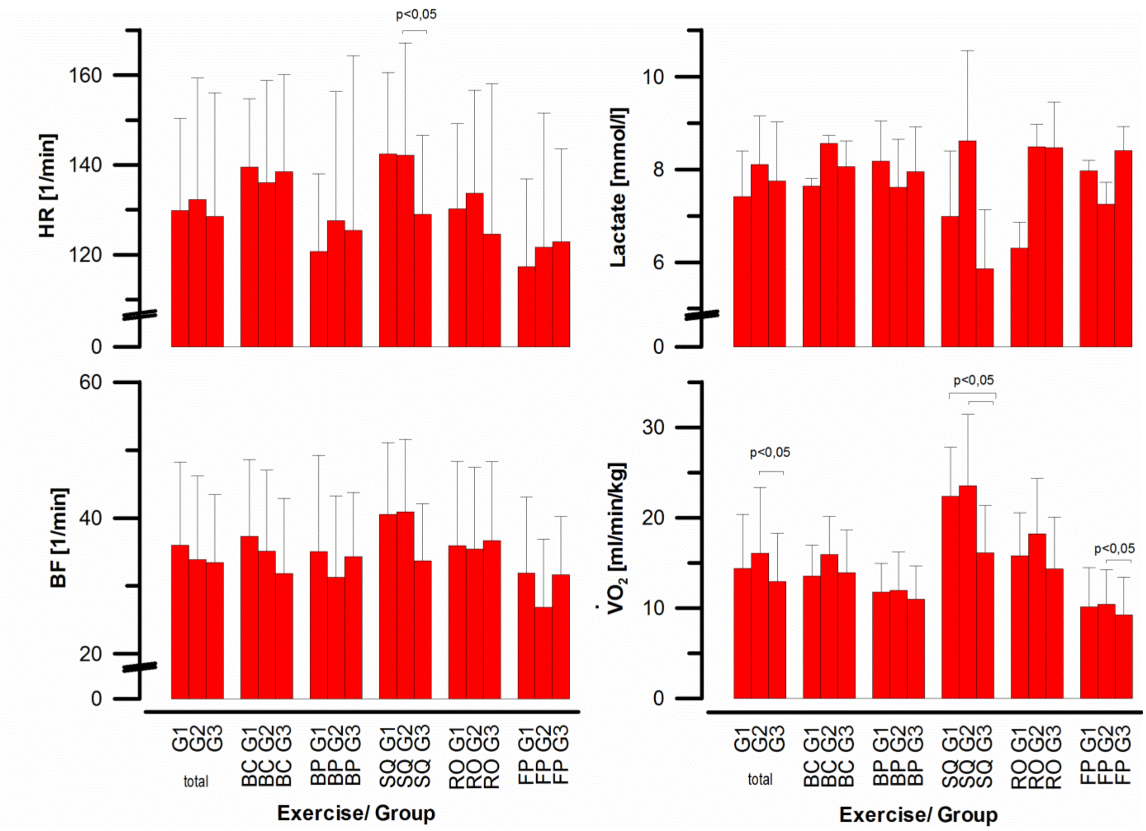

Figure 1. Physiological response of the three programs

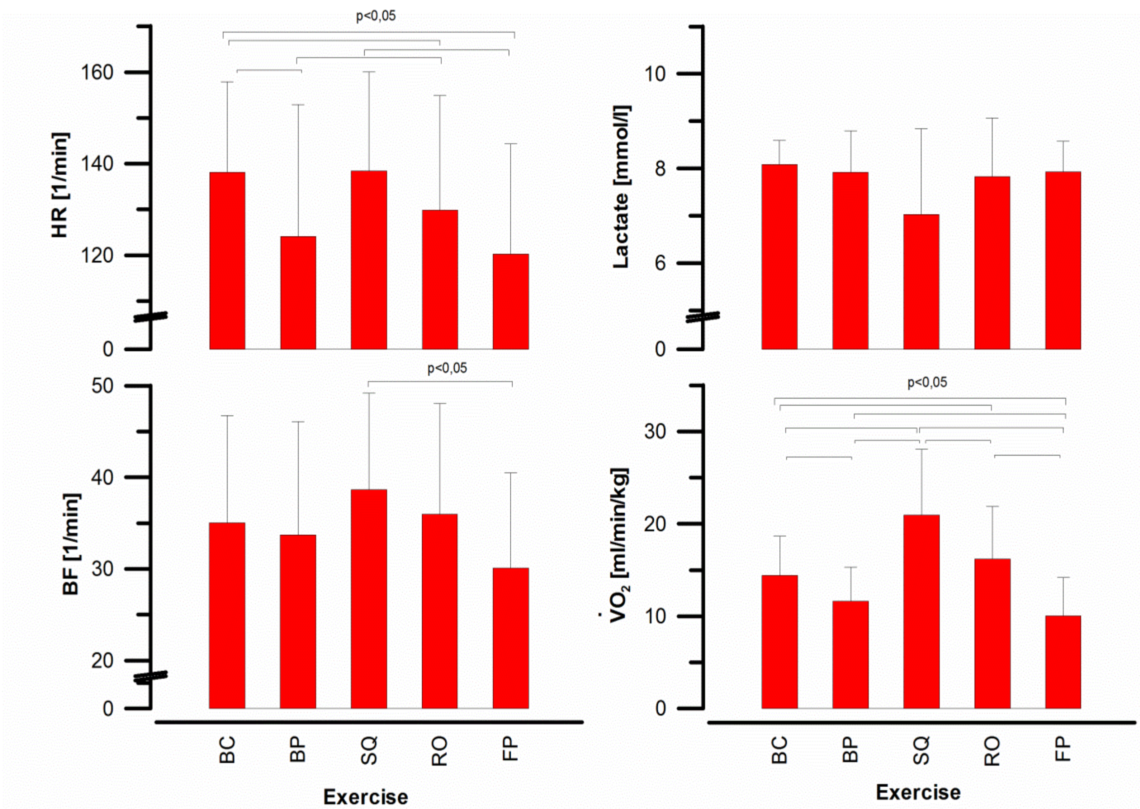

Figure 2. Physiological response of the exercises independent of exercise groups

It should be noted, that the measured physiological values are not exactly matching the applied physical loads of the program, due to a 30 second delayed adaptation of the $\dot{V}O_2$ [53]. The TUT in the G3 program could be too short to allow a complete representation of the acute load-dependent $\dot{V}O_2$-adaption. It may also be possible, that the physiological response was influenced by the different rest intervals between G1 and G2 [41]. Although three homogenous subject groups were present, the effects in a dependent design should be investigated in future studies. It is also necessary to examine the differences in physiological stress in programs that consist mainly of exercises with high muscle mass and great movement amplitude.

5. Conclusions

In summary, the present study show, that the physiological effects of the three different resistance training programs on $\dot{V}O_2$, HR, La and BF differed very little, despite the strongly differing RPI. The selection of the exercise seems to be especially important for the acute adaptations of $\dot{V}O_2$ and HR, but not for lactate accumulation.

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