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Changes in cardiopulmonary parameters during three sets of resistance training[1]

Summary

The positive effects of resistance training are well known. Unfortunately, there is a lack of studies investigating the acute cardiopulmonary response to this training modality. So far, we know, that the acute response depends on several aspects, e. g. intensity and rest interval. This cross-over study examined acute changes in cardiopulmonary parameters over the course of three progressive sets during standardized strength training.

On three study visits 14 healthy male participants (age: 24.5 ± 2.9 years; BMI: 24.1 ± 2.0 kg/m^2) performed three sets of ten repetitions with ascending intensities (50 %, 62.5 % and 75 % of their individual 3-Repetition Maximum). Heart rate, stroke volume, ventilation and oxygen uptake were measured during performance. Heart rate, ventilation and oxygen consumption increases significantly over the course of sets at all intensities. There were no significant changes for stroke volume.

The increase of parameters indicates an insufficient recovery time. Subsequent sets are performed in a pre-fatigued state, which leads to an increase in response. The steady course of stroke volume can probably be contributed to an immense increase in blood pressure and heart rate. The execution of a Valsalva maneuver might also lead to compromised cardiac filling.

Keywords: resistance training, cardiopulmonary response, sets

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Zusammenfassung

Die positiven Auswirkungen des Krafttrainings sind allgemein bekannt. Leider gibt es nur wenige Studien, die die akute kardiopulmonale Reaktion auf Krafttraining untersuchen. Bisher wissen wir, dass die akute Reaktion von verschiedenen Aspekten, wie z. B. von der Intensität und den Ruhepausen, abhängt. In dieser Cross-over-Studie wurden die akuten Veränderungen der kardiopulmonalen Parameter im Verlauf von drei progressiven Sätzen während eines standardisierten Krafttrainings untersucht.

Bei drei Studienterminen absolvierten 14 gesunde männliche Teilnehmer (Alter: 24,5 ± 2,9 Jahre; BMI: 24,1 ± 2,0 kg/m^2) drei Sätze mit zehn Wiederholungen mit unterschiedlichen Intensitäten (50 %, 62,5 % und 75 % ihres individuellen 3-Wiederholungs-Maximums). Herzfrequenz, Schlagvolumen, Ventilation und Sauerstoffaufnahme wurden während der Durchführung kontinuierlich gemessen. Die Herzfrequenz, die Ventilation und der Sauerstoffverbrauch steigen im Verlauf der Sätze bei allen Intensitäten signifikant an. Beim Schlagvolumen gab es keine signifikanten Veränderungen.

Der Anstieg der Parameter deutet auf eine unzureichende Erholungszeit hin. Nachfolgende Sätze werden in einem vorermüdeten Zustand durchgeführt, was zu einer Steigerung der Reaktion führt. Der stetige Verlauf des Schlagvolumens ist wahrscheinlich auf einen starken Anstieg des Blutdrucks und der Herzfrequenz zurückzuführen. Die Durchführung eines Valsalva-Manövers könnte ebenfalls zu einer Beeinträchtigung der Herzfüllung führen.

Schlagworte: Krafttraining, kardiopulmonale Antwortreaktion

1. Introduction

The positive effects of aerobic training are extensively studied (Cornelissen & Fagard, 2005; Hellsten & Nyberg, 2016; Yamamoto et al., 2001). In contrast, resistance training (RT) has just gained popularity in the general public during recent decades. Several studies demonstrated the positive effects of RT on different populations, e. g. on older adults and cardiac patients (Hunter et al., 2004; Pedersen & Saltin, 2006; Yamamoto et al., 2001). Benefits of RT include an increase in muscle strength, mass and endurance, prevention of osteoporosis, metabolic syndrome and muscle atrophy, improved low- and high-density lipoprotein cholesterol relation as well as a decrease of triglycerides and reduction of resting blood pressure (Damas et al., 2015; Kelley & Kelley, 2000, 2009; Meka et al., 2008; Westcott, 2012; Winett & Carpinelly, 2001). Organizations, such as the World Health Organization and the American Heart Association (Bull et al., 2020; Haskell et al., 2007; Nelson et al., 2007), recommend to combine RT and aerobic exercise in terms of prevention and rehabilitation for increased strength and greater cardiovascular benefit (Beckers et al., 2008; Pierson Lee et al., 2001; Volaklis & Tokmakidis, 2005; Wood et al., 2001).

During the 1980s and 1990s there has been great research interest in acute cardiovascular response to RT. Several studies measured changes in blood pressure, heart rate, stroke volume, cardiac output and left-ventricular function during different exercises and phases of RT, using direct measurement devices (Kleiner et al., 1996; Lentini et al., 1993; MacDougall et al., 1985; McKelvie et al., 1995; Meyer et al., 1999). However, pulmonary parameters were not included. Furthermore, the main focus was the evaluation of the blood pressure response and left-ventricular function during RT, particularly in cardiac patients, since there had been concerns regarding a negative impact of RT.

Next to endurance training, RT has become a main component in rehabilitation settings. The aim is to load the peripheral muscle sufficiently to stimulate adaptations, while avoiding great cardiovascular stress. While acute cardiopulmonary responses in endurance training have been extensively studied for various populations, this is not the case for RT. So far, we know that the acute physiological response to RT depends on intensity, volume, rest interval, breathing pattern, repetition speed, active muscle mass, type and phase of exercise (De Salles et al., 2009; Falz et al., 2019; Jansen et al., 2007; Kleiner et al., 1996; Lamotte et al., 2010; MacDougall et al., 1985; Mitchell et al., 1980; Ratamess et al., 2007; Volaklis & Tokmakidis, 2005). To the best of my knowledge the acute cardiopulmonary response over the course of subsequent sets has only been studied by two other studies (Jansen et al., 2007; Ratamess et al., 2007). However, with the purpose of giving more effective and safe RT prescriptions a better understanding of acute reactions to multiple sets of RT is needed. This cross-over study examined acute response of heart rate (HR), stroke volume (SV), ventilation (V_E) and oxygen consumption (VO_2) to a RT exercise over the course of three subsequent sets, executed in three ascending intensities (50 %, 62.5 % and 75 % of 3-Repetition Maximum (3-RM)). Based on previous findings HR, V_E and VO_2 are expected to increase over the course of subsequent sets. SV is expected to show a stable course.

2. Methods

The study was approved by the Ethics Committee of the Medical Faculty of the University of Leipzig (271/21-ek) and was conducted in accordance with the latest revision of the Declaration of Helsinki. Written informed consent was obtained from all participants. Participants with any kind of acute inflammatory, orthopedic, cardiac or pulmonary issues were excluded. Further exclusion criteria were current inactivity and orthopedic anomalies.

2.1 Participants

A total of 14 healthy, active male participants (N = 14) took part in this study (Table 1). All participants were familiar with the back squat technique and had experience in weight training for at least one year.

Table 1. *Baseline characteristics of participants, Mean ± SD*

Age and Performance Parameters	
Age	24.5 ± 2.9
Physical Activity (h/week)	7.1 ± 2.7
3-RM (kg)	94.5 ± 23.7
Anthropometric Parameters	
Height (cm)	183 ± 6.1
Mass (kg)	80.9 ± 7.2
BMI (kg/m^2)	24.1 ± 2.0
LBM (kg)	67.4 ± 5.6
FM (%)	13.8 ± 3.1
Baseline Parameter during IET	
HR (bpm)	77.3 ± 14
SV (ml)	107 ± 1.3
V_E (l/min)	13.6 ± 2.8
VO_2 (ml/min)	4212 ± 80

Annotation: 3-RM = Three Repetition Maximum, BMI = body mass index, LBM = lean body mass, FM = fat mass, IET = incremental exertion test, HR = heart rate, SV = stroke volume, V_E = ventilation, VO_2 = oxygen uptake

2.2 Procedure

Overall, the participants took part in four study visits (pre-examination, three squat sessions) with at least three rest days in between. Participants were asked not to perform any type of strenuous activity the day prior measurements.

2.3 Pre-examination

The pre-examination consisted of a comprehensive anamnesis (medical history, lifestyle questionnaire: physical activity, smoking, alcohol consumption) and measurement of body composition via bioelectrical impedance analysis measurement (Bioimpedance Analyzer BIACORPUS RC 4004M, MEDI CAL HealthCare GmbH, Germany) and an incremental exercise test (IET) on a semi recumbent ergometer (ergometrics 900, ergoline GmbH, Bitz, Germany). In order to determine the individual power, cardiac and pulmonary maximum output, as well as to check for abnormalities participants performed an IET to the point of exhaustion or the occurrence of any other critical indication (start at 50 W, increase of 15 W every minute at a constant speed of 60–70 rmp). Values from the IET are not included in this paper. Therefore, the IET procedure will not be explained further.

2.4 Squat sessions

The second visit consisted of the determination of the individual 3-RM. Participants performed multiple sets with three repetitions with increasing weight. The 3-RM was reached when participants stated that a fourth repetition would not be possible. After a 20-minute rest period, participants performed a standardized warm-up protocol and were then prepared with the measurement devices. Finally, participants performed three sets of 10 repetitions with four-minute rest interval at 50 % of their established 3-RM. The third and fourth appointments consisted of a warm-up followed by the same protocol using 62.5 and 75 % of their individual 3-RM.

Back squats were performed in a smith machine. Warm-up was standardized (five min ergometer at 50 W, 10 repetitions in the smith machine no added weight, five repetitions at 50 % and three repetitions at 75 % of planned weight). In order to standardize the squatting speed and maintain a constant pace, participants had to follow a protocol (two sec eccentric phase, two sec concentric phase, two sec standing phase, four min rest in between sets, no bottom pause). The start of each movement phase was visually cued via a screen in front of the participants. Participants had to perform a parallel squat and received auditory feedback, once the necessary depth was reached. During the warm-up sets participants were able to get familiarized with visual and auditory feedback.

2.5 Measurements

Although the investigation measured several cardiopulmonary parameters, only HR, SV, V_E and VO_2 will be analyzed and discussed in this paper. HR and SV were measured by impedance cardiography (Physioflow, Manatec Biomedical, Macheren, France). VO_2 and V_E were measured via a mobile spirometry device (K4b2, COSMED, Rome, Italy). All parameters were monitored continuously at rest, during training and five minutes post exercise. The values were averaged at 10-s intervals and peak values were calculated. Only mean values during sets will be further analyzed and discussed in this paper.

2.6 Statistical analysis

Data was analyzed using IBM SPSS statistics for Windows (Version 27.0. Armonk, New York USA) and GraphPad Prism 9 for Macintosh (GraphPad Software Inc, California USA). Significance level was defined as $\alpha < .05$. Multiple one-way repeated measures ANOVAs were conducted to determine whether there were statistically significant differences over the course of sets in each intensity. Post-hoc analysis with a Bonferroni adjustment was used for multiple comparisons. Data was normally distributed as assessed by Shapiro-Wilk test ($p > .05$). Boxplots were used to assess outliers. Few outliers were detected. Since they did not affect the results materially (ANOVAs were run with and without outliers, results were compared), outliers were included, and ANOVAs were carried out regardless of the outliers. Assumption of sphericity was assessed by Mauchly's test of sphericity. In case the assumption of sphericity was violated, a Greenhouse-Geisser correction was applied.

3. Results

Table two illustrates values of HR, SV, V_E and VO_2 for each intensity over the course of sets. Mean values of HR increased statistically significant among successive sets for all intensities (50 %: $F(2, 26) = 12.81$, 62.5 %: $F(1.36, 17.35) = 33.98$, 75 %: $F(2, 26) = 85.63$). SV did not show any significant mean difference and stayed relatively stable with each progressive set. V_E and VO_2 mean values increased significantly for all intensities among successive sets (VE: 50 %: $F(2, 26) = 18.61$, 62.5 %: $F(2, 26) = 2.58$, 75 %: $F(2, 26) = 52.38$; VO_2: 50 %: $F(2, 26) = 8.12$, 62.5 %: $F(2, 26) = 13.66$, 75 %: $F(2, 26) = 7.85$).

All parameter showed highest values during the last intensity.

3.1 Heart rate

Figure 1 shows significant differences for each parameter between first and second, second and third and first and third set. In the lowest intensity HR increased significantly from second to third and first to third. For the two other intensities HR increased significantly for all comparisons of sets.

3.2 Stroke volume

SV did not show any significant difference when comparing one set versus another for all intensities (Figure 1).

3.3 Ventilation

With the exception of second and third set at 50 % all increases were statistically significant (Figure 1).

3.4 Oxygen consumption

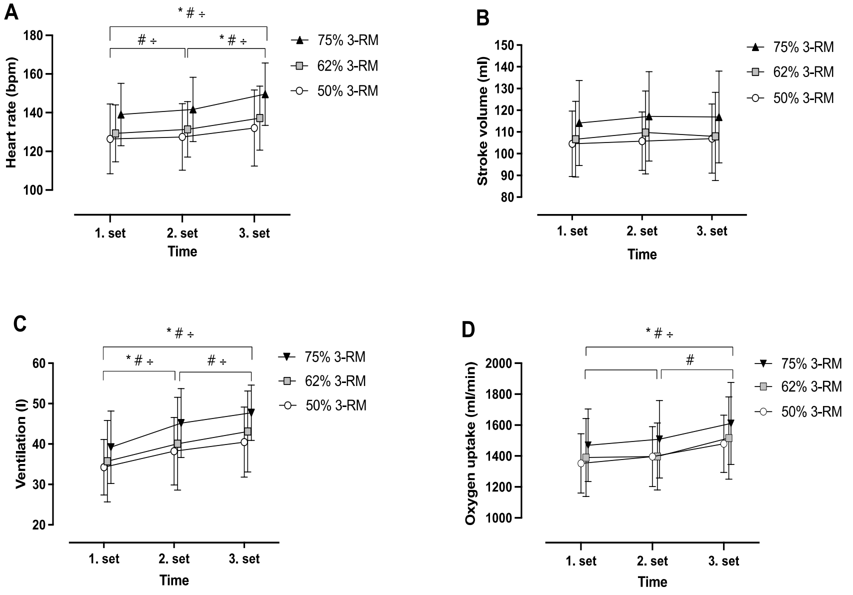
VO_2 increased significantly from first to third set for all intensities and from second to third at 62.5 % (Figure 1).

Table 2. *Mean ± SD and one-way repeated measure ANOVA*

	1st	2nd	3rd	p-value	η^2_p
50% 3-RM					
HR	126.43 ± 18.06	127.41 ± 17.18	132.41 ± 19.81	**.00**	.5
SV	104.54 ± 15.07	105.75 ± 13.49	106.94 ± 15.92	.59	.04
V_E	34.25 ± 6.87	38.16 ± 8.35	40.47 ± 8.66	**.00**	.59
VO_2	1352.18 ± 191.69	1395.75 ± 193.95	1479.03 ± 184.7	**.00**	.39
62,5% 3-RM					
HR	129.29 ± 14.69	131.35 ± 14.32	137.14 ± 16.57	**.00**	.72
SV	106.66 ± 17.43	109.77 ± 19.09	107.97 ± 20.34	.3	.09
V_E	35.71 ± 10.07	40.01 ± 11.48	43.1 ± 10.04	**.00**	.72
VO_2	1390 ± 252.15	1396.88 ± 216.99	1516.15 ± 265.88	**.00**	.51
75% 3-RM					
HR	139 ± 16.15	141.64 ± 16.65	149.59 ± 16.16	**.00**	.87
SV	114.14 ± 19.54	117.17 ± 20.58	116.89 ± 21.15	.09	.17
V_E	39.2 ± 8.98	45.17 ± 8.52	47.72 ± 6.85	**.00**	.8
VO_2	1469.59 ± 234.99	1508.39 ± 250.38	1610.86 ± 264.89	**.00**	.38

Annotation: HR = heart rate, SV = stroke volume, VE = ventilation, VO2 = oxygen uptake

Figure 1. Mean ± SD and post-hoc analysis



Annotation: A) heart rate, B) stroke volume, C) ventilation, D) oxygen uptake; * = significant difference in 50 %, # = significant difference in 62.5 %, + = significant difference in 75 %

4. Discussion

This paper aimed to investigate cardiopulmonary responses to a RT exercise over subsequent sets. As expected, except for SV, all parameters showed an increase with each successive set. Parameters were higher during 75 % of 3-RM compared to 50 % and 62.5 %.

The increase of HR, V_E and VO_2 throughout the protocol indicates an insufficient recovery time and could potentially indicate the occurrence of progressive overload. The American College of Sports Medicine (Ratamess et al., 2009) describes the progressive overload as a “gradual increase of stress placed upon the body during exercise” (S. 2). Therefore, it can be regarded as a key component necessary to stimulate an adaptation. More research is needed to evaluate if the progressive overload present in the cardiopulmonary parameters is associated with desired adaptations of a specific RT protocol.

Results suggest rising effort and fatigue with each successive set (Fleck, 1988; Jansen et al., 2007; MacDougall et al., 1985; Ratamess et al., 2007). Yet, the rest interval of four minutes was long enough for maintenance of ten repetitions over multiple sets, even at 75 % of 3-RM, but eventually not long enough for parameters to return to baseline values and a full replenishment of the ATP-phosphocreatine system (Kraemer, 1997; Ratamess et al., 2007). An increase in catecholamines might also be responsible for the increase in parameters (Lamotte et al., 2005). Ratamess et al. (2007) suggest at least two minutes of rest when performing two to three sets of RT for intensities greater than 75 % of 1-RM. They further explain the increase over sets is caused by a compounding effect. This means that subsequent sets are performed in a pre-fatigued state, hence, increasing fatigue rate in the following set, which leads to an increase in response. This is noteworthy as it can influence the training protocols regarding the desired type of adaptation. For example, if hypertrophy or strength adaptations are desired, longer, more recovering inter-set rest periods should be favored (Schoenfeld et al., 2016). If and how cardiopulmonary parameters are responsible for this bias towards longer rest periods needs further investigation.

Although not the main purpose of the study, Ratamess and colleagues (2007) compared HR, VO_2 and V_E (among other parameters) over the course of five subsequent sets during bench press. Participants performed five sets of ten repetitions at their 75 % of 1-RM and five sets of five repetitions at 85 % of 1-RM. Each condition was performed five times using different rest intervals. HR values ranged between approximately 140 and 160 bpm for all intensities and rest intervals. Values are comparable to the present study in which HR ranged from 126 to 150 bpm. Also, similar to the present study, V_E increased in succession of sets for all rest intervals. However, VO_2 values during longer rest intervals (3 and 5 min) are clearly lower compared to the present study in which participants rested for four minutes (3 min rest: 960 ml/min at 75 %, 890 ml/min rest at 85 %; 5 min rest: 780 ml/min at 75 %, 730 ml/min at 85 % vs. averaged values for intensities: 1408 ml/min at 50 %, 1434 ml/min at 62.5 %, 1529 ml/min at 75 %). Whereas 30 s rest interval resulted in comparable VO_2 values for both intensities (1460 ml/min at 75 %, 1360 at 85 %). In other words, less active total muscle mass and shorter rest intervals (< 1min) induced comparable acute VO_2 response as more active total muscle mass and longer rest intervals (> 2 min). This demonstrates that intensity is a contextual construct, and its definition needs to be in accordance with a desired outcome or adaptation. Another possible explanation could be the following: according to Lamotte et al. (2005) the relative intensity (% of RM) is the major factor determining the strength of the response, rather than the muscle mass. Hence, intensity becomes important when developed forces are equal. These findings could possibly be important for applications in rehabilitation settings since comparable cardiopulmonary response could be triggered using less active muscle mass or hypertrophic stimuli could be applied without triggering possibly undesired cardiopulmonary responses. However, the current study did not investigate different rest intervals and exercise protocols between the two studies varied. More research comparing acute response to different RT exercises (e. g. more global versus more local exercises), rest intervals and eventually even exercise order is needed in order to give specific (rehab) training recommendations.

In 2007 Jansen et al. investigated the acute HR and VO_2 response in four different RT exercises (squat, bench press, latissimus pulldown, neck press). Their results also were in line with the present study. HR and VO_2 increased over the course of four successive sets with ten repetitions. Unfortunately, only relative VO_2 values were given while HR values during squats also ranged from approximately 140 to 160 bpm. Also, the execution and type of the squat movement were not further explained. Their results, however, showed significantly higher VO_2 values during squat compared to the other exercises, while this was not the case for HR. This shows the difficulty of comparing different protocols and measured parameters, since also the relationship between parameters seems to differ based on exercise modalities, e. g. range of motion and cadence.

Lamotte and colleagues (2005) investigated HR values over four successive sets during leg press. Reported values are clearly lower compared to the present study (91 to 95 bpm). Also, the only significant difference was reported comparing the fourth and first set. A possible explanation might be the different study population, exercise protocol and relative intensity, as mentioned before.

Another study conducted by Gotshall and colleagues (1999) compared blood pressure response to three successive sets with ten repetitions of leg-press at 10-RM. Results showed a significant increase from first to second and second to third. Systolic blood pressure of 293 mmHg during the third set was recorded. However, they used a noninvasive measurement device which was applied to the finger. Direct methods might record even greater pressure response.

Although blood pressure and HR response does not seem to be linear during RT (Fleck, 1988), the results by Gotshall and colleagues (1999) might eventually be comparable, since both parameter increased significantly over sets (except first to second in 50 % of 3-RM in the present study). The relationship between HR and blood pressure over three successive sets is yet to be investigated.

As expected, SV did not increase over the course of subsequent sets in any intensity. Cardiac output increases during RT in order to generate sufficient blood circulation. However, SV does not seem to contribute to the increase during RT exercises (Lamotte et al., 2010; McKelvie et al., 1995; Meyer et al., 1999; Miles et al., 1987). Although cardiac output was not analyzed in this paper, data suggests similar results. Total peripheral resistance and blood pressure increase with the onset of RT, paired with an increase in HR, it leads to an apparent increase in myocardial contractility to ensure sufficient SV (Miles et al., 1987). Nevertheless, results indicate that the myocardium manages to maintain pump function despite increasing effort.

A further possible explanation for the missing increase in SV over sets could be the execution of a breathing pattern reminiscent of a Valsalva maneuver. Although participants were asked to not hold their breath during lifting, it is an unavoidable mechanism when performing at higher loads (MacDougall et al., 1992). The execution of Valsalva maneuver leads to an increase in intrathoracic pressure, which causes a further increase in blood pressure and reduced venous return, hence, leading to compromised cardiac filling (Lentini et al., 1993; MacDougall et al., 1992).

The only parameter showing a significant increase at the lowest intensity (first to second set at 50 % of 3-RM) is V_E. This indicates that energetic demands at least up to this point can be met with sufficient respiration. While VO_2 shows a slower increase (first to third, except 62.5 %). However, more research is needed to evaluate the onset of physiological responses of the cardiopulmonary system depending on the effort and intensity of RT.

5. Limitations

This paper only compared mean values during sets. However, higher values might have been measured during rest periods, since VO2 and SV seem to peak during the first minute after performance (Ratamess et al., 2007). Also, parameters change from repetition to repetition and even between movement phases (e. g. Lentini et al., 1993; Miles et al., 1987). Therefore, the present paper does not represent the entire magnitude of cardiopulmonary response.

RT protocols are extremely versatile and need to be considered within the constraints of their intended outcome. Consequently, it is not possible to compare different protocols if the intended outcome differs.

Intraindividual differences in local training status might have influenced the results. Although, all participants were experienced in RT, their sport background varied. Therefore, personal priorities in their RT protocols differed accordingly.

6. Conclusion

There is a lack of studies addressing acute cardiopulmonary response to RT. Furthermore, the few existing studies vary substantially in methodology (study population, exercise, intensity, sets, repetitions, rest interval, measurement devices, measurement time points, parameter), making it difficult to draw conclusions. However, all parameters showed a physiological course and progressed as expected. Single observations, such as the initial increase in V_E and main increase from first to third set in VO_2, could be made. More research using different populations, RT exercises and protocols is needed to fully understand the course of and relationship between the parameters.

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