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Original Article

Randomized controlled study on resistive vibration exercise (EVE Study): protocol, implementation and feasibility

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Abstract

Objectives: A training intervention comparing resistance exercise with or without whole-body vibration (WBV) was conducted to compare acute and chronic effects on functional and molecular parameters. **Methods:** A six-week training intervention was performed including 26 healthy males (26 years, SD=4). Two groups were analyzed in a parallel design performing either resistive exercise (RE, n=13) or resistive vibration exercise (RVE, n=13) training with weekly increasing vibration frequencies (20-40Hz). Resting and exercising blood pressure and heart rate were measured before and after the 6-week intervention. **Results:** Both training interventions decreased resting systolic blood pressure (P=0.003). Resting diastolic blood pressure was significantly decreased only in the RVE group (P=0.01). Exercising diastolic blood pressure was significantly decreased during the final training (P<0.001) with no additional effect of superimposed vibrations. Resistance exercise with superimposed vibrations evoked back pain to a higher degree than resistance exercise alone when training at frequencies above 30Hz (P<0.01). **Conclusions:** These data suggest positive effects of resistance exercise upon cardiovascular health and vascular responsiveness and a further beneficial effect of superimposed vibrations in decreasing resting diastolic blood pressure. Finally, development of back pain may be fostered by superimposed vibrations to high training loads, particularly at higher frequencies.

Keywords: Resistive Vibration Exercise, WBV, Blood Pressure, One-Repetition, Maximum, Training

Introduction

Regular performance of aerobic exercise is commonly known to have beneficial effects upon cardiovascular health such as decreases in heart rate and ambulatory blood pressure[1,2]. However, studies on cardiovascular adaptations to resistance exercise remain inconclusive. In the early 1980's, resistance exercise was believed to cause hypertension[3]. However, other studies showed that resting blood pressure was decreased by a resistance training intervention[4,5] whereas other studies showed no effect upon resting blood pressure in normotensive individuals[6-8]. The divergence in the reported effects indicates the need for further investigations in the field of cardiovascular adaptations to resistance exercise. Here we report acute and long-term responses of blood pressure and heart rate to a resistance training intervention performed with and without superimposed vibrations. Whole-body vibration (WBV) training has become increasingly popular during the past two decades and is nowadays applied in various fields like sport, rehabilitation and in clinical settings. Previous studies have made a great effort to describe physiological effects of whole-body vibration and have been reviewed elsewhere[9,10]. Unfortunately, many of the reported vibration-induced effects vary from study to study, which may derive from discrepancies in the applied training protocols, subject heterogeneity and divergence in the duration of the interventions. Furthermore, training supervision and diet control were neglected in many of the studies, and there was likewise no uniformity in the control conditions: studies either lacked a control group or compared their results to a passive

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control group; only few studies applied an exercise control condition[10]. Also, there is a lack of consistency in the way of reporting the results, as highlighted in the recommendations of the international society of musculoskeletal and neuronal interactions[11]. Many of the potential benefits of whole-body vibration may thus not have been clearly demonstrated. To the best of our knowledge, no study has yet compared acute effects of a specific exercise to its long-term adaptations. However, and considering that exercise is usually conducted regularly and over a longer period of time, it is pertinent to ask whether long-term training alters acute responses and if superimposed vibrations promote a beneficial training effect. Here we present the design, feasibility and demands of a conducted study that allows investigation of the adaptation of acute responses during exercise to a long-term training intervention. Acute functional parameters (cardiovascular responses, neuromuscular activation, oxygen consumption, muscle perfusion and oxygenation) are complemented with investigations of acute responses on circulating factors in serum as well as acute and long-term responses within muscle tissue. The various measurements within a single training study using an exercising control group will hopefully provide a broader insight into the effects of the vibration stimulus *per se*. The present article focuses on acute and long-term cardiovascular responses as well as feasibility and demands of the training.

Material and methods

Study design

The EVE study ("Molecular and functional **E**ffects of resistive **V**ibration **E**xercise") was conducted in a two-group parallel design and was carried out in compliance with the *Declaration of Helsinki* following approval by the Ethics Committee of the Northern Rhine medical association (Ärztekammer Nordrhein) in Düsseldorf (application no. 2010-174). After providing a written informed consent, 28 healthy male subjects were included into the study and stratified according to their vertical jumping height into two matched groups with comparable neuromuscular fitness, using the maximum vertical jump height as an indicator[12]. A coin was then tossed to determine which group would perform either resistive vibration exercise (RVE) or resistive exercise (RE) only. The study was conducted in two campaigns due to feasibility reasons: the first campaign with 12 subjects took place between October 2010 and March 2011, the second campaign with 16 subjects took place between May and October 2011.

Participants and group design

Healthy, male subjects were targeted who were recreationally physically active (exercised 2-3 times per week). Any competitive sports, participation in strength training during the past six months, smoking, diabetes as well as any current medication were considered as exclusion criteria. Subject recruitment involved a telephone questionnaire checking for general suitability (224 applicants), a medical screening comprising a short medical history, blood analysis (involving a complete blood count and investigation of clinical parameters *-creatinin, urea, protein, albumin, SGOT, SGPT, γGT, Lipase, alk. phosphatase, electrolytes, glucose, C-reactive protein and haematological parameters: PTT, aPTT, Quick, INR*), as well as a urine test checking for glucose, protein and urobilinogen. Finally, a stress electrocardiogram on a cycling ergometer and a training familiarisation were performed. The medical screening involved 60 applicants out of which 28 were included in the study. The subject's anthropometric data at baseline are given in Table 1, and no statistically significant group difference was found (P>0.08).

	RE group (n = 13)	**RVE group (n = 13)**	***P*-value**
Age [yrs]	23.4 (± 1.4)	24.3 (±3.3)	0.52
Body mass [kg]	75.0 (± 4.7)	74.7 (±6.9)	0.08
Height [m]	1.79 (± 0.05)	1.79 (±0.05)	0.31
BMI	23.4 (± 1.4)	23.5 (±2.1)	0.11
CMJ height [cm]	42.2 (± 4.6)	41.7 (±2.2)	0.97
Maximal performance on cycle ergometer test [W/kg body weight]	3.3 (± 0.3)	3.3 (± 0.4)	1.00

Table 1. Anthropometric data of EVE subjects at baseline. BMI: Body Mass Index, CMJ: Counter movement jump. There was no difference between the two groups.

Training design

The present study was designed to compare acute and long-term effects of two training interventions: Resistive Exercise (RE) and Resistive Vibration Exercise (RVE). Subjects trained for six weeks, 2-3 times per week with additional weights. In order to align the squatting movement, the weights were put on a guided barbell (PTS Dual action Smith, Hoist, U.S.A). A vibration platform (Galileo® Fitness, Novotech, Germany) was placed underneath, as illustrated in Figure1A. The subjects in the RVE group performed the resistive exercise training protocol with simultaneous side-alternating whole-body vibrations, whereas subjects of the RE group trained with the same setting, without superimposed vibrations. We aimed to test physiological responses at 40 Hz side-alternating vibration, which has not been tested before. Preliminary testing yielded that this is challenging for people not acquainted with whole-body vibration. We therefore decided to initially set the vibration frequency to 20 Hz and to increase the vibration frequency throughout the study to eventually arrive at 40 Hz.

Estimation of training load

The individual training load was set at 80% of the subjects One-Repetition Maximum (1-RM), which was estimated in the familiarisation session four weeks prior to the first training, applying the method of Baechle and Earle[13] and performing squats in a non-vibrating condition.

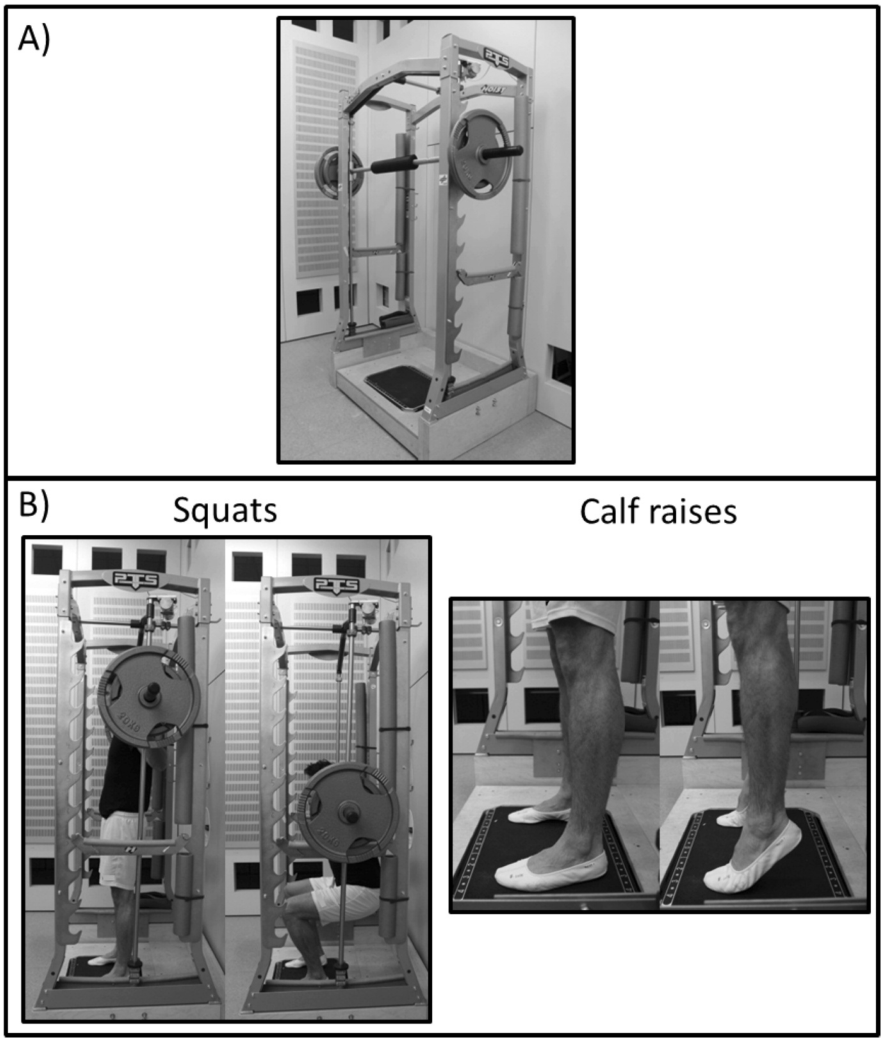

Figure 1. (**A**) Illustration of the training device. A guided barbell with a vibration plate placed underneath, embedded into a custom-built frame. (**B**) Illustration of the exercise movements. Squats (**left**) and calf raises (**right**).

% of the 1-RM	Repetitions
100	1
95	2
93	3
90	4
87	5
85	6
83	7
80	8
77	9
75	10

weight put on the barbell [kg] *wanted training load: 80 % of 1-RM [%]*

$$\frac{90 \quad * \quad 80}{87} = 82.76 \text{ kg} \xrightarrow{\text{rounding}} \mathbf{85\ kg}$$

estimated training load [%]
(according to 5 repetitions in left table)

training weight

Figure 2. Determination of training load. **Left:** calculation of the performed % of the One-Repetition. Maximum (1-RM) according to the number of concluded repetitions (adapted from Baechle and Earle). **Right:** example for estimation of training load at 80 % of the 1-RM.

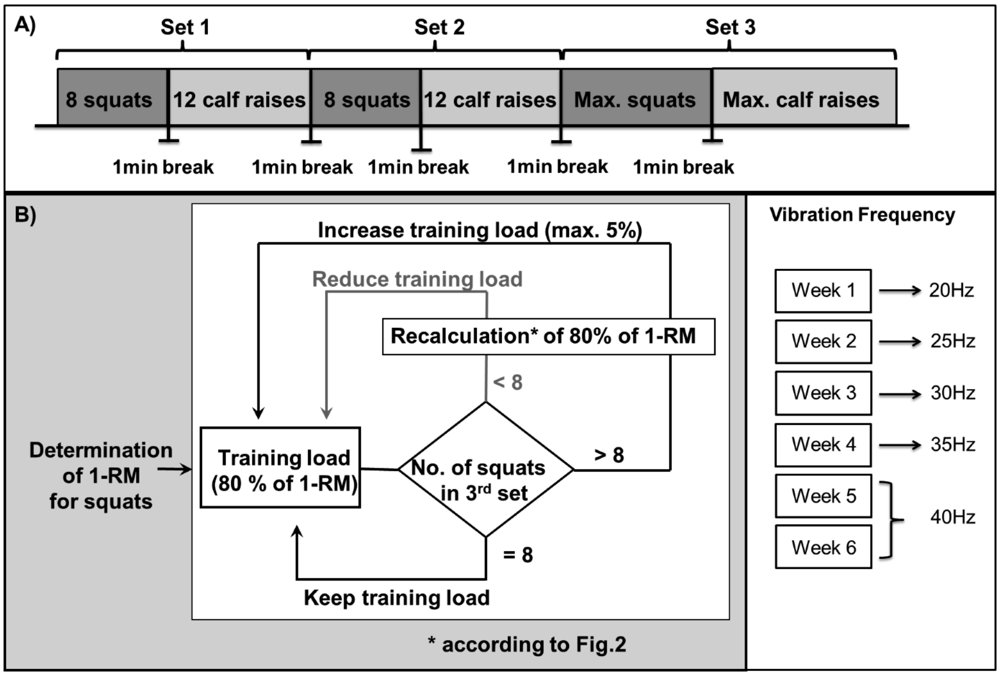

Figure 3. (**A**) Training design. After a warm-up, subjects performed three sets of squats and calf raises. The first two sets included 8 squats and 12 calf raises, in the third set, a maximum number of squats and calf raises was performed. (**B**) Increase of training intensity over the 6-week training intervention. **Left:** increase of training load for both intervention groups. **Right:** increase of vibration frequency in the resistive vibration exercise (RVE) group. 1-RM: One-Repetition Maximum.

Briefly, the guided barbell was initially loaded with weights corresponding to the subject's body weight plus 20 kg and subjects were asked to perform as many squats as possible. The corresponding % of the 1-RM was evaluated according to Baechle and Earle[13]. An example is illustrated in Figure 2: if the barbell was loaded with 90 kg and the subject's maximum number of repetitions was 5, which corresponds to 87% of the 1-RM, the training load was adjusted to 85 kg.

Training protocol

The training was supervised by a graduated exercise scientist throughout the study and two spotters were standing left and right of the guided barbell providing subject security. A metronome guided the training rhythm to provide standardisation of the movement. Squats were performed dynamically with 2 sec. eccentric and 2 sec. concentric phase; calf raises were performed with 1 sec. eccentric and 1 sec. concentric phase (Figure 1B). Each training session included a warm-up with the unloaded barbell (15 kg), which consisted of two sets; each set with 10 squats and 15 heel raises. The actual training was performed in three sets: the first two sets comprised 8 squats and 12 calf raises; in the third set, as many squats and calf raises as possible were performed (Figure 3A). Immediately after completion of the last set of squats, each subject's perceived exertion was rated via the Borg RPE Scale[14]. Altogether, the subjects concluded 16 training sessions in a period of 6 weeks (week 1-2: two sessions per week; week 3-6: three sessions per week). Both training regimens differed only in the vibration component.

Increase of training load and vibration frequency during the 6-week intervention

The number of squats in the third set was used to readjust the training weight to 80% of the 1-RM for the following training. When the number of squats in the third set was equal to 8, the training weight remained unchanged for the subsequent training. When the subjects performed more or less than 8 repetitions, the training weight was recalculated, i.e. increased or decreased for the next training. However, the top limit for weight increases was set at 10 kg in order to guarantee steady weight increments. The RVE group started the training with 20 Hz vibration with weekly increments by 5 Hz; during the last two weeks, vibration frequency was set at 40 Hz. A schematic overview of the incremental study design is displayed in Figure 3B.

Diet

During the initial and final training sessions, subjects ate a standardised breakfast two hours before training (two wheat bread rolls with butter and jam). During the long-term training intervention, subjects were asked to abstain from food two hours before every training session and to drink a protein energy drink (*Fresubin® protein energy drink,* Fresenius Kabi, Germany) one hour prior to training.

Study Week	-4	-3	-2	-1	1		2		3			4			5			6			+3d	+4d	+90d
Measurement / Training no.	BDC			Initial Training	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Final Training	Follow-up measurements		
Vibration frequency				20 Hz	20 Hz		25 Hz		30 Hz			35 Hz			40 Hz								
Diet (s=standardised, f=fastened)		f	f	s					f						f				f	s	f	f	
Protein Drink (1h pre training)					x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x			
Freiburg Questionnaire			x																		x		
Rating of Perceived Exertion				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x			
Estimation of training load	x																						
Familiarisation Session	x																						
Body Weight Determination			x																		x		
Jump tests	x																				x		x
Doppler Ultrasound		x							x						x				x		x		
MRS		x																			x		x
MVC		x																			x		x
MRI			x																			x	x
Gait Analysis			x																x				
Blood Pressure, Heart Rate				x																x			
Lactate Test	x			x					x						x					x	x		x
Spirometry during Training				x																x			
EMG during Training				x																x			
NIRS during Training				x																x			
Serum Collection				x																x			
Muscle Biopsy			x	x																		x	

Figure 4. Overview of the EVE-Study design. BDC (Baseline Data Collection) was performed during 4 weeks prior to the initial training; follow-up measurements were performed 3, 4 and 90 days (d) after the final training. MRS: Magnetic Resonance Spectroscopy, MVC: Maximal Voluntary Contraction, MRI: Magnetic Resonance Imaging, EMG: Electromyography, NIRS: Near-Infrared Spectroscopy.

Measurements

The present study was designed to characterize the acute and long-term effects of resistive exercise and superimposed vibrations on both functional and molecular levels. An overview of the measurements with the corresponding time points is depicted in Figure 4.

Determination of daily physical activity

The Freiburg Questionnaire[15] was applied to assess the subject's daily physical activities. Subjects filled the questionnaire one week prior to and three days after the 6-week training intervention.

Blood pressure and heart rate at rest and during exercise

Resting heart rate and blood pressure were recorded after 20 minutes in horizontal position with an automated sphygmomanometer (Medicus pc, Boso, Germany). Exercise blood pressure was measured during each break between the sets and immediately after training termination by a medical doctor using a manual sphygmomanometer. Heart rate was measured manually by an exercise scientist.

Rating of perceived exertion (RPE)

The Borg RPE scale[14] was used for the assessment of the perceived exertion of the training. Within 20 sec after the last set of squats, subjects provided their individual RPE.

Statistical analyses

Statistical analyses were performed using STATISTICA 10 for Windows (Statsoft, Tulsa, Oklahoma, USA, 1984-2010). For estimation of differences in training load increments, rating of perceived exertion, blood pressure and heart rate, a repeated measures ANOVA was applied with time (initial vs. final) and intervention (resistive exercise vs. resistive vibration

Training week	Vibration Frequency	Back RVE	Pain RE	Headache RVE	RE
1	20 Hz	-	-	-	-
2	25 Hz	-	-	-	-
3	30 Hz	3	1	1	-
4	35 Hz	1	1	2	-
5,6	40 Hz	4	-	-	-
	Sum	8**	2	3	0

Table 2. Important events during the study. Numbers of subjects are indicated perceiving headache or back pain in the respective training week. RE: resistive exercise group; RVE: resistive vibration exercise group. **Higher compared to RE group (chi-value<0.01).

exercise) as factors; Tukey's test was used for post-hoc testing. For estimation of daily physical activity (*Freiburg* Questionnaire), a paired, two-sided Student's t-test was performed to compare physical activity before and after of the 6-week training intervention; an unpaired, two-sided t-test was performed to test differences between the two intervention groups. For estimation of vibration-induced back pain, a chi-square analysis was performed. Values are given as means ± standard deviation, statistical significance was set at $P<0.05$.

Results

Freiburg Questionnaire of physical activity

Daily physical activities like walking, biking, stair climbing, activity at work, sleeping and weekly sportive physical activity did not differ before and after the 6-week training intervention (P-values between 0.12 and 0.96) and did not differ between the two intervention groups (P-values between 0.32 and 0.75).

Important events during the study

When training at frequencies above 30 Hz, eight of the RVE subjects complained about back pain. In one of the subjects, back pain was the cause for dropping out of the study. The sudden onset of back pain in the drop-out subject was caused by an incident during training. The impression of the personal trainer and his assistants present during that exercise session was that the incident resulted from training with poor body balance, which led to bending of the back. An independent orthopaedic surgeon diagnosed a facet joint syndrome L1-2, which did not implicate sensory or motor deficits. The back pain lasted for seven days after the incident and was ranked by the subject to an intensity of 8 using a scale ranging from 0 to 10, where 0 indicated "no pain" and 10 indicated "severe, unbearable pain". The subject had demonstrated questionable commitment before that event, which reinforced the decision was made to exclude him from the further participation.

Back pain reported by the other seven subjects that completed the study successfully was assessed via a questionnaire. All seven subjects reported low back pain without radiculopathy. One subject complained about pain during training, whereas the majority (6 out of 7 subjects) perceived back pain after training termination. The duration of the pain varied: two subjects reported acute pain until 1-2 hours after training, and four subjects reported pain until 2-3 days after training. The pain intensity estimated by the subjects ranged from 3 to 7 and was on average 4.4 (SD=1.4), using a 0-10 scale (as described above). None of the subjects had to take analgetics to relieve the pain. There were only two cases of back pain in the RE group: one subject complained about local neck pain at the site of weight application, the other subject complained about "light" muscle tenderness in the lumbar spine. Statistical analyses revealed that resistive vibration exercise at frequencies of 30 Hz and above caused back pain in a higher number of cases than resistive exercise alone (Chi-value<0.01); details are listed in Table 2.

Furthermore, four subjects in the RVE group complained about a training-induced headache with an onset after the second training set, out of which one subject dropped out after four weeks of training because of a headache that was reproducibly generated by the combination of vibration, application of the bar bell and calf raises. A post-hoc medical check revealed the absence of the physiological lordosis of the cervical spine as a likely explanation for this reaction.

Conduct of exercise: missed training sessions

In the RVE group, four subjects completed all 16 training sessions and nine subjects missed a single training session. In the RE group, ten subjects completed all 16 training sessions and three subjects missed a single training session.

Increase of training load

The training loads were comparable between the two groups at the initial training (RVE: 81.5±7.7 kg, RE: 75.2±6.5 kg; P=1.0) and increased over time in both groups ($P<0.001$). Compared to the initial training, the increase in training load over the six-week training intervention was significantly higher in the RE group and accounted for 59.8±17.3 %, compared to 46.9±19.0 % in the RVE group (time * intervention: $P<0.001$). As the weight increase was more pronounced in the RE group, post-hoc analyses reveal that RE subjects trained with significantly higher training loads compared to the RVE group in trainings 13 to 16 ($P<0.01$). During the final training, the RE group trained with 130.2±18.5 kg and the RVE group trained with 110.2±15.8 kg (P=0.003), see Figure 5.

Rating of perceived exertion (RPE)

The perceived exertion of the initial training was rated as "hard" according to the Borg RPE scale, and there was no difference between groups: 15.5±1.6 (RE) vs. 15.9±1.3 (RVE), P=0.52, see Figure 6. RPE data derived during the 6-week training reveal that superimposed vibrations did not alter RPE as there was no significant group effect (P=0.73). However, there was an overall increase in RPE over time (P=0.048). Post-hoc analyses showed that the RPE was higher during training 9-16 when compared to training 1-4 ($P<0.05$). During

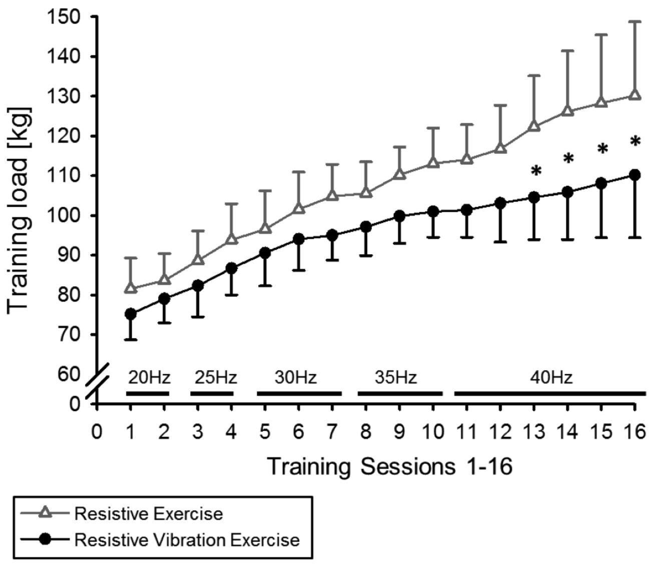

Figure 5. Training load increase during the 6-week training intervention. Bars indicating 20-40Hz refer to the applied vibration frequency in the RVE group. Training loads increased over time in both groups (time effect: $P<0.001$). The training load increase was more pronounced in the Resistive Exercise group and after the 13th training session, the RE group trained with significantly higher training loads (*$P<0.01$).

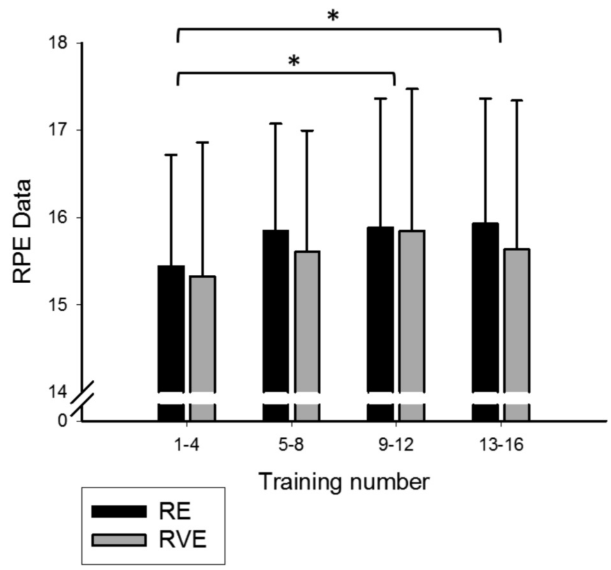

Figure 6. Rating of the training's perceived exertion. The subjects in both groups rated the perceivedexertion (RPE) of the training to "hard" and there was no difference between the Resistive Exercise (RE) and Resistive Vibration Exercise (RVE) groups. RPE was significantly higher in trainings 9-16 compared to trainings 1-4 (*$P<0.05$).

	Rest				During Training			
Group	**RE**		**RVE**		**RE**		**RVE**	
Variable	**Pre**	**Post**	**Pre**	**Post**	**Initial**	**Final**	**Initial**	**Final**
SBP [mmHg]	126 ± 8	118 ± 11**	122 ± 4	113 ± 9**	147 ± 18	143 ± 13	147 ± 13	142 ± 18
DBP [mmHg]	71 ± 9	65 ± 11	71 ± 6	62 ± 8**	81 ±8	72 ± 9 ***	82 ± 7	74 ± 10***
HR [bpm]	55 ± 9	52 ± 7	56 ± 8	54 ± 7	125± 17	127 ± 15	126 ± 21	131 ± 23

Table 3. Cardiovascular parameters at rest (left) and during exercise (right). Stars indicate significant difference (time effect) within the same group: *$P<0.05$; **$P<0.01$; ***$P<0.001$. *Pre* and *Post* refer to resting values before and after 6 weeks of training; *Initial* and *Final* Training refer to the first and last exercise session of the 6-week training intervention. SBP: systolic blood pressure; DBP: diastolic blood pressure; HR: heart rate.

the last training, RPE accounted for 15.9 in the RE group and 16.38 in the RVE group. Of note, RPE during the last training was comparable between groups ($P=0.15$), although the RE group trained with significantly higher training loads ($P=0.003$). Furthermore, there was no correlation between RPE and heart rate (R=-0.13; $R^2=0.017$; $P=0.42$) as previously described for endurance exercise[16].

Cardiovascular parameters at rest

Resting Systolic Blood Pressure (SBP) and Diastolic Blood (DBP) pressure were both decreased from pre levels during the follow-up measurement after 6 weeks of training (SBP: $P=0.003$; DBP: $P=0.001$) with no significant differences between the two groups (SBP: $P=0.06$; DBP: $P=0.5$) as depicted in Table 3. Post-hoc analyses revealed that the decrease of DBP was more pronounced in the RVE group as this group depicted significant decreases ($P=0.01$), whereas the decrease of DBP did not reach significance in the RE group ($P=0.055$). Resting heart rate (HR) remained unaffected by the training intervention in both groups ($P=0.14$), see Table 3.

Cardiovascular parameters during exercise

Blood pressure and heart rate measured within single training sessions were comparable between sets ($P>0.28$) and therefore, data of the three sets were pooled for further analysis. There was a trend of decreased systolic blood pressure during exercise after 6 weeks of training in both groups, which however failed to reach the level of significance ($P=0.052$). Diastolic blood pressure during exercise was significantly decreased in both groups ($P<0.001$). As a result of the decreased

DBP with unaltered SBP, exercise pulse pressure (=SBP-DBP) was significantly increased in both groups after 6 weeks of training (P=0.04). Six weeks of training did not alter exercise heart rate in neither of the groups (P=0.39), see Table 3. Exercise blood pressure and exercise heart rate did not differ when comparing RE to RVE (SBP: P=0.9; DBP: P=0.6; HR: P=0.5).

Discussion

Feasibility

The incremental design of the training was reflected by an increase in Borg RPE over time (Figure 6), as the training was perceived as significantly "harder" in training sessions 9-16 compared to training sessions 1-4. The subject's daily physical activities were comparable between the two groups and did not change over the duration of the study (*Freiburg* Questionnaire). These data indicate that the obtained results from the EVE study actually derive from the training intervention itself and were not induced by external factors.

While vibration frequency was increased on a weekly basis, the RVE group trained at equal or higher training loads compared to the previous week. Only in four cases out of 52 individual increases in vibration frequency (=4 frequency increases * 13 subjects), training loads had to be decreased due to an increase in vibration frequency when training with frequencies above 35 Hz. When training with frequencies between 20 and 30 Hz, superimposed vibrations were well tolerated. However, data from the present study suggest that the risk of low back pain is substantially increased when performing resistance exercise with superimposed vibrations and frequencies above 30 Hz (see Table 2). Seven out of thirteen subjects that concluded the study successfully complained about low back pain, which would probably be classed as uncomfortable, but not severe. The back pain might either derive from the vibration itself, or from the way that the guided barbell was employed, which was always with a certain reclination toward the back. This could have increased the amount of instability in the movement when training with high vibration stimulation. This lack of stability might have caused the training incident that led to the drop-out of one subject in the RVE group. However, it remains unknown whether the vibration component was actually the cause for the training incident.

Demands

Increase of training load with and without superimposed vibrations

There was no difference between the two groups concerning One-Repetition Maximum or jump height at the beginning of the study, indicating two groups with comparable muscular performances. As expected, training loads were increased over time. However, after the 13th training session, when RVE subjects trained with 40 Hz simultaneous vibrations, the increase of training weight was hampered (Figure 5) compared to the group training without vibrations. In the end of the study, the RE group trained at 18% higher training loads compared to the RVE group. It is known that sinusoidal vibrations engender increases in peak foot acceleration to the power of two[10], and thus, increases in vibration frequency lead to pronounced elevations of musculoskeletal forces. We conclude from our data that the increase of training weight (*external* training load) might be hampered by vibration-induced elevation of musculoskeletal forces (*internal* training load) and the combination of the two add up to the total muscle loading during RVE. This idea is supported by the Rating of Perceived Exertion data, which indicate that training at lower weights with 40 Hz WBV was perceived equally demanding as training without vibrations and higher weights.

Chronic cardiovascular adaptations at rest

There is strong evidence supporting beneficial effects of endurance exercise upon cardiovascular health such as decreases in blood pressure and heart rate[1,2]. However, limited data are available on the effect of long-term resistance exercise training in healthy, recreationally active people. Resistance exercise has been reported to have beneficial effects in obese subjects as well as in people with metabolic syndrome or hypertension[17-19]. Previous studies involving healthy young males show that resting systolic and diastolic blood pressures were decreased by a resistance training intervention[8,20]. Another study shows a 4% decrease in resting systolic with no change in diastolic blood pressure[5]. Results from the present study show that resting systolic and diastolic blood pressures were both decreased by 7 to 12 % after only six weeks of training and there were no alterations in resting heart rate. Our data support the view that high-resistance exercise is beneficial for cardiovascular health. Further, our data suggest that superimposed vibrations might be additionally beneficial as diastolic blood pressure was significantly decreased only in the RVE group.

Chronic adaptations of the acute cardiovascular responses to resistance exercise

It has been shown that body builders have lower systolic and diastolic blood pressures and heart rates during resistance exercise compared to recreationally active people[21]. Previous studies have reported that resistance training results in adaptations that hamper the acute training-induced increases in heart rate and blood pressure[22,23]. In the current study, we found that 6 weeks of resistive exercise decreased diastolic blood pressure during exercise whereas systolic blood pressure and heart rate were unaltered compared to the initial training. This decrease in <u>diastolic</u> blood pressure might derive from increased vasodilation during exercise and thus, the applied training interventions in the current study seem to have improved vascular responsiveness. This idea is supported by previous studies showing that WBV increases blood flow velocity after vibration termination[24,25], indicating vibration-induced dilation of feeding arteries. Our data reveal that only exercising diastolic blood pressure was decreased after 6 weeks of training, whereas systolic blood pressure remained unaltered, yielding increases in pulse pressure (=SBP-DBP). As pulse pressure is known to be proportional to stroke volume[26], there is evidence that the resistive exercise intervention conducted in this study increased cardiac stroke volume and maybe cardiac output. There was, however, no additional effect of superimposed vibrations, neither during the first training nor after 6 weeks of training.

Summary and Conclusions

In summary, both training interventions were feasible and the incremental training design was reflected by an increase in RPE. Superposition of vibrations to resistive exercise for some reasons hampered the increase of training load when training at frequencies above 35 Hz. Furthermore, our data show that 6 weeks of resistance exercise decreased resting blood pressure (systolic and diastolic) as well as exercising diastolic blood pressure. We conclude that WBV in combination with high-resistance exercise is well tolerated when training with frequencies below 35 Hz. However, when training with 35 Hz and above, this exercise type seems to foster back pain and to reduce training performance. It is possible that training with side-alternating vibration above 30 or 35 Hz may elicit sub-optimal results. Thus, it might not be recommendable to use these high frequencies combined with resistance exercise, at least not for non-athletes. Finally, our data also demonstrate a beneficial effect upon arterial blood pressure.

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