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Effects of whole body vibration in patients with chronic obstructive pulmonary disease – A randomized controlled trial☆

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Summary
Introduction: To date endurance and strength training are established and evidence-based exercise methods in patients with chronic obstructive pulmonary disease (COPD). There is an unmet need for further research in new and complementary exercise modalities. Additional whole body vibration training during pulmonary rehabilitation may be such a new approach that has not yet been investigated in patients with COPD.
Methods: Eighty-two patients (65 ± 9 yrs, FEV_1 pred. 38 ± 11%, female 51%) with COPD in GOLD stage III to IV assessed for a 3-week inpatient multidisciplinary rehabilitation program were on top randomly assigned to one of two intervention groups: (1) 3 × 3 min of bilateral dynamic squat exercises on a side-alternating vibration platform at 24–26 Hz three times per week (WBV) and (2) a control group (CON) with the same amount of exercise time without WBV.
Results: Thirty-six patients completed the study in each group. The improvement in 6-min walking distance was significantly higher in the WBV-group when compared to the CON-group (WBV: 64 ± 59 m, CON: 37 ± 52 m with a between-group difference of 27 m [95% CI, 1–53], $p = 0.046$). The time required for a sit-to-stand test also decreased more markedly in the WBV-group than in the CON-group (WBV: −4.0 ± 4.8 s, CON: −2.0 ± 3.1 s with

Abbreviations: 6-MWD, Six-minute-walking-distance; ATS, American Thoracic Society; BODE, The Body-Mass Index Airflow Obstruction Dyspnea and Exercise Capacity Index; BMI, Body-Mass-Index; CON, Control-group; COPD, Chronic obstructive pulmonary disease; CRQ, Chronic Respiratory Questionnaire; DLCO, Diffusion capacity of the lung for carbon monoxid; FEV_1, Forced expiratory volume in 1 s; GOLD, Global Initiative for Chronic Obstructive Lung Disease; HRQL, Health related quality of life; IQR, Interquartile range; LTOT, Long term oxygen therapy; MCID, Minimal clinical important difference; SST, Sit-to-stand test; WBV, Whole body vibration.

☆ This trial has been registered in the Clinical Trials registry (identification number NCT01380639).

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a between-group difference of −1.9 s [95% CI, −4.0 to 0.1], $p = 0.067$). Improvements in health-related quality of life were similar in both groups.
Conclusions: WBV training seems to be a promising new exercise modality for patients with COPD and may enhance the effects of a multidisciplinary rehabilitation program.

Introduction

Limited exercise capacity is one of the main systemic manifestations of chronic obstructive pulmonary disease (COPD) associated with poor health-related quality of life (HRQL), exacerbations and increased mortality risk.[1–3] Pulmonary rehabilitation is regarded as an evidence-based treatment for symptomatic patients with COPD to improve exercise tolerance, reduce symptoms of dyspnea and increase HRQL.[4,5] Exercise training is seen as a cornerstone in pulmonary rehabilitation programs.[6] Whilst the use of endurance and strength training are established and evidence-based exercise modalities in patients with COPD,[7,8] the validation of further complementary exercise methods is considered a remaining challenge.[9]

Exercising on a whole body vibration plate might be such a new and additional approach. During a whole body vibration (WBV) session, subjects exercise on a vibrating platform that produces sinusoidal oscillations. In healthy subjects it has been shown that performing resistance training on a vibrating platform induces greater neuromuscular and hormonal responses than resistance training alone by providing a more intense stimulus.[10] So far WBV has also been established in rehabilitation programs for patients with neurological diseases to improve postural control or for patients with osteoporosis to enhance bone mineral density.[11–13] Up to now the effects of WBV training in patients with pulmonary diseases have rarely been studied. Based on the assumption that an increase in muscle strength and performance are considered the major effects of WBV,[14,15] this could be a promising exercise modality for patients with COPD. Therefore we conducted this prospective randomized controlled trial to investigate the effects of WBV during multidisciplinary inpatient rehabilitation in patients with COPD.

Methods and materials

Study design

Consecutive patients admitted to a 3-week inpatient rehabilitation program were asked to participate in this randomized controlled parallel group study. Patients were not blinded to the intervention as this was not possible within this setting. Inclusion ran from April 2010 until April 2011. The trial was submitted to the Clinical Trials registry (identification number NCT01380639) and was approved by the Bavarian ethics committee (identification number 11050).

Study population

Eighty-two patients participated in this study. To attend the study, patients had to meet the following inclusion criteria: (1) assured diagnosis of COPD stage III or IV according to the Global Initiative for Chronic Obstructive Lung Disease (GOLD)[16] and (2) given written informed consent. Exclusion criteria were defined as follows: 1) status post surgery or post bone fracture, 2) status post deep vein thrombosis, 3) existing arterial aneurysm, 4) COPD exacerbation within the last 4 weeks or 5) non compliance to study protocol.

Intervention

Patients followed a multidisciplinary inpatient rehabilitation program of 3-weeks duration that included therapy units on 5 days per week. The rehabilitation program consisted of medical care, breathing therapy, education, nutritional counseling and psychological support. Exercise training consisted of endurance training (15 min cycling at 60% peak Watt) and strength training (4–6 exercises with 3 sets at the 20-repetition-maximum for major muscle groups). These components were equal for all patients. Additionally patients were randomly assigned to one of two intervention groups. Both groups attended a supervised squat exercise program. The only difference between groups was the surface on which the squats were performed. The first group (WBV), $n = 42$ performed squat exercises on a whole body vibration plate (GALILEO®, Novotec Medical GmbH, Pforzheim, Germany) at 24–26 Hz and 6 mm peak-to-peak amplitude (Fig. 2). The side-alternating movement of the GALILEO® plate evokes muscle contractions on the entire flexor and extensor chain of muscles in the legs and all the way up to the trunk.[17,18] Instead of voluntary muscle control like in common resistance training, the muscle contractions during vibration training (above 12 Hz) are caused by stretch reflexes.[19,20] The user has no direct influence on muscle activity itself and can only control body posture, movement and exercise objective.

The second group, regarded as control group (CON), $n = 40$ performed the same amount of supervised squat training on the floor. The training schedule for both groups consisted of three sets with 3-min sessions of self-paced squats 3 times per week.

Outcomes and measurements

Primary outcome parameter of the study was the change in 6-min-walking-distance (6-MWD). The 6-MWD was performed according to the guidelines of the American Thoracic Society (ATS).[21] The best out of two tests on day 1 and 2 was used as a baseline value to exclude any learning effects.[22]

As a second exercise test a sit-to-stand test was performed. For the sit-to-stand test subjects were asked to stand up and sit down from a standard chair (height 43 cm) as quickly as possible with their arms folded across their chest. The time that patients needed to perform 5

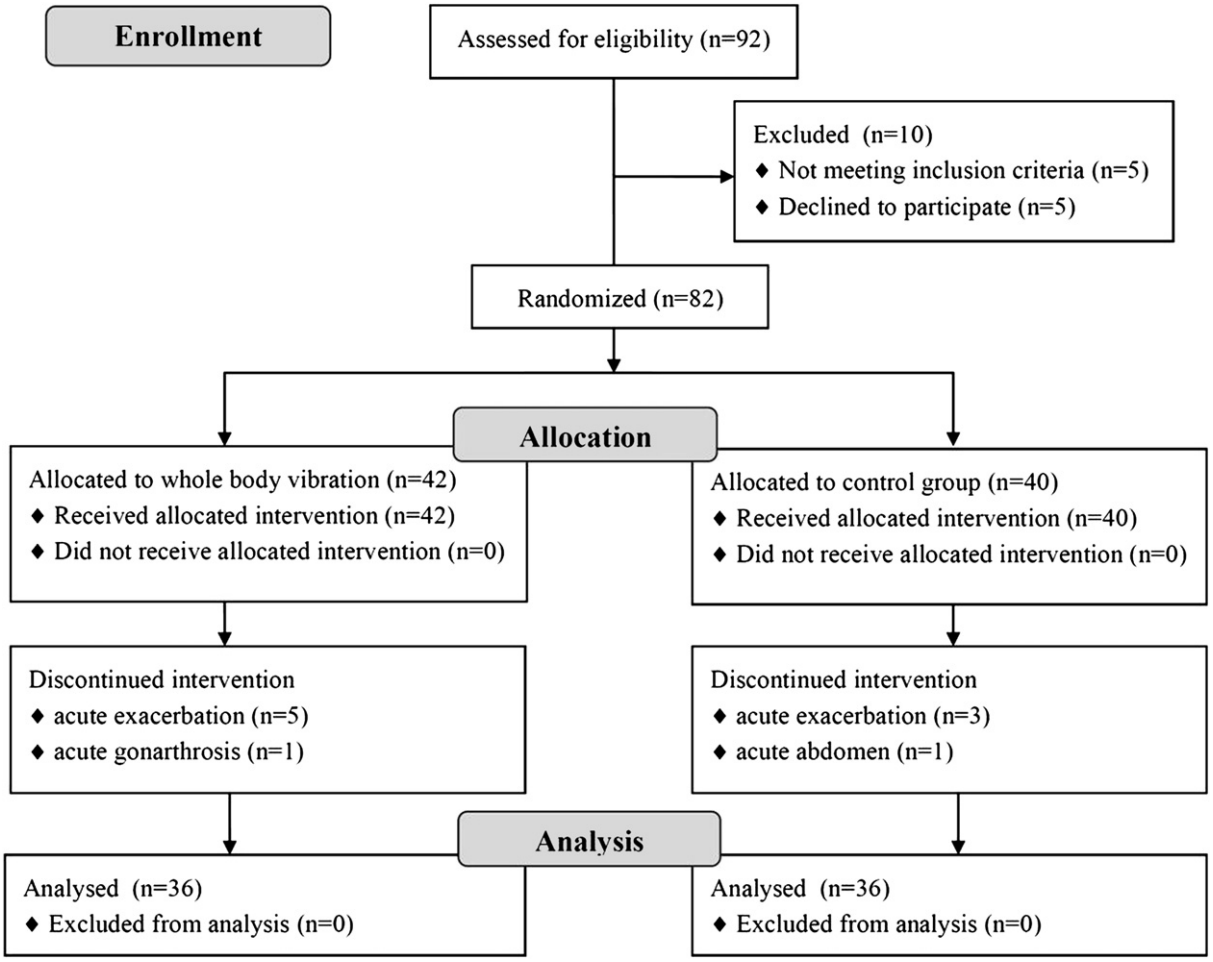

Figure 1 Study flow diagram.

repetitions in a row was measured.[23] As the sit-to-stand test examines a body movement which is very closely connected to activities of daily living it is regarded as an appropriate tool to determine functional status in patients with COPD.[24]

Lung function was measured with a Master Screen Bodyplethysmograph (Jaeger, Wuerzburg, Germany) in accordance with the ATS guidelines.[16,25]

General HRQL was assessed by self-administered German-language version of the Chronic Respiratory Questionnaire (CRQ).[26] The CRQ is a widely used instrument in pulmonary rehabilitation and measures the dimensions of dyspnea, fatigue, emotional function and the ability to cope with COPD (mastery). The scores in each domain range from 1 (most severe impairment) to 7 (no impairment).

The BODE-index, a simple and established multidimensional grading system was used to assess the degree of disease related impairment and to predict the risk of mortality among patients with COPD.[2] The BODE-index is made up of a 10-point scale in which higher scores indicate an advanced stage of COPD and a higher risk of death. It consists of the Body-Mass-Index (B), the degree of airflow obstruction [FEV_1] (O), the degree of dyspnea [MMRC scale] (D) and exercise capacity (E) measured by the 6-MWD.

All measurements were performed on day 1 and 21 of the rehabilitation program.

Statistical analysis

Data are presented as mean and standard deviation or mean and 95%-confidence interval unless otherwise stated. Within-group differences were analyzed using paired *t* test. Between-group comparisons of changes in outcome parameters were carried out by using an unpaired *t* test. For unevenly distributed data the Wilcoxon's signed rank test (intra-group) and the Mann—Whitney-*U*-test (inter-group) were applied. The level of significance was set at $p < 0.05$. All data analyzes were performed using PASW Statistics Version 18.0 (Chicago, IL, USA).

We determined that a sample size of 36 patients in each group would show the inferiority of WBV-training, assuming inferiority at the margin of the minimal clinically important difference (MCID) of 35 m[27] with an estimated standard deviation of 53 m in the 6-MWD between groups to yield a power of 80% at a one-sided alpha level of 2.5%.

Randomization procedure was performed by using two permuted blocks of equal length with a ratio of 1:1.

We handled missing data as follows. CRQ-data for 1 patient in each group were missing. These missing values were excluded from the final analysis. There were no missing data for exercise capacity, lung function or the BODE-index.

Figure 2 Squat exercise on the whole body vibration platform GALILEO®.

Results

Due to 10 out of 82 patients dropped out of the study (for reasons see Fig. 1) 72 patients completed the study and were considered for the final per-protocol analysis. Thirty-six out of 42 patients in the WBV-group (86%) and 36 out of 40 in the CON-group (90%). Randomization strategy allocated patients into two comparable groups (for baseline values see Table 1). Pulmonary rehabilitation was effective in both groups as assessed by a significant increase in 6-MWD of 64 ± 59 m ($p < 0.01$) in the WBV-group as well as 37 ± 52 m ($p < 0.01$) in the CON-group with a between-group difference of 27 m [95% CI, 1–53], $p = 0.046$ (Fig. 3). Patients in both groups increased their 6-MWD above the MCID of 35 m.[27] Patients also improved their exercise capacity in the sit-to-stand test as shown by a decreased test time (WBV-group: −4.0 ± 4.8 s, CON-group: −2.0 ± 3.1 s, between-group difference of −1.9 s [95% CI, −4.0 to 0.1], $p = 0.067$) (Fig. 3). After pulmonary rehabilitation HRQL improved significantly within both groups. Almost all items of the CRQ (except for *mastery* in the CON-group) improved more than the MCID of 0.5 points[28] (CRQ total score in the WBV-group: 3.09 ± 4.28 points and in the CON-group: 2.92 ± 3.13 points, between-group difference of 0.16 points [95% CI, −1.63 to 1.95], $p = 0.86$). For detailed changes in the CRQ scores see Fig. 4. The BODE-index decreased significantly and to a similar proportion in both groups (WBV-group: −0.7 ± 1.3 and in the CON-group: −0.9 ± 1.8, between-group difference: 0.2 [95% CI, −0.8 to 0.8], $p = 0.91$) (Table 2).

No serious adverse events such as injuries, cardiac events or an increase in respiratory symptoms were observed according to the study protocol.

Discussion

The idea of vibration training came up in the early 1970s in order to train Russian cosmonauts and prevent loss of bone mineral and muscle mass during space flights. In the 1990s vibration training was rediscovered for exercise training in professional athletes. During the past decade there has been increased interest in WBV for therapeutic uses. So far several meta-analysis and systematic reviews have investigated the effects of WBV with inconsistent results.[29,30] To date many studies concerning WBV research are methodologically weak and should be interpreted with caution.[31] Study protocols have used widely variable WBV parameters and most included only small sample sizes which complicate interpretation of these studies. Some but not all of the studies reported similar improvements in muscle performance, balance, and bone mineral density for WBV when compared to traditional exercise programs.[32–37]

Thus far only two studies have investigated the effects of WBV in patients with pulmonary diseases. In 2008 a German workgroup studied 8 patients with cystic fibrosis during a home-based training program on a WBV platform without a control group. After 6 months of training only a small increase in leg muscle power of 4.7% (range −16.4 to 74.5) could be found.[38] The second study investigated WBV versus conventional resistance training in 59 patients with COPD (FEV_1 pred. 47 ± 21%).[39] WBV was found to be a promising training modality, which yielded improvements of similar magnitude for exercise capacity, muscle force and quality of life as those obtained with conventional resistance training after 12 weeks of pulmonary rehabilitation.

Therefore we conducted this study to compare two exercise protocols implemented within an inpatient rehabilitation program of 3-weeks duration in patients with more advanced COPD. The aim of this investigation was to assess if supplemental exercise training on a vibration platform leads to superior effects when compared to a conventional multidisciplinary rehabilitation program. As most patients with COPD suffer from a decreased muscle mass and power,[40] WBV training could be a promising new exercise modality.

The mean improvement in exercise capacity (6-MWD) is comparable to the magnitude that was reported in former pulmonary rehabilitation programs of comparable durations.[41,42] However it is striking that patients in the WBV-group were able to improve their functional capacity to a significantly and considerably greater extent when compared to the CON-group. This is specifically remarkable as patients in both groups also performed supplemental endurance and strength training. The outcome of the sit-to-stand

Table 1 Baseline characteristics.

Characteristics	Patients randomized to rehabilitation		Patients completing rehabilitation	
	WBV-group (n = 42)	CON-group (n = 40)	WBV-group (n = 36)	CON-group (n = 36)
Age, yrs	64 ± 11	65 ± 7	64 ± 11	65 ± 7
Gender, female	23(55)	19(48)	18(50)	17(47)
LTOT, n	14(33)	15(38)	11(31)	13(36)
BMI, kg/m^2	25 ± 5	26 ± 6	24 ± 5	27 ± 6
BODE-index	4.3 ± 2.1	4.0 ± 2.0	4.0 ± 1.8	4.0 ± 2.0
6-MWD, m	342 ± 121	345 ± 105	349 ± 112	344 ± 104
6-MWD, % pred.	55 ± 19	57 ± 17	56 ± 18	57 ± 16
SST, sec.	15.7 ± 7.5	16.0 ± 7.5	15.7 ± 7.8	16.0 ± 7.5
FEV_1, % pred.	39 ± 11	38 ± 12	39 ± 11	38 ± 12
D_{LCO}	41 ± 16	43 ± 20	41 ± 17	44 ± 21
CRQ				
Total score	15.57 ± 3.29	14.34 ± 3.78	15.57 ± 3.29	14.57 ± 3.65
Dyspnea	3.42 ± 1.03	3.27 ± 1.33	3.42 ± 1.03	3.37 ± 1.30
Fatigue	4.03 ± 0.92	3.60 ± 1.02	4.03 ± 0.92	3.64 ± 1.02
Emotional function	4.20 ± 1.20	3.72 ± 1.20	4.21 ± 1.22	3.76 ± 1.21
Mastery	4.27 ± 1.25	4.11 ± 1.32	4.27 ± 1.25	4.23 ± 1.26

Data are presented in mean ± SD or number (%); WBV = whole body vibration, CON = control, LTOT = long-term oxygen therapy, BMI = body-mass-index, BODE-index = BMI-obstruction-dyspnea-exercise capacity-index; 6-MWD = 6-min-walking-distance, SST = sit-to-stand test, FEV_1 = forced expiratory volume (1 s), CRQ = chronic respiratory questionnaire.

test provided similar results in favor of the WBV-group although the between-group difference just failed to reach significance. We assume that these improvements in exercise capacity after WBV may be related to an increase in neuromuscular activation. One possibility for the WBV effect is through the vibratory stretch reflex in which the mechanical vibration elicits a myostatic stretch reflex mediated by the muscle spindle and Ia-afferents.[43] Other possible mechanisms of WBV benefits include enhancing postural control and improving quality of intermuscular coordination like the complex interplay of agonists and antagonists which are often disabled in patients with COPD.[44–46]

Despite of patients' better exercise capacity in the WBV-group there was no transfer to an additional improvement in HRQL or the BODE-index. The reason for this could be that at the beginning of the study patients in the WBV-group already had a remarkable higher total score in the CRQ (+0.94 points) as well as a higher score at the BODE-index (+0.4 points) than patients in the CON-group. We guess that this difference at baseline may have yielded a potential underestimation of the WBV-group results regarding these two secondary outcome parameters. As patients still perceive the burden of dyspnea after pulmonary rehabilitation it remains debatable whether the objective measured superior improvements in exercise capacity in the WBV-group may also be reflected by the subjective measurement method of a questionnaire.

This randomized controlled trial is also associated with some limitations. Although all exercise sessions were supervised and advices for a high standard of squat performance were given, we did not record the number of repetitions patients performed during their squat training. This may have yielded potential differences between individuals. Nevertheless we chose the self-pace approach to increase exercise feasibility. Another shortcoming may be that patients were not enrolled in a follow-up investigation, as our study did not focus on the long-term effects. Also the unblinded nature of the study protocol may have yielded a certain bias due to a placebo effect. Nevertheless it was not possible to blind patients or researchers to the exercise intervention.

In consideration of the short total exposure time to WBV (81 min in 3 weeks), the additionally attained effects are quite striking. Nevertheless, WBV training should not be considered as an alternative exercise modality which can be used instead of "normal" exercise training. Specific exercises for arms, accessory respiratory muscles or the upper trunk cannot be easily performed on a vibration plate and it is not possible to undertake endurance training on a vibration platform.

In conclusion, WBV training seems to be an effective and feasible exercise modality for patients with advanced COPD that may even enhance the effects of a comprehensive multidisciplinary rehabilitation program. Further studies are needed in order to define optimal intensity and duration of WBV as well as to investigate its possible long-term effects.

Author contributions

RG: contributed to the organization of the study, study design, data analysis, writing the manuscript and sharing scientific discussions.

IH: contributed to the organization of the study, study design and sharing scientific discussions.

SB: contributed to the organization of the study and data collection.

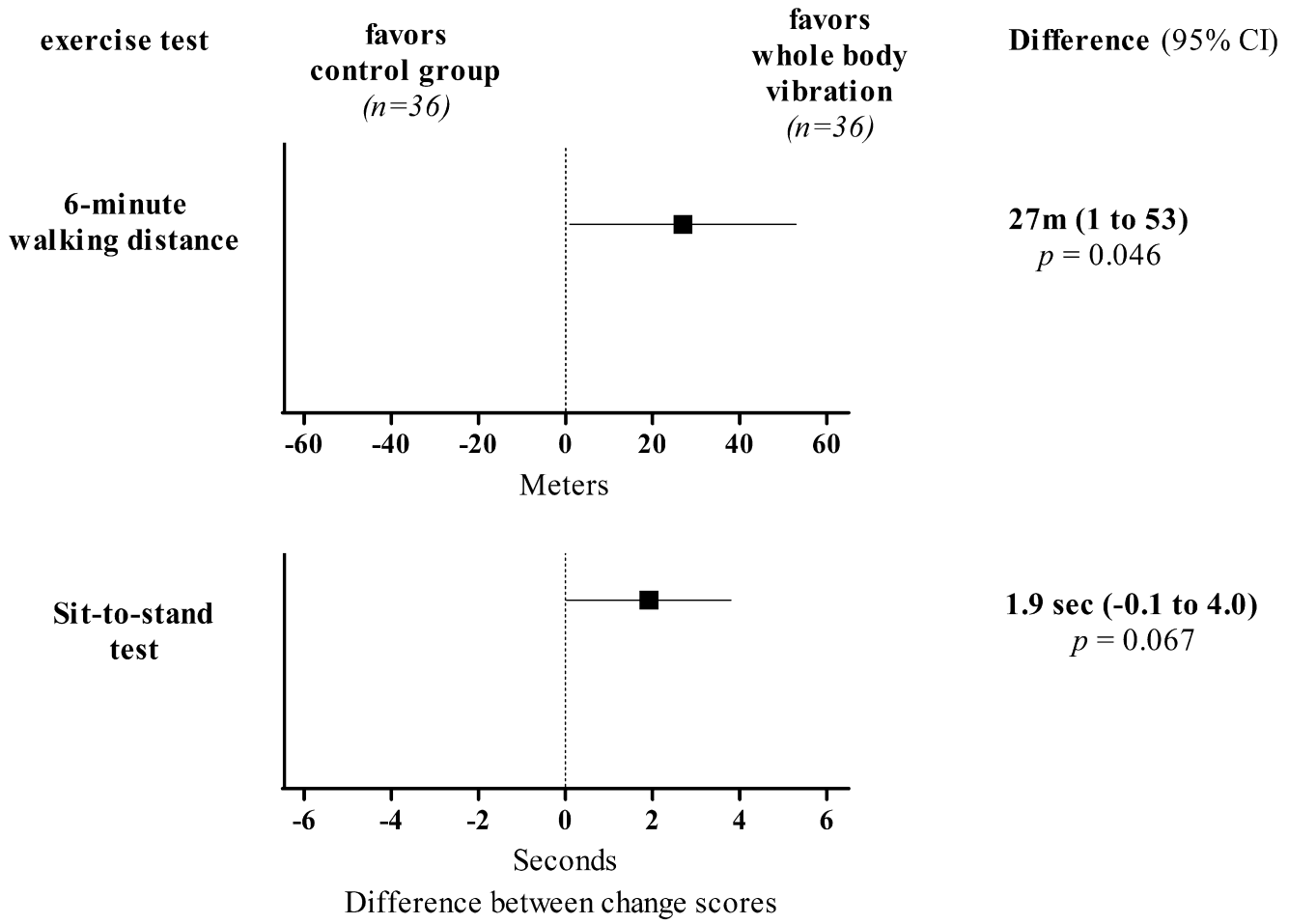

Figure 3 Comparison of exercise capacity (boxes with 95% confidence intervals represent point estimate for the differences between groups) after a 3-week multidisciplinary rehabilitation program with an additional squat exercise program on the floor (control group) or a squat exercise program during whole body vibration (WBV-group). Patients in the WBV-group increased their 6-minute-Walking distance by 27 m superior to the control group. Patients in the WBV-group decreased their time needed to perform the five repetition sit-to-stand test by 1.9 s superior to the patients in the control group.

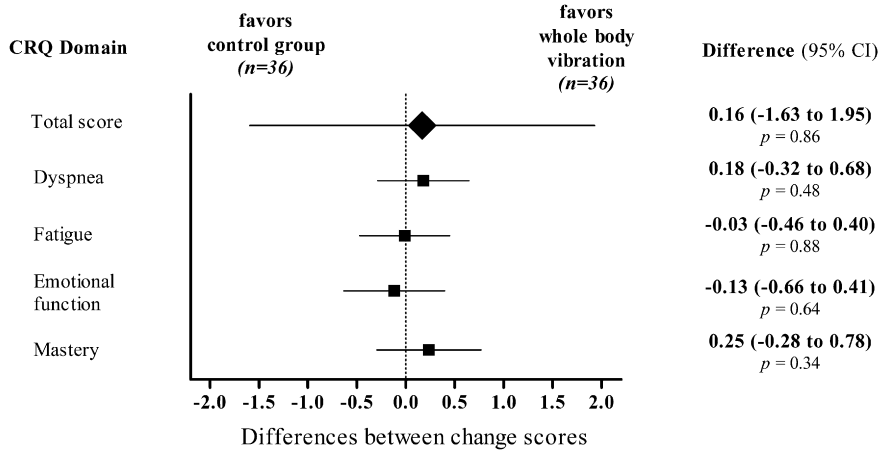

Figure 4 Comparison of health-related quality of life gathered by chronic respiratory questionnaire [CRQ] (boxes with 95% confidence intervals represent point estimate for the differences between groups) after a 3-week multidisciplinary rehabilitation program with an additional squat exercise program on the floor (control group) or a squat exercise program during whole body vibration (WBV-group).

Table 2 Comparison of treatment effects.

Outcome	Per protocol				Difference in intention-to-treat analysis (95% CI)
	Mean changes from baseline (SD)		Difference (95% CI)	*p* value	
	WBV-group ($n = 36$)	CON-group ($n = 36$)			
Primary					
6-MWD, m	64.0 ± 59.1[a]	37.3 ± 52.2[a]	26.7 (0.5 to 52.9)	0.046	21.3 (−3.1 to 45.5)
6-MWD, % pred.	10.5 ± 10.2[a]	6.1 ± 9.0[a]	4.3 (−0.2 to 8.8)	0.061	3.4 (−0.7 to 7.6)
Secondary					
SST, sec.	−4.0 ± 4.8[b,a]	−2.0 ± 3.1[a]	−1.9 (−4.0 to 0.1)	0.067	−1.6 (−3.4 to 0.3)
FEV_1, % pred.	0.8 ± 6.6	2.6 ± 5.7[a]	−1.8 (−4.7 to 1.1)	0.22	−1.7 (−4.2 to 0.9)
BODE-index	−0.7 ± 1.3[a]	−0.9 ± 1.8[a]	0.2 (−0.8 to 0.8)	0.91[c]	0.1 (−0.7 to 0.7)
CRQ					
Total score	3.09 ± 4.28[a]	2.92 ± 3.13[a]	0.16 (−1.63 to 1.95)	0.86	0.10 (−1.61 to 1.63)
Dyspnea	0.67 ± 1.13[a]	0.50 ± 0.84[a]	0.18 (−0.32 to 0.68)	0.48	0.13 (−0.13 to 0.58)
Fatigue	0.69 ± 0.86[a]	0.72 ± 0.87[a]	−0.03 (−0.46 to 0.40)	0.88	−0.05 (−0.44 to 0.34)
Emotional function	0.70 ± 1.30[a]	0.82 ± 0.68[a]	−0.13 (−0.66 to 0.41)	0.64	−0.13 (−0.61 to 0.34)
Mastery	0.58 ± 1.20[a]	0.33 ± 0.85[a]	0.25 (−0.28 to 0.78)	0.34	0.20 (−0.26 to 0.66)

Data are presented in mean ± SD unless otherwise indicated; WBV = whole body vibration, CON = control, 6-MWD = 6-min-walking-distance, SST = sit-to-stand test; FEV_1 = forced expiratory volume (1 s), BODE-index = Bodymass-obstruction-dyspnea-exercise capacity-index; CRQ = chronic respiratory questionnaire.

[a] Intra-group change of $p < 0.05$.

[b] Wilcoxon Test.

[c] Mann—Whitney *U* Test.

ED: contributed to the organization of the study and data collection.

AS: contributed to the organization of the study and data collection.

MD: contributed to the organization of the study and data collection.

DB: contributed to the organization of the study and data collection.

AJ: contributed to the study design and shared scientific discussions.

KK: contributed to the study hypothesis, study design, writing the manuscript and sharing scientific discussions.

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Conflict of interest

All authors (Rainer Gloeckl, Inga Heinzelmann, Sandra Baeuerle, Eva Damm, Anna-Lena Schwedhelm, Merve Diril, David Buhrow, Andreas Jerrentrup, and Klaus Kenn) acknowledge that there are no conflicts of interest with any companies/organizations whose products or services may have influenced this study or manuscript.

Ethics statement

This trial was approved by the Bavarian ethics committee (identification number 11050).

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