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ORIGINAL ARTICLE

Randomized Controlled Trial

Stochastic resonance whole body vibration increases perceived muscle relaxation but not cardiovascular activation: A randomized controlled trial

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Abstract

AIM

To investigate the acute effects of stochastic resonance whole body vibration (SR-WBV), including muscle relaxation and cardiovascular activation.

METHODS

Sixty-four healthy students participated. The participants were randomly assigned to sham SR-WBV training at a low intensity (1.5 Hz) or a verum SR-WBV training at a higher intensity (5 Hz). Systolic blood pressure (SBP), diastolic blood pressure (DBP), heart rate (HR) and self-reported muscle relaxation were assessed before and immediately after SR-WBV.

RESULTS

Two factorial analyses of variance (ANOVA) showed a significant interaction between pre- *vs* post-SR-WBV measurements and SR-WBV conditions for muscle relaxation in the neck and back [$F(1,55) = 3.35$, $P = 0.048$, $\eta^2 = 0.07$]. Muscle relaxation in the neck and back increased in verum SR-WBV, but not in sham SR-WBV. No significant changes between pre- and post-training levels of SBD, DBD and HR were observed either in sham or verum SR-WBV conditions. With verum SR-WBV, improved muscle relaxation was the most significant in participants who reported the experience of back, neck or shoulder pain more than once a month ($P < 0.05$).

CONCLUSION

A single session of SR-WBV increased muscle relaxation in young healthy individuals, while cardiovascular load was low. An increase in musculoskeletal relaxation in the neck and back is a potential mediator of pain reduction in preventive worksite SR-WBV trials.

Key words: Musculoskeletal system; Prevention; Blood pressure; Heart rate; Low back pain

Core tip: This randomized controlled trial shows musculoskeletal relaxation to increase after application of a single training of stochastic resonance whole body vibration (SR-WBV). SR-WBV increased muscle relaxation especially in those who suffered from musculoskeletal pain in the last year. Participants reported improved muscular relaxation while the cardiovascular activation as indicated by blood pressure and heart rate was very low. In addition to ergonomic interventions SR-WBV contributes to prevent muscle related pain at work.

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INTRODUCTION

Whilst evidence for long-lasting vibration exposure at work, as a risk factor for musculoskeletal disease (MSD), is substantial[1], recent research also showed the beneficial training effects of brief vibration experiences[2]. It is noteworthy that it is low frequency vibration exposure (5-12 Hz) that is more promising and seems safer than high frequency exposure at 20 to 60 Hz[3,4]. Stochastic resonance whole body vibration training (SR-WBV) consists of low frequency exposure and has been shown to reduce pain in those with chronic MSD[5]. The outcome of SR-WBV at the worksite is promising. Four weeks of SR-WBV were reported to increase musculoskeletal well-being in the workers of a steel manufacturing company[6], but also in employees that engage in sedentary work, especially those who suffered from back pain prior to SR-WBV[7]. The latest randomised controlled trial with eight weeks of SR-WBV also showed the positive effects of SR-WBV in the employees of a university hospital, especially in those with baseline health restraints[8]. In the same population, SR-WBV was also shown to increase posture control, which was assessed by mediolateral sway on a force plate before and after the eight-week trial[9]. The positive effects of SR-WBV were also shown in the musculoskeletal function of young healthy adults[10], and one more study confirmed electromyographically that activation of the descending trapezius muscle decreased after SR-WBV, while blood flow and skin temperature also increased in this area, and the energy cost of SR-WBV was low[11]. A change in back muscle activation from induced SR-WBV training for the sensorimotor system, and not primarily from an increase in fitness, seemed to be involved in the overall positive effects of SR-WBV on musculoskeletal well-being and function[7]. Therefore, it is a plus of SR-WBV that the self-reported physical demands seemed to be small for most participants, and no sweating was reported. Even so, not only the muscle relaxation that followed the activation of the descending trapezius muscle, but also the change in blood pressure and heart rate from SR-WBV, should be evaluated to estimate the overall demands of SR-WBV training. The current randomized controlled trial tests the hypothesis that 5Hz-SR-WBV improves muscle relaxation (H1), and that 5Hz-SR-WBV triggers cardiovascular activation (H2), whereas 1.5 Hz-SR-WBV (sham condition) has no effect on muscle relaxation or cardiovascular activation. Therefore, 5 Hz-SR-WBV should have the greatest effect on muscle relaxation in those who reported back, neck or shoulder pain in last 12 mo (H3). The test of the second hypothesis is essential. Minimal cardiovascular activation would allow individuals at modest cardiovascular risk to perform SR-WBV.

How SR-WBV works

SR-WBV benefits from the effects of stochastic resonance by applying vibrations of low frequency with a maximal degree of complexity and unpredictability. Ward and colleagues defined stochastic resonance as "a nonlinear cooperative effect wherein the addition of a random process, or 'noise' to a weak signal, or stimulus results in improved detectability or enhanced information content in some response"[12]. SR-WBV differs completely from simple frequency fast sinusoidal vibrations, like the ones applied by the most common and conventional sinusoidal vibration training devices. During SR-WBV, the human body cannot anticipate the upcoming vibration movements, and therefore, the body is constantly challenged to adapt its neural and muscular reactions and shows no muscular fatigue during the application[13-16]. SR-WBV seems to provoke an interaction of different types of neurophysiologic sensors and the adjustment of afferent and efferent signals, which probably acts as exercise for the sensorimotor system[13]. The observed increase in strength is mainly attributed to neural adaptation, which leads to improved inter- and intramuscular coordination, which, in turn, allows the increased activation of prime movers in specific movements, and better coordination in the activation of all relevant muscles[17] or a higher muscular activity in insufficient muscles, when compared to sinusoidal vibration[18]. A low risk of injury and only the rare manifestation of side-effects make SR-WBV an attractive preventive intervention[5,19].

Figure 1 Starting position on stochastic resonance whole body vibration device.

MATERIALS AND METHODS

Ethics

The study was performed in consensus with all requirement defined by the Swiss Society of Psychology. The study was conducted with the understanding and the consent of the human subject. The Ethical Committee of the responsible University faculty has approved the study.

Participants

Expecting a moderate effect size for the repeated measures, within-between interaction and a requirement of a 90% power to detect an existing difference, the required sample size was 64 participants. Sixty-four undergraduate and graduate students were asked for participation and all agreed to participate (34 female and 30 male psychology majors, mean age = 27.6 years, SD = 5.0 years). The inclusion criterion was acute health status. The exclusion criteria for participation were recorded anamnestically, and comprised acute, past or chronic arthropathologies, troubles in the cardiovascular system, psychopathology, spondylolysis, spondylolisthesis, tumors, disc prolapse with neurological failure, rheumatism, articular gout, osteoporosis, activated arthritis with inflammatory signs, stage 4 arthritis, fever, cold, *etc.* No participant had to be excluded from the study. All participants finished the study protocol.

Procedure

The study was conducted at a University facility. The participants completed a single SR-WBV training session. A special device was applied for SR-WBV (©Zeptor med plus Noise, FreiSwiss AG, Zurich, Switzerland). Its key features were two independently and one-dimensional (up/down) stochastically oscillating floorboards, with two passive degrees of freedom (forward/backward and right/left). Each SR-WBV session was supervised, and the participants were instructed to stand in an upright position on the footboards with their arms hanging loose to the side and with slightly bent knees and hips (Figure 1). Both legs should have contact to the plates. It was permitted to change the knee angle but participants were instructed not to stand up straight because in that position vibration is conducted to the head. Figure 1 was shown to demonstrate the posture to participants. The participants were randomly allocated to SR-WBV groups (5 Hz verum condition or 1.5 Hz sham condition). The randomisation was based on the use of a list of random numbers[20]. The session consisted of three series of SR-WBV, which lasted one minute each, with a one-minute break between them. The 5 Hz verum condition was used as the minimum effective SR-WBV stimulation loading parameter, while the 1.5 Hz sham condition can be expected to have no training effect[10,21]. Participants were blind with respect to their training frequency condition. The investigator did the setting of the frequency before the training session started. The setting-screen was additionally covered by a piece of paper so that the participants never knew the exact vibration frequency.

Blood pressure and heart rate

The blood pressure cuff was put into place at the beginning of the session before the participants filled out the questionnaire. Participants wore the ambulatory blood pressure device (blood pressure monitor Spacelabs © model 90207; readings taken by the Korotkoff method) throughout the experimental session. Blood pressure was recorded one minute before and after the SR-WBV session. In an ambulatory blood pressure assessment, the Spacelabs 90207 often is denoted as the "gold standard"[22]. To ensure the comparability of blood pressure levels measured during the presentations, all analyses are based on data recorded in a sitting position.

Muscular pain and relaxation assessment

Musculoskeletal pain was assessed with a question that addressed musculoskeletal pain in the back or neck/shoulders in the last 12 mo (never, less than monthly, less than weekly, less than daily, daily). It is part of a scale that measures psychosomatic complaints that was developed by Mohr *et al*[23] based on the previous work of Fahrenberg *et al*[24]. Muscular relaxation was assessed by a short version of the self-administered questionnaire of Burger *et al*[6] that was completed

Table 1 Mean values of study variables in verum stochastic resonance whole body vibration and sham stochastic resonance whole body vibration groups

Variable	Verum-SR-WBV (5 Hz SR-WBV) (*n* = 34)		Sham SR-WBV (1.5 Hz SR-WBV) (*n* = 30)		*t*	*P*
	Mean	SD	Mean	SD		
Systolic blood pressure						
Pre-training	129.67	12.78	120.9	9.68	3.05	0.003
Post-training	126.97	11.54	120.57	10.43	2.32	0.024
Diastolic blood pressure						
Pre-training	78.61	11.00	75.27	7.64	1.39	0.171
Post-training	79.00	8.92	75.13	8.37	1.78	0.080
Heart rate						
Pre-training	71.09	12.03	69.1	15.67	0.57	0.572
Post-training	69.94	11.51	68.4	13.25	0.50	0.620
Muscle relaxation						
Pre-training	6.47	2.06	6.87	2.47	0.70	0.488
Post-training	7.00	2.10	6.7	2.59	0.51	0.611
Age (yr)	27.76	3.70	27.4	6.15	0.28	0.779[1]
Sex	18 f, 16 m		16 f, 14 m		χ^2 = 0.001	0.975
BMI	22.58	2.59	21.68	2.80	1.34	0.187
Fitness	3.65	0.65	3.66	0.72	-0.05	0.963
Smoker (10 cigarettes or more)	12 (6)		7 (3)		χ^2 = 1.09	0.296
Smoking (cigarettes)	3.53	6.33	2.30	6.98	0.74	0.463
Cups of coffee before training	1.50	1.11	1.67	1.47	-0.52	0.608
Back, neck or shoulder pain in last 12 mo	2.71	1.00	2.63	1.40	0.24	0.815[1]

[1]Corrected for unequal variances. BMI: Body mass index; SR-WBV: Stochastic resonance whole body vibration; f: Female; m: Male.

before and after SR-WBV. The participants were asked to rate muscle relaxation on a 10-point Likert scale. The question was introduced, "At the moment, how do you rate your personal sensation in your muscles and joints (back, shoulder and neck, leg muscles, *etc.*)?", which was followed by "Relaxation in the muscles and joints", and the corresponding 10-point rating scale from "no relaxation" to "strongest imaginable relaxation".

Statistical analysis

Self-reported muscle relaxation, systolic blood pressure (SBP), diastolic blood pressure (DBP) and heart rate (HR) were analysed in a two-factorial ANOVA, including the repeated measurement (pre- *vs* post-session measurement) of SBP, DBP, HR and self-reported muscle relaxation as a within-subjects factor, and the SR-WBV training group condition (verum: 5 Hz, sham: 1.5 Hz) as a between factor.

We tested hypothesis 3 - expected gain in muscle relaxation to be the largest in verum SR-WBV and among those with musculoskeletal pain, compared with verum SR-WBV with no pain, and sham SR-WBV with and without pain - by planned contrasts as recommended by Strube *et al*[25]. The change in muscle relaxation (post-SR-WBV minus pre-SR-WBV) was the dependent variable. *P*-values were two-tailed with α set to 5%.

RESULTS

Participant characteristics

Before the training study started, the participants reported the frequency of musculoskeletal pain episodes in the back, neck or shoulders in the last 12 mo. Thirteen participants (20.3%) reported that they had never experienced pain during this period of time. Fifteen participants (23.4%) reported pain episodes less than monthly, and 21 participants (32.8%) reported pain episodes less than weekly. Ten participants (15.6%) reported pain episodes that occurred every week, but less than daily. Five participants (7.8%) experienced pain every day in the last 12 mo. Sixty-four healthy students participated in this study. Table 1 depicts the descriptive study results. The 64 participants were randomly assigned to SR-WBV conditions, and no significant differences in musculoskeletal pain episodes in the back, neck or shoulders in the last 12 mo were observed between the groups of verum SR-WBV and sham SR-WBV (Table 1). Thirty-four participants were assigned to verum SR-WBV, and 30 participants were assigned to sham-SR-WBV. The verum and sham SR-WBV groups did not differ significantly in any demographic characteristics or in baseline muscle relaxation or DBD and HR. However, the baseline and follow-up SBP was significantly higher in verum SR-WBV than in sham SR-WBV (Table 1). Table 2 shows the correlations between study variables. Pain episodes in the back, neck or shoulders in the last 12 mo were negatively related to sex, showing higher pain in women than in men. Fitness was negatively related to pain episodes in the back, neck or shoulders.

SR-WBV and improved muscle relaxation (H1)

The ANOVA results for the test of the first hypothesis are shown in Table 3. A significant interaction term indicated that verum SR-WBV improved muscle relaxation, while

Table 2 Correlations between study variables

Variables	SR-WBV condition	SBP pre	SBP post	DBP pre	DBP post	HR pre	HR post	Relax pre	Relax post	Age	Sex	BMI	Fitness	Smoking	Coffee
SR-WBV Condition															
SBP pre	-0.36^c														
SBP post	-0.28^a	0.83^e													
DBP pre	-0.18	0.63^e	0.57^e												
DBP post	-0.22	0.59^e	0.71^e	0.68^c											
HR pre	-0.07	0.02	0.01	0.22	0.22										
HR post	-0.06	0.03	0.07	0.21	0.24	0.76^e									
Relaxation pre	0.09	0.02	0.22	-0.04	0.01	0.04	-0.01								
Relaxation post	-0.07	0.09	0.24	0.03	0.03	0.01	-0.04	0.84^e							
Age	-0.04	0.36^c	0.40^c	0.24	0.23	-0.03	-0.11	0.26^a	0.26^a						
Sex	-0.01	0.26^a	0.36^c	-0.07	0.05	-0.16	-0.1	0.28^a	0.15	0.29^a					
BMI	-0.17	0.08	0.14	-0.14	0	-0.32^c	-0.19	-0.01	0.02	0.15	0.45^e				
Fitness	0.01	0.15	0.19	-0.13	-0.2	-0.19	-0.16	0.41^c	0.38^c	0.30^a	0.34^c	0.24			
Smoking (number of cigarettes)	-0.09	0.10	0.07	-0.12	0.06	0.25^a	0.37^c	-0.01	-0.07	0.07	0.36^c	0.28^a	-0.02		
Cups of coffee before training	0.07	0.09	0.01	-0.01	0.01	0.07	0.16	-0.28^a	-0.28^a	0.20	0.16	0.16	-0.18	0.33^c	
Back, neck or shoulder pain in last 12 mo	-0.03	-0.18	-0.30a	-0.04	-0.14	-0.08	0.03	-0.55^e	-0.59^e	-0.09	-0.27^a	0.02	-0.26^a	-0.03	0.24

$^a P < 0.05$, $^c P < 0.01$, $^e P < 0.001$: Correlations coefficients that significantly differ from zero. SR-WBV: Stochastic resonance whole body vibration; SBP: Systolic blood pressure; DBP: Diastolic blood pressure; HR: Heart rate.

Table 3 Results of two-factorial ANOVA

	Sum of squares	*df*	Mean square	*F*	*P*	Partial eta-square
Inner-subject effects						
Pre- *vs* post-training (*n* = 64)	1.05	1	1.05	1.32	0.255	0.021
Training group (5 Hz *vs* 1.5 Hz)	3.86	1	3.86	4.85	0.031	0.073
Within subjects error	49.32	62	0.80			
Between subjects effects						
Constant	8.91	1	8.91	1.18	0.282	0.021
Training group (5 Hz *vs* 1.5 Hz)	0.74	1	0.74	0.01	0.931	0.000
Between subjects error	608.92	62	9.82			

no change appeared in sham SR-WBV [F(1,62) = 3.86, P = 0.031, η^2 = 0.069]. Figure 2 shows the change in muscle relaxation in both study groups.

SR-WBV and increase in cardiovascular activation (H2)

In verum and sham SR-WBV, the mean levels in SBP, DBP and HR were almost the same before and after SR-WBV (Table 1). The ANOVAs of SBP, DBP and HR did not show significant interaction effects [SBP: F(1,61) = 1.92, P = 0.171, η^2 = 0.030; DBP: F(1,61) = 0.07, P = 0.792, η^2 = 0.001; HR: F(1,61) = 0.010, P = 0.919, η^2 = 0].

SR-WBV and back, neck or shoulder pain in last 12 mo (H3)

Verum SR-WBV was expected to have the greatest effects on muscle relaxation in those who reported back, neck or shoulder pain in last 12 mo. These individuals should benefit more from 5Hz SR-WBV than those without pain and those with and without pain in the sham SR-WBV condition. Figure 3 shows the change in the musculoskeletal relaxation for SR-WBV groups separately, for those with and without back, neck or shoulder pain in last 12 mo. As expected, the increase in muscle relaxation was the greatest in those with pain in the verum SR-WBV group, and was significantly greater than in all other groups, as shown in the planned contrast analysis [F(1,60) = 5.30, P = 0.025, η^2 = 0.081].

DISCUSSION

The current findings showed self-reported musculoskeletal relaxation increased significantly after verum SR-WBV, but not after sham SR-WBV, while SBP, DBP and HR did not change in either verum SR-WBV or sham SR-WBV. The current results confirm a recent more explorative investigation on acute effects of SR-WBV that showed increased muscle relaxation measured by electromyography and low cardiac activation measured by heart rate variability[11]. Confirmation was important

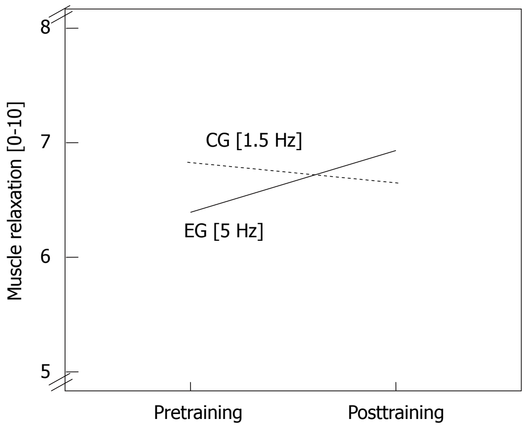

Figure 2 Self-reported muscle relaxation before and after stochastic resonance whole body vibration.

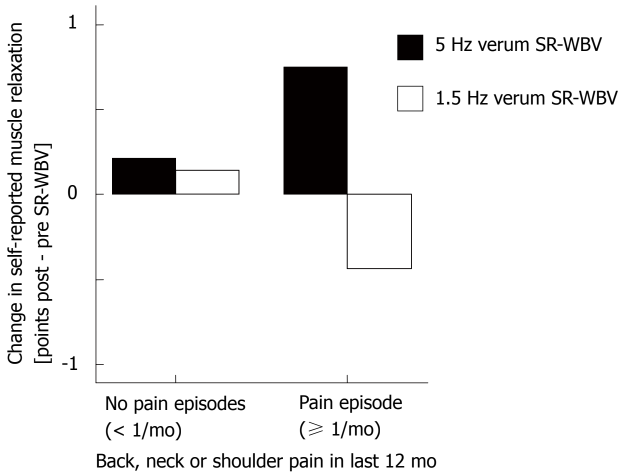

Figure 3 Change in self-reported muscle relaxation by stochastic resonance whole body vibration and back, neck or shoulder pain in last 12 mo before stochastic resonance whole body vibration.

because the previous investigation was based on a comparably small sample (one third of the sample size of the current study) and was based solely on a repeated measurements design[11]. Hence, the current randomized controlled trial increased the evidence that one trial of SR-WBV has beneficial musculoskeletal effects while cardiovascular load is moderate. Muscle relaxation after SR-WBV prevents musculoskeletal pain that may arise from consistently high muscle tension[1]. Repeated SR-WBV may decrease muscle tension and musculoskeletal pain. The present findings showed that participants who reported back, neck and shoulder pain episodes in the last 12 mo were the main beneficiaries of the overall positive effects of SR-WBV on muscle relaxation. Using repeated SR-WBV Elfering and colleagues found in a four-week worksite study that SR-WBV was more clearly linked to reduced pain in those who suffered from musculoskeletal pain prior to training, while those who were pain-free benefited less[15]. Thus, SR-WBV seems to have specific positive effects on the neuro-muscular system, while the absence of cardiovascular activation indicates that the positive effects are unlikely to be mediated by changes in overall fitness.

Four and eight-week worksite training studies showed SR-WBV can easily be done before, during or after work without having to change clothes or take a shower afterwards[6-9]. Further, the low cardiovascular demands of SR-WBV make SR-WBV a safe worksite prevention tool.

Even so, the beneficial effects of SR-WBV seem to contradict evidence of the harmful effects of vibration exposure at work[1]. However, a distinction should be made between SR-WBV and harmful vibration at work[26]. The damaging effects of vibration at work are caused by chronic exposure - with long exposure and short rest cycles - to a rather regular vibration that is often oscillating at a large amplitude or at frequencies of mechanical resonance[27]. In contrast, SR-WBV training efficiency and its therapeutic effects were summarised recently[5,27]. SR-WBV may have risks and benefits, and both should be studied. A review of 112 studies on whole body vibration reported very few side effects (0.00120% in 104 studies that used sinus whole body vibration, and 0.00069% in eight studies that used SR-WBV)[19]. More serious side effects have been exclusively found in studies that used sinusoidal whole body vibration, but not in studies that used SR-WBV[19]. SR-WBV seems to be a safe training intervention with usually harmless adverse effects when a careful evaluation of the medical history is performed before SR-WBV to evaluate contraindications or the potential risk factors of the subjects. In addition, one should avoid unnecessarily intense exposure to keep the risk of side-effects as low as possible. Therefore, we did 60-s trainings, which is the shortest period known to have a training effect. The next step in the evaluation should test worksite SR-WBV to reduce MSD, but it should also include an economic evaluation[28].

This study had an experimental design, and many potential confounders were controlled by randomisation. However, unexpectedly, baseline differences in SBP were observed between the SR-WBV groups, with higher SBP levels in verum SR-WBV. Thus, a regression to mean levels cannot be excluded in SBP measurement after SR-WBV. This is noteworthy; because of frequent measurement artefacts, SBP and DBP could only be measured after SR-WBV and not during SR-WBV. The participants were blind with respect to their verum *vs* sham SR-WBV condition. However, a blinding of the primary investigator was not feasible.

The participants benefited from low frequency 5 Hz SR-WBV after three one-minute trials within one 10-min training session. The participants with a frequent experience of back, neck and shoulder in last 12 mo had improved muscular relaxation after SR-WBV, whilst blood pressure levels and heart rate were nearly unchanged by SR-WBV. In addition to ergonomic intervention, training and participatory work redesign SR-WBV may help to prevent and reduce MSD at work.

COMMENTS

Background

Musculoskeletal pain is common and so far no experiment tested the acute effects of a single stochastic resonance whole-body vibration training (SR-WBV) on muscle relaxation and blood pressure.

Research frontiers

There is need for research on short, economic, and effective training intervention. In this experiment, author(s) showed a single short SR-WBV training to increase musculoskeletal relaxation.

Innovations and breakthroughs

The experiment showed benefits were higher in those with experience of musculoskeletal pain while cardiovascular activation was low.

Applications

In previous works including 4 or even 8 wk of SR-WBV was found to improve musculoskeletal pain and body balance, measured as self-report and as recorded body sway on a balance platform. Improved body balance is connected to a lower risk of slips and falls. Short trials of SR-WBV that amount to less than 10 min can be done at a worksite without a change of clothes or shoes. Cardiovascular demand with 5 Hz SR-WBV is low and permits SR-WBV in the untrained or elderly workforce.

Terminology

SR-WBV constantly challenges the neuromusculoskeletal coordination to adapt to unforeseeable change.

Peer-review

This is an interesting investigation and the authors are experts in stochastic resonance whole body vibration.

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