Sex-specific response to whole-body vibration training: a randomized controlled trial

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ABSTRACT: A few studies have indicated that males and females respond differently to whole-body vibration (WBV) training. However, the existing insights are still insufficient and they cannot be transferred to sex-specific practice planning. To evaluate the effect of 5-week WBV training on neuromuscular [countermovement jump (CMJ), squat jump (SJ)] and cardiovascular [heart rate and blood pressure] data, taking into account sex-specific effects. This is a comparative experimental study including 96 healthy adults, divided into two groups: a WBV group (25 females and 24 males) and a control group (27 females and 20 males). The participants attended nine to ten training sessions (twice a week for 5 weeks), each lasting approximately 30 min. Both groups performed the same exercise routine on the vibration training device. For the WBV group, the training device was vibrating during the whole training session, including the breaks. For the control group, it was turned off. Maximum jump height ($_H$, cm) and maximum relative power ($_{MRP}$, kW/kg) were noted during CMJ and SJ performed on a force plate. Resting (sitting) heart rate (bpm) and blood pressure (mmHg) were measured twice, before and after the intervention. For each parameter, Δdata (= before – after) was calculated. Interactive effects of sex (2) vs group (2) vs session (2) were noted only in males and they only concerned ΔSJ_{MPR} and ΔCMJ_H: compared to the control group, the WBV group had better ΔSJ_{MPR} (1.39 ± 3.05 vs -2.69 ± 4.49 kW/kg, respectively) and ΔCMJ_H (0.50 ± 6.14 vs -4.42 ± 5.80 cm, respectively). No sex-specific effect of WBV on neuromuscular (CMJ and SJ) or cardiovascular (heart rate and blood pressure) data was found.

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INTRODUCTION

Rest and recovery are two important aspects of exercise training [1]. A quick recovery is of great importance; it helps athletes improve or reach optimal performance and allows them to perform the best of their abilities over longer periods of time [1]. There are two different categories of recovery, short-term and long-term. Short-term recovery (i.e., immediate) is the most common form of recovery. It occurs during or after an exercise session/event [2]. Long-term recovery, which occurs within a seasonal training schedule, may include days or weeks incorporated into an annual athletic programme [2]. Different recovery procedures (e.g., massage, hyperbaric oxygenation, acceleration of venous return, electrostimulation, whole-body cryotherapy, immersion in cold water, vibration) [3–9] are available to athletes to speed

ABBREVIATIONS

BMI	: body mass index
CG	: control group
CMJ	: counter movement jump
DBP	: diastolic blood pressure
$_H$	: maximum jump height
HR	: heart rate
$_{MPR}$	: maximum relative power
SBP	: systolic blood pressure
SD	: standard deviation
SJ	: squat jump
WBV	: whole-body vibration
Δ	: before ($_1$) minus after ($_2$) the intervention
$_1$	: before the intervention
$_2$	: after the intervention

up recovery and to maintain a stable competitive state [1]. These procedures aim at accelerating the overall regeneration of athletes [6]. Vibration is an oscillatory activity caused by mechanical stimuli. Amplitude and frequency are the biomechanical parameters determining the intensity and magnitude of the oscillations [10, 11]. Whole-body vibration (WBV) platforms oscillate over a range of frequencies (1–60 Hz) and amplitudes or displacements (1–10 mm), varying according to the product. Acceleration indicates the vibration magnitude [12]. WBV, an emerging training method, has neuromuscular effects with various outcomes [13]. Despite having contradictory results [14–18], various studies and meta-analyses have reported strong evidence for improving strength and power, body balance, and vertical jumping performance [e.g., squat jump (SJ) and countermovement jump (CMJ)] in response to WBV training (intervention) [9, 19–33]. In addition to neuromuscular improvements, WBV training has also various acute and long-term effects on the cardiovascular system [34]. Acute cardiovascular effects of WBV training include an increase in skin blood flow, heart rate (HR), and oxygen consumption during and shortly after the exercise [35–38]. Long-term cardiovascular effects of WBV training include an increase in maximal oxygen consumption, reduction in HR and in diastolic and systolic blood pressure (DBP, SBP, respectively) [34, 39]. According to Mester et al. [26], deformation of blood vessels (observed in hydrodynamic analyses) causes an increase in total peripheral resistance, with its related consequences (i.e., opening of more capillaries resulting in more efficient gas and material metabolism between blood and muscle).

So far, sex-specific aspects of WBV training have been investigated only sparsely. The majority of investigations analysing the effects of vibration training have either included only a single sex [40–43] or, when both sexes were included, have not differentiated their results [29, 44–46]. This is surprising, since the few studies [23, 47, 48] investigating sex-specific differences with regard to responses to WBV training report that males and females vary in their response to the intervention. For instance, while Colson and Petit [23] reported smaller effects of WBV training on maximum power generation in females compared to males, Sañudo et al. [49] showed that females are able to increase their medio-lateral knee stability at about the same level as males. Merriman et al. [50] observed sex-specific differences in various physical performance data in older adults, with males being generally more responsive. Consequently, the authors concluded that sex needs to be considered as a co-factor in the studies involving both males and females [50]. In their meta-analysis including 12 studies, Osawa et al. [27] explicitly stated the investigation of both sexes within a study to be a limiting factor. Thus, the few results have indicated that males and females respond differently to WBV training, but the existing insights are still insufficient and they cannot be transferred to sex-specific practice planning.

Sex-perspectives of WBV training would significantly improve the accuracy of a study statement and optimize the relevance of biomedical research. Considering the previous points, the aim of this experimental comparative study was to evaluate the effect of a five-week WBV training programme on jumping performance (SJ and CMJ data) and cardiovascular (HR, SBP, DBP) data, taking into account sex-specific effects. The null hypothesis was that sex responds similarly to WBV training (i.e., males and females have similar SJ data).

MATERIALS AND METHODS

Study design

This was a comparative experimental study performed in Munich (Germany) during a period of seven weeks (including five weeks of training). Approval was obtained from the university human research ethics committee (Approval number: 2434/09). The study was carried out according to the principles stated in the Declaration of Helsinki. All the participants were informed of the benefits and risks (e.g., nausea and dizziness due to rapid, brief drop in blood pressure, blistering at points of contact with the therapy platform, itching in the regions of the body being treated) of the investigation prior to signing an institutionally approved informed consent document to participate in the study.

Sample size

The null hypothesis [51] was H0: $m_1 = m_2$, and the alternative hypothesis was Ha: $m_1 = m_2 + d$, where “d” is the difference between the two means of the two groups [control group (CG), WBV group]. The sample size was estimated using the following formula [51]: $N = [(r + 1)\ (Z_{\alpha/2} + Z_{1\text{-}\beta})^2 \delta^2]/r\ d^2$,where

- n_1 and n_2 are the sample sizes for the two groups, where $N = n_1 + n_2$;
- “$Z_{\alpha/2}$” is the normal deviate at a level of significance = 2.58 (99% level of significance);
- “$Z_{1\text{-}\beta}$” is the normal deviate at 1-β% power with β% of type II error (2.33 at 99% statistical power);
- “r” (= n_1/n_2) is the ratio of sample size required for the two groups (r = 1 gives the sample size distribution as 1:1 for the two groups);
- “s” and “d” are the pooled standard deviation (SD) and the difference in the main outcome (for example SJ) means of the two groups. Given the pioneer character of the present study, these two values were obtained from the study of Wallmann et al. [48] aiming to investigate the acute effects of WBV (vibration at 2 mm and 30 Hz for 60 s) on vertical jump for untrained males (n = 20) and females (n = 16). The Δ (before minus after WBV) mean of vertical jump height (cm) was -0.70 and 0.52, respectively for males and females, with a common SD equal to 1.20. The sample size for the study was 46 participants (23 males). To better elucidate the effects of sex and WBV, an additional CG of 46 participants (23 males) was also included.

Populations

Figure 1 presents the study flow chart. Adult participants (untrained people or recreational athletes) willing to participate in the study were included. The participants were recruited through the local

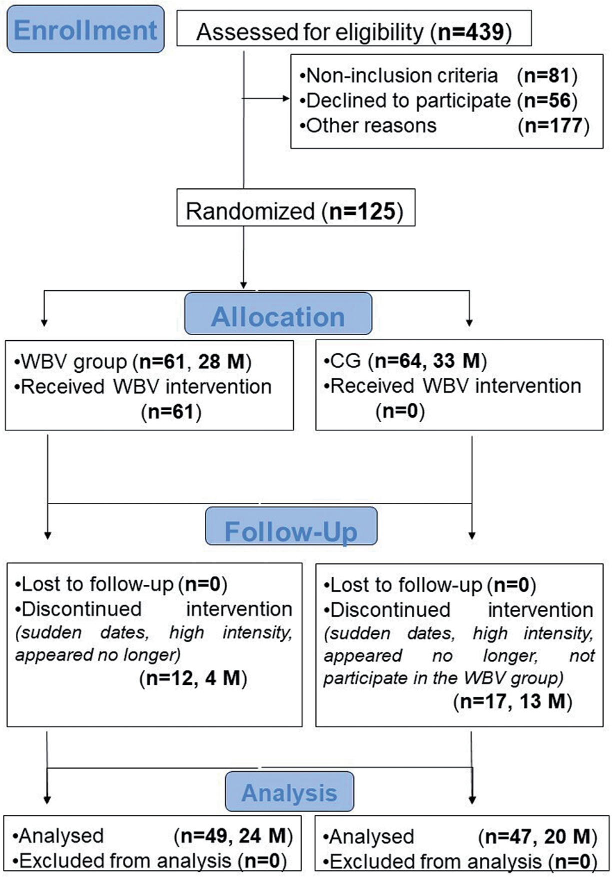

Figure 1. Consort diagram.
CG: control group. **M**: males. **WBV**: whole-body vibration.

residents' registration office. They were assigned either to the WBV group or to the CG using a permuted-block and stratified randomization (block size of 10, allocation ratio of 1:1, stratification based on SJ height). A medical history of chronic or acute diseases [e.g., diabetes mellitus, epilepsy, hypertonia, cardiac insufficiency, coronary artery disease, diseases of liver or kidneys, hyper- or hypothyroidism; rheumatoid arthritis, acute thrombosis, acute inflammation of the musculoskeletal system, activated arthrosis or arthropathy (i.e., acute joints inflammation and swelling), acute tendinitis, acute hernias, acute discopathy, fresh fractures, stone disorders of biliary and urinary tract, post-surgery status, fresh wounds and scars] and some other conditions (pregnancy, myopia from -5 dioptre, and active competitive sports) were applied as non-inclusion criteria. Reasons for discontinued intervention (e.g., sudden dates, high intensity, appeared no longer, non-participation in the WBV group) were applied as exclusion criteria.

The following anthropometric data were collected: age (years), height (cm), weight (kg). Body mass index (BMI, kg/m^2) was calculated.

Equipment and WBV stimuli

WellenGang Excellence rotating-type WBV devices (WellenGang GmbH, Ötisheim, Germany) were used for vibration training. The platform being flexibly mounted on steel springs on the central axis leads to side alternating, vertical rocking movements, generating sinusoidal vertical vibrations. For the WBV group, the training platform


a) b) c) d) e)

Figure 2. Training routine on the whole-body vibration (WBV) device.
a) WellenGang Excellence (formerly Qionic) rotating-type device
b) Squatting (training)
c) Calf raises (both/left/right - training)
d) Squat jumps (training)
e) Swinging (recovery)
Note: For the WBV group, the training device was vibrating during the whole session, including the breaks when the participants sat on the device, while the training device was turned off for the control group.

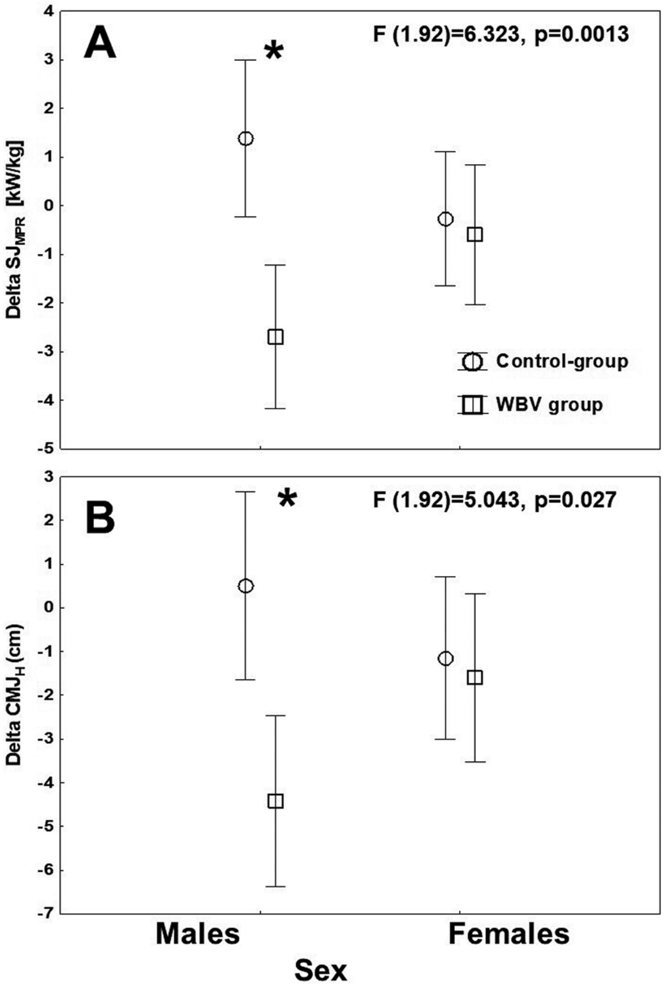

Figure 3. Sex-specific effects on exercise data
CMJ$_H$**:** countermovement maximal jump height. SJ$_{MPR}$**:** squat jump maximal power relative. WBD: whole-body vibration. Δ: data session$_1$ minus data session$_2$. Session$_1$**:** before the intervention. Session$_2$**:** after the intervention.
Data were expressed as mean (95% confidence interval).
P: analysis of variance: sex (males/females) vs group (WBV group/control group). Tukey post hoc test: *Control group male vs WBV group male.

was vibrating with an amplitude of 2–3.5 mm, and a frequency of 20 Hz. Mean accelerations had a range of about 5 m/s^2 (ankle) to 0.5 m/s^2 (knee). This setting was within the range used for medical rehabilitation and sports training applications [27, 31, 33].

Training

The participants attended nine to ten training sessions, each lasting approximately 30 minutes. The training strategy (for untrained adults), was based on some recommendations from the literature [46, 52, 53], and applied the following criteria: intensity (50–70% of one-rep-max; corresponding to 10 to 20 repetitions, up to individual muscular exhaustion); duration (3 sets/unit with four exercises each) and frequency (2 units/week). The training sessions were held twice a week with at least one day between two consecutive sessions over a period of five weeks. Each training session consisted of three exercise blocks with a 5-min break between them (Box I, Figure 2). During the break, the participants were instructed to sit on the training device. Within the exercise blocks, four exercises were performed with a 10-s active rest between them, where the participants performed low-intensity alternating calf raises. Both groups conducted the same exercise routine on the vibration training device. For the WBV group, the training device was vibrating during the whole session, including the breaks when the participants sat on the device, while the training device was turned off for the CG.

Procedures

The participants were examined twice, before ($_1$, i.e.**,** one week prior to the intervention) and after ($_2$, i.e., at least five days after the last training session) the intervention. The test protocol included measuring, before/after the intervention, some cardiovascular data [HR$_1$ and HR$_2$ (bpm), SBP$_1$, SBP$_2$, DBP$_1$ and DBP$_2$ (mmHg)], and neuromuscular data [maximum jump height ($_H$, cm) and maximum relative power ($_{MRP}$, kW/kg) during SJ (SJ$_{H1}$, SJ$_{H2}$, SJ$_{MPR1}$ and SJ$_{MPR2}$) and CMJ (CMJ$_{H1}$, CMJ$_{H2}$, CMJ$_{MPR1}$ and CMJ$_{MPR2}$). For each

BOX I. Training routine

Exercises Block I	Duration [s]		Exercises Block II	Duration [s]		Exercises Block III	Duration [s]	
Squatting	60	**5-min Break**	Squatting	60	**5-min Break**	Squatting	60	**5-min Rest**
Swinging	10		Swinging	10		Swinging	15	
Squat jumps	30		Squat jumps	30		Calf raises (left/right)	60	
Swinging	10		Swinging	10		Swinging	15	
Calf raises (left/right)	60/60		Squatting	40		Squat jumps	30	
Swinging	10		Swinging	10		Swinging	10	
Squat jumps	60		Squat jumps	30		Squat jumps	60	

Note: The 3 exercise blocks were performed at each training session with a 5-minutes break in between. Training sessions were performed twice weekly over 5 weeks.

parameter, a ∆data (= before minus after the intervention) was calculated.

To evaluate cardiovascular data, a physician manually measured the participants' HR and blood pressure values (stethoscope and blood pressure cuff) in a sitting position after a 10-minute rest. HR was expressed as absolute value (bpm) and as percentage (HR%) of the predicted maximal HR (predicted maximal HR (bpm) = 210 – (0.65 x Age)) [54].

Prior to jump performance testing, the participants underwent an individual warm-up on a standardized bicycle ergometer and familiarized themselves with the test procedure by performing two test jumps in each condition. CMJ is a leg flexion from the standing position immediately followed by a maximal vertical jump, while SJ consists in a maximal vertical jump from a flexed situation. Both tests were performed with hands on hips. The vertical jump tests were conducted using the force plate (Performance tester, Gallileo2000, Netherlands). Force data were collected at 250 Hz (Logger Pro 3.5.0, Vernier Software & Technology) with an accuracy of 1.2 N as specified by the manufacturer. Two trials were completed for each test with a 2-minute rest period between jumps. The best ones (highest jumps) were retained for further analysis. Outcome data were maximum jump height (SJ_H, CMJ_H) based on flight time [cm] and MRP [kW/kg].

Statistical analyses

The Shapiro-Wilk normality test was used to evaluate data for underlying assumptions of normality. Outcome data were determined to be distributed normally. So, means and SDs were used as summary statistics. Student's *t*-test was used to compare data of the two independent groups (males vs females for the same intervention, or CG vs WBV group for the same sex). The Wilcoxon test was used to compare data of the two sexes for the same intervention. Comparisons of the cardiovascular and neuromuscular data were made between the two sexes via a factorial analysis of variance in order to analyse the higher-order interactive effects of multiple categorical independent factors [sex (2, males/females) vs group (2, WBV/CG) vs sessions (2, before/after)]. Comparisons of the ∆data were made between the two sexes via a factorial analysis of variance in order to analyse the higher-order interactive effects of multiple categorical independent factors [sex (2) vs group (2)]. Tukey post hoc analysis was performed with pairwise comparisons when significant interactions were found. Hedge's ΔSJ_H value was used for effect size measurement between males and females in the WBV group [55]. An effect size of ≤ 0.2 was described as a small effect, around 0.5 as a medium effect, around 0.8 as a large effect, and more than 1.30 as a very large effect [55]. All mathematical computations and statistical procedures were performed using Statistica software (Statistica Kernel version 6; Stat Software. France). The significance level was set at 0.05.

RESULTS

Out of the 439 participants assessed through the local residents' registration office, 125 were eligible and were willing to participate in the study. Among them, 29 withdrew, leaving a total number of 96 healthy adults [44 males (20 controls), 52 females (27 controls)], forming the final data set (Figure 1).

Descriptive data

Table 1 exposes the participants' anthropometric characteristics, divided according to sex and intervention. Its main conclusions were:

TABLE 1. Anthropometric characteristics of participants divided according to sex and intervention.

			Males (n = 44)		Females (n = 52)	
Data		**Session**	**Control-group (n = 20)**	**WBV group (n = 24)**	**Control-group (n = 27)**	**WBV group (n = 25)**
Age	(yr)	-	36 ± 5	33.3 ± 6.3	35 ± 5	33.7 ± 6.8
Height	(cm)	-	182 ± 6	178.7 ± 7.0	167 ± 6*	168.4 ± 5.8*
Weight	(kg)	1	83.6 ± 9.7	78.5 ± 9.1	65.3 ± 11.2*	61.8 ± 8.3*
		2	83.5 ± 9.0	78.6 ± 9.5	65.3 ± 11.0*	62.0 ± 9.0*
BMI	(kg/m^2)	1	25.2 ± 2.4	24.5 ± 2.1	23.3 ± 4.0	21.8 ± 3.0*
		2	25.1 ± 2.1	24.6 ± 2.2	23.4 ± 4.0	21.9 ± 3.2*
∆Weight	(kg)	-	0.2 ± 2.0	-0.2 ± 1.3	-0.1 ± 1.1	-0.1 ± 1.6
∆BMI	(kg/m^2)	-	0.1 ± 0.6	-0.0 ± 0.4	-0.0 ± 0.4	-0.0 ± 0.6

Note: BMI: body mass index. WBV: whole-body vibration. ∆: data session$_1$ minus data session$_2$. Session$_1$**:** before the intervention. Session$_2$**:** after the intervention. Data were mean ± SD.

*P < 0.05 (Student T test): males vs. females for the same intervention.

$^¥$P < 0.05 (Student T test): control-group vs. WBV group for the same sex.

$^\varpi$P < 0.05 (Wilcoxon test): session$_1$ vs. session$_2$ for the same sex and the same intervention (for weight and BMI).

i) For each sex, both groups had similar anthropometric data. Moreover, weight and BMI were similar for both sessions.
ii) Compared to males, females in the CG had lower height and weight (for both sessions), and females in the WBV group had lower height, weight and BMI (for both sessions).

Neuromuscular data

Table 2 presents the participants' neuromuscular data, divided according to sex and intervention. Its main conclusions were:

i) In males, compared to the CG, the WBV group had higher CMJ$_{H2}$, CMJ$_{MPR2}$, SJ$_{H2,}$ and SJ$_{MPR2}$, and it had lower ΔCMJ$_{H}$, ΔCMJ$_{MPR}$, ΔSJ$_{H}$ and ΔSJ$_{MPR}$. In females, both groups (i.e., CG and WBV group) had similar data.
ii) During session$_{2}$, males in the WBV group had higher values of CMJ$_{H}$ by 4.42 cm, CMJ$_{MPR}$ by 2.71 kW/kg, SJ$_{H}$ by 2.09 cm, and SJ$_{MPR}$ by 2.69 kW/kg compared to session$_{1}$. However, females in the WBV group had higher values of CMJ$_{H}$ by 1.60 cm, and SJ$_{H}$ by 1.39 cm.
iii) Compared to males, females in the CG had lower data (except for ΔCMJ$_{MPR}$, ΔSJ$_{H}$, and ΔSJ$_{MPR}$), and females in the WBV group had lower data (except for ΔCMJ$_{H}$, ΔCMJ$_{MPR}$, ΔSJ$_{H}$, and ΔSJ$_{MPR}$). The ΔSJ$_{H}$ effect size was medium (Hedges' unbiased d = -0.222).

Cardiovascular data

Table 3 presents the participants' cardiovascular data, divided according to sex and intervention. Its main conclusions were:

i) Compared to the CG, males in the WBV group had a lower DBP$_{2}$, and females in the WBV group had a lower ΔHR (cpm,%).
ii) Compared to session$_{1}$, males in the WBV group had a lower DBP by 5 mmHg, and females in the WBV group had lower HR by 3 bpm, and DBP by 4 mmHg during session$_{2}$.
v) Compared to males, females in the CG had lower SBP$_{1}$, SBP$_{2}$ and DBP$_{1}$, and females in the WBV group had similar data.

TABLE 2. Neuromuscular data of the participants divided according to sex and intervention.

Data		Session	Males (n = 44)		Females (n = 52)		Factorial ANOVA
			Control-group (n = 20)	WBV group (n = 24)	Control-group (n = 27)	WBV group (n = 25)	
SJ$_{H}$	(cm)	1	32.24 ± 6.15	34.42 ± 7.11	22.19 ± 5.18*	22.54 ± 3.97*	F(1,184) = 0.174, p = 0.676
		2	31.79 ± 5.79	36.51 ± 7.12$^{¥\varpi}$	22.40 ± 4.44*	23.93 ± 4.44$^{*\varpi}$	
SJ$_{MPR}$	[kW/kg]	1	44.95 ± 7.49	46.60 ± 7.94	33.02 ± 5.67*	33.26 ± 4.60*	F(1,184) = 1.048, p = 0.307
		2	43.57 ± 6.70	49.29 ± 6.96$^{¥\varpi}$	33.29 ± 5.16*	33.85 ± 5.70*	
CMJ$_{H}$	(cm)	1	39.31 ± 8.82	40.61 ± 7.15	26.24 ± 6.35*	26.38 ± 4.40*	F(1,184) = 1.160, p = 0.282
		2	38.81 ± 8.09	45.03 ± 9.60$^{¥\varpi}$	27.39 ± 5.90*	27.97 ± 6.34$^{*\varpi}$	
CMJ$_{MPR}$	[kW/kg]	1	50.90 ± 10.08	53.75 ± 9.30	36.93 ± 6.18*	38.04 ± 5.03*	F(1,184) = 0.491, p = 0.484
		2	50.13 ± 9.48	56.47 ± 9.32$^{¥\varpi}$	37.52 ± 6.04*	38.92 ± 6.84*	
ΔSJ$_{H}$	(cm)	-	0.44 ± 3.11	-2.09 ± 3.60$^{¥}$	-0.22 ± 3.07	-1.39 ± 2.52	F(1,92) = 1,136, p = 0.289
ΔSJ$_{MPR}$	[kW/kg]	-	1.39 ± 3.05	-2.69 ± 4.49$^{¥}$	-0.26 ± 3.41	-0.60 ± 3.33	F(1,92) = 6,323, p = 0.013
ΔCMJ$_{H}$	(cm)	-	0.50 ± 6.44	-4.42 ± 5.80$^{¥}$	-1.15 ± 3.37	-1.60 ± 3.56*	F(1,92) = 5,043, p = 0.027
ΔCMJ$_{MPR}$	[kW/kg]	-	0.77 ± 5.17	-2.71 ± 5.37$^{¥}$	-0.59 ± 4.14	-0.88 ± 3.63	F(1,92) = 2,873, p = 0.093

Note: CMJ$_{H}$**:** counter movement jump maximal jump height. CMJ$_{MPR}$**:** counter movement jump maximal power relative. SJ$_{H}$**:** squat jump maximal jump height. SJ$_{MPR}$**:** squat jump maximal power relative. WBD: whole-body vibration. Δ: data session$_{1}$ minus data session$_{2}$. Session$_{1}$**:** before the intervention. Session$_{2}$**:** after the intervention. Data were mean ± SD**.**

*P < 0.05 (Student T test): males vs. females for the same intervention.
$^{¥}$P < 0.05 (Student T test): control-group vs. WBV group for the same sex.
$^{\varpi}$P < 0.05 (Wilcoxon test): before vs. after for the same sex and the same intervention.
Factorial ANOVA: sexes (2) vs. groups (2) vs. sessions (2).
Factorial ANOVA: sexes (2) vs. groups (2) for Δdata.

TABLE 3. Cardiovascular data of the participants divided according to sex and intervention.

Data		Session	Males (n = 44)		Females (n = 52)		Factorial ANOVA
			Control-group (n = 20)	WBV group (n = 24)	Control-group (n = 27)	WBV group (n = 25)	
HR	(bpm)	1	69 ± 8	70 ± 9	71 ± 8	72 ± 8	F(1,184) = 0.149, p = 0.699
		2	70 ± 10	67 ± 9	73 ± 9	69 ± 8$^{\varpi}$	
HR	(%)	1	37 ± 5	37 ± 4	38 ± 5	38 ± 4	F(1,184) = 0.145, p = 0.703
		2	37 ± 6	36 ± 5	39 ± 5	37 ± 4	
SBP	(mmHg)	1	124 ± 16	126 ± 13	114 ± 9*	114 ± 10	F(1,184) = 0.832, p = 0.362
		2	127 ± 11	122 ± 12	115 ± 13*	115 ± 12	
DBP	(mmHg)	1	77 ± 8	75 ± 7	72 ± 8*	72 ± 8	F(1,184) = 0.000, p = 0.988
		2	76 ± 8	71 ± 7$^{¥\varpi}$	71 ± 7	68 ± 8$^{\varpi}$	
ΔHR	(bpm)	-	-1 ± 9	3 ± 8	-2 ± 8	3 ± 6$^{¥}$	F(1,92) = 0.368, p = 0.545
ΔHR	(%)	-	-0 ± 5	2 ± 4	-1 ± 4	2 ± 3$^{¥}$	F(1,92) = 0.373, p = 0.542
ΔSBP	(mmHg)	-	-3 ± 12	4 ± 10	-1 ± 11	-1 ± 9	F(1,92) = 2,140, p = 0.146
ΔDBP	(mmHg)	-	1 ± 9	5 ± 7	0 ± 7	4 ± 8	F(1,92) = 0.000, p = 0.983

Note: ANOVA: analysis of variance. DBP: diastolic blood pressure. HR: heart-rate. SBP: systolic blood pressure. WBD: whole-body vibration. Δ: data session$_1$ minus data session$_2$. Session$_1$**:** before the intervention. Session$_2$**:** after the intervention. Data were mean ± SD.

*P < 0.05 (Student T test): males vs. females for the same intervention.

$^{¥}$P < 0.05 (Student T test): control-group vs. WBV group for the same sex.

$^{\varpi}$P < 0.05 (Wilcoxon test): before vs. after for the same sex and the same intervention.

Factorial ANOVA: sexes (2) vs. groups (2) vs. sessions (2).

Factorial ANOVA: sexes (2) vs. groups (2) for Δdata.

Sex-specific effects

Significant interactive effects of sexes (2) vs groups (2) vs sessions (2) were noted for ΔSJ_{MPR} and ΔCMJ_H (Table 2). The Tukey post hoc test revealed that differences involved only males: compared to the CG, the WBV group had better ΔSJ_{MPR} and ΔCMJ_H (Figures 3A and 3B, respectively). Concerning cardiovascular data, no significant interactive effect of sex (2) vs group (2) vs session was noted (Table 3).

DISCUSSION

The main objective of the present comparative experimental study was to evaluate the sex-specific response to squat training with WBV by measuring some neuromuscular and cardiovascular data. This study revealed no sex-specific response to WBV for either neuromuscular or cardiovascular data. Therefore the null hypothesis was retained.

To date, the few studies [23, 49, 50] investigating the sex-specific aspects of WBV training have reported that males and females vary in their response to WBV. However, the existing insights are still insufficient and they do not allow a transfer to sex-specific practice planning.

Effects of WBV on neuromuscular data: comparison of CG vs WBV group and session$_1$ vs session$_2$

Compared to the CG, the WBV group had higher CMJ_{H2}, CMJ_{MPR2}, SJ_{H2}, and SJ_{MPR2}, lower ΔCMJ_H, ΔCMJ_{MPR}, ΔSJ_H and ΔSJ_{MPR} (for males), and similar data (for females). Compared to session$_1$, the WBV group had higher CMJ_H, CMJ_{MPR}, SJ_H and SJ_{MPR} for males, and higher CMJ_H and SJ_H for females during session$_2$. The aforementioned results are in line with various other studies focusing on the effects of WBV on jumping performance [9, 23, 25, 27–33] and power [9, 19–27]. Before contemplating the sex gap effect, it is worth summarizing the latest hypotheses that might explain the dramatic increase in CMJ and SJ output recorded in this study and elsewhere. In 12 recreationally active males, Turner et al. [33] reported that improvement of CMJ performance is dependent on the adopted frequency of WBV. The authors reported that 40 Hz is more significant than 30-, 35-, and a 0-Hz position-matched control impact of vibration frequency on CMJ performance [33]. These results suggest that for vertical WBV at a peak-to-peak displacement of eight mm, a frequency of at least 40 Hz is required for acute training or performance benefits (e.g., warm-up) in recreationally active individuals, thus being more likely to induce chronic adaptations [33]. In fact, in recreational participants using a vertical vibration platform, Turner et al. [33] found that acute exposure to WBV at 40 Hz and at peak-to-peak displacement of 8 mm is sufficient to significantly improve CMJ performance. The findings of Turner et al. [33] are in agreement with those in the present research, although the amplitude was 3–3.5 mm and the vibration was 40 Hz. However, the participants in our protocol performed training over a 5-week period, constituting a major difference with the aforementioned study. More information related to the neuromuscular theory of WBV are detailed in the Appendix.

Effects of WBV on cardiovascular data: comparison of CG vs WBV group and session$_1$ vs session$_2$

Compared to the CG, the WBV group had lower DBP_2 in males and lower ΔHR (cpm,%) in females. Compared to session$_1$, the WBV group had lower DBP in males, and lower HR and DBP in females during session$_2$. The aforementioned results are in line with various other studies focusing on the effects of WBV on cardiovascular data [56–59]. On the one hand, preliminary research indicates that WBV can influence HR variability [56–59]. Licurci et al. [59] reported that a single session of WBV in volunteers standing upright for 10 min on an oscillating platform, with a vibration frequency set at 20 Hz (displacement ± 6 mm; orbital vibration), improves HR variability and may also help reduce the risk of cardiac ailments for the elderly population. Wong et al. [58] also reported that WBV training with a vertical acceleration of 25–40 Hz for eight weeks improves the sympathovagal balance in sedentary obese postmenopausal women. Likewise, Severino et al. [57] suggested that a 6-week WBV training programme improves the percentage of HR variability and body fat in postmenopausal obese females. They also reported that changes in the sympathovagal balance are correlated with the body fat percentage. According to Wong and Figueroa [58], the mechanisms by which WBV training enhances sympathovagal balance are still unclear. However, improvement of baroreflex sensitivity, nitric oxide bioavailability and angiotensin II levels appear to play a vital role [58]. On the other hand, there is "evidence" that blood pressure can be decreased sustainably as a result of WBV interventions [34]. Our results with regard to the impact of WBV on blood pressure are supported by other studies involving lower numbers of participants. For instance, it was shown through a 6-week intervention on 10 females that both SBP and DBP decreased by 5.3 mmHg [34]. Figueroa et al. [39] reported that WBV exercise training is an effective exercise modality for decreasing arterial stiffness in postmenopausal females with prehypertension and hypertension. The possible mechanisms underlying the effects of WBV training on arterial function and blood pressure are the improvement of endothelial and autonomic functions [34]. Additional information concerning the exact underlying mechanisms are detailed in the Appendix.

There are some methodological differences between the aforementioned studies and the present one. These variants are mainly linked to the number of participants (n = 15 [39], n = 27 (14 in the CG) [57]), the differentiation between the two sexes, and the existence of a CG. For instance, in some studies [39, 57, 58], participants were randomly assigned to a WBV training group or a non-exercising CG.

Sex-specific effects of WBV

Compared to males, females had lower SJ_H, SJ_{MPR}, CMJ_H and CMJ_{MPR} (for both CG and WBV group), lower ΔCMJ_H (for CG), lower SBP_1, SBP_2 and DBP_1 (for CG), and similar cardiovascular data (for WBV group). However, interactive effects of sex (2) vs group (2) vs session (2) were noted only in males and they concerned ΔSJ_{MPR} and ΔCMJ_H: compared to the CG, the WBV group had better ΔSJ_{MPR} and ΔCMJ_H.

Significant increases in performance parameters in males due to the support of male hormones, especially during strength training, are confirmed by the literature [60–62]. Our results are in line with the few publications related to this issue. In fact, a growing body of literature indicates that alternative training stimuli, such as WBV [63, 64], are effective in improving muscle performance in adults. A previous review [65] concluded that in adults, relative training-related strength increases are similar between males and females if the same exercise stimulus is delivered. In young people, and according to Peitz et al. [63] sex has no major impact on resistance training-related outcomes (e.g., maximal strength, 10 repetition maximum).

Study limitations

This study has three main limitations. The first one concerns the lack of blinding [66]. In fact, a participant who is aware that he is not receiving "active" intervention may be less likely to comply with the study protocol, and is more likely to leave the study without providing outcome data [66]. However, the CG involved in this study performed the same exercises, and the percentages of loss during the follow-up were similar between the two groups [26.56 vs 19.67%, p = 0.36, respectively for CG and WBV group (Figure 1)]. The second limitation concerns the lack of an objective determination of the participants' physical activity level (via a questionnaire for example). One previous study compared the effects of WBV in trained (10 recreationally bodybuilders) and untrained (n = 9 students) participants [67]. It showed that in the untrained group, WBV caused a significant increase in the mean velocity and acceleration. However, in the trained group, WBV did not cause any improvement in performance [67]. The last limitation concerns the low number of applied training sessions [10 sessions (two training sessions/week for five weeks)] and the magnitude of its effect on the neuromuscular and cardiovascular data. On the one hand, our training protocol was derived from the literature [46, 52, 53]. On the other hand, our training protocol was intermediate with these reported in some related studies [e.g., 6 sessions (1 time/week for 6 weeks) [68], 9 sessions (3 times/week for 3 weeks [69]), 12 sessions (3 times/week for 4 weeks [20]), 36 sessions (three times/week for 12 weeks [70]); 72 sessions (three times/week for 24 weeks [24, 43])].

CONCLUSIONS

To conclude, WBV shows positive effects on some neuromuscular and cardiovascular data that are not sex-specific.

Establishments where the work was performed

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Appendix for this article is available online (link).

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