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Original Article

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A comparison of the effect of two types of vibration exercise on the endocrine and musculoskeletal system

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Abstract

Background: Whole body vibration (WBV) is a novel training intervention but a comparison of different methods of WBV has rarely been performed. **Aim:** To compare the short and medium term effects of two regimens of WBV on endocrine status, muscle function and markers of bone turnover. **Patients and Methods:** Over a period of 16 weeks, 10 men with a median age of 33 yrs (range, 29,49), were randomised to stand on the Galileo platform (GP) or Juvent1000 platform (JP) 3 times/wk. The total study duration was 16 weeks with measurements performed in a 4 week period of run-in, 8 weeks of WBV and a 4 week period of washout. These measurements included an assessment of anthropometry, body composition, muscle function and biochemical markers of endocrine status and bone turnover. To assess immediate effects of WBV, measurements were also performed at 60 mins before and 5, 30 and 60 mins after WBV. To assess immediate effects of WBV, measurements were also performed at 60 mins before and 5, 30 and 60 mins after WBV. **Results:** GP at 22 Hz was associated with an immediate increase in serum GH, rising from 0.07 μg/l (0.04,0.69) to 0.52 μg/l (0.06,2.4) (p=0.06), 0.63 μg/l (0.1,1.18) (p=0.03), 0.21 μg/l (0.07,0.65) (p=0.2) at 5 mins, 20 mins and 60 mins after WBV, respectively. An immediate effect was also observed in median serum cortisol which reduced from 316 nmol/l (247,442) before WBV to 173 nmol/l (123,245) (p=0.01),165 nmol/l (139,276) (p=0.02) and 198 nmol/l (106,294) (p=0.04) at 5 mins, 20 mins and 60 mins after WBV, respectively. Median serum CTX reduced significantly after 8 weeks of WBV training in the GP group from 0.42 ng/ml (0.29,0.90) pre-WBV to 0.29 ng/ml (0.18,0.44) at the end of WBV training (p=0.03). Over the 8 weeks, there was a reduction in median serum cortisol in the GP group from 333 nmol/l (242,445) (pre-WBV) to 270 nmol/l (115,323) (WBV) (p=0.04). None of the changes observed in the JP group reached statistical significance. Neither group showed any significant effect on muscle function, IGF-1, testosterone, leptin, CRP, creatine kinase, insulin or other markers of bone turnover. **Conclusion:** WBV can stimulate GH secretion, reduce circulating cortisol and reduce bone resorption. These effects are independent of clear changes in muscle function and depend on the type of WBV that is administered.

Keywords: Whole Body Vibration, Growth Hormone, Cortisol, Bone Markers

Introduction

In whole body vibration (WBV), the vibration platform delivers high frequency mechanical stimuli with small amplitude which are transmitted through the body where they introduce mechanical loading to the musculoskeletal system through bone, muscle and sensory receptors[1]. Although WBV is an increasingly popular form of training that has been reported to have beneficial effects on bone health[1,2], muscle mass[3-5], and hormonal profile[6], the underlying mechanisms that explain these effects remain unclear[7]. WBV can be delivered by two broad categories of exercise devices: devices that reciprocate vertical displacements on the left and right side of a fulcrum (sinusoidal vibration) and generate higher lateral than vertical acceleration and devices that have a plate which oscillates up and down in a vertical axis (vertical vibration)[8] and which produce greater strain in the vertical axis than in the lateral axis[9]. Given that WBV may represent an effective non-pharmacologic, user-friendly, therapeutic intervention for osteoporosis and sarcopenia[10]; there is a need for more critical evaluation

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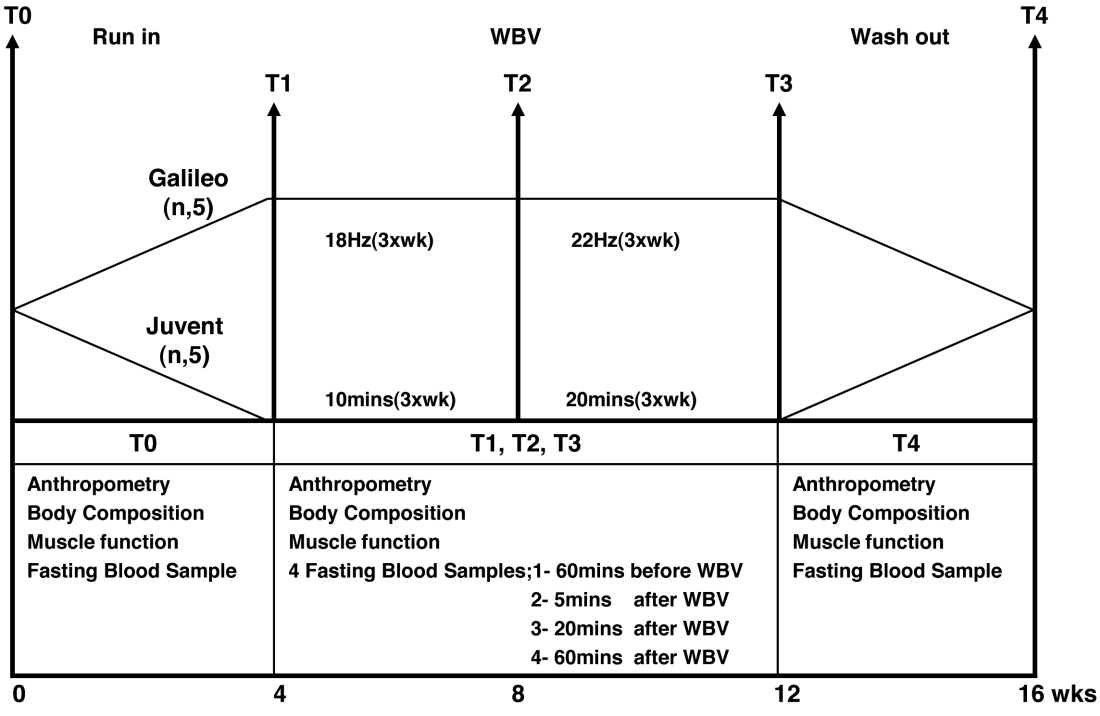

Figure 1. Study protocol consists of 5 time points (T0-T4) over a period of 16 weeks. At T0, the participants were randomised into two groups; GP and JP. At T0 and T4, weight, height, muscle function, body composition and a fasting blood sample were collected. WBV was performed for a period of 8 weeks from T1 to T3, 3 times/wk with different frequency and duration. The measurements at these time points were similar to T0 and T4. In addition, 4 fasting blood samples were also collected at T1, T2 and T3; the first sample was collected was 60 mins before WBV and the others were collected at 5, 20 and 60 mins after WBV.

Abbreviations:
Whole Body Vibration (WBV)
Galileo WBV (GP)
Juvent WBV (JP)
Growth Hormone (GH)
Insulin-like growth factor-1 (IGF-1)
Bone-specific Alkaline Phosphatase (BAP)
Osteocalcin (OCN)
Cross Linked C-Telopeptide of Type I Collagen (CTX)
Tartrate-resistant acid phosphatase 5b (TRAP5b)
Sclerostin (Scl)
Creatine Kinase (CK)

and comparison of the systems that deliver this stimulation.

The devices that deliver WBV can be broadly categorised according to their peak acceleration; low intensity WBV platforms which produce a gravitational force less than 1 g regardless of frequency and high intensity WBV platforms (g force of more than 1 g)[11]. An example for a low-intensity WBV platform is the Juvent 1000 platform and a high-intensity WBV platform is Galileo platform. Physical exercise is closely linked to a diverse range of hormonal effects and although there are some studies which have investigated the short-term effects of WBV on the endocrine axis, there is a scarcity of knowledge about the medium-term effects of WBV on endocrine targets that are reported to be responsive to physical exercise. In addition, there are currently no studies that have compared the effect of the two different methods of WBV on the endocrine profile as well as muscle function. This study was, therefore, performed to compare the effects of sinusoidal and vertical WBV delivered through the Galileo platform (GP) and the Juvent1000 platform (JP), respectively on a range of outcome measures related to the endocrine and musculoskeletal system. It was hypothesized that WBV with different magnitudes may elicit different patterns of musculoskeletal and endocrine responses.

Method and Material

Subjects

All potential candidates had a physical examination to determine their general health and were excluded if they had any chronic illness, recent fractures, skeletal anomalies or implants. Following informed consent, 14 healthy men were recruited to the study but 4 subjects withdrew as one subject had a hamstring injury before starting WBV and the remaining 3 could not attend the exercise visits. A total of 10 men with a median age of 33 years (range, 29, 49) completed the study. Ethics approval was obtained from the University of Glasgow Research Ethics Committee.

Parameters	WBV	T0	T1	T2	T3	T4
Tanita						
BMI	**GP**	24(23,28)	24(23,28)	25(23,28)	24(22,28)	24(22,28)
	JP	24(23,29)	23(23,30)	23(23,30)	23(23,30)	23(23,30)
FAT%	**GP**	17(16,25)	18(16,23)	19(15,34)	17(15,23)	18(16,22)
	JP	19(17,29)	19(18,28)	19(17,30)	19(18,30)	19(17,27)
Mechanography						
Jump Height (cm)	**GP**	41(32,51)	41(39,51)	43(41,50)	45(43,55)	44(41,52)
	JP	51(35,55)	42(36,52)	43(35,52)	48(32,52)	49(33,55)
F max (kN)	**GP**	2.13(1.65,2.81)	1.88(1.60,2.72)	1.94(1.75,2.43)	1.79(1.60,2.28)	1.92(1.63,2.21)
	JP	1.87(1.77,2.77)	2.11(1.73,2.63)	2.24(1.77,2.48)	2.27(1.70,2.55)	2.00(1.73,2.75)
P maxt (kW)	**GP**	3.51(3.18,3.93)	3.76(3.16,4.03)	3.84(3.41,4.1)	3.80(3.53,4.08)	3.71(3.54,3.95)
	JP	3.85(3.58,4.43)	3.72(3.50,4.77)	3.80(3.53,4.7)	3.90(3.27,4.98)	3.71(3.22,4.66)
Biochemical Markers						
CK (IU/L)	**GP**	203(68,300)	141(64,462)	185(97,390)	149(84,261)	168(126,270)
	JP	136(118,234)	135(77,150)	123(104,338)	125(83,185)	117(78,253)
Leptin (ng/ml)	**GP**	8.4(7,16.6)	9.6(4.7,11.9)	6.6(6.4,12.4)	13.1(5.4,13.2)	9.8(4.2,13.2)
	JP	9.2(6.7,14.9)	8.9(5,21.3)	10(3.7,23.9)	11(6.6,14.8)	8.2(5.1,14.7)
Insulin (uU/ml)	**GP**	6.4(4.6,21.8)	7.3(3.8,17.3)	4.4(2.2,9.7)	10.6(0.3,24.4)	7.1(5.2,10)
	JP	10.7(5.2,14.3)	7.7(4.6,10.2)	9.6(4.3,11.3)	7.55(4.8,16.1)	8.9(7.1,27.7)
Testo (nm/L)	**GP**	16(13,28)	18(12,26)	16(12,28)	16(10,30)	17(12,31)
	JP	20(9,21)	18(10,25)	22(12,24)	19(12,21)	19(9,22)
GH (µg/l)	**GP**	0.14(0.04,0.73)	0.05(0.04,1.03)	0.09(0.04,0.30)	0.04(0.04,0.69)	0.09(0.04,3.68)
	JP	0.07(0.04,0.22)	0.04(0.04,0.15)	0.05(0.04,0.23)	0.07(0.04,0.09)	0.04(0.04,0.31)
IGF1 (ng/ml)	**GP**	246(21,289)	240(207,479)	223(183,282)	231(166,347)	214(210,348)*
	JP	200(179,228)	208(159,257)	200(132,233)	187(132,266)	173(118,209)
Cortisol (nmol/l)	**GP**	351(242,445)	316(247,442)	284(225,285)	255(115,323)	341(203,433)
	JP	367(175,444)	289(202,454)	272(133,342)	332(28,380)	337(268,380)
Glucose (mmol/L)	**GP**	5.0(4.5,5.4)	4.3(3.7,5.7)	4.8(4.7,5.7)	5.6(4,6.3)	5.1(4.4,5.8)
	JP	5.6(5.3,5.8)	5.3(4,5.6)	5.3(5,5.5)	5.3(5.1,6)	5.3(4.9,5.7)
BAP (µg/l)	**GP**	19(10,32)	20(10,25)	14(12,14)	14(14,36)	16(5,49)
	JP	13(12,33)	16(10,20)	12(11,26)	12(7,17)	13(9,28)
OCN (ng/ml)	**GP**	17(11,19)	17(14,23)	18(14,22)	18(5,24)	18(15,29)
	JP	19(10,28)	18(11,25)	18(12,30)	12(7,26)	17(9,26)
CTX (ng/ml)	**GP**	0.48(0.30,0.86)	0.35(0.29,0.90)	0.28(0.20,0.38)	0.29(0.18,0.44)	0.45(0.40,0.66)
	JP	0.65(0.19,1.18)	0.41(0.20,0.70)	0.31(0.15,1.09)	0.43(0.30,0.48)	0.38(0.29,0.77)
TRAP5b (ng/ml)	**GP**	3.2(1.9,6.2)	3.8(2.2,5)	2.4(1.9,4.7)	3.9(2.3,5)	4.1(0.5,6.8)
	JP	2.8(2.14,3.6)	1.9(1,3.9)	2.7(2.1,3.8)	1.62(1.61,2)	3(1.4,4)
Scl (ng/ml)	**GP**	0.38(0.16,0.60)	0.31(0.02,0.53)	0.22(0.18,0.32)	0.39(0.19,0.52)	0.37(0.20,0.54)
	JP	0.27(0.23,0.85)	0.37(0.19,0.84)	0.41(0.21,0.79)	0.30(0.07,0.55)	0.30(0.05,0.81)

Table 1. Physical and biochemical parameters at every time point (T0-T4) in GP group and JP group. body mass index (BMI), Fat mass percent (FM%), Jump height (cm), force maximum total (F max), power maximum total (P max), growth hormone (GH), insulin like growth factor-1 (IGF-1), bone specific alkaline phosphatase (BAP), osteocalcin (OCN), Serum cross linked c-telopeptide of type I collagen (CTX), Tartrate-resistant acid phosphatase 5b (TRAP5b), sclerostin (Scl) and creatine kinase (CK).

Study procedures

An initial interview was conducted to describe the purpose and the aims of the study and the tests that would be performed. The total study duration was 16 weeks and was divided into three periods; a Run-In period of 4 weeks, a WBV period of 8 weeks followed by a 4 week Wash Out period (Figure 1). The measurements were performed at 5 time points (T0, T1, T2, T3, and T4). T0 was at the beginning of the Run-In period; T1, T2 and T3 were at the beginning, half-way and the end of the WBV period; and, T4 was at the end of the Wash-Out period. To assess the short-term effect of WBV, multiple samples were collected at T1, T2 and T3 at 60 mins before WBV and 5, 30 and 60 mins after WBV. To assess the medium-term effects, samples collected at T0 and the first sample collected at T1 were jointly analysed as pre-WBV, samples collected at T2 and T3 were jointly analysed as WBV and those collected at T4 were referred to as post-WBV. The blood samples were collected between 08.00 and 09.00 am, after a minimum of 8 hours of fasting. The participants were not allowed to consume food and drinks during the treatment. All blood samples were

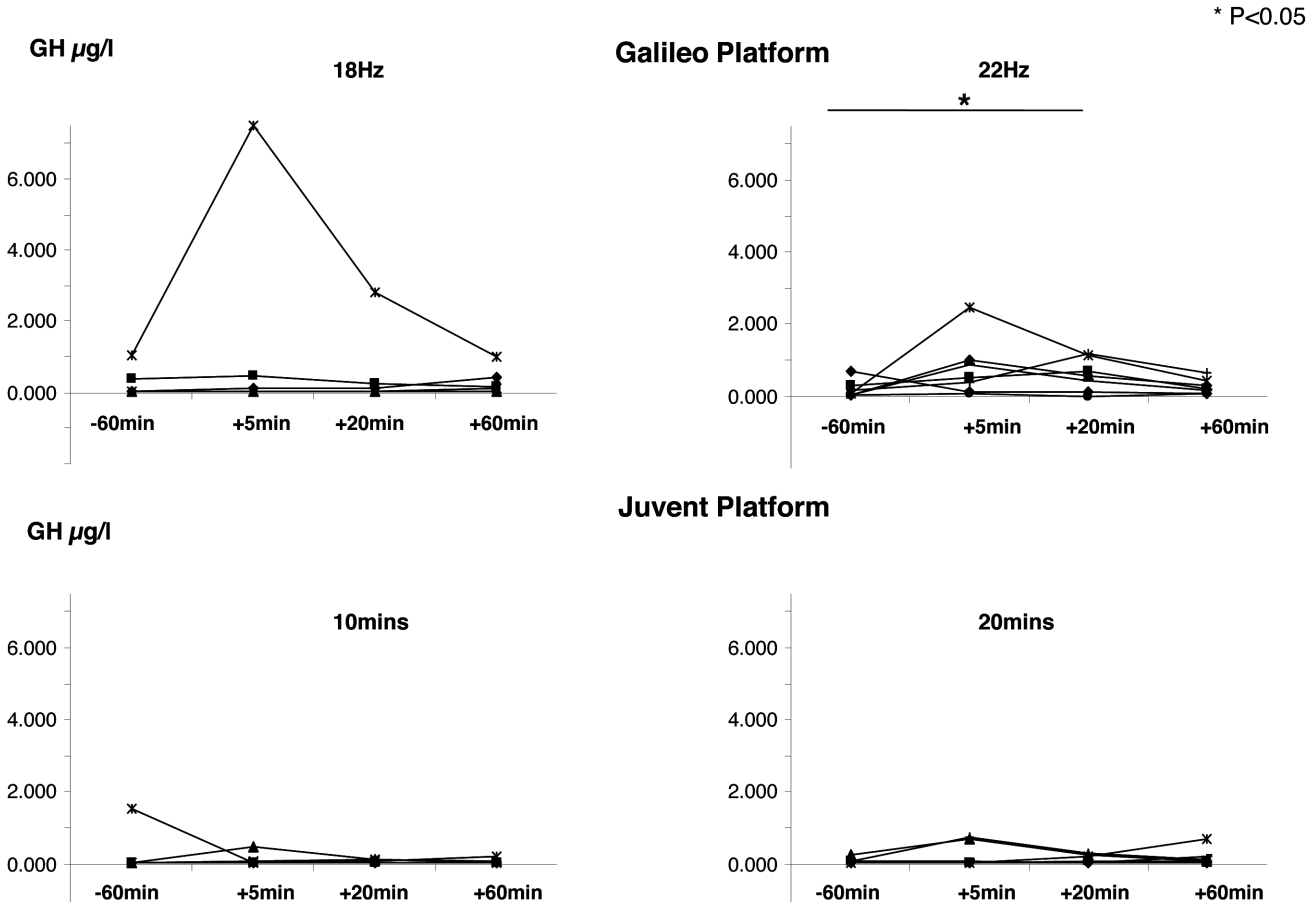

Figure 2. Short term effect of WBV on GH. GP group had WBV at frequency of 18 Hz at (T1) and 22 Hz at (T2, T3). JP group stood for 10 mins at (T1) and 20 mins at (T2, T3). *p<0.05.

collected via an indwelling venous cannula and centrifuged at 2600-2800 rev/min for 10 min, and the serum was subsequently stored at -70 C.

Exercise Regimen

At T0, all participants were randomised to receive WBV by the Galileo device (Novotec, Pforzheim, Germany) or Juvent 1000 DMT (Juvent Medical Inc, Somerset, USA) on 3 days every week over the WBV period. For the Galileo platform (GP), the WBV intensity used for the first 4 weeks (from T1 to T2) was at the frequency of 18 Hz, the peak-to peak displacement 4mm and the acceleration 2.6 g whereas; for the second 4 weeks (from T2 to T3), the frequency increased to 22 Hz, the peak-to peak displacement remained constant at 4 mm and the acceleration increased to 3.8 g. The two different settings allowed an a comparison of different settings with the same device. All sessions were supervised and each exercise visit consisted of 3 bouts of WBV with each bout lasting for 3 min with one minute rest in between the bouts. For the Juvent platform (JP), the WBV intensity was kept constant at 32-37 Hz of frequency with a peak-to peak displacement 0.085 mm and an acceleration of 0.3 g for 10 mins in the first 4 weeks (from T1 to T2); in the second 4 weeks (from T2 to T3), the duration of exposure doubled to 20 mins for each session. Details of the WBV regimen are outlined as recommended by the International Society of Musculoskeletal and Neuronal Interactions[12]. These regimens for the two devices were chosen as they have previously been reported to exert a beneficial effect on musculoskeletal health[13,14]. All participants were instructed to stand still on the vibration platforms without shoes and, in the case of GP, with slight flexion of the knees.

Body composition and muscle function

Anthropometry included height, weight and body composition measurements were performed using a Harpenden Stadiometer and Tanita (TBF-300, Tokyo, Japan), respectively. Muscle force, power, velocity and jump height were assessed by Leonardo mechanography (Novotec Medical, Pforzheim, Germany). A two-leg jump was assessed as a counter movement with freely moving arms and the subjects were instructed to jump as high as possible. Vertical jump height (cm), power max total (kW), power max/kg (W/kg), efficiency (%) and

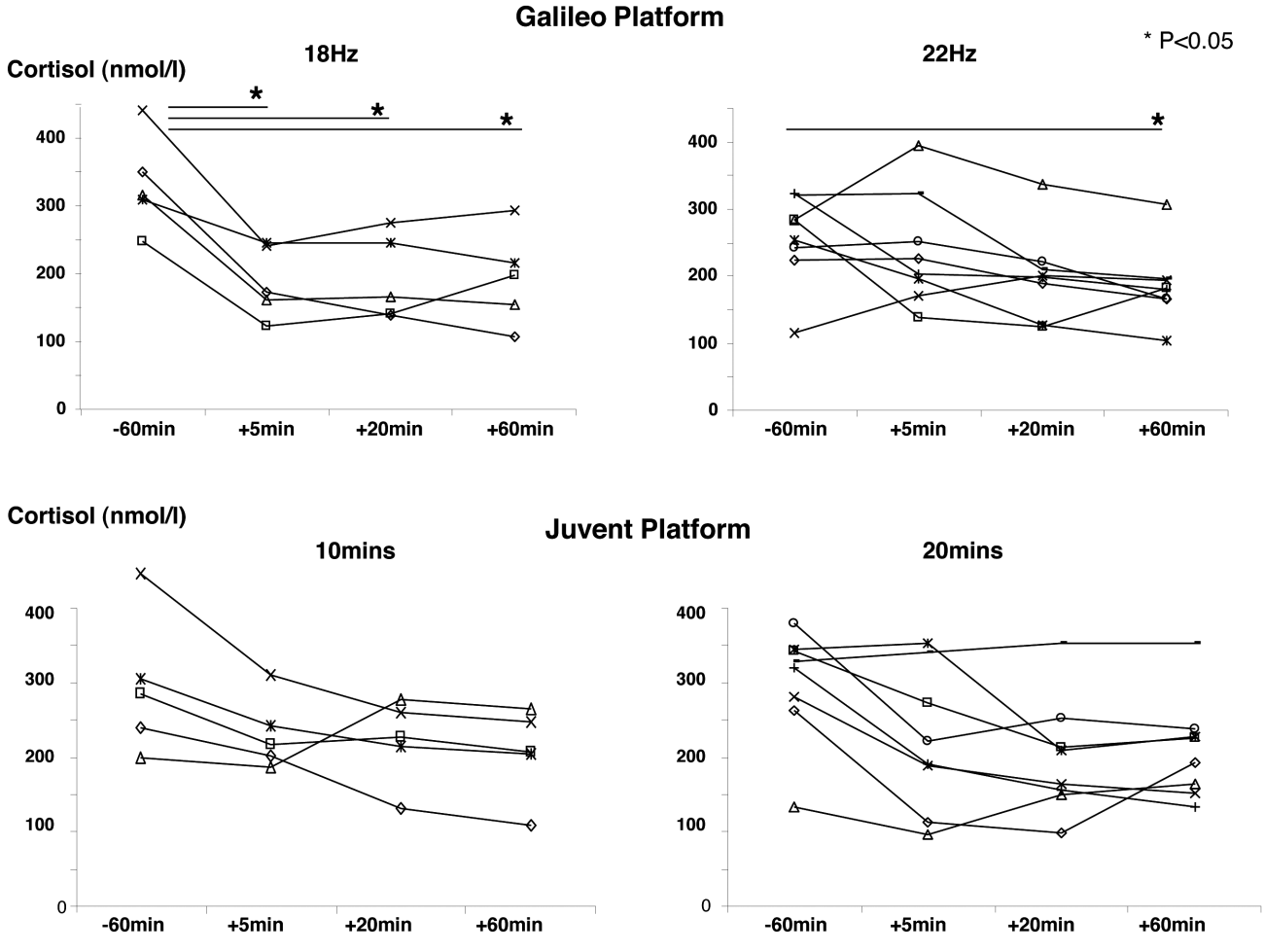

Figure 3. Short term effect of WBV on serum cortisol. GP group had WBV at frequency of 18 Hz at (T1) and 22 Hz at (T2, T3). JP group stood for 10 mins at (T1) and 20 mins at (T2, T3). *p<0.05.

Esslinger Fitness Index (EFI) (%) were all assessed. Each participant was asked to jump at least three times at each time point and the result of highest jump was included. Handgrip strength was assessed with the Jamar handgrip dynamometer (Preston, Jackson, MI, USA) using the dominant arm and the highest measurements were recorded.

Biochemical Assays

The short effect of WBV was assessed by measuring serum growth hormone (GH), cortisol, creatine kinase (CK) and glucose and the medium term effect was assessed by measuring markers of bone turnover, Insulin, Insulin-like growth factor 1 (IGF-1), Testosterone, Leptin and C-reactive protein (CRP). Serum bone-specific alkaline phosphatase (BAP) was measured by Ostase® BAP immunoenzymetric assay (immunodiagnostic systems Ltd (IDS Ltd, Boldon, UK) with an intra-assay CV of 5.5% to 7.3%. Serum osteocalcin (OCN) was measured using N-MID® osteocalcin ELISA (IDS Ltd, Boldon, UK) with an intra-assay CV of 3.3% to 9.7%. Serum cross linked C-telopeptide of type I collagen (CTX) was determined using serum crossLaps® ELISA (IDS Ltd, Boldon, UK) with an intra-assay CV of 1.9% to 4.2%. Serum tartrate-resistant acid phosphatase 5b (TRAP5b) was detected by using bone TRAP(r) Assay (IDS Ltd, Boldon,UK) with the intra-assay CV of 1.7% to 3.4%. Serum sclerostin (Scl) was detected by using TECO Sclerostin Elisa Kit (Pathway Diagnostic Ltd, Dorking, UK) with an intra-assay CV of 1.1% to 3.9%. Serum GH and insulin were measured by the Siemens Immulite 2000 Erlangen, Germany. Between-run CV was less than 5% for both measurements. Serum IGF-1 concentration was determined using IGF-1 ELISA kit (Mediagnost IGF-1, Reutlingen, Germany), with an intra-assay CV of 5.5% to 9.5%. Serum cortisol concentration was evaluated using Architect Cortisol (Abbott Diagnostics, Abbott Park, USA) with an intra-assay CV of 6.8% to 10%. Serum testosterone concentration was determined using Abbott automated immunoassay platform (Abbott Diagnostics, Abbott Park, USA). Between-run CV was from 3% to 5%. Serum leptin concentration was determined by an in-house RIA with an intra-assay CV from 2.8% and 6%. Serum CK and glucose

		GP			
		-60 min	**+5 min**	**+20 min**	**+60 min**
GH (µg/l)	**18 Hz**	0.05(0.04,1.03)	0.11(0.05,1.5)	0.11(0.04,2.83)*	0.16(0.04,1.02)
	22 Hz	0.07(0.04,0.69)	0.52(0.06,2.47)	0.63(0.10,1.18)	0.21(0.07,0.65)
Cortisol (nmol/l)	**18 Hz**	316(247,442)	173(123,245)*	165(139,276)*	198(106,294)*
	22 Hz	269(115,323)	214(139,394)	200(125,337)	181(104,306)*
CK (IU/L)	**18 Hz**	141(64,462)	172(76,489)	137(65,422)	155(79,492)
	22 Hz	167(84,390)	157(78,329)	153(77,350)	147(94,343)
Glucose (mmol/L)	**18 Hz**	4.3(3.7,5.7)	4.5(3.4,4.8)	5.4(3.7,5.5)	5.3(3.7,5.8)
	22 Hz	5.4(4,6.3)	5.4(4.6,6.1)	5.7(4.6,6.1)	5.6(4.6,5.9)
		JP			
		-60 min	**+5 min**	**+20 min**	**+60 min**
GH (µg/l)	**10 mins**	0.04(0.04,1.52)	0.04(0.04,0.48)	0.05(0.04,0.12)	0.04(0.04,0.20)
	20 mins	0.05(0.04,0.23)	0.05(0.04,0.72)	0.05(0.04,0.27)	0.08(0.04,0.68)
Cortisol (nmol/l)	**10 mins**	289(202,454)	220(190,315)	231(133,282)	211(111,270)
	20 mins	301(328,380)	206(97,352)	187(99,352)	209(133,353)
CK (IU/L)	**10 mins**	135(77,150)	134(88,154)	140(89,145)	136(109,414)
	20 mins	123(83,338)	138(92,348)	135(86,340)	142(85,341)
Glucose (mmol/L)	**10 mins**	5.3(4,5.6)	4.9(4.1,5.6)	5.1(4.1,5.4)	4.7(4.2,5.8)
	20 mins	5.3(5,6)	5.3(4.2,6.3)	5.1(4.2,5.9)	5.1(4.8,5.4)

Table 2. Short term effect of WBV on biochemical parameters in GP and JP groups. These markers included serum GH, cortisol, CK and glucose. These measurement were taken at four discrete time points; 60 minutes before WBV (-60 mins), 5 minutes (+5 min), 20 minutes (+20 mins) and 60 minutes (+60 mins), after completing the WBV training, respectively. *significant difference from -60 min, $p<0.05$.

were measured using CK Kit and glucose reagent kit respectively (The ARCHITECT c System, Abbott Laboratories). Within-run coefficients of variation for CK and glucose were (from 3.4% to 4.1%) and (from 1.6% to 2.6%), respectively. CRP was assessed by CRP Vario (Sentinel Diagnostics, Abbott Diagnostics) with an intra-assay CV from 3.6% to 8.6%.

Statistical Analysis

Results are presented as median and ranges and inter-group differences were assessed using Mann-Whitney tests or Kruskal-Wallis tests. Statistical analysis was performed with Minitab16 (Minitab, Coventry, UK), with significance set at a level of 5%. The correlation between the variables was measured by a regression test and r-value. Furthermore, ANOVA test (General Linear Model) was performed to assess repeated measures. The short term effect of biochemical markers was assessed by the changes occurred from the measurements before the WBV training (-60 mins) and after WBV training (5, 20, 60 mins) respectively. The data for the three study periods, run-in, WBV and wash-out were analysed by studying data at T0 and T1 for run-in, data at T2 and T3 for WBV and data at T4 for wash-out.

Results

Baseline characteristics

Table 1 shows the results for all the physical and biochemical measurements of the two groups over the study period. The reported median vibration training compliance for both study groups was 100% (18,100).

Body composition and muscle function

In the GP group, median jump height at pre-WBV (T0-T1) was 41 cm (32,51) and 44 cm (41,55) during the WBV sessions (T2-T3) (p=0.08) as compared to 44 cm (41,52) (p ,0.12) at post-WBV (T4). In the JP group, median jump height was 46 cm (35,55), 45 cm (32,52) and 49 cm (33,55) pre-WBV, during WBV sessions (p=0.6) and at post-WBV (p=0.9), respectively. There were no significant changes in the other parameters of muscle function. There were also no significant changes in body composition.

Short term effect of exercise on biochemical markers

At 18 Hz (T1), GP was associated with a non-significant increase in serum GH, but at 22 Hz (T2 and T3), serum GH rose from 0.07 µg/l (0.04,0.69) at 60 mins pre-WBV to 0.52 µg/l (0.06,2.4) (p=0.055), 0.63 µg/l (0.1,1.18) (p=0.026), 0.21 µg/l (0.07,0.65) (p=0.2) at 5 mins, 20 mins and 60 mins post-WBV, respectively. In contrast, JP was not associated with any significant change in serum GH (Figure 2). At 18 Hz, GP was associated with a reduction in serum cortisol from 316nmol/l (247,442) at 60 mins pre-WBV to 173 nmol/l (123,245) (p=0.01), 165 nmol/l (139,276) (p=0.02) and 198 nmol/l (106,294) (p=0.04) at 5 mins, 20 mins and 60 mins post-WBV, respectively. At 22 Hz, GP was associated with a reduction in serum cortisol from 269 nmol/l (115,323) at 60 mins before WBV to 214 nmol/l (139,394) (p=0.5), 200 nmol/l (125,337) (p=0.08) and 181 nmol/l (104,306) (p=0.04) at 5 mins, 20 mins and 60 mins post-WBV, respectively. In the JP group there were no significant changes in serum cortisol (Figure 3).

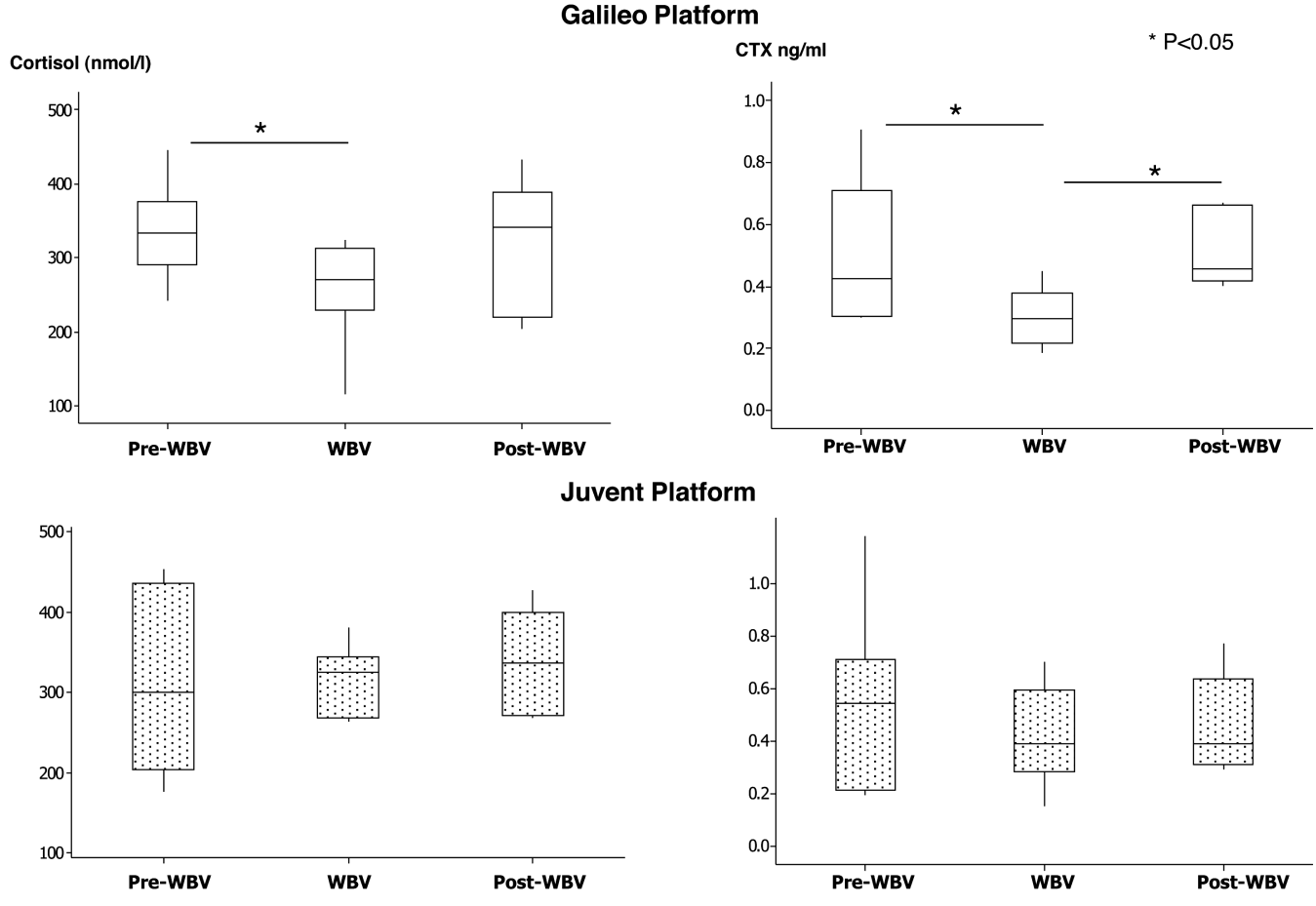

Figure 4. Medium term effects of WBV on serum cortisol and serum CTX. The data are presented for three study periods; run-in (T0 to T1), WBV (T2, T3) and wash-out (T4). *p<0.05.

Serum CK, as a marker of the effect of exercise on muscle, did not show any significant change in either of the two groups with different frequency and durations. There was no significant change in serum glucose in both groups (Table 2).

Medium term effects on biochemical markers

Median serum CTX, a marker of bone resorption fell significantly over 8 weeks of WBV training in the GP group from 0.42 ng/ml (0.29,0.90) pre-WBV to 0.29 ng/ml (0.18,0.44) at the end of WBV training (p=0.029). After 4 weeks of stopping exercise, median serum CTX of the post-WBV measurement increased to 0.45 ng/ml (0.40,0.66) (p=0.01). There were no significant changes in the JP group. WBV was not associated with any significant change in BAP, OCN, TRAP5 and Scl in either group (Table 3). Over the 8 weeks, there was a reduction in median serum cortisol in the GP group from 333 nmol/l (242,445) (pre-WBV) to 270 nmol/l (115,323) (WBV) (p=0.04) (Figure 4). GH, IGF-1, testosterone, leptin, CK and insulin did not show any significant changes over the period of exercise (Table 3).

Discussion

WBV with Galileo and Juvent was well tolerated with a high rate of compliance in the study population. Apart from very mild itching, which was experienced particularly over the shins and thighs and which has been reported previously[15], the exercise regimens were not associated with any adverse reactions. In addition, the current study showed that, over the short-term, exercise with GP was associated with increased serum GH and decreased cortisol concentration. The lowering of circulating cortisol was also observed over the medium term and this fall was also associated with a reduction in bone resorption.

The exact mechanism of WBV is still poorly understood. However, the most commonly cited mechanism of WBV is that it applies tonic vibration[16]. Roelants et al[17] concluded that WBV led to activation of lower limb muscles to a magnitude that ranged from 13% to 82% of maximal muscle contraction. However, vibration cannot elicit tonic reflexes when the amplitude is less than 1 mm[18]. Therefore, the anabolic effect of WBV on bone may be produced by other mechanisms. Fur-

	TP	Pre-WBV (T0,T1)	WBV(T2,T3)	Post-WBV(T4)
Leptin (ng/ml)	**GP**	9(4.7,16.6)	9.5(5.4,13.2)	9.8(4.2,13.2)
	JP	9(5,21.3)	11(3.7,23.9)	8.2(5.1,14.7)
Insulin (uU/ml)	**GP**	6.8(3.8,21.8)	8.4(0.3,24.4)	7.1(5.2,1)
	JP	8.5(4.6,14.3)	7.6(4.3,16.1)	8.9(7.1,27.7)
Testos (nm/L)	**GP**	17(12,28)	16(10,29)	17(12,31)
	JP	19(9,25)	20(12,24)	19(9,22)
GH (µg/l)	**GP**	0.09(0.04,1.03)	0.07(0.04,0.69)	0.09(0.04,3.68)
	JP	0.05(0.04,1.52)	0.05(0.04,0.23)	0.04(0.04,0.31)
IGF1 (ng/ml)	**GP**	243(207,479)	227(166.6,347)	214(217,384)
	JP	204(159,257)	193(132,266)	173(118,209)
Cortisol (nmol/l)	**GP**	333(242,445)	269(115,323)[1]	341(203,433)
	JP	299(157,454)	324(133,380)	337(268,428)
Glucose (mmol/L)	**GP**	4.9(3.7,5.7)	5.4(4,6.3)	5.1(4.4,5.8)
	JP	5.3(4,5.8)	5.3(5,6)	5.3(4.9,5.7)
BAP (µg/l)	**GP**	19(9,31)	14(12,36)	16(5,49)
	JP	13(10,33)	12(7,26)	13(9,28)
OCN (ng/ml)	**GP**	17.(11,22)	17(5,24)	18(14,29)
	JP	18(10,27)	16(7,30)	17(9,25)
CTX (ng/ml)	**GP**	0.42(0.29,0.90)	0.29(0.18,0.44)[1]	0.45(0.40,0.66)[2]
	JP	0.54(0.19,1.18)	0.39(0.15,1.09)	0.38(0.29,0.77)
TRAP5b (ng/ml)	**GP**	3.5(1.9,6.2)	3.3(1.9,5)	4.1(0.5,6.8)
	JP	2.4(1,3.9)	2.3(1.6,3.8)	3(1.4,4)
Scl (ng/ml)	**GP**	0.35(0.02,0.60)	0.27(0.18,0.52)	0.37(0.20,0.54)
	JP	0.32(0.19,0.85)	0.31(0.07,0.79)	0.30(0.06,0.81)
CK (IU/L)	**GP**	172(64,462)	167(84,390)	168(126,270)
	JP	135(77,234)	123(83,338)	117(78,253)

Table 3. Medium term effect of WBV on biochemical parameters in GP and JP groups. These parameters included serum leptin, insulin, testosterone, GH, IGF-1, cortisol, glucose, BAP, OCN, CTX, TRAP5b, Scl and CK. The measurements were assessed at three different times; run-in (T0, T1), WBV (T2, T3) and wash-out (T4). [1] Significant difference between pre-WBV and WBV ($p<0.05$). [2] Significant difference between WBV and post-WBV ($p<0.05$).

thermore, the effect of WBV on the musculoskeletal system may be dependent on a range of WBV parameters (frequency, amplitude and g force)[19]. Torvinen et al[5] demonstrated that WBV amplitude is positively correlated with muscle performance while others believed that frequency is the most important variable in WBV[7,20].

Vibratory exercise has been suggested to have a beneficial effect on muscle strength. Previous studies have suggested that over the short-term, WBV can increase vertical jump height[21-23]. Although we did not assess the immediate effect of WBV on jump performance, there was no significant change in muscle function over the 8 weeks for either vibratory platform. We did observe a positive trend for an improvement in vertical jump height in those subjects who stood on the Galileo platform but it is possible that we may have observed a significant change with a larger sample size or over a longer period of study. Our study was based on previous research that has reported significant changes in biochemical parameters after WBV. Over a similar study period to ours, Wyon et al[23] found that 6 weeks of WBV at 35 Hz for 5 minutes twice a week increased vertical jump height and another group has recently reported that 4 weeks of WBV training (three times a week with a frequency 40 Hz, 4 mm) could improve muscle function when added to the conventional training of basketball players[24]. However, improved muscle function over such periods is not a universal finding as reported in a 14 week study of WBV training (30 to 35 Hz frequency and 4 mm) in female basketball players[25].

Previous studies of the acute hormonal responses to WBV exercise have so far reported variable results. However, the investigators reported a significant increase in testosterone and GH and a decrease in the serum concentration of cortisol in healthy young men after 10 min of WBV exercise (6 mins, 26 Hz, peak-to-peak displacement of 4 mm; acceleration, 17 g)[6]. The association between exercise and immediate GH secretion is well established[26], but the association between serum GH secretion and WBV in young men is variable with some reporting a rise[6,27] and some reporting a lack of association[28,29]. In the current study, GH increased significantly only in the GP group when the frequency was 22 Hz, suggesting that the effect on GH secretion may be dependent on exercise intensity.

The changes that we observed in serum cortisol immediately after WBV have also been reported by others[6,28]. Furthermore, several studies report that the moderate to high intensity

exercise as characterised by VO_2 max of 60-90% is associated to an increase in serum cortisol, but low intensity exercise actually resulted in a reduction in circulating cortisol levels[30,31]. The reported VO_2 max of WBV is less than 50%[14] and, therefore, WBV can be classified as low intensity exercise. In this study, we assessed exercise intensity by measuring serum CK and there was no difference between the two study groups. WBV training as well as other forms of exercise are reported to be associated with a concurrent increase in lactate and CK[32,33]. In peripheral tissues, corticosteroid hormone action is determined, in part, through the activity of 11β-hydroxysteroid dehydrogenases (11β-HSD), two isoenzymes which interconvert hormonally active cortisol (F) and inactive cortisone (E). 11β-HSD type 2 (11β-HSD2) inactivates F to E in the kidney; whilst 11β-HSD type 1 (11β-HSD1) principally performs the reverse reaction activating F from E [34]. Intense physical exercise has been reported to be associated with an increase in the conversion of cortisone to cortisol by stimulating 11β-HSD1 activity[35] whereas low intensity exercise results in a reduction in circulating cortisol levels[30,31]. In addition, GH may inhibit 11β-HSD1, increasing conversion of cortisol to cortisone[34] and in the raised GH following exercise may be one possible mechanism for the observed reduction in circulating cortisol over the short-term as well as the medium term. It is possible that the fall in cortisol was due to the normal circadian pattern but this paatern was not observed in the group randomised to JG.

WBV has been reported to be osteogenic in several animal models[1,36,37] however; in humans this is less clear. Recent studies suggest that whole-body vibration (WBV) can improve measures of bone health for certain clinical conditions and ages[2,38]. Our results did not show any positive effects on osteoblast activity but there was a significant negative effect on osteoclast activity as observed by a decrease in serum CTX, a marker of bone resorption, in the GP group. Our results are consistent with previous reports of suppressed osteoclast activity after 15 min of daily WBV in mice[38]. WBV at 1.5 g may also be associated with reduced pyridinoline crosslinks production in aging mice[40]. More recently, WBV training for 8 weeks (3 times/wk) in post-menopausal women was associated with in a significant reduction in N-telopeptide-x when compared with sham vibration exposure[14].The reduction in bone resorption in these studies, as well as ours, may be due to the observed reduction in circulating cortisol. TRAP5b, another marker of bone resorption also reduced in both groups but the reduction was not significant. It is possible that the positive effect on bones is mediated via osteocyte signalling and we, therefore, measured Scl which increases in response to unloading through antagonizing Wnt/β-catenin signalling[41]. Our results suggest that in these healthy young adults, the reduction in biochemical markers of bone resorption was independent of changes in Scl.

In summary, this is the first study which has compared the effects of two different forms of WBV on muscle and endocrine function. Given its small size and the short duration of the study, the findings need to be confirmed in a larger group of individuals over a longer study period. However, our preliminary results suggest that WBV, as delivered through the Galileo platform was associated with a measurable increase in circulating GH and a decrease in circulating cortisol. These changes were not associated with any changes in muscle function over this period but a significant fall in bone resorption was, nevertheless, observed. It is possible that some of the beneficial effects of WBV on bone health are mediated through its effects on bone turnover through alteration in GH and cortisol production rather than through muscle function.

References

1. Verschueren SMP, Roelants M, Delecluse C, Swinnen S, Vanderschueren D, Boonen S. Effect of 6-month whole body vibration training on hip density, muscle strength, and postural control in postmenopausal women: A randomized controlled pilot study. J Bone Miner Res 2004;19:352-9.
2. Ward K, Alsop C, Caulton J, Rubin C, Adams J, Mughal Z. Low magnitude mechanical loading is osteogenic in children with disabling conditions. J Bone Miner Res 2004;19:360-9.
3. Cardinale M, Bosco C. The use of vibration as an exercise intervention. Exerc Sport Sci Rev 2003;31:3-7.
4. Delecluse C, Roelants M, Verschueren S. Strength increase after whole-body vibration compared with resistance training. Med Sci Sports Exerc 2003;35:1033-41.
5. Torvinen S, Kannus P, Sievanen H, Jarvinen TAH, Pasanen M, Kontulainen S, Jarvinen TLN, Jarvinen M, Oja P, Vuori I. Effect of a vibration exposure on muscular performance and body balance. Randomized cross-over study. Clin Physiol Funct Imaging 2002;22:145-52.
6. Bosco C, Iacovelli M, Tsarpela O, Cardinale M, Bonifazi M, Tihanyi J, Viru M, De Lorenzo A, Viru A. Hormonal responses to whole body vibration in men. Eur J Appl Physiol 2000;81:449-54.
7. Bazett-Jones DM, Finch HW, Dugan EL. Comparing the effects of various whole-body vibration accelerations on counter-movement jump performance. J Sports Sci Med 2008;7:144-50.
8. Rittweger J, Schiesel H, Felsenberg D. Oxygen uptake during whole-body vibration exercise: comparison with squatting as a slow voluntary movement. Eur J Appl Physiol 2001;86:169-73.
9. Gusi N, Raimundo A, Leal A. Low-frequency vibratory exercise reduces the risk of bone fracture more than walking: a randomized controlled trial. BMC Musculoskelet Disord 2006;7:1-8.
10. Cardinale M. Wakeling J. Whole body vibration exercise: are vibrations good for you? Br J Sports Med 2005;39:585-9.
11. Wysocki A, Butler M, Shamliyan T, Kane RL. Whole body vibration therapy for osteoporosis: State of the Science. Ann Intern Med 2011;155:680-6.

12. Rauch F, Sievanen H, Boonen S, Cardinale M, Degens H, Felsenberg D, Roth J, Schoenau E, Verschueren S, Rittweger J; International Society of Musculoskeletal and Neuronal Interactions. Reporting whole-body vibration intervention studies: recommendations of the International Society of Musculoskeletal and Neuronal Interactions. J Musculoskelet Neuronal Interact 2010;10:193-8.
13. Muir J, Judex S, Qin Y, Rubin CT. Safety of whole body vibration, considered for the prevention and/or treatment of osteoporosis, relative to standards set by the international safety organization. J Bone Miner Res 2006; 21:S294
14. Walker SJ, Climstein M, Naughton G, Baker M, Singh MF,Torode MA. Randomized Controlled Trial of Whole Body Vibration Exposure on Markers of Bone Turnover in Postmenopausal Women. Gerontologist 2008;48:695.
15. Rittweger J, Beller G, Felsenberg D. Acute physiological effects of exhaustive whole-body vibration exercise in man. Clin Physiol 2000;20:134-42.
16. Eklund G, Hagbarth KE. Normal Variability of Tonic Vibration Reflexes in Man. Exp Neurol.1966;16:80-92.
17. Roelants M, Verschueren SM, Delecluse C, Levin O, Stijnen V. Whole-body-vibration-induced increase in leg muscle activity during different squat exercises. J Strength Cond Res 2006;20(1):124-9.
18. Fallon JB, Macefield VG. Vibration sensitivity of human muscle spindles and Golgi tendon organs. Muscle Nerve 2007;36:21-9.
19. Luo J, McNamara B, Moran K. The use of vibration training to enhance muscle strength and power. Sports Med 2007;35:23-41.
20. Jordan MJ, Norris SR, Smith DJ, Herzog W. Vibration training: An overview of the area, training consequences, and future considerations. J Strength Cond Res 2005; 19:459-66.
21. Cochrane DJ Stannard SR. Acute whole body vibration training increases vertical jump and flexibility performance in elite female field hockey players. Br J Sports Med 2005;39:860-5.
22. Lamont HS, Cramer JT, Bemben DA, Shehab RL, Anderson MA, Bemben MG. Effects of A 6-Week Periodized Squat Training Program with Or Without Whole-Body Vibration on Jump Height and Power Output Following Acute Vibration Exposure. J Strength Cond Res 2009; 23:2317-25.
23. Wyon M, Guinan D, Hawkey A. Whole-Body Vibration Training Increases Vertical Jump Height in A Dance Population. J Strength Cond Res 2010;24:866-70.
24. Colson SS, Pensini M, Espinosa J, Garrandes F, Legros P. Whole-Body Vibration Training Effects on the Physical Performance of Basketball Players. J Strength Cond Res 2010;24:999-06.
25. Fernandez-Rio J, Terrados N, Fernandez-Garcia B, Suman OE. Effects of Vibration Training on Force Production in Female Basketball Players. J Strength Cond Res 2010;24:1373-80.
26. Stokes K. Growth hormone responses to sub-maximal and sprint exercise. Growth Horm IGF Res 2003;13:225-38.
27. Sartorio A, Lafortuna CL, Maffiuletti NA, Agosti F, Marazzi N, Rastelli F, Rigamonti AE, Muller EE. GH responses to two consecutive bouts of whole body vibration, maximal voluntary contractions or vibration alternated with maximal voluntary contractions administered at 2-h intervals in healthy adults. Growth Horm IGF Res 2010;20:416-21.
28. Cardinale M, Soiza RL, Leiper JB, Gibson A, Primrose WR. Hormonal responses to a single session of whole-body vibration exercise in older individuals. Br J Sports Med 2010;44:284-8.
29. Di Loreto C, Ranchelli A, Lucidi P, Murdolo G, Parlanti N, De Cicco A, Tsarpela O, Annino G, Bosco C, Santeusanio F, Bolli GB, De Feo P. Effects of whole-body vibration exercise on the endocrine system of healthy men. J Endocrinol Invest 2004;27:323-7.
30. Davies CTM, Few JD. Effects of Exercise on Adrenocortical Function. J Appl Physiol 1973;35:887-91.
31. Hill EE, Zack E, Battaglini C, Viru M, Viru A ,Hackney AC. Exercise and circulating cortisol levels: The intensity threshold effect. J Endocrinol Invest 2008;31:587-91.
32. Kanter MM, Lesmes GR, Kaminsky LA, La Ham-Saeger J, Nequin ND. Serum creatine kinase and lactate dehydrogenase changes following an eighty kilometer race. Relationship to lipid peroxidation. Eur J Appl Physiol Occup Physiol 1988;57:60-3.
33. Gojanovic B, Feihl F, Liaudet L, Gremion G, Waeber B. Whole-body vibration training elevates creatine kinase levels in sedentary subjects. Swiss Med Wkly 2011;141: doi:10.4414/smw.2011.13222.
34. Stewart PM, Toogood AA, Tomlinson JW. Growth hormone, insulin-like growth factor-1 and the cortisol-cortisone shuttle. Horm Res 2001;56:1-6.
35. Dovio A, Roveda E, Sciolla C, Montaruli A, Raffaelli A, Saba A, Calogiuri G, De Francia S, Borrione P, Salvadori P, Carandente F, Angeli A. Intense physical exercise increases systemic 11 beta-hydroxysteroid dehydrogenase type 1 activity in healthy adult subjects. Eur J Appl Physiol 2010;108:681-7.
36. Rubin C, Xu G, Judex S. The anabolic activity of bone tissue, suppressed by disuse, is normalized by brief exposure to extremely low-magnitude mechanical stimuli. FASEB J 2001;15:2225-9.
37. Garman R, Rubin C, Judex S. Small oscillatory accelerations, independent of matrix deformations, increase osteoblast activity and enhance bone morphology. PLoS One 2007;2:e653.
38. Rubin C, Recker R, Cullen D, Ryaby J, McCabe J, McLeod K. Prevention of postmenopausal bone loss by a low-magnitude, high-frequency mechanical stimuli: A clinical trial assessing compliance, efficacy, and safety. J Bone Miner Res 2004;19:343-51.
39. Xie LQ, Jacobson JM, Choi ES, Busa B, Donahue LR, Miller LM, Rubin CT, Judex S. Low-level mechanical vi-

brations can influence bone resorption and bone formation in the growing skeleton. Bone 2006;39:1059-66.
40. Wenger KH, Freeman, JD, Fulzele S, Immel D.M, Powell BD, Molitor P, Chao YJ, Gao HS, Elsalanty M, Hamrick MW, Isales CM, Yu JC. Effect of whole-body vibration on bone properties in aging mice. Bone 2010;47:746-55.
41. Gaudio A, Pennisi P, Bratengeier C, Torrisi V, Lindner B, Mangiafico RA, Pulvirenti, I, Hawa G, Tringali G, Fiore CE. Increased sclerostin serum levels associated with bone formation and resorption markers in patients with immobilization-induced Bone loss. J Clin Endocrinol Metab 2010;95:2248-53.