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Research article

Effects of whole-body vibration training on sprint running kinematics and explosive strength performance

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Abstract
The aim of this study was to investigate the effect of 6 wk of whole body vibration (WBV) training on sprint running kinematics and explosive strength performance. Twenty-four volunteers (12 women and 12 men) participated in the study and were randomised (n = 12) into the experimental and control groups. The WBV group performed a 6-wk program (16-30 min·d^{-1}, 3 times a week) on a vibration platform. The amplitude of the vibration platform was 2.5 mm and the acceleration was 2.28 *g*. The control group did not participate in any training. Tests were performed Pre and post the training period. Sprint running performance was measured during a 60 m sprint where running time, running speed, step length and step rate were calculated. Explosive strength performance was measured during a counter movement jump (CMJ) test, where jump height and total number of jumps performed in a period of 30 s (30CVJT). Performance in 10 m, 20 m, 40 m, 50 m and 60 m improved significantly after 6 wk of WBV training with an overall improvement of 2.7%. The step length and running speed improved by 5.1% and 3.6%, and the step rate decreased by 3.4%. The countermovement jump height increased by 3.3%, and the explosive strength endurance improved overall by 7.8%. The WBV training period of 6 wk produced significant changes in sprint running kinematics and explosive strength performance.

Key words: Sprinting kinematics, explosive strength, countermovement jump, strength training.

Introduction

Whole-body vibration (WBV) is a neuromuscular training method that has recently received a great deal of interest. Documentation shows that a low-amplitude, high-frequency stimulation of the whole body improves muscle strength, body balance and mechanical competence of bones (Bosco et al., 1998; 1999b; Delecluse et al., 2003; Falempin and In-Albon, 1999; Flieger et al., 1998; Rittweger et al., 2000; Rubin and McLeod, 1994; Rubin et al., 2001; Torvinen et al., 2002a). In WBV training, the participant stands on a platform that generates vertical sinusoidal vibration at frequencies between 25 and 50 Hz. These mechanical stimuli are transmitted to the body where they stimulate sensory receptors, most likely muscle spindles. This causes the activation of the alpha-motoneurons and initiates muscle contractions comparable to the "tonic vibration reflex" (Burke and Schiller, 1976; Hagbarth and Eklund, 1966).

Bosco et al. (1999a; 1999b) revealed that a single vibration bout resulted in a significant temporary increase in muscle strength of the arm flexors and lower extremities, whereas 10 days WBV training of vertical sinusoidal vibrations at a frequency of 26 Hz the explosive power produced a significant increase (Bosco et al., 1998). A placebo controlled study showed that a single bout of WBV transiently improves isometric strength of the knee extensors and vertical-jump performance by 3.2% and 2.5%, respectively (Torvinen et al., 2002b). These effects were recorded 2 min after the intervention, but disappeared in the following 60 min. Runge et al. (2000) showed that after two months of WBV training, the muscle performance improved in elderly people by 18%. Torvinen et al., (2002a) showed that after four months of WBV training, the vertical jump height increased by 8.5%, whereas the lower limb extension strength as well as grip strength, shuttle run and balance, did not improve. Despite that, Delecluse et al. (2003) showed that after three months of WBV training, isometric and dynamic knee extensor strength improved by 16.6% and 9.0% respectively, whereas an equal number of moderate resistance training sessions induced similar gain (14.4% and 7.0% respectively). Additionally the vertical jump height increased by 7.6% only after the WBV training, while there was no effect of any of the interventions on maximal speed of knee movement, as measured by means of ballistic tests.

Romaiguere et al. (1993) showed that the recruitment thresholds of the motor units during vibration are lower compared to voluntary contractions, which may resulting in a more rapid activation of the high-threshold fast twitch motor units and consequently a greater training stimulus (Rittweger et al., 2000; 2003). These findings stimulate a growing interest in the potential of WBV training to improve sprinting ability, since optimal motoneuron excitability and fast twitch fibre recruitment are two determining factors of sprint performance (Delecluse, 1997; Romaiguere, 1993). Cochrane et al. (2004) examined the short term effects of 9 WBV training sessions (total exercise 10 min, 2 repetitions of 1 min, 5 static exercises) on CMJ and sprint performance (time of 5, 10 and 20 m) in non-elite athletes and found no significant changes. Additionally, Delecluse et al. (2005) investigated the effects of 5 weeks WBV training (total exercise 9 – 18 min, 3 repetitions of 30 – 60 s, 6 static and dynamic exercises) on sprint performance (30 m) in elite athletes and found no significant changes. However, it is presently unclear whether a long term WBV training improves sprinting performance in non-experienced athletes.

Despite the above noted findings, and the increasing use of different vibration devices among athletes and health and fitness clubs as an alternative training method,

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conclusive scientific evidence on the efficacy of WBV training on sprinting performance is still lacking. The aim of this study was to investigate the effects of a 6-week WBV intervention on sprinting performance in terms of selected kinematics characteristics of sprint running and on explosive strength/jumping performance in terms of CMJ height and total number of jumps performed in 30CVJT on non-experienced athletes, using a randomized controlled study design. As WBV training is reported to elicit a high degree of motoneuron excitability and fast twitch recruitment (Rittweger et al., 2003), it was hypothesized that WBV training would result in significant increase in sprint running kinematics and explosive strength /jumping performance in non-experienced athletes.

Methods

Participants and study design

Twenty-four young, healthy volunteers (12 women and 12 men) participated in this study (age 21.3 ± 1.2 years, mass 66.0 ± 10.5 kg, height 1.69 ± 0.09 m, % of body fat 18.8 ± 6.8 % and maximum running speed 8.15 ± 0.869 $m \cdot s^{-1}$). All participants were active athletes in the past (3 years ±5 months), but none of them were engaged in regular, organised physical activities nor in sports or strength/power training at least 3 months before the initiation of the study. There was no health issue or other reason for exclusion from the study. Participants were asked to avoid any additional training throughout the period of the study and to maintain a normal food intake. Informed consent was obtained from each participant before data collection. In addition, after a detailed explanation of the training and test protocol, as well as the possible risks and benefits of the study was provided. Lastly, approval was granted by the university ethics board.

A two group, pre-post design was used in this study to determine whether a 6-wk period of WBV training would result in a considerable increase in selected kinematic characteristics of sprint running and explosive strength of vertical jumping tests. The participants were randomly assigned to two groups (equal gender in each group), which included a WBV group and a control group (n = 12). The WBV training group was trained for six weeks, 3 times a week, with at least 1 day of rest between two sessions, after completion of a standardised 20-min warm-up of a 10 min run, 5 min stretching exercise, and 6 × 30 m progressive sprints; the control group did not perform any kind of training. There was no significant difference between the two groups before training.

WBV training

The WBV training group trained on a WBV platform (Power Plate®) 3 times a week for a 6 weeks period. The duration of the daily stimulus was 16 min, which consisted of 3 sets of 8 repetitions (2 repetitions of each exercise) of 40 s, where the rest between the sets and repetitions was 2 and 1 min respectively. As there are no scientific-based WBV programs the training program of this study was based on similar protocols that resulted in significant changes in muscle performance (Delecluse et al., 2003; Torvinen et al., 2002a). The program was comprised of four static exercises: squatting (90° knee angle), standing in a position with slightly flexed knees (120° knee angle), and standing on one leg (120° knee angle). In the 4th week of WBV training, the duration of each repetition increased by 20 s, and one repetition per exercise was added for each of the remaining weeks in accordance with the overload principle. The frequency of vibration was set at 30 Hz, which produced a peak-to-peak amplitude of 2.5 mm and an acceleration of 2.28 g. Recovery periods between the repetitions were 1 min.

Test protocol

A battery of tests were performed at the start (pre-test) of the study and after 6 weeks of training (post-test) to measure the effects of training. Prior to performing the tests, the body mass, body height and the % of body fat were obtained (Durnin & Womersley, 1974). The participants were informed about the test procedures and were asked to perform all these tests at maximal intensity. Additionally, all participants performed 4 familiarization sessions of all the tests. Pre and Post-tests were performed at least 72 h after the last familiarization or training session to avoid any acute effect of training sessions on test results.

Sprint tests

In the first day of performance testing, the participants performed three maximal 60 m sprints, using a standing start, after completion of the standardised 20-min warm-up. The sprints were performed in an indoor track and field gym at a constant temperature of 25^{o} C. The participants were provided with 10 min rest between sprints (McArdle et al., 1991). The time and average velocity at distances of 10 m, 20 m, 40 m, 50 m and 60 m were obtained using the Brower timing systems (Brower, USA). Additionally, the step length of each participant was recorded by a high speed video camera (Redlake, USA).

The filming of the sagittal plane of a full stride (two consecutive steps) of all three sprints, performed with sampling frequency of 125 Hz. The camera was placed at the point of 55 m and 10 m apart from the performance plane, such that its optical axis was approximately horizontal, forming an angle of 90° with the horizontal plane of running. A metal calibration frame (2 x 2 m) was filmed such that the x-axis was parallel to the horizontal and the y-axis was perpendicular to the horizontal. The best of three sprints was recorded for further analysis.

Step length was calculated according to the methods of Paradisis & Cooke (2006), where step rate was calculated according to the formula:

$$SR = AV \div SL$$

where SR = step rate, AV = average velocity of distance interval 50 – 60 m and SL = step length of distance interval 50 – 60 (Paradisis & Cooke, 2006). As two consecutive steps were recorded two step lengths and rates were calculated.

Jumping tests

In the second day of testing, in order to assess the explosive strength /jumping performance, a CMJ test and a 30CVJT were performed. For the CVJ test the participants were asked to perform a maximal vertical jump with hands positioned at the waist to assess the lower-limb explosive performance capacity. For the 30CVJT the participants were asked to perform continuously as many maximal vertical jumps as they could, over a 30 s period with hands positioned at the waist to assess the lower-limb explosive endurance capacity (Bosco et al., 1983). From the 30CVJT, the total number of jumps (NJ), the average height (AH) and the average power (AP) of the 30CVJT were calculated. These tests were performed on a contact mat, recording the flight time in milliseconds. The obtained flight time (t) was further used to determine the lift of the center of gravity (h), i.e., $h = gt^2/8$, where $g = 9.81\ m{\cdot}s^2$. The best of three trials was recorded to determine the tests' score.

Statistical analysis

The effect of the WBV training on sprint running kinematics and jumping performance was analyzed by means of ANOVA for repeated measures [2 (group) - 2 (time)] using the least square method (LS means). In the event of significant main effects, a Post-hoc Tukey test was used to locate the differences. The significance level for the tests was set at $p < 0.05$ and the data was presented as mean ± SD. All analyses were executed using the statistical package SPSS 12.

Results

Anthropometric data of the participants

A repeated-measures ANOVA showed no significant main effect for the pre and post training tests for the body mass, height, and % of body fat (Table 1).

Table 1. Anthropometric characteristics of the subjects. Data are means (±SD).

	Body Mass (kg)	Body Height (m)	% Body Fat
WBV			
Pre	66.3 (9.7)	1.71 (.08)	17.5 (5.1)
Post	66.2 (9.9)	1.71 (.08)	17.2 (5.1)
%diff	-.2	.0	-2.1
C			
Pre	67.8 (11.5)	1.72 (.11)	17.5 (7.1)
Post	67.2 (11.1)	1.72 (.11)	16.9 (6.1)
%diff	-.9	.0	5.7

Abbreviations: WBV = whole body vibration training group, C = control group.

Kinematic characteristics

The results showed a significant main effect for the two groups for time for 10 m ($p < 0.05$), 20 m ($p < 0.05$), 40 m ($p < 0.05$), 50 m ($p < 0.05$) and 60 m ($p < 0.05$). After 6 weeks of training for the WBV training group the time of 10 m improved significantly by 4.3% ($p < 0.05$), whereas for the C group it was not statistically significant. The time of 20 m improved significantly by 3.0% ($p < 0.05$) for the WBV training group, whereas for the C group it was not statistically significant. The time of 40 m improved significantly by 2.2% ($p < 0.05$) for the WBV training group, whereas for the C group it was not statistically significant. The time of 50 m improved significantly by 2.1% ($p < 0.05$) for the WBV training group, whereas for the C group it was not statistically significant. . Finally, the time of 60 m improved significantly by 2.1% ($p < 0.05$) for the WBV training group, whereas for the C group it was not statistically significant (Table 2).

The results showed a significant main effect for the two groups for the step length 1 ($p < 0.05$) and step rate ($p < 0.05$). The step length 1 improved significantly by 5.6% ($p < 0.05$) after 6 weeks of training for the WBV training group, whereas for the C group it was not statistically significant. The step rate 1 decreased significantly by 3.9% ($p < 0.05$) after 6 weeks of training for the WBV training group, whereas for the C group it was not statistically significant. Similar results produced for both step length 2 and rate 2 (Table 3).

Table 3. Results for step length and rate of the 60 m sprint test. **Data are means (±SD).**

	SL 1 (m)	SL 2 (m)	SR 1 (Hz)	SR 2 (Hz)
WBV				
Pre	1.95 (.14)	1.97 (.14)	4.19 (.38)	4.14 (.30)
Post	2.06 (.14)	2.05 (.16)*	4.02 (.30)*	4.02 (.31) *
%diff	-5.6	-4.5	-3.9	-2.8
C				
Pre	1.99 (.20)	1.96 (.19)	4.14 (.26)	4.19 (.29)
Post	2.00 (.18)	2.00 (.21)	4.12 (.26)	4.11 (.29)
%diff	.6	2.3	-.3	-1.9

Abbreviations: WBV = whole body vibration training group, C = control group, SL 1 = stride length of the first stride, SL 2 = stride length of the second stride, SR 1 = stride rate of the first stride, SR 2 = stride rate of the second stride

* Significantly different from Pre test ($p < 0.05$) as determined by repeated measures analysis of variance and *post-hoc* Tukey tests.

The results showed a significant main effect for the two groups for the running speed in the 0 –10 m and 50 – 60 m intervals ($p < 0.05$ and $p < 0.05$). The running speed in the 0 – 10 m interval improved significantly by 4.9% ($p < 0.05$) after 6 weeks of training for the WBV training group, whereas for the C group it was not statistically

Table 2. Time results obtained from the different distance intervals of the 60 m sprint test. Data are means (±SD).

	10 m (s)	20 m (s)	40 m (s)	50 m (s)	60 m (s)
WBV					
Pre	1.96 (.10)	3.30 (.16)	5.76 (.31)	6.99 (.42)	8.19 (.44)
Post	1.88 (.14)	3.20 (.18) *	5.63 (.31) *	6.85 (.39) *	8.01 (.40) *
%diff	-4.3	-3.0	-2.2	-2.1	-2.1
C					
Pre	1.97 (.13)	3.33 (.19)	5.84 (.38)	7.07 (.49)	8.35 (.61)
Post	1.96 (.15)	3.31 (.17)	5.82 (.36)	7.04 (.47)	8.33 (.60)
%diff	-.7	-.6	-.4	-.4	-.3

Abbreviations: WBV = whole body vibration training group, C = control group.

* Significantly different from Pre test ($p < 0.05$) as determined by repeated measures analysis of variance and *post-hoc* Tukey tests.

significant. The running speed in the 50 – 60 m interval improved significantly by 2.2% ($p < 0.05$) after 6 weeks of training for the WBV training group, whereas for the C group it was not statistically significant (Figure 1).

Explosive strength

The results showed a significant main effect for the two groups for the CMJ ($p < 0.05$), for the NJ in the 30CVJT ($p < 0.05$), for the AH of the 30CVJT ($p < 0.05$), and the AP of the 30CVJT ($p < 0.05$). The CMJ improved significantly by 3.3% ($p < 0.05$) for the WBV training group, whereas for the C group it was not statistically significant. The NJ in the 30CVJT improved significantly by 7.8% ($p < 0.05$) for the WBV training group, whereas for the C group it was not statistically significant. The AH in the 30CVJT improved significantly by 7.2% ($p < 0.05$) for the WBV training group, whereas for the C group it was not statistically significant. Finally, the AP in the 30CVJT improved significantly by 8.4% ($p < 0.05$) for the WBV training group, whereas for the C group it was not statistically significant (Table 4).

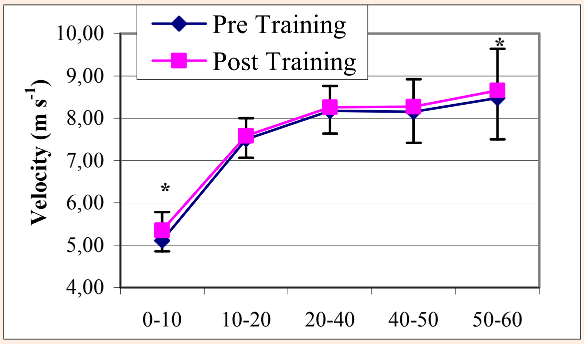

Figure 1. Progression in running velocity for the 60 m sprint test for all subjects. * significantly different ($p < 0.05$) between Pre and Post training.

Discussion

This is the first study that experienced the effects of 6 wk of WBV training on the kinematical characteristics of sprint running in non experiences athletes. The results of this study clearly indicate that performance in 10 m, 20 m, 40 m, 50 m and 60 m significantly improved after WBV training with an overall improvement of 2.7%. Additionally the step length, step rate and running velocity were improved by 5.1%, 3.4% and 3.6% respectively (mean improvements). It can be argued that increasing the step length could produce a faster velocity. However, if the step length increased and the muscle force remained the same, the step rate should decrease (Paradisis and Cooke, 2006). According to that, producing a slower step rate should lose the gain from a greater step length. The results of the present study indicate that the gain of the step length was greater than the decrease of the step rate (5.6% vs -3.9%;), so the net effect was an improvement of the running velocity.

However, the induced improvement in sprint running kinematics found in the present study contracts with the results of Cochrane et al. (2004) and Delecluse et al. (2005). The different results between the present study and that of Cochrane et al., (2004) could be partially explained by the use of other WBV training programs (total exercise 16 – 36 min per session vs 10 min), different duration of the respective training volume (18 training sessions vs 9), different frequency vibration (30 Hz vs 26 Hz) and different sprint test distances (60 m vs 20 m), respectively. It should be mentioned that Cochrane et al., (2004) concluded that the short duration (9 training sessions) could have contributed to the lack of significant changes.

Table 4. Results obtained from the explosive strength tests. Data are means (±SD).

	CMJ (cm)	NJ	AH (cm)	AP (watt)
WBV				
Pre	33.1 (4.9)	28.0 (2.0)	25.2 (3.9)	18.8 (3.6)
Post	34.2 (4.4)*	30.2 (3.0)*	27.0 (3.7)*	20.4 (4.0)*
%diff	3.3	7.8	7.2	-8.4
C				
Pre	35.2 (6.1)	29.2 (5.0)	24.2 (4.3)	18.3 (2.1)
Post	35.2 (6.5)	30.1 (3.3)	23.8 (3.)	18.9 (3.0)
%diff	.3	3.1	1.4	3.4

Abbreviations: WBV = whole body vibration training group, C = control group, CMJ = countermovement jump, NJ = number of jumps performed in the 30 s continuous vertical jumping test, AH = mean height of jumps performed in the 30 s continuous vertical jumping test, AP = mean power of jumps performed in the 30 s continuous vertical jumping test.
* Significantly different from Pre test ($p < 0.05$) as determined by repeated measures analysis of variance and *post-hoc* Tukey tests.

The differences between the present study and that of Delecluse et al. (2005) were the WBV training programs (total exercise 16 – 36 min per session vs 9 – 18 min), the duration of the respective training period (5 wk vs 6 wk), the frequency of vibration (30 Hz vs 35 - 40 Hz), the sprint test distances (60 m vs 30 m) and the participants (non-experienced vs elite sprint-trained athletes) respectively. Most probably in sprint-trained athletes, high resistance training, plyometric drills and sprint running exercise already render a specific training of fast-twitch fibers (Ross and Riek, 2001). In these athletes, muscle strength, motoneuron excitability, fast-twitch fiber recruitment and reflex sensitivity are well developed (Delecluse, 1997; Ross and Riek, 2001). This may explain why WBV training did not affect sprint running performance in sprint-trained athletes, despite the significant changes in non-experienced athletes shown in the present study, as this latter group had a much larger margin to increase the neural drive to the muscle (Delecluse et al., 2005).

The CMJ height, a measure of explosive strength, increased by 3.3% after the 6 wk of WBV training. In addition, the 30CVJT, a measure of explosive strength endurance, improved overall by 7.8%. The induced improvement in CMJ found in the present study is comparable to the 8.5% in the study of Torvinen et al. (2002a) and to the 7.6% in the study of Delecluse et al. (2003). The differences in CMJ height improvements could be partially explained by the use of other WBV training programs and the different duration of the respective training periods. In the study of Torvinen et al. (2002a), participants trained 4 min per session on the WBV platform, compared with a systematic increase of the training volume from 3 to 20 min per session in the study by Delecluse et al. (2003) and a systematic increase of the training volume from 16 to 36 min per session in this study. Additionally, the training period in the studies of Torvinen et al. (2002a) and Delecluse et al. (2003) was 12 wk, where in the present study it was 6 wk.

The first phase of training adaptation is characterised by an improvement of neural factors, whereas changes in the morphological structure of the muscle could take from several months to years (Moritani and DeVries, 1979). It is likely that the mechanism by which the WBV training can enhance neuromuscular activation is a biological adaptation connected to the neural potentiation (Delecluse et al., 2003). Komi (2000) provided evidence for the involvement of the stretch reflex, and thus Ia afferent input in the force potentiation during a stretch-shortening contraction (SSC) in the CMJ. The stimulation of the sensory receptors and the afferent pathways with WBV might thus lead to a more efficient use of the stretch reflex. The sensory stimulation that is the basis of muscle activity in WBV training seems hereby crucial to the facilitation of the SSC and the improvement the CMJ.

At motor unit level, it is suggested that the tonic vibration reflex affects primarily the ability of the participants to generate high firing rates in high-threshold motor units (Bongiovanni et al., 1990). During a WBV stimulus, skeletal muscles undergo small changes in muscle length, most likely since mechanical vibration is able to induce a tonic excitatory influence on the muscles exposed to it called "tonic vibration reflex" (Seidel, 1988). This reflex activates the muscle spindles, mediates the neural signals by Ia afferents (Hagbarth, 1973), and finally, activates the muscle fibres via large α -motoneurons. The tonic vibration reflex is also able to cause an increase in recruitment of the motor units through activation of muscle spindles and polysynaptic pathways (De Gail, 1966) and increase facilitation of the reflex action on the motoneuron pool (Romaiguere et al., 1993). Additionally, the recruitment thresholds of the motor units during WBV are expected to be lower compared with voluntary contractions (Romaiguere et al., 1993), probably resulting in a more rapid activation and training of high-threshold motor units.

Rittweger et al. (2003) investigated the acute effects of WBV (26 Hz, 12 mm) and found that EMG mean frequency of the m. vastus lateralis during isometric contraction and the amplitude of the patellar tendon reflex were significantly higher after squatting exercise with WBV rather than without WBV. This finding indicates enhanced central nervous excitability, particularly with respect to recruitment of predominantly fast twitch fibres. Therefore, it could be suggested that WBV training renders specific training of fast-twitch fibres (Rittweger, 2000), which have an important contribution to high-speed movements.

Conclusion

Concluding, WBV training period of 6 wk, through the muscle contractions it provokes, produced significant positive changes is selected kinematical characteristics of sprint running (step length, step rate and running velocity) and selected explosive strength characteristics (jump height, total number of jumps performed in a period of 30 s) in non experienced sprinters. However, more research is necessary in order to clarify the effects of WBV training on specific characteristics of sprinting such as contact time, eccentric and concentric phases of contact time and flight time, as well as the effects of WBV training with specific sprint positions exercise and the use of concurrent WBV and sprint training in non elite athletes.

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Key points

- WBV training.
- Sprint running kinematics.
- Explosive strength performance.

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