Effects of Whole Body Vibration Training on Muscle Strength and Sprint Performance in Sprint-trained Athletes

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ABSTRACT

Despite the expanding use of Whole Body Vibration training among athletes, it is not known whether adding Whole Body Vibration training to the conventional training of sprint-trained athletes will improve speed-strength performance.

Twenty experienced sprint-trained athletes (13 ♂, 7 ♀, 17-30 years old) were randomly assigned to a Whole Body Vibration group (N=10: 6 ♂ and 4 ♀) or a Control group (N=10: 7 ♂, 3 ♀). During a 5 week experimental period all subjects continued their conventional training program, but the subjects of the Whole Body Vibration group additionally performed three times weekly a Whole Body Vibration training prior to their conventional training program. The Whole Body Vibration program consisted of unloaded static and dynamic leg exercises on a vibration platform (35-40Hz, 1.7-2.5 mm, Power Plate®). Pre and post isometric and dynamic (100°/s) knee-extensor and -flexor strength and knee-extension velocity at fixed resistances were measured by means of a motor-driven dynamometer (Rev 9000,Technogym®). Vertical jump performance was measured by means of a contact mat. Force-time characteristics of the start action were assessed using a load cell mounted on each starting block. Sprint running velocity was recorded by means of a laser system.

Isometric and dynamic knee-extensor and knee-flexor strength were unaffected (P>.05) in the Whole Body Vibration group and the Control group. As well, knee-extension velocity remained unchanged (P>.05). The duration of the start action, the resulting start velocity, start acceleration and sprint running velocity did not change (P>.05) in either group.

In conclusion, this specific Whole Body Vibration protocol of 5 weeks had no surplus value upon the conventional training program to improve speed-strength performance in sprint-trained athletes.

Key words: vibration exercise, resistance training, athletics, explosive strength, start action

INTRODUCTION

Whole body vibration (WBV) training is rapidly gaining in popularity in health and fitness centres, as an alternative method to improve muscle performance. It has recently been shown that WBV training is as efficient as resistance training to improve knee-extensor strength and jump performance in young [11] and in older [20] untrained women.

Previous studies suggested that WBV provokes length changes in the muscle which stimulates sensory receptors, most likely muscle spindles, eliciting the 'tonic vibration reflex' [8]. Additionally it has been shown that the recruitment thresholds of the motor units during vibration are lower compared to voluntary contractions [21], possibly resulting in a more rapid activation and consequently a greater training stimulus of the high-threshold fast twitch motor units [17,18]. Previous studies also suggested that WBV increases motoneuron excitability due to a more efficient use of the reflex pathways [6,11,18,21].

These findings resulted in a growing interest in the potential of WBV in the training program of sprint-trained athletes. An optimal motoneuron excitability and fast twitch fibre recruitment are two determining factors of sprint performance [12,22]. Actually an increasing number of highly trained athletes already combine WBV and resistance training with the main objective to improve speed-strength performance. However, it is presently unclear whether adding WBV training to the conventional training of sprint-trained athletes improves speed-strength performance.

In this study changes in knee-extensor and knee-flexor strength, maximal knee-extension velocity, jump performance, sprint running velocity and force-time characteristics of start action were measured following a 5 week training period of additional WBV training in sprint-trained athletes. As WBV may impact on motoneuron excitability and/or fast twitch fibre recruitment [18], it was hypothesized that WBV training, added to conventional training, could improve maximal strength and/or speed-strength performance in these athletes.

METHODS

Subjects

Three experienced sprint coaches allowed their athletes to participate in the study, from which eighteen male and seven female sprint-trained athletes (17-30 years old) were selected and volunteered to participate. The mean (±SD) 100m sprint performance was: 11.45 ± 0.42 seconds for the male athletes and 12.46 ± 0.59 seconds for the female athletes. All athletes performed between 5 to 9 training sessions weekly for at least 3 years including sprint-specific training and resistance training. Reasons for exclusion from the study were:

experience with WBV training, current injuries and a history of overuse injuries. All subjects were randomly assigned to a Whole Body Vibration group (WBV, N=13: 9 ♂ and 4 ♀) or a Control group (CO, N=12: 9 ♂ and 3 ♀), ensuring an even distribution of the athletes from the three coaches among each of the two training groups.

In total 20 of the 25 athletes completed the study properly. There were 5 dropouts (WBV, N=3 and CO, N=2). Four male athletes (WBV, N=2 and CO, N=2) had to leave the study due to injury/health problems not related to the study protocol (ankle distortion, sickness). One male athlete (WBV) left the study due to unexpected changes in his professional career. All remaining subjects of the WBV group (N=10) completed all 15 WBV training sessions, and subjects in both WBV and CO groups (N=10) continued their conventional training program supervised by their coach. The basic characteristics of the remaining 20 subjects (WBV and CO) who completed the study are given in Table 1.

INSERT TABLE 1

Conventional training program

The three coaches involved in this study developed their training programs according to the 'Essentials of strength training and conditioning' as described in the work of Baechle and Earle [3]. In consultation with the coaches the experimental protocol was implemented in the conventional training program at the end of the preparatory period (pre-competitive). In this period the sprinter's interval (10s–60s) and speed training (2-3 sessions weekly) intensifies to near competitive pace. Speed training drills (2 sessions weekly) are performed in assistive (towing) and resistive (uphill) modalities. Plyometric drills (1 session weekly) mimic sprinting. The resistance training program (3 sessions weekly) involves performing explosive exercises at high loads (75-95% of 1RM) and low volumes (3-5 sets of 2-5 repetitions).

During the experimental period (5 weeks) all subjects continued this conventional training program, but subjects of the WBV group performed three times weekly a WBV training prior to their normal training sessions. The personal coaches supervised the conventional training and guaranteed that there was no appreciable difference in conventional training between the WBV and the CO groups during the experimental period.

WBV training program

The WBV training program consisted of unloaded static and dynamic standard leg exercises (Table 2) on a vibration platform (80 x 40 cm, Power Plate®, The Netherlands). At the moment there are no scientific-based WBV programs for athletes available. Therefore, the WBV program of this study is based on a similar protocol that resulted in significant increases in muscle performance in untrained subjects [11,19]. In this study the training progression in the 5 week WBV program was quicker compared to untrained subjects who trained 12 weeks to reach a similar training volume and intensity.

The training volume increased systematically over the training period by increasing the total duration of vibration exposure (Table 2). The training intensity was increased by: shortening the rest periods, by increasing the amplitude and/or the frequency of the vibration stimulus. The acceleration of the platform was measured by and accelerometer (MTN 1800, Monitran, Bucks, UK) and varied between 2.28 g and 5.09 g. The subjects were asked to report possible side effects or adverse reactions in their training diary. Exercise specialists closely supervised all WBV sessions.

INSERT TABLE 2

Test Protocol

Isometric and dynamic muscle strength

The strength of the knee-extensors and knee-flexors was recorded on a motor-driven dynamometer (REV9000, Technogym ®, Italy) by a standard protocol of isometric and isokinetic tests. The tests were performed unilaterally on the right side. After a standardized warm-up maximal voluntary isometric torque (Nm) of the knee-extensors and -flexors at knee joint angles of 90° and 130° were measured (The intraclass correlation coefficient (ICC) for test-retest reliability is 0.93). The subjects also performed a series of isokinetic knee extension-flexion movements against the lever arm of the dynamometer (knee joint angle between 90° and 160°) at a velocity of 100°/s (ICC = 0.98).

Maximal knee-extension velocity

Maximal knee-extension velocity was recorded on the dynamometer using resistances on the lever arm of 1%, 20%, 40% and 60% of the isometric maximum measured at 90° knee angle. Subjects were asked to extend the lower leg as fast as possible from a knee joint angle of 90° to an angle of 160° (180° is full knee-extension). Maximal angular velocity at the knee (°/s) was taken as the criterion measure of maximal knee-extension velocity (ICC between 0.87 and 0.96).

Jump performance

A vertical counter movement jump (CMJ) with hands positioned on the waist, was used to assess the explosive strength of the lower limbs following stretch of the agonist muscles. Subjects were instructed not to lift their knees during the flight and landing phase. This test was performed on a contact mat, recording the flight time in milliseconds. The obtained flight time (t) was used to determine the increase in height of the center of gravity (h), i.e. $h=gt^2/8$, where $g = 9.81 m/s^2$ (ICC = 0.99) [2,7].

Start action

The kinetic parameters of the start action were recorded by means of two load cells, mounted on the back of the starting blocks. As both blocks were mounted on ball-bearings, horizontal force-time characteristics could be recorded. In a pilot study two sprint starts out of these blocks were performed on a force plate (Type Z11730, Kistler®) to validate the system. When comparing the data from both measuring devices the largest difference in force did not exceed 1.5%, while time variables differed 0.8% maximally.

The subjects were asked to perform three sprint starts out of the blocks. Each athlete strives to leave the blocks at the highest possible horizontal speed. Therefore start velocity is generally considered as the most relevant parameter to determine the quality of the start action [13,15]. However block clearance time is crucial as well, as sprint performance is finally judged by a time measurement. In this study experienced sprint-trained athletes were instructed to leave the blocks 'as quickly and powerfully as possible' and three variables were analyzed to determine the quality of the start action:

- *Start time* = the duration of the push-off action against the blocks, disregarding the reaction time (ICC = 0.93)
- *Horizontal start velocity* = the horizontal speed of the body's centre of gravity on leaving the blocks (ICC = 0.94)
- *Horizontal start acceleration* = start velocity divided by start time (ICC = 0.93)

The start action resulting in the highest start acceleration was selected for pre-post intervention analysis. All sprint tests were performed indoors to avoid variable weather conditions.

Sprint running velocity

The subjects performed two 30-m sprints out of starting blocks. Position-time data were continuously recorded over 30-m distance by means of a laser beam (IBEO lasertechnik®), oriented towards the lower back of the runner. These data were filtered (Matlab 6.5, Natick, USA) and finally the running velocity at the 5-m intervals from 0-30 m were computed. The fastest run was recorded for analysis (ICC between 0.95 and 0.98).

Statistical Analysis

The changes in strength, maximal knee-extension velocity, CMJ, start action variables and sprint running velocity (dependent variables) in the WBV and CO groups (independent variables) were analyzed before and after the experimental period of 5 weeks. Statistical analysis was performed with an ANOVA for repeated measures: [2 (group) x 2 (time)] for strength, CMJ and start action variables; [2 (group) x 2 (time) x 4 (resistance)] for knee-extension velocity and [2 (group) x 2 (time) x 6 (distance)] for the sprint velocity data. Overall F-values were checked for possible 'time effects' (pre-post) and interaction effects (group x time). Differences in pre-test values between groups were assessed using one-way ANOVA model. Test/retest reliability of all measurements were assessed using the Intraclass Correlation Coefficient (ICC). All analyses were executed using the statistical package Statistica, version 6 (Statsoft, Inc.). All values are reported as means ± standard deviation (SD). Significance level was set on P<0.05.

RESULTS

Training experiences

There were no reports of adverse side effects of WBV training. Most subjects enjoyed the vibration loading and did not consider it as physically strenuous although they generally reported a moderate degree of muscle fatigue at the end of each session.

Isometric and dynamic strength

At the pre-test there were no significant differences between the WBV group and the CO group (Table 3) in isometric or in dynamic strength of knee-extensors and knee-flexors (P>.05). Isometric and dynamic strength of knee-extensors and knee-flexors did not change over time in either WBV or CO groups. There was no significant (P >.05) time effect and no significant interaction effect (group x time).

INSERT TABLE 3

Maximal knee-extension velocity

No significant difference was found between the WBV group and the CO group in knee-extension velocity (1%, 20%, 40%, 60%) at pre-test. As can be seen in Figure 1, representing knee-extension velocity with an external resistance of 1%, 20%, 40% and 60% of isometric maximum, no significant changes (P>.05) from pre- to post-test were observed in both WBV and CO groups. There was no significant interaction effect (group x time x resistance) over the 5 week training period either (P>.05).

INSERT FIGURE 1

Counter movement jump performance (CMJ)

At the pretest there was no significant (P >.05) difference in CMJ height between the WBV group and the CO group (Table 3), and no changes over time (P >.05) in either group were found. Therefore CMJ height was not affected by WBV training. There was also no significant (P >.05) interaction effect (group x time).

Start action

At pre-test no significant (P >.05) difference between the WBV group and the CO group was found when start time, horizontal start velocity and horizontal start acceleration were considered (Table 3). None of these parameters changed after 5 weeks in either WBV or CO groups. There was no significant (P >.05) time effect and no significant interaction effect (group x time).

Sprint running velocity

Figure 2 represents the sprint running velocity at 5m, 10m, 15m,… and 30m in the WBV group and the CO group at pre- and post-test. The velocity curves of 30 meters sprint of both WBV group and CO groups were not significantly different (P >.05) at pre-test. The velocity curve did not change from pre- to post-test in the either WBV or CO groups. The statistical analyses of the velocity curve revealed no significant ‘group x time x distance’ effect following 5 weeks of training.

INSERT FIGURE 2

DISCUSSION

Despite the expanding use of WBV, as a supplement to the conventional training in athletes, the main findings of this study showed that this specific WBV protocol of 5 weeks in addition to conventional training in sprint-trained athletes did not affect: maximal leg muscle strength, maximal knee-extension velocity, vertical jump height, sprint running velocity, and force-time characteristics recorded during the sprint start.

The absence of any effect of WBV training on isometric and dynamic knee-extensor and knee-flexor strength is in contrast with some studies performed on untrained subjects, in which significant improvements in maximal knee-extensor strength were detected by means of a similar WBV training program for 12 weeks [11,19]. Some other studies in a non-athletic but physically active population, however, reported no change in knee-extensor strength following 4 months (25-35Hz, 2mm, 4 x 1-min vibration) [24] or following 11 weeks WBV training (30Hz, 8mm, 8 x 1-min vibration) [10]. The knee-extension velocity during tests performed at 1%, 20%, 40% and 60% of the isometric maximum was also unaffected in the present study. This latter is in line with the results of a study with untrained subjects [11]. The absence of any effect on jump performance in sprint-trained athletes corresponds to a study in physically active subjects who followed 11 weeks WBV training [10]. But this latter finding is in contrast with some previous studies that reported positive effects on explosive strength in untrained as well as in physically active subjects [5,11,24].

It was hypothesized that WBV training could increase maximal strength and speed-strength performance in sprint-trained athletes as the recruitment thresholds of the motor units during isolated muscle vibration are lower compared with voluntary contractions [21]. However it is unclear yet to which extent findings on isolated muscle vibration can be directly linked to WBV. A recent study on WBV found two indications of an enhanced central nervous excitability, particularly with respect to recruitment of predominantly fast twitch fibers [18]. 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 (26Hz, 12mm) than without WBV [18].

Most probably in sprint athletes high resistance training, plyometric drills and sprint running exercise already render a specific training of fast-twitch fibres [22]. In these athletes muscle strength, motoneuron excitability, fast-twitch fibre recruitment and reflex sensitivity are well developed [12,22]. This may explain why WBV training did not affect muscle performance in sprint-trained athletes despite it being recently shown that this protocol increased performance in previously untrained subjects [11,19]. However, this latter group has a much larger margin to increase the neural drive to the muscle.

As this is the first study with highly-trained athletes, it is also possible that limitations in the design of the WBV training program may have undermined the chances for potential adaptations, as will be discussed further. Differences in WBV program (vibration frequency, amplitude, type of exercises, duration of vibration exposure, etc.) can also explain the conflicting results in previous WBV studies in untrained and recreationally physically active subjects [5,10,11,19,24]. Except for differences in vibration frequency and amplitude, it is remarkably that in these studies the vibration exposure of one WBV session varied between 4 min [24] and 20 min [11]. There are indications that positive effects of WBV on muscle performance are associated with longer vibration exposures [11]. It is likely that a prolonged session of standing on the WBV platform will result in full motor unit activation. This may lead to motor unit fatigue and consequently to strength gain [23].

However, the present study found no improved muscle performance in highly-trained athletes compared to untrained subjects following a similar WBV program [11,19]. It is evident that such a WBV program impacts more on untrained subjects as their baseline knee-extension strength was about forty percent lower [11] compared to highly trained athletes. Not only muscle strength but also intrinsic muscle properties are different. Repetitive stretch-shortening actions during sprint running exploit the qualities of the muscle-tendon complex leading to high muscle-tendon stiffness in athletes compared to untrained subjects [14]. In addition, during running, changes in leg muscle activity in the pre-landing phase increase muscle stiffness to protect muscle fibers from damage due to impact vibrations during the landing [25]. In this way, the stiff muscle-tendon complex of athletes is well developed to minimize length changes in the muscle [4] and to damp vibrations [16].

Based on these previous remarks it must be questioned whether the vibration loading provided by the current WBV program was strong enough by itself to enhance muscular performance in sprint-trained athletes. Although some studies found an increase in leg extensor muscle activity up to 34% as compared to standing on the platform without WBV [9,11], the values reached only 10-50% of the muscle activity during a maximal voluntary contraction [10]. The highly-trained athletes of this study reported a moderate degree of muscle fatigue after the WBV sessions. A training stimulus, however, should result in a progressive overload of the muscle. Therefore, in performing conventional resistance exercise the training load of an athlete is systematically individualized as the weights to be lifted are determined as a percentage of the maximal strength (one repetition maximum, 1RM) of that specific person [1]. However in most WBV studies, as well as in the present study, the WBV stimulus was identical for all subjects. There was also no additional loading (weights, dumbbells,…) when the static and dynamic exercises were performed on the vibration platform. Therefore additional loading during WBV, a more individualized approach and a higher vibration loading might have been required for stimulating any adaptive response in the muscles of sprint-trained athletes.

A final remark in this study is the duration of the training period. It is possible that in highly-trained subjects a longer period of training is required for significant effects to be detected. The data indicate that there were no changes in any of the recorded variables either following five weeks of WBV training or conventional training (control condition). In highly-trained athletes with many years of training history, it is difficult to obtain statistically significant training effects even following longer training periods. The relative short training period in this study is based on findings of a previous study that found improved muscle performance already after 10 days WBV training (26Hz, 10mm, 5 sets of 2 min) in physically active subjects engaged in team sports [5]. These spectacular findings cannot be confirmed in this study.

In conclusion, the main findings of this study showed that 5 weeks of WBV training by means of this specific protocol did not improve knee-extensor and knee-flexor strength, knee-extension velocity, jump performance, force-time characteristic of the start action or sprint running velocity, when the WBV training was performed prior to conventional training sessions in sprint-trained athletes. It is suggested that the intensity and volume of the specific WBV protocol may not be high enough for these highly-trained athletes. Further research is necessary to demonstrate and to investigate the potential role of WBV in the training of sprint-trained athletes.

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Table 1: Subject Characteristics

	WBV (N=10)		**CO (N=10)**		
	♂ (N=6) **Mean ± SD**	**♀ (N=4)** **Mean ± SD**	**♂ (N=7)** **Mean ± SD**	**♀ (N=3)** **Mean ± SD**	**P-value**
Age (yr)	21.7 ± 3.2	20.0 ± 2.1	20.6 ± 4.2	23.3 ± 5.8	.54
Body mass (kg)	70.7 ± 6.7	59.8 ± 1.8	74.9 ± 6.6	61.7 ± 5.9	.21
Height (cm)	179.5 ± 7.7	170.5 ± 7.3	183.7 ± 5.9	167.7 ± 4.0	.46

Values are mean ± SD

P-value: results of one-way ANOVA between pre-test group means **(**♂+♀**)**

WBV = Whole Body Vibration training group; CO = Control group

Table 2: Description of the WBV program

Exercises performed on the WBV platform	
High squat	Knee angle 125°, Hip angle 140°
Deep squat	Knee angle 90°, Hip angle 80°
Wide stance squat	Feet in apart, toes pointed slightly outwards, knee angle 90°
One legged squat	Knee angle 125°, Hip angle 140°
Lunge	Front foot on platform, back foot on ground, front knee angle 90°
Calves	High squat while standing on the toes

Execution of exercises	
Isometrically	holding the position
Dynamically (except for lunge)	slowly move up (3s) and down (3s)

WBV Program	Start	Week 3	Week 5
Volume			
Number of exercises (N)	6	6	6
Series of one exercise (N) (2 isometrically and 1 dynamically)	3	3	3
Duration of vibration exposure without rest (s)	30	45	60
Total duration of vibration exposure in one session (min)	9	13,5	18
Intensity			
Rest period between exercises (s)	60	20	5
Vibration amplitude (mm)	1.7	1.7-2.5	2.5
Vibration frequency (Hz)	35	35-40	40

Table 3: Muscle strength, jump performance and start action variables (mean ± SD) before (pre) and after 5 weeks of training (post) in the Whole Body Vibration (WBV) group and the Control (CO) group. No significant changes from pre to post were found.

	WBV group (N = 10: 6 ♂, 4 ♀)		**CO group** (N = 10: 7 ♂, 3 ♀)		**P-value**	
	pre	post	pre	post	time	group x time
Isometric knee-extensor strength (N.m)	191.2 ± 42.4	196.1 ± 40.0	229.9 ± 68.0	230.6 ± 57.3	.64	.73
Isometric knee-flexor strength (N.m)	107.8 ± 27.4	106.8 ± 28.6	109.9 ± 23.1	112.5 ± 30.3	.77	.51
Dynamic knee-extensor strength (N.m)	180.0 ± 39.5	191.0 ± 44.6	212.7 ± 43.1	212.2 ± 45.5	.17	.13
Dynamic knee-flexor strength (N.m)	103.9 ± 22.4	107.8 ± 26.8	118.6 ± 22.8	119.8 ± 23.7	.07	.32
Vertical jump height (mm)	395.8 ± 75.5	408.5 ± 64.5	418.6 ± 70.9	403.7 ± 67.4	.88	.07
Start time (ms)	364.3 ± 26.9	364.3 ± 23.0	374.2 ± 25.8	375.2 ± 22.3	.81	.81
Horizontal start velocity (m/s)	2.74 ± 0.17	2.72 ± 0.26	2.83 ± 0.29	2.83 ± 0.25	.67	.81
Horizontal start acceleration (m/s^2)	7.58 ± 0.92	7.50 ± 1.05	7.63 ± 1.07	7.57 ± 0.88	.54	.92

P-value: ANOVA for repeated measures