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ORIGINAL ARTICLE
EXERCISE PHYSIOLOGY AND BIOMECHANICS

Acute effects of whole-body vibrations on the fatigue induced by multiple repeated sprint ability test in soccer players

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ABSTRACT

BACKGROUND: We tested the hypothesis that whole-body vibration (WBV) positively affects the fatigue process ensuing from repeated bouts of maximal efforts, as induced by repeated sprints' ability (RSA). Eleven male soccer players performed three sets of six repeated shuttle sprints (40 meters).

METHODS: Eleven male soccer players (age 23.6±4.5 years) were cross-randomized to perform WBW before RSA and during the recovery between sets (WBV-with) or to warm-up and passive recovery between sets (WBV-without). The effects of WBV were quantified by sprint time (ST) and blood lactate concentration (LA), collected up to 15 min after completion of tests.

RESULTS: ST during RSA showed a better maintenance of performance in the WBV-with compared to WBV-without condition in all three sets, reaching a statistical significance between-groups during the 2nd and 3rd set ($P<0.05$). No significant differences in ST over the sets were detected in WBV-with, whereas a significant decrease was observed in the WBV-without condition ($P<0.001$). LA recovered significantly faster from the 9th to 15th minute of recovery in WBV-with as compared to WBV-without ($P<0.05$).

CONCLUSIONS: These findings would indicate that WBV performed during recovery between RSA sets can delay the onset of muscle fatigue resulting in a better maintenance of sprint performance.

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KEY WORDS: Muscles; Exercise; Soccer.

Whole body vibration (WBV) has been shown to be an effective and easy training method to increase physical performance. Indeed, WBV is currently used in different fields, ranging from training of elite athletes[1, 2] to osteoporosis' therapy[3, 4] and chronic lower back pain.[5] The transient positive effect observed after a few minutes (from 5 to 10 minutes) of WBV on jump height,[2, 6, 7] maximal muscular force and power[8, 9] force-velocity relationship[1, 10] and linear sprint[11, 12] has been attributed mainly to neural factors, including an excitatory reflex response of the agonist muscles[13, 14] with a simultaneous inhibitory effect on antagonist muscles,[15] leading to a synergic activity of agonist and antagonist muscles and increased motor unit synchronization.[16-18] Recently, it has been reported that the vibratory stimulus induces a prolonged inhibitory effect on the antagonist muscles that is greater than the excitatory effect on the agonist muscles.[19, 20] This would result in a relative increase in jump performance.[21] However, the effects of WBV on muscular performance over prolonged time frames and, even more, on muscles fatigue have not been fully defined.[22] It has been reported that the vibratory stimulus applied during the resting phase of a high intensity interval training (HIIT) could increase the cross-sectional area (CSA) of myosin heavy chain-2A (MyHC-2A) fibers, a typical feature of HIIT, and of preventing the decrease in anaerobic performance.[23] Delaying as much as possible muscular fatigue is of paramount importance in sports such as soccer, in which several short-duration maximal efforts, interspersed with short in-between recovery periods,[24] are required for the whole duration of the match. Indeed, in the soccer game, the reduced capability of maintaining high levels of anaerobic efforts over time is one of the main limiting factors of performance.[25] RSA is a part of the usual training routine in soccer and other team sports because it well reproduces some fundamental features of performance over the course of the real match.[25-28] Interestingly, it has been reported that in soccer players WBV, performed during the recovery phases of single Repeated Sprint Ability (RSA) test, induces a delay in fatigue onset, while maintaining the performance up to the last two of six repetitions in 40 meters' shuttle sprints.[29] Developing a prolonged RSA test, that could allow to increase the work in a domain physiologically determined by internal limits of power generation capacity over time, can be of great practical interest for soccer players' performance. Following this concept, the WBV could represent a useful neuromuscular stimulus in delaying the onset of muscle fatigue. To the best of our knowledge, no study addressed the effects of WBV before and after (*i.e.*, in the recovery time) each set of a multiple consecutive RSA test in professional soccer players. The aim of this study was to test the hypothesis that application of WBV before and during multiple consecutive RSA tests (*i.e.*, 3 sets) that would increase the muscle load more than only one set, could improve athletic performance and delay the onset of muscle fatigue. To this aims, we applied the WBV before the RSA tests and during the resting phase of each set evaluating the sprint time in each repetition along with blood lactate concentration (LA) and LA removal time during recovery.

Materials and methods

Participants

Eleven professional male soccer players, recruited from S.P.A.L. Soccer Team (Ferrara, Italy), volunteered to participated in this study. Anthropometric data were age 23.6±4.5 years, height 1.78±0.6 m, body mass 75.8±12.8 kg and BMI 23.71±2.98 kg·m^{-2}. The players were homogenous regarding their training status and soccer practice level, ranging from 4 to 8 years at this competitive level (*i.e.,* Italian Lega Pro) and trained at least 5 sessions per week. RSA as training method, have been always part of their usual training during the competitive seasons. All subjects participated at the national championship during this investigation, followed the same training schedule and did not undergo to any strenuous exercise before the experimental tests. Moreover, the players were advised to maintain a regular diet during the day before testing (*i.e.*, 60%, 25%, and 15% of carbohydrates, fat, and protein, respectively) and to refrain from smoking and caffeinated drinks during the 2 hours preceding testing. The exclusion criteria were recent history of muscle injuries or trauma that could affect the experiment. Written informed consent was obtained from all the participants after explanation in detail of the aims, benefits, and risks involved in this experiment. The study was approved by the Institutional Research Board of Tor Vergata University, Rome, Italy. All procedures were carried out in accordance with the Declaration of Helsinki.

Study design

The study was conducted with a cross-over design. Accordingly, athletes were randomly assigned to perform just before starting the RSA tests and between RSA sets: 1) WBV; or 2) exercise involving walking, jogging over short distances of 5 to 10 m (see below) and *vice-versa*. The tests with (WBV-with) and without (WBV-without) WBV were performed in the same week two days apart, at the same hours of the day (*i.e.*, 2:00-4:00 p.m.) and in the same soccer field made of a natural grass surface. In both test days, the players wore the same appropriate soccer shoes. In the day preceding the test no additional strength, power or plyometric training was allowed to the players. The times obtained by each player during each sprint of RSA (*i.e.*, sprints 1-6 for three sets) performed with WBV and without WBV were recorded and taken as an index of performance.

Field tests

Repeated-sprint ability test

This RSA shuttle test consisted in three sets of 6 repetitions each of shuttle sprinting over 40 m (20+20 m), with the exercise to rest ratio 1:3, which is considered the most suitable to promote the specific adaptations in soccer players to this type of training.[25] Resting time between sets was three minutes. Considering that shuttle sprints are integral part of soccer assessment, the familiarization with test was deemed not necessary. A standardized warm-up, consisting of slow jogging, dynamic stretching, and three sub-maximal shuttle sprints was performed before RSA test in both groups. Immediately after the warm-up, players performed a preliminary single shuttle sprint (20+20 m) to assess their best individual sprint time. This trial was used for subsequent 6×40 m shuttle sprint test analyses. After the first preliminary single shuttle sprint, subjects rested for 5 min and thereafter the players underwent WBV for 5 minutes or performed walking and jogging over short distances of 5 to 10 m for 5 minutes (WBV-without). No static-stretching exercises were allowed before any test. Sprint time over the first 40 m shuttle test had to be not slower than 5% of the individual's best 40 m performance time, to be considered valid.[30] All the players performed the tests with a self-administered start, after an informative audio signal of readiness. They sprinted just to the line at 20 m of distance, touched the line with one foot and came back to the starting line as faster as possible. After 20 s of recovery, the players started again. Each shuttle sprint performance was measured using a telemetric photocells system (Muscle Lab, Ergotest, Norway). To avoid undue switch-on of the timing system, players had to position the front foot immediately before a line set 30 cm from the photocell beam. The photocell beam was positioned at 70 cm height and 2 m apart and maximum performance was induced through strong verbal encouragements during the whole test duration. Immediately before each repetition, the participant assumed the ready position and waited the countdown and the start signal. The reaction times were not assessed as a part of this study. The reliability of the tests used in this study had been previously assessed in a similar population of soccer players.[31] To track changes on sprinting performance and consequently examine acute fatigue during repeated sprinting, the percent of the variation between the total best (6 × best sprint score) and actual total sprint performance (TT) were considered.[32]

Blood lactate measurement

A sample of arterialized blood was drawn from the ear lobe and immediately analyzed with a validated lactate analyser (Arkray Lactate Pro LT-1710; Arkray, Kyoto, Japan). Lactate concentration (LA) was determined in resting condition before the warm-up phase (baseline), immediately after each RSA set, at 3, 6, 9, 12 and 15 min after the ending the test (*i.e.*, recovery).

WBV protocol

We used a vibrating platform with one rotatory eccentric engine (OMeV T1 model®, Power club, Ferrara, Italy) which was positioned close to the RSA testing starting line. The vibration frequency was set at 35 Hz with a peak-to-peak displacement of 3.2 mm and an acceleration of about 53 $m \cdot s^{-2}$ (5.4 g where 1g=9.81 $m \cdot s^{-2}$). The WBV protocol consisted in 5 repetitions, 1 min each, of vibration in the squat position with bent legs at 90° at the knee and the arms free along the body, alternated to a 1 min of rest on the platform. During the last minute of rest, after the last repetition of WBV, the players took place close the start line in ready position. In the resting time between RSA sets, after blood lactate collection, the players underwent an additional minute of WBV. During recovery without WBV the players spent their time walking and jogging close the test area.[33] We decided for a passive recovery in the WBV-without group instead of an active one, because this latter might influence, to some extent, blood lactate clearance, possibly biasing the comparison between the two resting modes (WBV-with *vs.* WBV-without).[34, 35] Passive recovery is commonly used among high-level professionals[28, 36] and seems to promote a better performance and a reduced physiological stress across different phases of short-distance repeated sprints.[37]

Statistical analysis

The assumption of normality was tested with the Shapiro-Wilk Test on each variable. A multivariate between-within subject analysis of variance was conducted to assess any significant difference in mean RSA variables and blood lactate test between WBV-with and WBV-without conditions. Furthermore, the RSA data were analyzed by 1-way repeated measures analysis of variance. Tukey's *post-hoc* test of critical difference was used to locate significance between means. The effect size, partial eta squared (η_p^2), was calculated to assess meaningfulness of differences. Effect sizes (ES) were interpreted using the following criteria: 1) <0.01 – very small; 2) from >0.01 to <0.06 – small; 3) from >0.06 to <0.14 – medium; and 4) >0.14 – large. For all analyses, a P value less than 0.05 was considered statistically significant. Confidence interval on the difference between means were set at 95% level (CI 95%). Data are presented as mean±SD.

TABLE I.—*Average time, relative decrement, and best time during repeated sprint test (RSA_{mean}, RSA_{dec}, and RSA_{best}, respectively) in different sets in WBV-with and WBV-without.*

Variables	All sets	Set 1	Set 2	Set 3
RSA_{mean} (s)				
WBV-with	7.99±0.23	7.92±0.17	8.02±0.25	8.03±0.27
WBV-without	8.21±0.32	7.98±0.22	8.25±0.24§	8.40±0.34§#
Difference	-0.22*	-0.06	-0.23*	-0.37*
Difference (CI 95%)	-0.42; -0.02	-0.23; 0.12	-0.44; -0.01	-0.64; -0.10
ES	0.20	0.02	0.19	0.29
$RSA_{dec\ (\%)}$				
WBV-with	3.16±1.37	3.66±1.01	3.13±1.26	2.68±1.69
WBV-without	4.27±1.43	3.85±0.91	4.51±1.78	4.46±1.51
Difference	-1.12	-1.19	-1.38*	-1.78*
Difference (CI 95%)	-2.04; -0.19	-1.04; 0.67	-2.75; -0.01	-3.21; -0.35
ES	0.24	0.01	0.18	0.25
RSA_{best} (s)				
WBV-with	7.71±0.28	7.56±0.30	7.77±0.28	7.80±0.23
WBV-without	7.84±0.32	7.61±0.22	7.89±0.21	8.01±0.39
Difference	-0.13	-0.05	-0.13	-0.21
Difference (CI 95%)	-0.33; 0.07	-0.29; 0.18	-0.35; 0.10	-0.49; 0.08
ES	0.08	0.01	0.06	0.10

Data are expressed as mean±SD, effect sizes and 95% confidence intervals (95% CI).
*P<0.05, different from WBV-with; §P<0.001, different from set 1; #P<0.05, different from set 2.

Results

Chronometric data obtained during RSA are illustrated in Table I and in Figure 1. A significant for a better maintenance for the RSA mean time in the WBV-with in comparison to the WBV-without condition emerged in all three sets (P=0.036, ES=0.202), which was statistically significant in RSA sets 2 and 3 (RSA set 1, P=0.497, ES=0.023; RSA set 2, P=0.041, ES=0.192; RSA set 3, P=0.009, ES=0.294). In the WBV-with no significant differences were detect in RSA mean time among the three sets (P>0.05). On the contrary, in WBV-without condition significant differences in RSA mean time among RSA sets were detected (RSA 1 *vs.* RSA 2, P=0.0001, ES=0.809; RSA 2 *vs.* RSA 3 P=0.008, ES=0.518; RSA 1 *vs.* RSA 3, P=0.001, ES=0.736). Interestingly, players in the WBV-with showed significant sprint performance decrements from the third sprint onward in all three sets of the RSA test (P= 0.05 Set1; P=0.03 set 2; P=0.04 set 3) whereas sprint time deterioration occurred earlier (from the third sprint in the first set and from the second sprint in the second and third set) in the WBV-without (P=0.05 Set 1; P=0.004 set 2; P=0.0008 set 3) (Figure 1). Percentage in RSA decrements (% dec) showed no significant differences among sets within-condition (P>0.05), whereas the differences among sets between- conditions were significantly different in the last two sets of RSA (RSA dec set 2, P=0.048, ES=0.181; RSA dec set 3, P=0.017, ES=0.253) (Table I). The difference within-

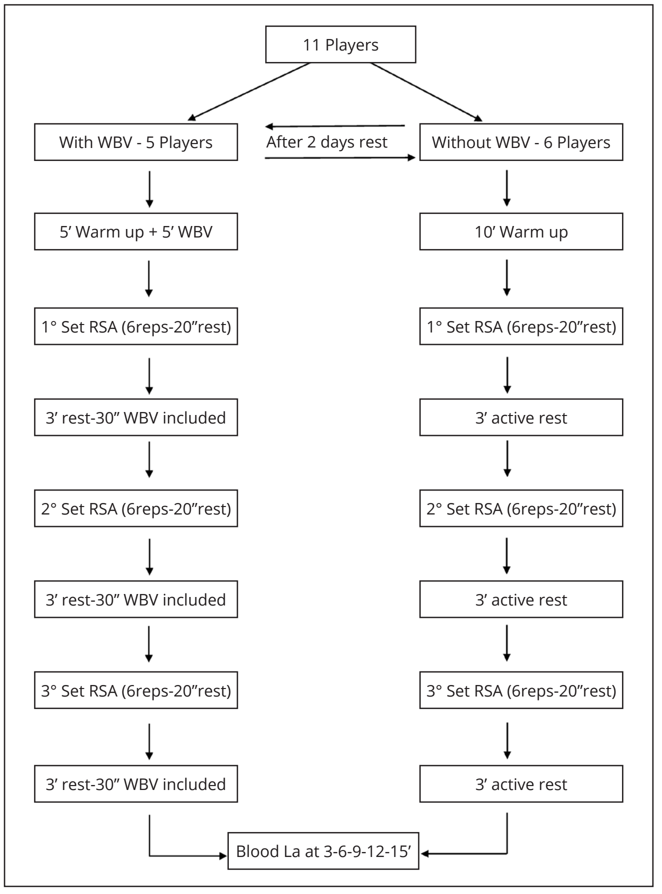

Figure 1.—Flow diagram of study design.

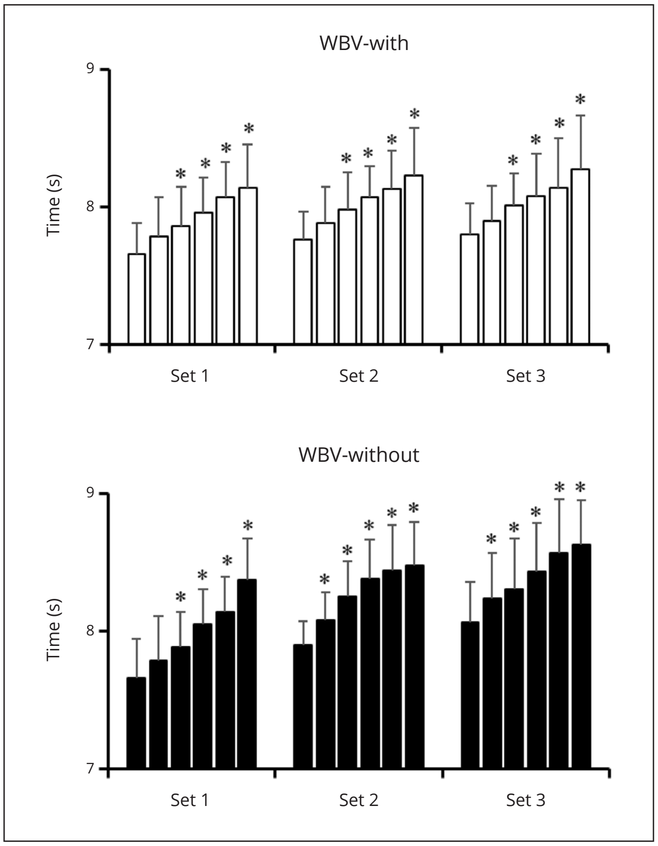

Figure 2.—Sprint profile (N.=11) of the repeated sprint ability test (3×6×20+20m).
*P<0.05, significantly different from the first sprint bout.

and between conditions in RSA best performance was not significant (P>0.05).

Blood lactate

Data on LA concentration are reported in Figure 2. No significant differences in LA were detected at baseline as well as at the end of each set of RSA between WBV-with and WBV-without conditions. However, LA recovered significantly faster from 9th to 15th minute from the end of RSA in WBV-with as compared to WBV-without (LA 9th, P=0.026, ES=0.223; LA 12th, P=0.006, ES=0.322; LA 15th, P=0.017, ES=0.252).

Discussion

The main finding of this study was that WBV performed during the recovery phases between RSA sets results in an improved maintenance of sprint performance (Figure 1). This is the first study to investigate the acute effects of WBV on performance during multiple RSA sets, that represent a fundamental routine of usual training program in soccer and other team sports.[25-28, 38] The hypothesis tested in the present investigation was that WBV performed before and during recovery between sets, could delay the fatigue induced by muscular efforts as induced by multiple RSA. Our hypothesis was fulfilled, in that WBV was capable to delay the onset of muscle fatigue, as indicated by the different RSA mean time between WBV-with and WBV-without conditions in the last two RSA sets (Table I). This concept is supported by the finding of a lack of significant changes in sprint performance over time in the WBV-with. Padulo *et al.*[29] have recently reported a maintained sprint time in the last two repetitions of just one set of RSA when WBV was performed in the resting periods between shuttle sprints. Our study confirms and extends the above finding[29] in that we investigated the effects of WBV during multiple sets of RSA, in which muscular fatigue condition is greater than during one set only, indicating the effectiveness of WBV in maintaining sprint performance over more prolonged time periods. An issue with RSA practice is related to the transition from an anaerobic alactacid metabolism to a lactacid and a mixed anaerobic/aerobic metabolism, which would lead to an increase in muscular fatigue resulting in a reduced sprint performance.[28] The results of this study would indicate that WBV applied during the resting times between repeated sprint efforts counteracts, at least in part, the occurrence of muscle fatigue. This reasoning is supported by the observation that in the WBV-with condition the sprint performance was maintained in all the RSA sets, without a significant decline in performance over the sets, whereas in the WBV-without condition a decay in sprint performance was observed. A further interesting finding ensued from this study is the effect exerted by WBV on the kinetic of blood lactate removal after the end of the whole RSA routines. In WBV-with condition a faster removal of LA was observed in comparison to WBV-without, despite the magnitude of LA production during RSA was not significantly different between the two conditions (Figure 2, 3). Whether this finding is of relevance to the issue of the delay/recovery of muscle fatigue, warrants further investigations. This study, by its nature, cannot define the mechanism(s) through which WBV exerted its positive effects. However, some speculations could be advanced. Indeed, the acute effects reported in this study could be explained through several mechanisms. The first one could be related to neuroelectrical adaptations. In fact, some studies have linked the increase in jump performance after WBV exposure to increased neural activity of the agonist mus-

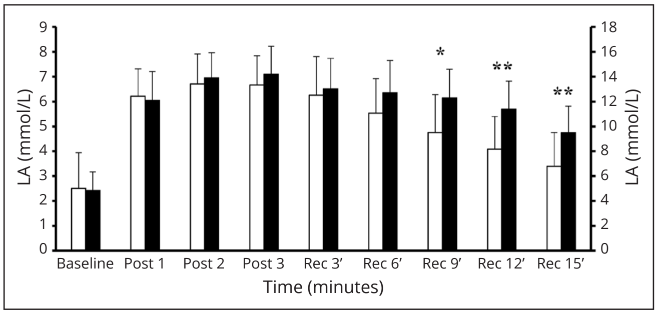

Figure 3.—Blood Lactate concentrations over time in WBV-with (empty columns) and WBV-without (black columns) groups.
*P<0.05; ** P<0.01.

cles,[14, 39] a reduced activity of the antagonist muscles[19] and changes in muscles elasticity. The Tonic Vibration Reflex, recorded in the agonist muscles during vibration treatment would exert in turn a prolonged postinhibitory effect on the antagonist muscles after vibration stimulus, because of the reciprocal innervation that characterizes the stretch reflex activity.[40] Consistent with this explanation, an increased speed of contraction in explosive movements with a concomitant decrease of antagonist muscles EMGs activity has been reported.[21] In this context, the lack of improvement in sprint performance in 1 RSA set might have occurred because of a too short exposure (5 min) to vibration, used in our experiment, before the 1 RSA set, that could have been not long enough to condition consistently the neuromuscular system.[41] In addition to neuromuscular activity, WBV, with the related microcontractions induced by the Tonic Vibration Reflex, might have also acted on cell membrane excitability, counteracting by this way the impairment in Na^+/K^+, Ca^{++}, ATPase activity which is linked to fatigue development through a reduction in the amplitude of action potential and a slowing of impulse conduction associated to an impairment in sarcoplasmic activity related to influx-efflux Ca^{++} ions involved in the acto-myosin cross-bridges formation, resulting in a global decline of force development.[38, 42, 43] Linked to the above mechanism, would be the effect of WBV on the excitatory input from type Ia afferents to the motor neuron pool, that induces a transient restoration of motor units discharge rate.[13, 44, 45] As far as the faster removal of LA observed with WBV is concerned, we hypothesize that this phenomenon could be related to the increase of blood perfusion[46] and to the vasodilator effects of vibrations on small arterioles and capillaries.[47] This effect might be advantageous for the delivery of oxygen and nutrients to exercising muscles and the removal of end by-products, included LA. This phenomenon could result in a faster recovery from fatiguing intermittent runs.

Conclusions

In conclusion, the results of this study highlight new aspects of WBV that concern the fatigue process. A brief exposure (~30s) to WBV during recovery time between repeated sprints, in addition to baseline exposure performed before test (5min), could have been able to reduce neuromuscular fatigue thus permitting a more prolonged anaerobic muscular activity before the decay of performance would ensue. Developing an RSA combined with WBV could be of great practical interest in team sports in which short duration maximal efforts are alternated with short in-between recovery. Further studies are needed to clarify the biochemical pathways underlying the effects of WBV on fatigue processes.

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