The Acute Effect of Whole Body Vibration on Repeated Shuttle-Running in Young Soccer Players

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The aim of this study was to investigate the acute effects of whole-body vibration (WBV) on Repeated Sprint Ability (RSA). Seventeen male soccer players (16.71±0.47 y) performed three RSA tests (Randomized crossover study design). The second RSA test was done with WBV (RSA2) to assess the effect of WBV. The studied variables were: best time (BT), worst time (WT), total time (TT), the fatigue index (FI) of RSA, and post-test blood lactate (BLa). ANOVA with repeated measures showed no differences between RSA1 and RSA3, while there were significant differences in all variables studied. TT= [RSA2 0.93% and 1.68% lower than RSA1 and RSA3 respectively; $p<0.05$], BLa= [RSA2 16.97% and 14.73% greater than RSA1 and RSA3 respectively; $p<0.001$], WT= [RSA2 1.90% and 2.93% lower than RSA1 and RSA3 respectively; $p<0.01$], and FI= [RSA2 30.64% and 40.15% lower than RSA1 and RSA3 respectively; $p<0.0001$]. When comparing individual sprints, WBV showed a significant effect at the 5^{st} sprint: RSA2 2.29% and 2.95% lower than RSA1 and RSA3 respectively ($p<0.005$), while at the 6^{st} sprint: RSA2 2.75% and 4.09% lower than RSA1 and RSA3 respectively; $p<0.005$. In conclusion, when applying WBV during the recovery periods of Repeated Sprint Ability efforts, most of the performance variables improved.

Key words: field testing, shuttle running, soccer players, fatigue, change of direction, team sports.

Introduction

Match analysis studies have demonstrated that soccer requires well trained players to repeatedly produce maximal actions of short duration (<7s) with relatively brief recovery periods in-between with many changes of direction and changes of activity during the game [38]. In this context, shuttle running for testing or training, is considered as a specific performance model for soccer [37]. Consequently, shuttle running as intermittent training and testing protocols have been proposed to assess and improve soccer players' fitness and to identify talent [32]. In order to meet the requirements of a performance model, Bishop et al. [3] codified training according to the ability of performing sprints or repeated sprint ability (RSA) that is considered to be typical effort pattern for soccer performance [31].

The RSA can be defined as the ability to keep the sprint performance relatively unchanged over time [30]. Moreover, the ability to repeat multiple sprints at high intensity was validated as a reliable index of physical performance in soccer [38]. Besides, RSA would reproduce the typical intermittent characteristic of soccer games related to the amount of high-intensity activities completed during the match [38]. Therefore, Bishop et al. and Chaouachi et al. have investigated new methods to improve the speed during RSA with small effects on the performance [2, 10]. Other authors investigated the acute effect of whole body vibration (WBV) on linear sprinting (30m) using different frequencies of stimulation (30 to 45 Hz) [5, 6].

In the literature, experiments have shown acute effects of WBV on explosive and reactive exercises [8, 11, 18, 22] that have been primarily attributed to neural factors, such as increased motor unit synchronization, stretch reflex potentiation, increased synergist muscle activity, and increased inhibition of the antagonist muscle [8, 11, 22].

The shuttle run during RSA field testing (e.g., 6 shuttle-sprints of 40m: 20+20m), stimulates actions that require different mechanical inputs (acceleration, deceleration and changes of direction) with high muscular work and specific energy needs [26] which could affect the kinematic of gait during running [27]. Considering that the acceleration-deceleration phases and the changes of direction are related to the explosive-reactive strength and power [36, 39], that in turn are improved by applying WBV [11, 18, 22], it has been hypothesized that WBV improves the overall RSA performance.

Therefore, the aim of this study was to assess, during the on-field RSA testing, the effects of WBV on the performance variables (best time, worst time, total time, fatigue index) and post-testing blood lactate accumulation.

Material and Methods

Participants

Seventeen male soccer players recruited from a Junior Soccer Team "Cagliari Calcio S.P.A." (age: 16.71±0.47 years; body mass: 68.59±6.76 kg; height: 1.79±0.05 m; BMI: 23.8±1.33 $kg·m^{-2}$) volunteered to participated in this study. The inclusion criteria were high level soccer practice, ~5 years training (5.75 ± 1.23 years) and ~8 hours of training per week. The participants were used to train with shuttle running and they have been participating at the national championships at that time of the investigation. The participants were homogeneous with regard to their training status, as none of the participants underwent any endurance strenuous activity and resistance training outside of their normal endurance training schedule. Written consent was obtained from the participants' parents/guardians after being thoroughly informed of the study design. All experimental procedures were approved by the University Human Research Ethics Committee, which followed the ethical standards of the International Journal of Sports Medicine [19].

Experimental setting

Outdoor field tests were completed on a certified synthetic turf pitch with players wearing appropriate soccer shoes. The average weather conditions during the three days of experiment were as follows: average wind speed (~1.4 $m·s^{-1}$), with testing session starting at 4:00 p.m. (~22.5°C), and lasting till ~5:00 p.m. (~23.5°C). A single-group, repeated-measures study design was used in which WBV was the independent variable, whereas sprint' times and blood lactate concentration were the dependent variables. The experiment was performed on three days with 3 days in-between each testing session. On the first and third testing days the participants performed standard RSA test [21]. However, in the second test they performed the RSA with WBV during the recovery phases. No additional strength, power, and plyometric training was performed during the testing period.

Repeated-sprint ability shuttle test

During each session, the participants completed similar 10-min warm-up at low-intensity running (~8 $km \cdot h^{-1}$) and striding, followed by three, sub-maximal 40-m shuttle sprints (40m= 20+20m with a change of direction (COD) of 180° and 1 min of recovery in-between) and 5-min of recovery before starting the RSA test. Players were already familiar with this test as it was part of their routine assessment. Therefore, no familiarization with the trials was necessary.

The RSA [21] test on the first day and third day (RSA1 and RSA3, respectively) consisted of six maximal 40m shuttle-sprints (20+20m) separated by 20-s of recovery and with the same exercise (~1:3) to rest ratio [34]. The participants started from a line, sprinted for 20m, touched the second line with a foot and then came back to the starting line as fast as possible. After 20 seconds of passive recovery, the participants repeated the exercise. The time for each single shuttle sprint was recorded using a photocell gate (Brower Timing System, Salt Lake City, UT, USA; accuracy of 0.01 seconds). Few seconds (~2.5s) before the start of each sprint (RSA1/3), the participants assumed the ready position and waited for the next starting signal. This test was designed to measure both repeated sprint and change of direction abilities. Each player was instructed and verbally encouraged to produce a maximal effort during all sprints. If the performance in the first sprint of the RSA test was worse than the criterion score (i.e., an increase in time greater than 2.5%), the test was immediately stopped and the participants were required to repeat the RSA test with maximum effort after a 5-min rest.

For the RSA2, WBV was applied during the recovery periods. Because applying WBV during each recovery period seemed to be an intense stimulus [14], it was decided to apply WBV alternatively to a passive recovery. This procedure, also allowed us to verify if the performance of single sprint was influenced by the preceding WBV or passive recovery. Thus, the subjects were divided into two groups that underwent in randomized order (Latin Square design) RSA-2 with alternation of WBV/passive rest (RSA2/V) and at the same time passive rest/WBV (RSA2/R) recovery periods. For comparison with RSA-1 and 3, the RSA-2 performances were separately collected for each sprint (sprints 1 to 6 for WBV and also for passive recovery).

Whole-body vibration treatment

The vibrating platform used for the study was the Power Plate pro5™ (Power Plate International LTD, The Netherlands), positioned at 50 cm from the RSA-starting/finishing line so as to reduce the time required for the soccer players to take place on the platform. The vibration frequency was set at 45 Hz, with a peak-to-peak displacement of about 2.2 mm [24] and an acceleration of about 7.7-g (1 g= 9.81 $m\cdot s^{-2}$). The vibrating platform used shows a high reliability for the accelerations delivered between unloaded and loaded condition [28]. As mentioned above, the protocol was designed in order to balance the recovery period between each sprint (with or without WBV). During WBV, each subject spent a total of ~5s between the start/finish positions on the vibration plate (WBV/Sprint). WBV treatment during the active recovery lasted ~15s, i.e. 20s of recovery minus the time necessary for decelerating and coming back to the platform (~2.5s) and then to go off the platform and prepare for the next sprint (~2.5s). During WBV the participants stood on the plate with the knees flexed at ~90° and the heels raised ~10 cm [17]. In addition, the participants leaned slightly forward, with their hands on the vibration plate’s handle to partly support their upper body. During the passive recovery the participants underwent the exact same protocol and assumed the same position for the same duration but the vibrating plate was turned off.

Lactate sampling and measurement

Blood lactate (BLa) concentration (mmol·L^{-1}) was determined at the third minute after the end of the tests (RSA1, RSA2, RSA3) as reported in the literature [20]. A micro sample of arterialized blood from the ear lobe was taken and immediately analysed with a validated lactate analyzer (Arkray Lactate Pro LT-1710 - Kyoto, Japan).

Statistical analysis

The analysis was performed using the statistical software XLSTAT 12.3.01 (Addinsoft, SARL, New York). All data were expressed as mean values with standard deviation (mean±SD). The statistical analysis was conducted using a mixed models repeated measures ANOVA with a compound symmetry working covariance matrix on the following dependent variables: best time (BT), worst time (WT), total time (sum of time in all sprints) (TT), the fatigue index (FI), and blood lactate concentration (BLa). The same model was used to analyse the effect of repeated sprints on the time variable in the three test conditions (RSA1, RSA2 and RSA3), while the effect of each sprint on the time among the tests (RSA1, RSA2, and RSA3) was analysed using a one-way ANOVA.

The values were positively skewed, and we applied a Box-Cox transformation to obtain normally distributed responses. The significance level was set at $p \leq 0.05$. Significant "F" values were followed by multiple comparisons to locate differences. A *Bonferroni* correction was used to adjust the "p" value in relation to the number of contrasts that were performed. For testing the repeatability of the measure, we performed an Intra-class Correlation Coefficient (ICC) between RSA1 and RSA3. Post hoc analysis was performed to calculate the effect size (ES) for all the variables between RSA1, RSA2, and RSA3 and to estimate the sample size and power.

Results

The results are summarized in **Table 1**. Comparison of RSA1 and RSA 3 (without WBV treatment) has shown highly reliable data, with an ICC of 0.851. Data analysis showed a significant main effect of WBV on the TT ($F_{(2.48)}=3.944$, $p=0.026$). The lowest total time to perform the test was found at RSA2 and the comparison showed statistically significant difference between RSA2 and RSA3 ($p=0.002$).

WBV significantly affected the WT ($F_{(2.48)}=8.107$, $p<0.001$). By multiple comparisons significant differences were revealed between RSA2 vs. RSA1 ($p=0.002$) and between RSA2 vs. RSA3 ($p<0.0001$), but not between RSA3 vs. RSA1 ($p=0.203$). FI showed a similar main effect of WBV ($F_{(2.48)}=10.439$, $p<0.0001$). The difference between RSA1 vs. RSA 3 was again not significant ($p=0.717$). WBV also had a significant effect on the BLa measured at post-test ($F_{(2.48)}=7.729$; $p<0.001$). The highest BLa value was found at post- RSA2 and comparisons showed statistically significant differences between RSA2 vs. RSA1 ($p<0.001$) and between RSA2 vs. RSA3 ($p<0.001$). Again, the BLa difference between RSA3 and RSA1 was not significant ($p=0.981$). Nevertheless, BT was not affected by WBV ($F_{(2.48)}=0.761$, $p=0.473$).

A significant main effect (**Fig. 1a**) among the test conditions (RSA1, RSA2, and RSA3) was revealed at the 5^{th} ($F_{(2.50)}=8.052$, $p<0.001$) and 6^{th} sprints ($F_{(2.50)}=9.348$, $p<0.0001$). Contrasts for the fifth sprint showed significant differences between RSA2 vs. RSA1 ($p<0.005$) and between RSA2 vs. RSA3 ($p<0.0001$), while the difference between RSA1 and RSA3 was not significant ($p=0.398$). For the 6^{th} sprint, significant differences had the same loci, that is; comparison RSA2 vs. RSA1 ($p=0.007$) and between RSA2 vs. RSA3 ($p<0.0001$). The difference between RSA1 and RSA3 was not significant ($p=0.154$).

Comparisons between individual sprint results during RSA (1, 2, and 3) are reported in **Table 2,** whereas during RSA 2 the differences between sprints performed after passive recovery (R) and sprints occurring after WBV (V) were not significant ($p>0.05$) (**Fig. 1b**).

Post hoc analysis of the data revealed large effect size (ES) between RSA2 vs. RSA1 and between RSA2 vs. RSA3 for BLa (respectively 0.81 and 0.82, respectively), TT (0.50 and 0.87), WT (0.80 and 0.90), and FI (0.90 and 0.90), with the exception of BT (0.41 and less than 0.20). The Power estimated (for two-tailed alpha = 0.05) were: 0.90 for BLa; 0.50-0.90 for TT; 0.90 and more for WT; and 1.00 for FI. Therefore, the sample size of the present study (*n*= 17) was well-powered to finding a real difference (from 50 to 100% of chance) in the following variables: BLa, TT, WT, and FI.

Conversely, the present study was under-powered to detect relatively small but functionally relevant changes in BT. However, the ES between RSA2 vs. RSA3 and between RSA2 vs. RSA1 was respectively of 0.20 and 0.41, respectively, which means just means a 30% chance of detecting a significant difference with 100 (*n*= 100 for the difference between RSA2 vs. RSA3) and 40 subjects (*n*= 40 for the difference between RSA2 vs. RSA1). It is highly unlikely, therefore, that a larger sample size would have led to a different outcome in BT.

Discussion

The aim of the present study was to investigate the effectiveness of WBV as a potential new training tool to be used between repeated sprints. In accordance with our hypothesis, the results suggest that WBV could represent an appropriate and effective method to improve RSA and to reduce fatigue.

In the literature, acute WBV has been shown to improve muscle power, strength, and flexibility [8, 12]. It has been suggested that acute WBV may improve muscular performance via neurogenic potentiation effects involving the spinal reflexes and muscle activation [8]. The repeated eccentric–concentric actions induced by WBV have been shown to increase the muscular work and elevates the metabolic rate [33]. However, the impact of WBV applied during the recovery phases in athletes during high intensity intermittent sprints has not yet been investigated.

Cafarelli et al. [7] suggested that tendon vibration, used as a mechanical massage to accelerate the recovery process by increasing blood flow to the involved muscles, didn’t induce any significant effect to remove waste products and stimulate the muscle receptors to increase muscular tension. Using a similar approach in term of type of vibrations, Bakhtiary et al. [1] reported that 50 Hz local vibration applied to each lower limb significantly reduced the creatine kinase levels in the 24h post-exercise and increased the recovery after isometric force production. In the two latter studies the vibration was applied locally and perpendicularly to muscle axis. In other words, in the mentioned studies the vibrations acted locally as a mechanical massage and this condition is completely different from the hyper-gravity determined by applying WBV. In light of these considerations, these two studies are not comparable to the present one in which the subjects were exposed to an acceleration load of 7.7 g (45 Hz, 2.2 mm).

From a methodological point of view, only two investigations by Bullock et al. [5, 6] seem partially comparable to the present study. In both studies [5, 6], the authors reported conflicting results applying a vibration intervention (WBV) between short running sprints (until 30 m distance) in elite skeleton athletes. However, examining the two investigations shows that in the first study [5] significant effects on sprint time were obtained applying a lower vibration load than during the second study [6]. Specifically, in the first study [5] experimenters applied three series of sixty seconds (3×60s, with a 1:3 work relief ratio) and the acceleration load was about of 7.2 g (frequency of 30 Hz, and amplitude of 2 mm). Whereas in the second study [6], in an attempt to obtain a greater effect, the number of series and repetitions was the same (3×60s) but they increased the work relief ratio (1:1) and the acceleration load reached the value of 16.3 g (frequency of 45 Hz and amplitude of 2.2 mm). Therefore, considering that the same population undertook the treatment (elite skeleton athletes [5]) it is quite reasonable to think that the vibration load (in the second study [6]) was too high and subsequent fatigue compromised the benefits.

Although the present study results cannot be directly compared with those of Bullock et al. [5, 6] for several differences (i.e. experimental design, vibration load, subjects, and outcome measures). It is interesting to underline that the present results showed, similarly to the first study of Bullock et al. [5], significant effects in the reduction of the increment of performance time during the successive sprints. Specifically, in the study of Bullock et al. the effect size was small (0.31), but it was obtained in a small numbers (*n*= 6) of high level skeleton athletes (including 2 Olympians, 1 of whom is a former World Champion, 1 is Under-23 World Champion, and 2 World

Cup athletes) of whom their capacity of acute and chronic responses could be attenuated and depend on the specificity of the training stimulus [40].

In the present study, the specific RSA2 protocol (with WBV) also showed that the 5th and 6th sprints were significantly affected even when these were not directly preceded by WBV. This could mean that the WBV effect has a relatively prolonged and/or a cumulative effect, altering not only the immediate subsequent sprint time, but also the next one that occurs between ~27 and ~34s post WBV.

Although we could not demonstrate any significant WBV effect on each single sprint performance during RSA2, a potential point of concern in the present results was the relatively small sample size for this type of analysis (*n*= 8/9 when R and V are compared) (**Fig. 1b**). Post-hoc analysis of these data showed that we would have been able to detect WBV effects on each single sprint time in the order of 0.82-1.93% with a larger sample size (*n*= 25-75). It may be argued that the present study was under-powered to detect moderate, but functionally relevant, changes in the several sprints time during RSA2. Therefore, in the present study, we cannot discriminate if the WBV effect on each sprint time was acute and/or residual [23]. Anyway, this result is not surprising from a logical point of view as this experiment was designed to investigate the WBV effect on the overall RSA performance.

1. The major finding of the present study, using WBV acutely, was the increased RSA performance in several variables, that is: TT, WT, and FI. Considering shuttle run in RSA (6 shuttle-sprints of 40m: 20+20m), the altered results in TT, WT and FI could be explained by the fact that the kinematics characteristics (acceleration, deceleration, and changes of direction) were positively affected by improvements on reactive strength and power following WBV treatment [16, 18]. In this context, Sheppard and Young [35] proposed a deterministic model for the agility, in which the change of direction ability, assumes a key role and is considered as the interplay of several physical and neuromuscular components. According to the above mentioned model, the change of direction speed is related to several parameters including: acceleration speed, reactive

strength, left-right muscle imbalance, concentric strength-power, eccentric strength and technique [10]. Therefore, defining the RSA as a specific task to develop the change of direction performance we cannot exclude a possible WBV effect on some of its neuromuscular components and/or on their interactions [11]. In addition, the improved fatigue index of the RSA test, observed in the present study, could be related to an increase in neuromuscular efficiency induced by WBV [4]. This enhancement in FI could have been induced by an improved co-ordination of the synergistic muscles and increased inhibition of the antagonists [9, 16].

2. The results of this study also showed that the effects of WBV on the time performance variables (TT, WT, and FI) were associated to an increase in BLa. The changes of direction during RSA require athletes to perform running actions in which they must rapidly decelerate and stop, implying eccentric muscular efforts and increasing energy cost. Moreover, subjects must then re-accelerate, and this action stimulates essentially the anaerobic metabolism and the fast twitch muscle fibers [15]. In the literature, experiments on sprint training have showed improvements in sprint time performance accompanied by an increase in the post-exercise muscle/blood lactate [25]. In the latter studies, the authors argued that an additional number of glycolitic muscle fibers (Type IIB), which have relatively high net lactate production, were recruited and one study of them showed also an increased motor unit activation (direct evidence) [13]. Recently, Pollock et al. [29] have reported direct evidence that acute WBV affects the motor unit recruitment (MUr) reducing the thresholds of fast-twitch fibers. This preferential effect of WBV on higher MUr may be responsible for the improvements in sprint time performance accompanied by an increase in blood lactate observed in the present study. However, further studies, including EMG measurements, are needed to explain exactly the physiological mechanisms behind these improvements.

In conclusion, by alternatively using WBV in the recovery phases during the RSA, we demonstrated that most of the time performance variables were improved (except Best Time) and accompanied by an increase in the post-exercise (RSA) blood lactate. Future investigations should focus on the chronic effects of WBV on-field RSA performance.

References

1 *Bakhtiary AH, Safavi-Farokhi Z, minian-Far A.* Influence of vibration on delayed onset of muscle soreness following eccentric exercise. Br J Sports Med 2007; 41 : 145-148

2 *Bishop D, Girard O, Mendez-Villanueva A.* Repeated-sprint ability - part II: recommendations for training. Sports Med 2011; 41 : 741-756

3 *Bishop D, Spencer M, Duffield R, Lawrence S.* The validity of a repeated sprint ability test. J Sci Med Sport 2001; 4 : 19-29

4 *Bosco C, Iacovelli M, Tsarpela O, Cardinale M, Bonifazi M, Tihanyi J, Viru M, De LA, Viru A*. Hormonal responses to whole-body vibration in men. Eur J Appl Physiol 2000; 81 : 449-454

5 *Bullock N, Martin DT, Ross A, Rosemond CD, Jordan MJ, Marino FE*. Acute effect of whole-body vibration on sprint and jumping performance in elite skeleton athletes. J Strength Cond Res 2008; 22 : 1371-1374

6 *Bullock N, Martin DT, Ross A, Rosemond D, Jordan MJ, Marino FM*. An acute bout of whole-body vibration on skeleton start and 30-m sprint performance. Eur J Sport Sc 2009; 9 : 35-39

7 *Cafarelli E, Sim J, Carolan B, Liebesman J*. Vibratory massage and short-term recovery from muscular fatigue. Int J Sports Med 1990; 11 : 474-478

8 *Cardinale M, Bosco C*. The use of vibration as an exercise intervention. Exerc Sport Sci Rev 2003; 31 : 3-7

9 *Cardinale M, Pope MH*. The effects of whole body vibration on humans: dangerous or advantageous? Acta Physiol Hung 2003; 90 : 195-206

10 *Chaouachi A, Manzi V, Chaalali A, Wong DP, Chamari K, Castagna C*. Determinants analysis of change of direction ability in elite soccer players. J Strength Cond Res 2011; 26 : 2667-2676

11 *Cochrane DJ*. Vibration exercise: the potential benefits. Int J Sports Med 2011; 32 : 75-99

12 *Cochrane DJ, Stannard SR, Firth EC, Rittweger J*. Acute whole-body vibration elicits post-activation potentiation. Eur J Appl Physiol 2010; 108 : 311-319

13 *Creer AR, Ricard MD, Conlee RK, Hoyt GL, Parcell AC*. Neural, metabolic, and performance adaptations to four weeks of high intensity sprint-interval training in trained cyclists. Int J Sports Med 2004; 25 : 92-98

14 *Da Silva-Grigoletto ME, Vaamonde DM, Castillo E, Poblador MS, Garcia-Manso JM, Lancho JL*. Acute and cumulative effects of different times of recovery from whole body vibration exposure on muscle performance. J Strength Cond Res 2009; 23 : 2073-2082

[15] *Dellal A, Keller D, Carling C, Chaouachi A, Wong dP, Chamari K*. Physiologic effects of directional changes in intermittent exercise in soccer players. J Strength Cond Res 2010; 24 : 3219-3226

[16] *Di Giminiani R, Manno R, Scrimaglio R, Sementilli G, Tihanyi J*. Effects of individualized whole-body vibration on muscle flexibility and mechanical power. J Sports Med Phys Fitness 2010; 50 : 139-151

[17] *Di Giminiani R, Masedu F, Tihanyi J, Scrimaglio R, Valenti M*. The interaction between body position and vibration frequency on acute response to whole body vibration. J Electromyogr Kinesiol 2013; 23 : 245-251

[18] *Di Giminiani R, Tihanyi J, Safar S, Scrimaglio R*. The effects of vibration on explosive and reactive strength when applying individualized vibration frequencies. J Sports Sci 2009; 27 : 169-177

[19] *Harriss DJ, Atkinson G*. Update--Ethical standards in sport and exercise science research. Int J Sports Med 2011; 32 : 819-821

[20] *Hirvonen J, Rehunen S, Rusko H, Harkonen M*. Breakdown of high-energy phosphate compounds and lactate accumulation during short supramaximal exercise. Eur J Appl Physiol Occup Physiol 1987; 56 : 253-259

[21] *Impellizzeri FM, Rampinini E, Castagna C, Bishop D, Ferrari BD, Tibaudi A, Wisloff U*. Validity of a repeated-sprint test for football. Int J Sports Med 2008; 29 : 899-905

[22] *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 : 459-466

[23] *Luo J, McNamara B, Moran K*. The use of vibration training to enhance muscle strength and power. Sports Med 2005; 35 : 23-41

[24] *Martinez-Pardo E, Romero-Arenas S, Alcaraz PE*. Effects of Different Amplitudes (High vs. Low) of Whole-Body Vibration (WBV) Training in Active Adults. J Strength Cond Res 2012; [Epub ahead of print]

[25] *Mohr M, Krustrup P, Nielsen JJ, Nybo L, Rasmussen MK, Juel C, Bangsbo J*. Effect of two different intense training regimens on skeletal muscle ion transport proteins and fatigue development. Am J Physiol Regul Integr Comp Physiol 2007; 292 : R1594-R1602

[26] *Morio C, Chavet P, Androuet P, Foissac M, Berton E, Nicol C*. Time course of neuro-mechanical changes underlying stretch-shortening cycle during intermittent exhaustive rebound exercise. Eur J Appl Physiol 2011; 111 : 2295-2305

[27] *Padulo J, D'Ottavio S, Pizzolato F, Smith L, Annino G*. Kinematic Analysis of Soccer Players in Shuttle Running. Int J Sports Med 2012; 33 : 459-462

[28] *Pel JJ, Bagheri J, van Dam LM, van den Berg-Emons HJ, Horemans HL, Stam HJ, van der SJ*. Platform accelerations of three different whole-body vibration devices and the transmission of vertical vibrations to the lower limbs. Med Eng Phys 2009; 31 : 937-944

[29] *Pollock RD, Woledge RC, Martin FC, Newham DJ*. Effects of whole body vibration on motor unit recruitment and threshold. J Appl Physiol 2012; 112 : 388-395

[30] *Rampinini E, Bishop D, Marcora SM, Ferrari BD, Sassi R, Impellizzeri FM*. Validity of simple field tests as indicators of match-related physical performance in top-level professional soccer players. Int J Sports Med 2007; 28 : 228-235

[31] *Reilly T*. Energetics of high-intensity exercise (soccer) with particular reference to fatigue. J Sports Sci 1997; 15 : 257-263

[32] *Reilly T, Williams AM, Nevill A, Franks A*. A multidisciplinary approach to talent identification in soccer. J Sports Sci 2000; 18 : 695-702

[33] *Rittweger J, Mutschelknauss M, Felsenberg D*. Acute changes in neuromuscular excitability after exhaustive whole body vibration exercise as compared to exhaustion by squatting exercise. Clin Physiol Funct Imaging 2003; 23 : 81-86

[34] *Ruscello B, Tozzo N, Briotti G, Padua E, Ponzetti F, D'Ottavio S*. Influence of the number of trials and the exercise to rest ratio in repeated sprint ability, with changes of direction and orientation. J Strength Cond Res 2012; [Epub ahead of print]

[35] *Sheppard JM, Young WB*. Agility literature review: classifications, training and testing. J Sports Sci 2006; 24 : 919-932

[36] *Spencer M, Pyne D, Santisteban J, Mujika I*. Fitness determinants of repeated-sprint ability in highly trained youth football players. Int J Sports Physiol Perform 2011; 6 : 497-508

[37] *Stolen T, Chamari K, Castagna C, Wisloff U*. Physiology of soccer: an update. Sports Med 2005; 35 : 501-536

[38] *Wragg CB, Maxwell NS, Doust JH*. Evaluation of the reliability and validity of a soccer-specific field test of repeated sprint ability. Eur J Appl Physiol 2000; 83 : 77-83

[39] *Young W, McLean B, Ardagna J*. Relationship between strength qualities and sprinting performance. J Sports Med Phys Fitness 1995; 35 : 13-19

[40] *Zehr EP, Sale DG*. Ballistic movement: muscle activation and neuromuscular adaptation. Can J Appl Physiol 1994; 19 : 363-378