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ACUTE EFFECT OF WHOLE BODY VIBRATION ON RUNNING GAIT IN MARATHON RUNNERS

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Abstract

The Aim Of The Research. The present study aimed to create an experimental model that uses high frequency mechanical vibration to quantify the decline of performance, without running 42195m (distance of marathon race), and clarify the alterations in kinematics parameters in marathon runners. The hypothesis is that these vibrations will produce an alteration on the running gait. For this reason we studied the kinematics of the footstep in marathon runners before and after a session of 10' mechanical whole body vibration (WBV).
Methods. Fifteen male marathon runners performed on a treadmill at Iso-Efficiency Speed, with and without WBV (10 min at 50Hz – 2 mm. with a 1':1' work to relief ratio). A digital camera Hi-Speed (210 Hz) for motion recording was used to perform video analysis and heart rate was measured. The follow parameters were analysed: step length (SL), flight time (FT), step frequency (SF), contact time (CT), heart rate (HR) and the internal work (W_{INT}).
Results. Two-way analysis of variance (ANOVA) revealed that: SL decreased ~4% (p < 0.0001) and SF increased ~4% (p < 0,0001). FT decreased ~7,2% (p < 0,001) whereas CT remained constant. This effect occurred during the first minute: SL decreased ~3,5% (p < 0,001) and SF increased ~3,3% (p < 0,001), while during the second minute SL decreased ~1,2% (p = 0,017); SF increased ~1.1% (p < 0,02). From the third minute onwards, there was a return to the pre-vibration condition. The W_{INT} increased by ~4% (p < 0,0001) and there was an effect on the HR of ~1.5% (p < 0,0001).
Conclusions. This study have proposed an experimental approach for determining the alteration which occurs due to WBV not only on cyclic neuromuscular patterns but also on the running kinematics of marathon runners, where these variations have an effect on the internal work and heart rate. Despite the potential benefits of vibration training, it is essential that the implications of this type of treatment needs to be acquired prior to its use in sport setting. Ten minutes of WBV was able to produce a similar alteration of the running kinematics as well as marathon race, and the exact mechanisms remain to be elucidated.
Key Words: Whole Body Vibration, Running Gait, Iso-Efficiency Speed, Internal Work, Motor Control.

Introduction

Among all sports events, the marathon race is a competition with a special fascination and has been extensively studied by scientists (Padulo et al., 2011; Padulo et al., 2012b). The researchers' goal was to analytically understand the mechanisms that underlie this sport performance (Padulo et al., 2011). In fact, interesting research has elucidated that after a marathon race there is an increase of step frequency and a reduction in step length. In both variables the percentage difference was ~4% between the start and finish of the marathon race (Hausswirth, Bigard, Guezennec, 1997; Kyrolainen et al., 2000). This reduction in step length is also associated with a significant reduction of muscular activity by electromyography (EMG) of the vastus lateralis, gastrocnemius, and soleus after the marathon, compared to the pre-marathon condition (Avela et al., 1999).

The main factor that determines the reduction of EMG activity and the mechanical parameters is muscle fatigue (Bakhtiary, Safavi-Farokhi, Minian-Far, 2007). In fact, the soleus and gastrocnemius have the important role of allowing plantar flexion (Kyrolainen et al., 2000) and are used intensively in the marathon race. On average, the number of steps taken by the elite athletes is about 28000 while for amateur runners it is about 52000 (Padulo et al., 2011). The reduction of the biomechanical variables (step length) also occur during the half-marathon (Meardon, Hamill, Derrick, 2011) and in shorter competitions, like the 5000m (Girard et al., 2011), where the velocities are higher than those of the marathon and half-marathon. Unfortunately, the only way to quantify the efficiency and any reductions of the athletes' performance is to run a marathon (~3 hours).

Over the last decade, research that uses mechanical vibration (Annino et al., 2007; Di Giminiani et al., 2010) for affecting EMG of the lower limbs muscles, including the vastus lateralis, the soleus, and

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gastrocnemius has emerged (Torvinen et al., 2002). In sport, mechanical vibration is used for training purposes. The effects of different vibration protocol depend on various neural facilitatory and inhibitory mechanisms, and on cellular and molecular changes in the muscle fibers (Pietrangelo et al., 2009). WBV tasks generate neuromuscular, metabolic and hormonal responses, significant changes in several motor variables (Issurin, 2005).

WBV is a potentially quick method for increasing power performance than traditional training. Optimal acute effects can be attained using as little as 30 seconds of WBV, and they are highest from 1 to 5 minutes post-treatment. Additionally, high frequencies were most effective when applied in conjunction with high displacements (Adams et al., 2009). Furthermore, mechanical vibration <45 Hz (Cochrane D.J., 2011) may create conditions of muscle fatigue (Torvinen et al., 2002) like those encountered after an endurance race. The present study aimed to create an experimental model that uses high frequency mechanical vibration to quantify the decline of performance, without running 42195m (distance of marathon race), so as to clarify the alterations in kinematics parameters in marathon runners. The hypothesis is that these vibrations will produce an alteration on the running gait. For this reason we studied the kinematics of the footstep in marathon runners before and after a session of 10' mechanical whole body vibration (WBV) at 50 Hz.

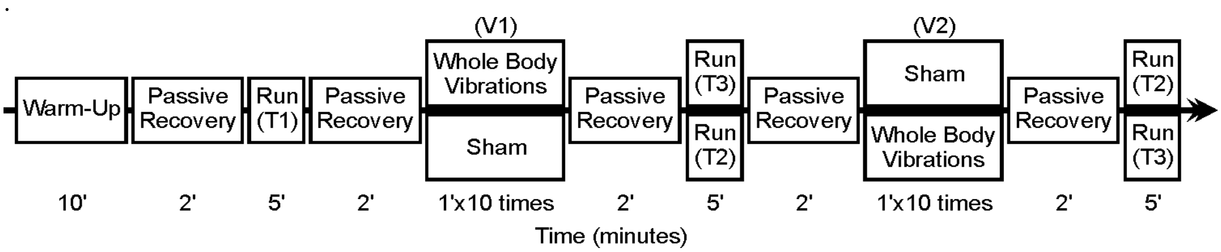
Methods

Fifteen male marathon runners (age 41.06±3.71 years; body mass 67.44±3.55 kg; body height 172±3.42 cm; BMI 22.84±1.35 kg/m^2, training background of 8±0.12 years and who had covered 131±2.78 kilometres per week last year with personal best marathon race ~2h 48' participated in this study). The subjects were healthy without any muscular, neurological and tendineous injuries and did not report any consumption of drugs. After being informed of the procedures, methods, benefits and possible risks involved in the study, each subject reviewed and signed an informed consent form prior to participation in the study, in accordance with the ethical standards.

Testing was carried out in a Human Performance Laboratory. All the participants were in good health at the time of the study. Research reported a high correlation (r= 0.93) between over-ground and treadmill running for biomechanical analysis (Riley et al., 2008). Within this study, in order to better standardize the slope and the velocity (Padulo et al., 2011; Padulo et al., 2012a), tests were performed on a motorized treadmill (Run Race Technogym® Run 500, Italy).

All participants wore marathon-running shoes and performed a standardized 10 minutes warm-up, which consisted of running at 9 km·h^{-1} to familiarize themselves with the treadmill. A randomized crossover study was administrated and the procedure followed by each participant was: 10 minutes of warm-up 5 min of standardized active muscular stretching, 2' passive recovery, 5 minutes running (T1), 2' passive recovery, one set on vibration device (sham condition or WBV) (V1), 2' passive recovery, 5 minutes running (randomised T2 or T3), 2' passive recovery, one set of vibration treatment (WBV or sham condition) (V2), 2' passive recovery and 5 minutes running (cross-randomised T3 or T2). The sequence (V1 and V2) was randomized across participants with a Latin square design (Fig. 1).

To evaluate the effect of the condition fatigue (squat position without vibration) and the reliability of the measures, each participant was tested at Iso-Efficiency Speed (IES) (Padulo et al., 2012b) in two occasions (Test – Retest). Each test consisted of 5 minutes running at IES on a 0% slope. The IES for each participant was calculated as the average speed during the participant's best performance in a 10000m race (recorded within the six month period, prior to testing) minus 1 km·h^{-1} in agreement with other studies (Padulo et al., 2012b).



The vibration platform used for the study was: Power Plate pro5^{TM} UK (PP). As demonstrated from other studies (Pel et al., 2009), the vibration frequency (50 Hz), peak-to-peak displacement (2.2 mm) and peak acceleration ~0.9 g (~9.81 m·s^{-2}) in PP showed a good reliability for the measures (ratio 1.0) between unloaded and loaded vibration, allowing replication of the study (Rauch et al., 2010). For the WBV, ten bouts of 60s vertical sinusoidal vibrations at 50 Hz (according to the manufactures instructions) with a 1:1 work to relief ratio were used. The WBV was performed with the heels raised 5 cm off the platform, the knee at 90° flexion and leaning slightly forward, with their hands on the vibration plate's handle to support their upper body. The sham condition was performed using the same protocol without vibration.

Two-dimensional (2D) video data were collected while the participants' running on the treadmill using a single high speed digital camera (Casio FH20) sampled at 210 Hz and collected in accordance with a previous study protocol (Padulo et al., 2011). The camera was positioned on a 1.5 m high tripod, 6 m from the participant and was located perpendicular to the plane of motion at the participant's sagittal plane (Belli et al., 1992). The film sequences were analyzed off-line using Kinovea^{TM} 0.8.15 motion analysis software. The following kinematic variables were studied: (i) contact time (ms), (ii) flight time (ms), (iii) step length (meter), (iv) step frequency (Hz); for each velocity 150 steps were sampled for frequency calculation (Padulo et al., 2011; Padulo et al., 2012a; Padulo et al., 2012b).

Kinematic markers were taped on both feet of each participant. Since the velocity of the treadmill was known, both step length (SL) and step frequency (SF) could be calculated (Padulo et al., 2012a). The contact time (CT) and flight time (FT) were calculated by counting the frames in contact and flight on the 2D data, then dividing by the sampling rate, 210 (1 frame = 210 Hz ≈ 0.0048 sec). The CT and FT were calculated for both the left and right foot. The CT was defined and calculated as the time between initial contact with the ground and the last frame of contact before toe-off. The FT was defined and calculated as the time between toe-off and subsequent initial contact of the contralateral foot. Initial contact and toe-off were visually detected. In accordance with previous studies (Padulo et al., 2011) SF was calculated as: SF= [1000/(CT+FT)]; alternatively SL was calculated with the following equation: SL= (speed $km\cdot h^{-1}$/3.6/SF).

The internal work (W_{INT}) was also calculated with the formula (Equation 1) proposed by Nardello et al.. (Nardello, Ardigo, Minetti, 2011)

$$W_{INT} = SF\cdot v\cdot(1+(DF\cdot(1-DF)^{-1})^{2})\cdot q \qquad (1)$$

Where SF is the step frequency (Hz), v is the velocity ($m\cdot s^{-1}$), DF is the duty factor i.e. deflection of the duration of stride period when each foot is on the ground (%) and q value of 0.08 referring to the inertial properties of the oscillating limbs.

The heart rate (HR) was recorded throughout the experiment and an average computed during the full five minutes for each condition (Sport Tester PE 3000; Polar Electro, Kempele, Finland). The HR was expressed in percentage of maximum theoretical heart rate (HR_{max}) by Equation 2 (Miller, Wallace, Eggert, 1993).

$$HR_{MAXTheo} = 271 – (0.85 \times age) \qquad (2)$$

The results are expressed as mean ± *SD*. The variables investigated were: Contact Time (CT), Flight Time (FT), Step Length (SL), Step Frequency (SF), Internal Work (W_{INT}), Heart Rate (HR) and the Percentage of Heart Rate with respect to the maximal theoretical heart rate (HR%). The effect size was calculated for all variables between pre and post-testing. The thresholds for small, moderate, and large effects were 0.20, 0.50, and 0.80, respectively. Assumption of normality was verified using the Shapiro-Wilk W. Test, after that, on the variables CT, FT, HR and HR% a one-way analysis of variance (ANOVA) with repeated measures was used to compare responses in each variable across the three tests (T1, T2 and T3). Moreover, on SL and SF a two-way analysis of variance (ANOVA) was carried out with repeated measures adding Assessment Time as a second factor, with five levels (1<5 min), to investigate the changes over time. For this analysis we were not interested in the main factor Assessment Time but in the interaction Test × Assessment Time. When a global difference over time was determined, *Bonferroni* post hoc analysis was used to identify where changes occurred. Statistical analysis was performed using SPSS 16.0 software. The level set for significance was $p \leq 0.05$.

Results

All participants completed the study without any objective side-effects. Neither subjective adverse reactions nor exhaustive fatigue were reported after the vibration bout. Most of the participants reported that the whole body vibration was "stimulating" for the lower extremities. The results are reported in the Table 1. The CT of the feet on the ground did not change significantly even though is decreased $F_{(2,30)}$=2.792, p = 0.077 (small effect) while the FT decreased significantly $F_{(2,30)}$=21.629, p < 0.0001 with a large effect.

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Table 1. Effects among tests

Variables	**Mean (SD)**			**Δ%**			**p^2**
	T1	**T2**	**T3**	**T2/T1**	**T3/T1**	**T3/T2**	
Step Length (m)	1.351 (0.102)	1.352 (0.098)	1.299 (0.103)	0.074%	4.003%*	-4.08%*	0.834
Step Frequency (Hz)	3.047 (0.121)	3.046 (0.126)	3.17 (0.137)	-0.033%	3.88%*	3.912%*	0.813
Contact Time (ms)	194 (14)	195 (14)	191 (16)	0.513%	-1.57%	-2.094%	0.157
Flight Time (ms)	134 (16)	134 (16)	125 (17)	0%	-7.2%*	-7.2%*	0.590
Internal Work (J/(kg*m))	2.043 (0.191)	2.042 (0.199)	2.124 (0.196)	-0.049%	3.965%*	4.016%*	0.812
Hart Rate (bpm^{-1})	156 (10)	157 (10)	159 (10)	0.637%*	1.923%*	1.274%*	0.510
Hart Rate (%max)	66 (4.05)	66.6 (4.09)	67.4 (4.13)	0.901%*	2.077%*	1.187%*	0.484

Mean and standard deviation (SD) with perceptual difference (Δ% and significant * $p < 0.05$) between tests and effect size (p^2)

The W_{INT} increase after vibrations $F_{(2,30)}=64.662$, $p < 0.0001$ (large effect), as well as the HR frequency increased over the three tests $F_{(2,30)}=15.818$, $p < 0.0001$ (moderate effect). We obtained the same result by calculating the percentage of the HR_{max} of each participant $F_{(2,30)}=15.623$, $p < 0.0001$ (moderate effect). The main effect of Test was found significant for the SL $F_{(2,30)}=9.183$, $p < 0.001$ (moderate effect) (Table 1) and the interaction Test × Assessment Time $F_{(8,120)}=47.322$, $p < 0.0001$ (moderate effect). Pair wise comparisons showed that the vibrations reduced the effect in the first minute (Δ% between T3 and T1 -3.456%, and Δ% between T3 and T2 -3.379%), and also in the second minute (Δ% between T3 and T2 -1.053%).

While the trend analysis of the SF showed a significant difference among the three tests $F_{(2,30)}=9.76$, $p < 0.001$ (moderate effect) (Table 1). Pair wise comparisons showed an increment of the SF after vibrations and a significant interaction of Test × Assessment Time $F_{(8,120)}=53.701$, $p < 0.0001$ (moderate effect). Pair wise comparisons showed that the vibrations had an effect in the first minute (Δ% between T3 and T1 3.258%, and Δ% between T3 and T2 3.227%) and in the second minute in (Δ% between T3 and T2 1.259%).

Discussions

This study investigated the acute effects of mechanical vibrations in marathon runners and found a significant decrease of the running step length while the step frequency increased at post-vibrations. The experimental model used (crossover) allowed not to use a control group. Indeed, the test retest (T1, T2) performed by all participants did not reveal any significant difference for all variables. The only significant differences observed were for HR and HR%, however, the differences were very low, i.e. around 1 beat·min^{-1}.

Analysis of the pre-and post WBV data showed a reduction of step length ~4% (Fig. 2), and a corresponding increase of the step frequency of ~4% (Fig. 2) and these changes occurred at a constant speed. Obviously, decreasing the step length also decreases the flight time of ~7.2%. (Fig. 2), whereas, the contact time remained constant (Fig. 2). By analyzing these parameters minute by minute, it was observed that this effect occurred principally in the first minute (step length decreased ~3.5%, step frequency increased ~3.3%) and in the second minute of running (step length decreased ~1.2%; step frequency increased ~1.1%). From the third minute onwards, this gap returned to the pre-vibration conditions.

These results are in agreement with our hypothesis: that 10 minutes of whole body vibrations (with 1min:1min work to relief ratio) at 50 Hz produce an alteration of the running kinematics. The results are in line with what occurs during endurance races like the marathon (Hausswirth et al., 1997; Kyrolainen et al., 2000). In athletes of good level, running the marathon at nearly constant velocity for about ~2h30'a decrease in the step length of ~4% has been observed (Hausswirth et al., 1997; Kyrolainen et al., 2000). Indeed, during the endurance races, while maintaining a constant speed the athletes reduced the stride time as a result of fatigue (Meardon et al., 2011). The factor that the marathon and mechanical vibration have in common is the alteration of the running kinematics even if it is induced by different factors.

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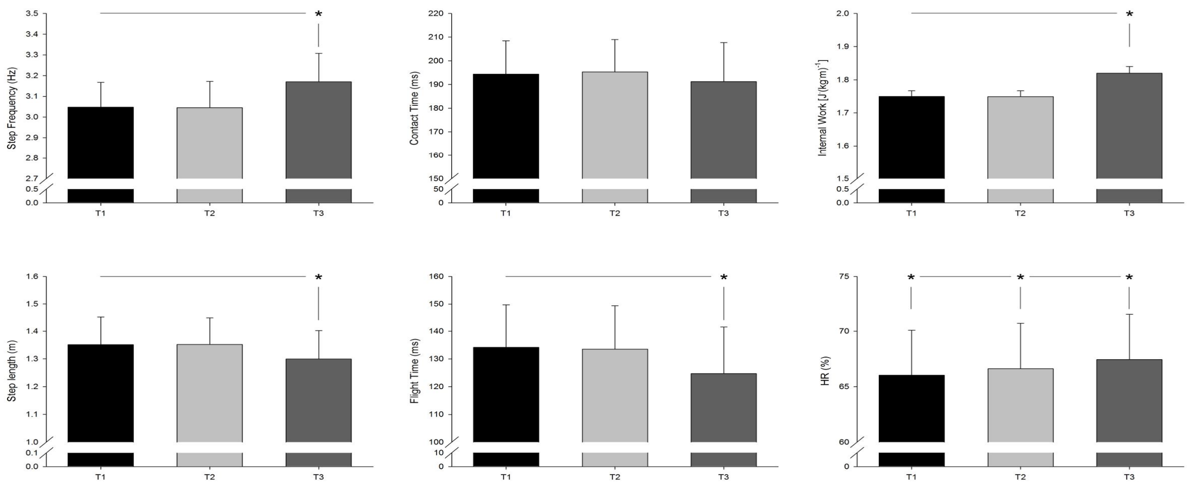

Figure 2 Average of the kinematic variables over the three tests (T1, T2 and T3). Histograms represent mean ± inter-subject standard deviation. *Significant difference (two-tails paired *t*-test, $p < 0.05$).

During the marathon, the muscle fatigue mainly depends on the depletion of muscle glycogen (Callow, Morton, Guppy, 1986) and the decrease of neuromuscular response (Kyrolainen et al., 2000). Indeed, the EMG activity of muscles involved in plantar flexion show a decrease in signal amplitude of the soleus, gastrocnemius, and vastus lateralis (Avela et al., 1999). The WBV can generate a fatigue without the depletion of muscle glycogen and influence the EMG activity of the lower limbs muscles, among which the vastus lateralis, soleus and gastrocnemius (Torvinen et al., 2002).

Furthermore, the WBV can generate an increased blood flow in the muscles undergoing vibration (Kerschan-Schindl et al., 2001). Therefore, in different ways we could obtain a neuro-physiological alteration of the muscles, as in the marathon race (Bosco et al., 1999; Cardinale & Bosco, 2003). The effects produced by the marathon race or by the vibrations are transient: as regards the vibrations we observe the recovery of the running kinematic pattern equal to the pre-test after 4 minutes (two minutes break plus two minutes running).

The hypothesis about this rapid remission of the effects of vibrations, could be related to the temporary effects on central motor command. Where vibration stimulus is capable of generating kinaesthetic illusion (Naito et al., 2000), at spinal level, through the inhibition of the antagonist muscle (via Ia inhibitory neurons) there is an alteration of the inter-muscular coordination patterns causing a decrease of muscular strength (Romaiguere et al., 1991). Probably the duration of these effects that continue for several minutes, after vibration exposure (Roll et al., 1980), in a cyclic movement like running at constant speed, as in this study, is no longer apparent after 3 minutes when the physiological neuromuscular conditions are restored.

Moreover, it cannot be excluded that WBV could lead to an alteration of the neuro-muscular properties of the type II fibres because 10 minutes of intermittent vibrations are not able to induce fatigue in those of the type I. In support of this consideration, previous studies have observed the acute effects of WBV in participants practicing strength/power sports which require a prevalence of type II fibre performance (Kofotolis et al., 2005). The WBV, like the marathon race, changes the running kinematic, but also influences the internal work, increasing the step frequency by around 4% and also the internal work by about ~4% (Fig. 2).

Although, a certain variability of the running kinematics is physiological (Hausswirth et al., 1997) and decreases during the race, it may be possible to find the best trade off between the length and frequency of the steps in order to reduce the stress of the tissues (Kyrolainen et al., 2000). Unmonitored, these changes may become a limiting factor of the performance, because if the stride frequency gets too high, the internal work (Hausswirth et al., 1997) and the energy expenditure to maintain a constant speed also increase.

Conclusions

In conclusion, this study have proposed an experimental approach for determining the alteration which occurs due to WBV not only on cyclic neuromuscular patterns but also on the running kinematics of marathon runners, where these variations have an effect on the internal work and heart rate. Despite the potential benefits of vibration training, it is essential that the implications of this type of treatment needs to be acquired prior to its use in athletic situations. Future research should be done with the aim of understanding the biological effects of different protocols on muscle performance.

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