Strength-Training with Whole-Body Vibration in Long-Distance Runners: A Randomized Trial

Bertuzzi, Romulo, Pasqua, Leonardo A, Bueno, Salomão, Damasceno, Mayara V, Lima-Silva, Adriano E, Bishop, David and Tricoli, V (2013) Strength-Training with Whole-Body Vibration in Long-Distance Runners: A Randomized Trial. International Journal of Sports Medicine, 34 (10). pp. 917-923. ISSN 0172-4622 (print) 1439-3964 (online)

TITLE*:*

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ABSTRACT

A parallel group randomized trial was designed to analyze the impact of 6 weeks of strength training programs performed with or without whole-body vibration on muscular and endurance performance parameters in long-distance runners. Twenty two endurance runners were allocated into strength with whole-body vibration (n = 8), without (n = 8), and control (n = 6) groups. Before and after experimental period the subjects performed the following tests: a) maximum dynamic strength test, b) maximal incremental treadmill test, and c) time to exhaustion at velocity corresponding to maximal oxygen uptake. The fractions of the aerobic and anaerobic contribution in time to exhaustion test were also calculated. Both strength trained groups showed a similar increased maximum dynamic strength (~18%). The aerobic contribution was enhanced for strength training group without whole-body vibration (~25%) after experimental period. No statistical differences were observed in any other variable. These results suggest that 6 weeks of strength training performed with or without whole-body vibration improve similarly the maximum dynamic strength in long-distance runners. In addition, both training modes studied had no deleterious effects on the traditional parameters of endurance performance, with traditional strength training program results in increased aerobic contribution during high-intensity aerobic exercise.

Keyword: maximal oxygen uptake, respiratory compensation point, time to exhaustion, aerobic metabolism contribution, anaerobic metabolism, maximum dynamic strength

INTRODUCTION

Endurance running performance exhibits a well-documented association with several physiological parameters such as maximal oxygen uptake ($\dot{V}O_2max$), respiratory compensation point (RCP), and time to exhaustion at the velocity corresponding to $\dot{V}O_2max$ (T_{lim}) [3,14,17]. Over the past three decades, a wide number of studies have reported beneficial effects of traditional strength training (ST) on these endurance parameters [12,13,18,26,27]. For instance, Støren et al. [26] reported significant increases in maximum dynamic strength (~33%) and the T_{lim} (~21%) after 8 weeks of ST performed by long-distance runners. It has been pointed out that an improvement in maximum strength, and consequently a lower relative force generated at the same absolute running intensity, may increase oxygen availability to the active muscles and increase the running performance [26]. In addition, it is known that ST increases anaerobic work capacity [4] and dynamic explosive force production [18] in long-distance athletes. Together, these adaptations may contribute to higher ATP availability [1] and superior storage and utilization of the elastic energy of the lower limbs [18] during high-intensity aerobic exercise.

ST combined with whole-body vibration (ST_{WBV}) is a relatively new training mode and has demonstrated additional chronic effects on maximum strength. The constant changes in the acceleration vector produced by a whole-body vibration platform are believed to enhance neural activation and structural properties of skeletal muscles, resulting in a superior muscle adaptation [22,28]. Recently, Osawa and Oguma [20] demonstrated that ST_{WBV} elicited a superior increase in muscle strength compared with ST alone. It has been proposed that exogenous stimulation of skeletal muscle with vibration could contribute to an increase in muscle mass [20] and motor unit recruitment [22], which may result in more pronounced muscular adaptation. Because the gains in muscle strength can increase performance in endurance sports [18], ST_{WBV} could be a beneficial alternative training mode for long-distance athletes.

To date, no study has been conducted to analyze the adaptations provided by ST_{WBV} in endurance athletes. Therefore, the purpose of this prospective randomized study was to determine the impact of these two different strength-training modes on muscular (maximum dynamic strength) and endurance performance ($\dot{V}O_2max$, RCP, and T_{lim}) parameters in long-distance runners. In light of past studies that have reported a superior increase in muscle strength provided by ST_{WBV} [20,28], we hypothesized that ST_{WBV} could contribute to more pronounced increases in muscular, resulting in an improved endurance performance parameters when compared with ST alone.

Materials and Methods

Trial design

The current study was conducted using a parallel group design using a 1:1:1 ratio as previously suggested [26]. Before and after the 6-week strength training programs, the runners were required to visit the laboratory on three different occasions separated by at least 72 h over a 2-week period. In the first visit, a maximal incremental treadmill test was performed to determine the cardiorespiratory parameters. A high-intensity constant-load exercise test was performed in the second visit to determine the T_{lim}. The maximum dynamic strength was assessed using the one-repetition maximum half-squat test (1RM) in the third visit. The 1RM familiarization test was conducted at the end of the first and second visits with 20 min of passive recovery between the tests. All of the tests were performed at the same time of day at a constant room temperature (20-24^{o}C) at least 2 h after the most recent meal. The subjects were instructed to refrain from any exhaustive or unaccustomed exercise 48 h before the test and to refrain from taking nutritional supplements during the experimental period.

Participants

Thirty recreational long-distance runners from local sport clubs were invited to participate in this study. Eligibility criteria included participate in local 10-km competitions with the best performances ranged from 35 to 45 minutes, and perform only low-intensity continuous aerobic training (50-70% $\dot{V}O_2max$). The exclusion criteria included the following: previous strength or plyometric training experience, use of dietary supplement, smokers, vegetarian diet, neuromuscular disorders, and cardiovascular dysfunctions. Six participants dropped out before intervention period due logistics issues (Figure 1). Thus, twenty-four athletes were randomly allocated by a computer-generated random sequence into ST (n = 8, age 31 ± 5 years, body mass 70.1 ± 8.0 kg, height 173.7 ± 5.0 cm), ST_{WBV} (n = 8, age 34 ± 6 years, body mass 70.2 ± 8.3 kg, height 172.2 ± 5.1 cm), and control (C, n = 6, age 33 ± 7 years, body mass 69 ± 7 kg, height 173.3 ± 8.0 cm). The athletes performed the strength-training programs at the School of Physical Education and Sport of University of São Paulo (São Paulo, Brazil) from January to June 2010 during a non-competitive season. The subjects' running training volumes were expressed as the mean distances covered, which were assessed through a training log recorded for three weeks prior to the beginning of the study and for the last three weeks before the completion of the study. The participants received a verbal explanation about the possible benefits, risks, and discomfort associated with the study and signed a written informed consent before participation in the study. The study was conducted in accordance with ethical standards of the IJSM [8] and was approved by the local Ethics Committee for Human Studies.

*** Insert Figure 1 ***

Interventions: strength training programs

The strength-training programs were focused on strength development of the leg extensors, which have been considered to be the major muscle group recruited during running [27]. The training load increased gradually according to the overload principle (Table 1). In addition to their normal endurance training, the runners performed half-squat training sessions twice weekly (separated by 72 hours) for 6 weeks. During the first week, the loads were calculated ~70% 1RM. Over the next weeks, participants were encouraged to increase their RM loads as their strength improved during throughout the experimental period and assistance was permitted during the last repetitions. During this 6-week training period, the runners were instructed to maintain their previous endurance training routine. The athletes were also instructed to perform the strength training on different days than the endurance training. A standardized warm-up exercise consisting of a 5-minute treadmill run at 9 $km \cdot h^{-1}$ followed by light lower-limb stretching exercises was performed before each training sessions. All of the participants were instructed to perform the half-squat exercise with the appropriate technique and with a natural pacing. The training load was progressively increased by increasing the number of maximum repetitions completed. A 3-min resting interval between the sets was used throughout the training period. The average training load applied during each training session was expressed as the %1RM for the statistical analyses.

Both the ST and ST_{WBV} groups performed half-squats on a Smith machine over a commercial whole-body vibration platform (Power Plate, IL, USA). However, the platform was turned off for the ST group. During the recovery periods, the whole-body vibration platform was also turned off for the ST_{WBV} group. The peak-to-peak displacement was maintained at 6 mm, and the frequency was increased progressively during the entire training period in the ST_{WBV} group (Table 1). This progression was chosen because a variety of combinations of the applied amplitudes (1.7-5.0 mm) and frequencies (12-45 Hz) have been previously shown to be beneficial for muscular long-term exercise in the legs [22,24]. The foot position was standardized for all of the participants, and whole-body vibration was applied when the bar of the Smith machine was positioned on the shoulders of the runner. The subjects were required to use the same athletic shoes during the training sessions. The training sessions were individually supervised to control the half-squat technique, training loads and training logbook. All of the runners were instructed to maintain their previous endurance training routine throughout the ST training period.

*** Insert Table 1 ***

Primary outcome variable: maximum dynamic strength

The participants were familiarized with all the procedures, equipment, and proper exercise techniques prior to data collection. Body position and foot placement were determined by measuring tapes fixed on both the bar and on the ground. An adjustable-height wooden seat was placed behind the subjects to keep the bar displacement and knee flexion angle constant on each half-squat repetition. The subjects' settings on the Smith machine were recorded to guarantee the same positioning across familiarization and testing sessions.

Before the 1RM test, the participants performed a brief general warm-up exercise composed of a 5-min treadmill run at 9 $km \cdot h^{-1}$ followed by light stretching of the lower limbs. Following the initial warm-up run, the participants performed a specific warm-up exercise composed of five repetitions at 50% of the estimated 1RM in the first set followed by a set of three repetitions at 70% of the estimated 1RM in the second set. A three-minute interval was allowed between the sets. After the second warm-up set, the subjects rested for three minutes before performing five trials to achieve the 1RM load (i.e., the maximum weight that could be lifted once using the proper technique) with a three-minute interval between the attempts.

Secondary outcome variables: cardiorespiratory parameters and time to exhaustion at $\dot{V}O_2max$

Cardiorespiratory parameters were measured during a maximal incremental test. After a 3-min warm-up at 8 $km{\cdot}h^{-1}$, the speed was increased by 1 $km{\cdot}h^{-1}$ every minute until exhaustion, which was defined as the inability to maintain the running pace. The subjects received strong verbal encouragement to continue as long as possible. Throughout the test, gas exchanges were measured breath-by-breath using a gas analyzer (Quark b^2, Cosmed, Rome, Italy) and were subsequently averaged over 20-s intervals. The air was collected and analyzed for oxygen fractions, carbon dioxide and ventilation volume using a face mask (Hans Rudolph, Kansas City, MO, USA) covering the nose and mouth. Before each test, the gas analyzer was calibrated using ambient air and a gas of known composition containing 12% O_2 and 5% CO_2. The turbine flowmeter was calibrated using a 3-L syringe (Quinton Instruments, Seattle, WA, USA). Heart rate was monitored during the test using a heart rate transmitter (model S810, Polar Electro Oy, Kempele, Finland) coupled with the gas analyzer. The maximal heart rate was defined as the highest value obtained at the end of the test (HR_{MAX}). Blood samples (25 µl) were collected from the ear lobe immediately after exercise and three and five minutes after exercise to determine the peak blood lactate ($[La^-]$peak) concentration. Lactate concentrations were measured using an automatic blood lactate analyzer (Yellow Springs 1500 Sport, Ohio, USA). The $\dot{V}O_2max$ was determined based at criteria previously defined [14]. The velocity corresponding with the $\dot{V}O_2max$ was established as the minimal velocity to elicit the $\dot{V}O_2max$ [3]. If a runner achieved $\dot{V}O_2max$ during a stage that was not maintained for 1 min, the velocity during the previous stage was considered to be the minimal velocity to elicit the $\dot{V}O_2max$. The RCP was determined by three independent investigators as the point of a nonlinear increase in the $\dot{V}e/\dot{V}CO_2$, a constant increase in the $\dot{V}e/\dot{V}O_2$, and the first decrease in the expiratory fraction of CO_2 [17].

Before the T_{lim} test, the participants performed a standardized warm-up exercise, which consisted of a 5-min treadmill run at 8 $km{\cdot}h^{-1}$ followed by 5-min light stretching of the lower limbs. Following the warm-up exercise, the 5-min resting baseline $\dot{V}O_2$ was measured while the subjects were stationary on the treadmill. The minimal velocity to elicit the $\dot{V}O_2max$ was added, and the test began with the participant's feet astride the moving belt and hands holding the handrail. The time to exhaustion was measured by a manual stopwatch to the nearest second from the moment the participant released the handrail (approximately 2 s) until the participant grasped it again. The subjects received strong verbal encouragement to continue as long as possible. Throughout the test, the heart rate was continuously recorded (Polar Electro Oy, Kempele, Finland), and the $\dot{V}O_2$ was measured breath-by-breath (Quark, Cosmed, Rome, Italy). The peak oxygen uptake ($\dot{V}O_{2peak}$) was established as the mean of the last 20 s of $\dot{V}O_2$, whereas the peak heart rate (HR_{peak}) was defined as the highest value measured at the end of the exercise. Blood samples (25 µl) were collected from the ear lobe at rest, immediately after exercise, and during the 3rd and 5th minute of recovery to determine the peak blood lactate concentration (Yellow Springs 1500 Sport, Ohio, USA).

The trapezoidal method was used to calculate the oxygen uptake over time during the constant-load test. The aerobic energy contribution in the T_{lim} (W_{AER}) was determined by subtracting the resting baseline $\dot{V}O_2$ from the $\dot{V}O_2$ area integrated over time [2]. The contribution of anaerobic metabolism in the T_{lim} (W_{ANAER}) was obtained by the oxygen deficit method. Initially, the on-response breath-to-breath $\dot{V}O_2$ was fitted using a mono-exponential model as previously suggested by Özyener et al. [21] (Eq.1) (Origin 6.0, Microcal, Massachusetts, USA). Equation 2 was employed to obtain the oxygen deficit [16].

$$\dot{V}O_{2(t)} = \dot{V}O_{2baseline} + A[1-e^{-(t-\delta)/\tau}] \qquad [1]$$

$$\text{Oxygen Deficit} = A_1 \cdot \tau \qquad [2]$$

Where $\dot{V}O_{2(t)}$ is the oxygen uptake at time t, $\dot{V}O_{2baseline}$ is the baseline oxygen uptake, A is the asymptotic amplitude, δ is the time delay, and τ is a time constant.

A caloric equivalent of 20.9 $kJ \cdot L\ O_2^{-1}$ was considered for the two energy systems [5]. The total energy expenditure (W_{TOTAL}) was calculated as the sum of the aerobic and anaerobic systems. The W_{AER} and W_{ANAER} were also expressed as percentages of the W_{TOTAL}.

Sample size calculation

Calculation of sample size was based on the assessment of a main effect for difference in 1RM using the mean and the standard deviation for maximum dynamic strength described in previous studies [13,26]. Expecting an effect size around to 1.0, a two-sided 5% significance level, and that the desired power is at least 0.80, a sample size of at least 5 participants per group was necessary. Assuming that almost 20% of participants do not fully comply with instructions (drop out rate), the sample size was increased to 8 participants into each group.

Statistical analyses

Data normality was assessed using the Shapiro-Wilk test, and all of the variables were normally distributed. The results are reported as means and standard deviations (±SD). The effects of training on primary and secondary outcomes were tested using a two-way (group x time) analysis of variance (ANOVA). When a significant F value was detected, Tukey's post-hoc test was used to allocate significant differences. Repeated measures analyses of variance with Bonferroni correction for multiple comparisons were used to compare the average strength training loads (%1RM) performed by the ST and ST_{WBV} groups during the experimental period. The average strength training loads (%1RM) performed by the ST and ST_{WBV} groups during each training session were compared using an unpaired *t*-test. A paired *t*-test was used to compare the aerobic and anaerobic metabolism contribution estimated during the T_{lim}. The significance level was set at $p \leq 0.05$. All of the statistical analyses were performed using Statistica 8 (StataSoft Inc., Tulsa, OK, USA).

RESULTS

The flux of participants through the stages of the study is described in figure 1. During intervention period, two participants dropped out of the control group due to the development of muscular injuries not associated with running training, and their data were not included in the statistical analyses (C = 6). All of the subjects who finished the study in the training groups completed over 90% of the scheduled training sessions. It is important to note that participant did not report any discomfort or any adverse event produced by strength training programs.

Results analyzed as completed by participants

Primary outcome variable

No significant differences were observed in the baseline values in any of the groups. The mean 1RM increased significantly by 17 ± 8% and 18 ± 7% ($p \leq 0.05$) after training intervention for the ST and ST_{WBV} groups, respectively (Figure 2). However, the differences observed in the 1RM between the trained groups were not significant. No statistical differences were observed in the 1RM for the C group after the experimental period. Both training groups progressively increased the average training load expressed as the %1RM from the first to the last training session (Figure 2; $p \leq 0.05$). No statistical differences were detected between the groups in regards to the average training load applied in each training session.

*** Insert Figure 2 ***

Secondary outcome variables

As shown in table 2, there were no significant changes in the parameters of endurance performance measured during the maximal incremental treadmill test before and after the experimental period ($p > 0.05$). In addition, no statistical differences were observed in the running training volume expressed as the mean weekly distance covered before (ST: 58 ± 10 km·wk^{-1}, STwbv: 61 ± 12 km·wk^{-1}, and C: 57 ± 11 km·wk^{-1}) and after (ST: 60 ± 10 km·wk^{-1}, STwbv: 59 ± 12 km·wk^{-1}, and C: 59 ± 11 km·wk^{-1}) the completion of the study.

*** Insert Table 2 ***

Table 3 shows the physiological responses and absolute estimates of the energy contributions during the T_{lim}. There were no significant differences among the three groups before the training period with respect to all the variables. No statistical changes were detected in the variables measured during the T_{lim} for the C group after the training period. The absolute W_{AER} was statistically higher than the absolute W_{ANAER} for the three groups both before and after the experimental period ($p \leq 0.05$). Correspondingly, the relative W_{AER} was also higher than the relative W_{ANAER} for all the groups both before and after the experimental period ($p \leq 0.05$) (Figure 3). The increase observed in the absolute W_{AER} after training was significantly larger in the ST (25%) group compared with the ST_{WBV} group (18%) ($p \leq 0.05$). The change in the W_{AER} was accompanied by an increase in the W_{TOTAL} for the ST group ($p \leq 0.05$), which resulted in a reduction in the relative W_{ANAER} contribution ($p \leq 0.05$). Despite these metabolic changes, no statistical differences were recorded in the T_{lim} after training for all the groups ($p > 0.05$). In addition, no statistical differences were observed between the measurements obtained before and after training in all of the variables measured during the T_{lim} for the C group.

*** Insert Table 3 and Figure 3 ***

DISCUSSION

The main objective of this study was to investigate the impact of 6-weeks of strength training performed with or without whole-body vibration on the muscular adaptations and traditional parameters of endurance performance. To the best of our knowledge, this is first study to provide primary data comparing the effectiveness of ST_{WBV} and ST in long-distance runners. The main findings were that both strength-training modes similarly improved the maximum strength without deleterious effects in the endurance predictors.

Vibration refers to an oscillatory displacement with alternating changes in velocity and direction, which results in increased workload training. Wilcock et al. [28] reported that a person standing on a whole-body vibration platform vibrating at 30 Hz with peak-to-peak displacement of 6 mm would be exposed to an extra 7.7*g* of force. It is believed that this mechanical stimuli may cause greater neuromuscular adaptations resulting from a number of factors, such as an increase in the sensitivity of the stretch reflex, stimulation of Ia-afferents via the muscle spindle, and augmented muscle mass [22,28]. In the present study, no statistical differences between the training workload (%1RM) applied at each training session were observed between the trained groups. This means that the ST_{WBV} group was submitted to an additional stimulus provided by vibration platform during the entire training period. However, our data showed that the extra stimulation provided by vibration did not result in significantly larger gains in muscle strength in endurance athletes when compared with ST alone. This is in line with the findings of a systematic review that showed several randomized-controlled trial studies from high to moderate quality observing increases in maximum strength in the lower limb muscles after vibration training in untrained subjects, but not in trained athletes [22]. Thus, it is plausible to suspect that the additional effects of vibration training previously reported in the literature may be diminished in long-distance athletes because of the smaller adaptive potential and slower rates of improvement compared with untrained subjects.

Our results are consistent with previous research that has observed no deleterious effects in the $\dot{V}O_2max$ and the RCP in long-distance athletes participating in a strength-training program. Millet et al. [19] submitted well-trained triathletes ($\dot{V}O_2max$ ~69 $ml \cdot kg^{-1} \cdot min^{-1}$) to 14-weeks of traditional strength training and observed no significant changes in the $\dot{V}O_2max$ or RCP. In turn, Hautala et al. [9] observed that a strength training program based on the recommendations of the American College of Sports Medicine enhanced the $\dot{V}O_2max$ in healthy subjects ($\dot{V}O_2max$ ~34 $ml \cdot kg^{-1} \cdot min^{-1}$). Thus, it appears that changes in these physiological variables are dependent on initial aerobic fitness. The lack of improvement in the $\dot{V}O_2max$ may be explained by the observation that strength training sessions elicit oxygen uptake values less than 50% of the $\dot{V}O_2max$ [15]. Therefore, the stimulus would be insufficient to promote adaptations in the maximal aerobic power of trained athletes. Concerning ST_{WBV}, it was plausible to suspect improvements in the $\dot{V}O_2max$ and RCP since that whole-body vibrations training sessions require additional oxygen uptake when compared with traditional strength training [23]. However, the results of the present study show that the additional stimulus provided by the whole-body vibration platform was not sufficient to improve these physiological parameters in trained long-distance runners. Taken together, these findings suggest that the initial fitness level of the athletes may influence the level of adaptations in the $\dot{V}O_2max$ and RCP independently of whether the stimulus is provided by strength training alone or by strength training combined with whole-body vibration.

Previous studies have analyzed the effects of ST programs on the physiological parameters measured during the T_{lim} [12,26]. It has been suggested that the lower relative force generated at the same absolute running intensity after a ST program may enhance local blood flow [26]. It has been observed that the critical occlusion level of blood flow occurs at approximately 45-60% of the maximal voluntary contraction [11]. Thus, a decrease of the relative force generated at the same absolute running intensity as a result of the increase in the maximum dynamic strength could be important for oxygen availability for the exercised muscles. However, the results of the present study do not support this hypothesis. We observed similar improvements in the maximum dynamic strength (~18%) in the both training groups, but only the ST group had an increase ~25% in the W_{AER}. Goreham et al. [7] have reported decreased lactate accumulation and glycogen depletion resulting from a traditional ST program, which suggests a change in the oxidative potential of the skeletal muscle. These adaptations may provide higher ATP availability in the exercised muscles via oxidative phosphorylation. Nevertheless, this hypothesis should be analyzed with caution because we were unable to obtain muscle samples. Further research is needed to examine the underlying mechanisms controlling muscle skeletal adaptations after ST programs that result in a higher W_{AER} during high-intensity aerobic exercises.

Although the W_{AER} increased in the ST group, it was not sufficient to change the T_{lim}. In addition, it is important to note that the relative anaerobic contribution was also reduced after ST due the increased W_{TOTAL}. This finding is in contrast with previous studies that detected 11-21% enhancements in the T_{lim} after participation in a ST program [13,26]. Interestingly, it has been shown that the enhanced endurance performance after ST was accompanied by a greater contribution of the anaerobic metabolism system. For instance, Mikkola et al. [18] recently submitted long-distance runners to a ST program and observed a significant increase (3%) in both endurance performance and maximal anaerobic running test performance. These results suggest that the changes in anaerobic metabolism after ST are crucial for improvements in endurance performance. In fact, some authors have demonstrated that the W_{ANAER} is a critical determinant of performance during long-distance events with durations similar to the T_{lim} in our study (~350 s) [10]. Because the load used in both the ST and ST_{WBV} groups is likely to have resulted in increased neural adaptations (~90% 1RM) in the absence of significant stress of the anaerobic energy system [6], probably our athletes were most likely not able to increase the ability to quickly resynthesize ATP via anaerobic metabolism.

The current study presented some relevant limitations. First, it is important to note that our sample was composed by moderately-trained athletes. Furthermore, all participants had no previous strength or plyometric training experience. Thus, caution should be exercised in extrapolating these findings to highly-trained athletes individuals who frequently perform training sessions using exercises that are strength- or power-dependent. Second, the period of intervention could be considered short to draw definitive conclusions about the impact of the ST and ST_{WBV} in the muscular and physiological parameters studied. Finally, due the need to utilize the whole-body vibration platform, the training protocol was limited to only one exercise (i.e. half-squat on a Smith machine), which may have resulted in a lower strength training volume than those often used in the ‘‘real world’’.

In conclusion, the results of the present study showed that 6 weeks of strength training performed with or without whole-body vibration improve similarly the maximum dynamic strength of long-distance runners. In addition, both training modes studied had no deleterious effects on the traditional parameters of endurance performance.

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