Effect of jumping interval training on neuromuscular and physiological parameters: a randomized controlled study

Jonathan Ache-Dias¹, Rodolfo A. Delligrana¹, Anderson S. Teixeira², Juliano Dal Pupo¹ and Antônio R. P. Moro¹

¹ Biomechanics Laboratory, Center of Sports - CDS, Federal University of Santa Catarina, 88040-900, Florianópolis, Santa Catarina, Brazil.
² Physical Effort Laboratory, Center of Sports - CDS, Federal University of Santa Catarina, 88040-900, Florianópolis, Santa Catarina, Brazil.

Corresponding author:
Jonathan Ache Dias, Ph.D.
Biomechanics Laboratory, Center of Sports - CDS, Federal University of Santa Catarina, 88040-900, Florianópolis, Santa Catarina, Brazil.
Tel/fax: +55 48 3721-8530
E-mail: jonathanache@gmail.com
Abstract

This study analyzed the effect of four weeks of jumping interval training (JIT), included in endurance training, on neuromuscular and physiological parameters. Eighteen recreational runners, randomized in control and experimental group, performed 40 min of running at 70% of velocity at peak oxygen uptake (vVO$_{2peak}$), three times per week. Additionally, experimental group performed the JIT twice per week, consisted by four to six bouts of continuous vertical jumps (30s) with five-minute interval. Three days before and after training period the countermovement (CMJ) and continuous jump (CJ$_{30}$), isokinetic and isometric evaluation of knee extensors/flexors, progressive maximal exercise and submaximal constant-load exercise were performed. The JIT provoked improvement in neuromuscular performance, indicated by increased jump height (JH$_{CMJ}$) (4.7%; Effect Size, ES = 0.99) and power output (≈3.7%; ES ≈ 0.82) of CMJ and rate of torque development of knee extensors in isometric contraction (29.5%; ES = 1.02); anaerobic power and capacity, represented by the mean of JH$_{INI}$ (7.4%; ES = 0.8) and peak power output (PPO$_{INI}$) (5.6%; ES = 0.73) of the first jumps of CJ$_{30}$ and the mean of JH$_{ALL}$ (10.2%, ES = 1.04) and PPO$_{ALL}$ (9.5%, ES = 1.1) considering all jumps of CJ$_{30}$; and aerobic power and capacity, represented by peak oxygen uptake - VO$_{2peak}$ (9.1%, ES = 1.28), vVO$_{2peak}$ (2.7%, ES = 1.11) and velocity corresponding to the onset of blood lactate accumulation - vOBLA (9.7%, ES = 1.23). These results suggest that the JIT included in traditional endurance training induces moderate-to-large effects on neuromuscular and physiological parameters.

Keywords: high-intensity interval training; plyometric training; exercise adaptations; metabolism; muscle power.
Introduction

High-intensity interval training (HIIT) is considered the most time-efficient way to improve the athlete’s physical performance (Billat 2001; Laursen and Jenkins 2002). HIIT consists of short (<45 s) and long (one to eight min) bouts of high-intensity exercises interspersed with recovery periods (Billat 2001; Buchheit and Laursen 2013). It is very well documented that HIIT may induce improvements in both anaerobic and aerobic metabolism, depending on the manipulation of the intensity and duration of bouts and recovery periods (Rodas et al. 2000; Burgomaster et al. 2005; Hazell et al. 2010). In general, HIIT protocols that use maximal or near to maximal intensities (~90–120% of VO\textsubscript{2max}), or all-out exercises (sprint interval training, SIT), have been considered as the most effective for this purpose (Laursen et al. 2002; Midgley et al. 2006).

The effects of HIIT have been studied for decades, the results showing that this type of training induces improvements mainly in maximal aerobic power (Laursen et al. 2002; Midgley et al. 2006). Furthermore, HIIT seems to improve the determinant variables of endurance running performance such as velocity at maximal oxygen uptake (VO\textsubscript{2max}) (Denadai et al. 2006), running economy (RE) (Billat et al. 1999; Denadai et al. 2006; Helgerud et al. 2007), velocity at lactate threshold (vOBLA) (Denadai et al. 2006) and time to exhaustion (T\textsubscript{lim}) (Esfarjani and Laursen 2007).

Several training regimens, such as running (Billat et al. 1999; Denadai et al. 2006; Helgerud et al. 2007; Macpherson et al. 2011), cycling (Burgomaster et al. 2005; Hazell et al. 2010), swimming (Sperlich et al. 2010) and rowing (Driller et al. 2009), have frequently been used in HIIT. SIT, including bouts of 10 to 30 s with a work-to-rest ratio close to 1:8 (i.e. a 30 s
effort and 240 s recovery period), is a common model used in cycling and running (Burgomaster et al. 2005; Hazell et al. 2010; Macpherson et al. 2011). To our knowledge, no previous study has examined the use of alternative exercise modes, such as continuous vertical jumps, in SIT training.

Vertical jump training is often used in field sports of several modalities that need to develop muscle power and other expressions of explosive strength (Markovic et al. 2007). On the other hand, a relationship between vertical jump height and middle- and long-distance running performance is shown in the literature (Hudgins et al. 2013), suggesting the importance of power output for endurance performance (Turner et al. 2003; Spurrs et al. 2003). Jump training, besides inducing changes in the capacity of muscle to generate power, may also increase musculotendinous stiffness (Fouré et al. 2010), improving the use of the stretch-shortening cycle (SSC). Consequently, the energy cost may be optimized (Spurrs et al. 2003). In this way, the importance of neuromuscular training to endurance performance may be evidenced (Bonacci et al. 2009).

Thus, aiming to develop SIT with a jumping training regimen, we proposed jumping interval training (JIT), which uses the intermittent application of a continuous vertical jump test with a duration of 30 s (CJ30) performed at maximal intensity. The CJ was developed by Bosco et al. (1983) as a method for evaluating mechanical power and anaerobic metabolism, and is used here as a training method. The CJ30 was recently considered valid and reliable based on the Wingate test (Dal Pupo et al. 2014). Therefore, the objective of this study was to analyze the effect of four weeks of JIT, included in a traditional endurance training of recreational runners, on neuromuscular and physiological parameters.
Materials and methods

Participants

Twenty-six recreational runners volunteered to participate in this study. All meeting inclusion criteria, but four declined due to injury or work commitments. The following inclusion criteria were adopted: a) women or men that included running in their daily training routine between two and five times a week in the last two months; b) age ranging from 18 to 40 years; c) a good standard of movement in performing jumps. The exclusion criteria were: having performed regular plyometric training in the last three months and presenting injuries in the last two months. Twenty-two participants (12 women and 10 men) were randomly divided into two groups (experimental group – EG and control group – CG) according to v\(\text{VO}_{2}\text{peak}\) identified from a previous progressive maximal aerobic test. When two participants of the same sex presented v\(\text{VO}_{2}\text{peak}\) with a difference lower than 0.5 km.h\(^{-1}\) their aerobic power was considered the same and so they were allocated to the EG or CG by tossing a coin. Nine participants in the EG (five women and four men; age = 24.3 ± 3.1 years; fat percentage = 18.6 ± 7.1; body mass = 63.1 ± 10.1 kg; height = 1.6 ± 0.9 m) and nine in the CG (five women and four men; age = 31.3 ± 5.7 years; fat percentage = 17.6 ± 6.9; body mass = 66.3 ± 13.9 kg; height = 1.7 ± 1.2 m) completed the training. Four participants (two men and two women) declined due to work commitment or injury during the training period. All participants provided written informed consent. Ethical approval was obtained from the local Human Research Ethics Committee and the protocol was written in accordance with the standards set by the Declaration of Helsinki. This study is a randomized controlled trial with two parallel groups, which followed the CONSORT recommendation (Schulz et al. 2010).
Testing procedures

The participants were evaluated in two separate sessions with a 24 h interval. The test sessions were performed three days before and after the training period. Prior to the first session (72 h) the participants were familiarized with the jump tests. In the first session, the following evaluations were performed: an anthropometric test, a countermovement jump test (CMJ), CJ$_{30}$ and a progressive maximal exercise test, with the latter two tests being separated by a 45-minute interval. At the end of the first session, familiarization with the isokinetic evaluation protocol was carried out. In the second session, the isokinetic evaluation and submaximal constant-load test were performed. A 15-minute interval between tests was adopted. The participants were requested to refrain from training in the 24 h that preceded the testing sessions, to maintain their regular diet, and to avoid smoking and caffeinated drinks. All procedures were conducted in the laboratory at a temperature of 24 °C.

Evaluation protocols

Initially, the CMJ and CJ$_{30}$ evaluation were preceded by three very brief static stretching exercises (one set of 5s duration with short movement amplitude) for lower limbs and a specific warm-up (submaximal jumps). Three CMJs were performed on a force platform (Quattro Jump, Kistler, Switzerland) with the same body position adopted for CJ$_{30}$. The CJ$_{30}$ consisted of maximal continuous vertical jumps performed for 30 s. The participants were required to keep the trunk as vertical as possible, and hands were placed on hips (akimbo). They were also asked to flex their knees at $\approx$90° in the transition between the eccentric and concentric phases, which is considered the best angular position to maximize vertical jump performance. Verbal feedback
was provided to the subject during the test to encourage them to maintain knee angle at approximately 90° and maximum performance until the end of the test. From ground reaction force measured by the force platform, the jump height (JH\textsubscript{CMJ}), peak power output (PPO\textsubscript{CMJ}) and mean power output (MPO\textsubscript{CMJ}) were calculated for the CMJ. With regard to the CJ\textsubscript{30}, the PPO was calculated from ground reaction force and the jump height was calculated from 2-D kinematic analysis using a video camera with a sample frequency at 120 Hz (Canon SX510 HS, Tokyo, Japan). The jump height was considered as the difference between the initial height and the highest height reached by great trochanter point (reflexive mark) during the jump (Dias et al. 2011).

In the progressive maximal exercise test, the peak oxygen uptake (VO\textsubscript{2peak}), velocity at VO\textsubscript{2peak} (vVO\textsubscript{2peak}), maximal heart rate (HR\textsubscript{max}) and velocity at onset of blood lactate accumulation (vOBLA) were measured. Respiratory measures were obtained breath by breath using an automated open-circuit gas analysis system (Quark PFT Ergo, Cosmed, Rome, Italy) and data were reduced to 15 s averages. The treadmill (IMBRAMED, model ATL 10200) was set at a 1% gradient with an initial starting velocity of 7 km.h\textsuperscript{-1} for women and 8 km.h\textsuperscript{-1} for men, which was subsequently increased by 1 km.h\textsuperscript{-1} every three min until volitional exhaustion. The participants were strongly encouraged, verbally, to exert maximum effort. The maximal effort was deemed to be achieved if the incremental test met two of the following criteria: a) respiratory exchange ratio (RER) ≥ 1.15; b) HR\textsubscript{max} age-predicted ≥ 90% (Laursen et al. 2002); and (c) LAC\textsubscript{max} ≥ 8 mmol.L\textsuperscript{-1} (Bassett and Howley 2000). Between each stage, there was a rest interval of 30s, in which 25 µL of capillary blood was collected from the ear lobe to measure the blood lactate concentration [La]. The blood lactate samples were analyzed using an electrochemical analyzer (YSI 2300 STAT, Yellow Springs, OH, USA). The vOBLA was
determined by linear interpolation using the intensity at a fixed [La] of 3.5 mmol.L\(^{-1}\) (Denadai et al. 2006). Heart rate was recorded every five seconds throughout the tests (Polar RS800sd, Kempele, Finland) and HR\(_{\text{max}}\) was defined as the highest heart rate value recorded during the test.

Isokinetic and isometric peak torque of the knee extensor and flexor muscles of each participant’s right leg were measured using an isokinetic dynamometer (Biodex System 4\(^\text{\textregistered}\), Biodex Medical Systems, Shirley, NY, USA). Isokinetic concentric and eccentric actions were tested at an angular velocity of 120°.s\(^{-1}\). Rate of torque development during maximal isometric contraction for both knee extensors (60° of knee flexion) and flexors (30°) was calculated in time intervals of 0–200 ms. Prior to evaluation, the participants performed a brief stretching exercise of the quadriceps and hamstring and a warm-up on a cycle ergometer (25 W) for five minutes.

After isokinetic evaluation, the participants performed a submaximal constant-load exercise on a motorized treadmill to evaluate the running economy (RE). First, the participants walked at 4 km.h\(^{-1}\) for three minutes as a warm-up, followed by six minutes of running at 9 km.h\(^{-1}\), with oxygen uptake (VO\(_2\)), carbon dioxide produced (VCO\(_2\)) and HR all being measured. Running economy was considered as the VO\(_2\) and the energy cost (EC), based on updated nonprotein respiratory quotient equations as described in Shaw et al. (2014).

**Training protocol**

Both groups performed running sessions of 40 minutes on the treadmill at 70% of \(v\text{VO}_2\text{peak}\), three times per week (Monday, Wednesday and Friday) for four weeks. Additionally, the EG performed the JIT twice a week (Tuesday and Thursday). The JIT sessions consisted of intermittent bouts of 30 s of maximal continuous jumps (CJ\(_{30}\)) with five minutes of recovery.
period, with two min being active (walking on the treadmill at 5 km.h\(^{-1}\)) and three passive. The number of bouts increased from four to six in the first three weeks (four in the first, five in the second and six in the third bouts), decreasing to five in the last week. All the JIT sessions were preceded by the follow sequence: a) brief stretching of the quadriceps, hamstring and triceps surae; b) warm-up comprising three minutes of treadmill walking at 5 km.h\(^{-1}\), 10 s of hopping and five submaximal CMJ. At the end of each session, the rating of perceived exertion (RPE; Borg CR-10 scale) was obtained.

**Statistical analysis**

Data are presented as mean ± standard deviation or median ± interquartile range. The Shapiro-Wilk test was used to check the normality of the data distribution. The mathematical routines were developed in Matlab (MathWorks, Natick, MA, USA). For testing the effect of training on the variables, a split-plot ANOVA with repetitive measures was used with a between-participants factor (group: EG and CG) and within-participants factor (time: pre and after training). The Box-Cox test was used to verify the heteroscedasticity of the data. For post hoc analysis (pairwise comparison), the Bonferroni test was used. Additionally, the effect size (ES) for repeated measures was calculated to analyze the magnitude effects of training (Faul et al. 2007). The following criteria for effect sizes were used: $<0.1 = \text{trivial}$, $0.1–0.3 = \text{trivial/small}$, $0.3–0.5 = \text{small}$, $0.5–0.7 = \text{small/moderate}$, $0.7–1.1 = \text{moderate}$, $1.1–1.3 = \text{moderate/large}$, $1.3–1.9 = \text{large}$, $1.9–2.1 = \text{large/very large}$ and $>2.1 = \text{very large}$ (Lamberts et al. 2010). Alternatively, the Mann-Whitney U test and Wilcoxon test were used when the data presented non-normal distribution. The Pearson product-moment was used to analyze the correlation between $\Delta PPO_{\text{CMJ}}$ ($PPO_{\text{CMJ}}$ after training - $PPO_{\text{CMJ}}$ before training) and the $\Delta vVO_{2\text{peak}}$ ($vVO_{2\text{peak}}$...
after training - vVO\textsubscript{2peak} before training). All tests were performed using SPPSS 17.0 software (SPSS Inc., USA).

Results

Baseline

Baseline values (pre training) for all variables did not differ between groups (Tables 1, 2 and 3).

Neuromuscular parameters

During the training period, the CMJ variables (Table 1) had increased by 4.7% (ES = 0.99, dif = 1.78 ± 1.69 cm) for JH\textsubscript{CMJ}, 3.7% (ES = 0.82, dif = 100.81 ± 121.29 W) for PPO\textsubscript{CMJ} and 3.5% (ES = 0.83, dif = 50 ± 59.45 W) for PMO\textsubscript{CMJ} in the EG, whereas there was no significant change in the CG (p > 0.05).

The rate of torque development of knee extensors (RTD\textsubscript{EXT}) showed a interaction effect (time x group; F = 4.85, p = 0.04) and had increased by 29.6% (ES = 1.02, dif = 183.00 ± 179.93 Nm.s\textsuperscript{-1}) in the EG after the four weeks of training, whereas no increase was observed for the CG (Table 2). The rate of torque development of knee flexors (RTD\textsubscript{FLE}) during knee flexors increased by 13.5% (304.04 Nm.s\textsuperscript{-1} to 353.03 Nm.s\textsuperscript{-1}) for both the EG and the CG (time effect; F = 11.28, p = 0.01). No effects were verified for the isokinetic and isometric peak torque (Table 2).

Parameters of CJ\textsubscript{30}
A moderate increase of JH\textsubscript{INI} (7.4%; ES = 0.87; dif = 2.55 ± 2.91 cm), PPO\textsubscript{INI} (5.6%; ES = 0.73; dif = 142.78 ± 180.08 W), JH\textsubscript{ALL} (10.2%, ES = 1.04, dif = 3.06 ± 2.92 cm) and PPO\textsubscript{ALL} (9.5%, ES = 1.1, dif = 209.82 ± 191.06 W) was verified after JIT for the EG; no increase was observed for the CG (Table 1).

**Aerobic indices**

The aerobic indices also presented changes induced by JIT (Table 3). ANOVA revealed an interaction effect for vVO\textsubscript{2peak} (F = 10.57; p = 0.01), VO\textsubscript{2peak} (F = 12.51; p = 0.01) and vOBLA (F = 8.74; p = 0.01). In pairwise comparison, a moderate-to-large increase of vVO\textsubscript{2peak} (2.7%, ES = 1.11, dif = 0.37 ± 0.31 km.h\textsuperscript{-1}), VO\textsubscript{2peak} (9.1%, ES = 1.28, dif = 0.29 ± 0.20 L.min\textsuperscript{-1}) and vOBLA (9.7%, ES = 1.23, dif = 0.98 ± 0.81 km.h\textsuperscript{-1}) was found only for the EG. Additionally, HR decreased (1.84%, time effect; F = 5.12; p = 0.03) during the submaximal constant-load exercise after the training period for both the EG and the CG.

Additionally, we found a moderate correlation (r = 0.63, p < 0.01) between the ΔvVO\textsubscript{2peak} (vVO\textsubscript{2peak} after training - vVO\textsubscript{2peak} before training) and ΔPPO\textsubscript{CMJ} (PPO\textsubscript{CMJ} after training - PPO\textsubscript{CMJ} before training).

**Table 3 near here**

**Discussion**

The present study aimed to examine the chronic effects (4 weeks) of SIT performed with a jumping training regimen. The major finding was that the inclusion of JIT in traditional
endurance training enhanced the neuromuscular performance and indices related to the anaerobic 
and aerobic metabolism of recreational runners, whereas no adaptations were verified in the 
control group. The JIT was proposed based on the SIT model, with efforts performed at maximal 
intensity (all-out), using an exercise mode (vertical jump) with high neuromuscular and eccentric 
load. According to subjective perception of physical effort measured after each of eight sessions, 
the JIT intensity was considered very strong to extremely strong (RPE = 9.12 ± 0.64), suggesting 
that the training was performed with close to maximal effort.

As expected, the JIT improved jump performance, as indicated by a moderate increase of 
jump height ($JH_{CMJ}$) and power output ($PPO_{CMJ}$ and $MPO_{CMJ}$) (Table 1). Data presented by 
Markovic (2007) in a meta-analysis showed that a similar magnitude of effects caused by 
plyometric training was verified for jump height (range from 4.7% to 8.7%, $ES = 0.88$). It is well 
documented in the literature (Komi 2000) that the main mechanism that enhances jump 
performance from plyometric training is the increase of the ability of individuals to use the 
neural and elastic characteristics of the SSC. The SSC enhances the power in the concentric 
phase of a jump when compared to isolated muscle actions and may be evidenced in drop jump 
training due to the stimuli of impact of drop height (Komi 2000). In this sense, the JIT may be 
considered a sequence of deep drop jumps, in which many CMJ are performed preceded by a 
drop. According to Komi and Gollhoger (1997), muscular stiffness and stretch reflexes play an 
important role in the increase of force and power during SSC.

A moderate increase of $RTD_{EXT}$ was verified with the inclusion of JIT, while no changes 
were observed for isokinetic peak torque in either knee extension or flexion (Table 2). In line 
with our findings, Kyrolainen et al. (2005) also found an increase of $RTD_{EXT}$ (35%) after 10 
weeks of drop jump training in recreationally active men. These results are of practical interest
for coaches and physical conditioning trainers, and highlight the applicability of JIT, in particular
for improving an individual’s ability to develop rapid strength during the early phases of muscle
contraction.

The variables $JH_{\text{INI}}$ and $PPO_{\text{INI}}$ of first jumps (20%) and $JH_{\text{ALL}}$ and $PPO_{\text{ALL}}$ considering
all jumps of the CJ$_{30}$ were used to represent the anaerobic power and capacity, respectively, as
suggested by Dal Pupo et al. (2014). Based on this, it was verified that both anaerobic power and
capacity were moderately increased after the JIT (Table 1). The magnitude of improvements for
anaerobic variables is comparable with previous studies that analyzed the effect of SIT in cycling
or running with bouts of 30 s and four min of recovery. These studies found an increase of peak
(4% to 12%) and mean (6% to 17%) power output or mean mechanical work, evaluated in 30 s
all-out effort (McKenna et al. 1997; Macdougall et al. 1998; Barnett et al. 2004; Hazell et al.
2010), suggesting an impact of this training model on anaerobic metabolism. Thus, JIT may be
considered more effective for enhancing anaerobic metabolism than other traditional HIIT.

The JIT also caused a moderate-to-large increase of the maximal aerobic power ($vVO_2$peak
and $VO_2$peak) and capacity ($vOBLA$) parameters (Table 3). This is in line with most studies that
analyzed the effects of SIT, in which improvements have been shown not only in anaerobic
metabolism, but also in aerobic power (from 6.5% to 15%) (Mckenna et al. 1997; Macdougall et
al. 1998; Barnett et al. 2004; Hazell et al. 2010) for recreationally active individuals. Thus, SIT
models have been considered, according to a systematic review and meta-analysis (Sloth et al.
2013), as time-efficient models of training, when compared with low-intensity endurance
training, to improve the aerobic power of sedentary and recreationally active individuals.

Results shown by a previous study (Macpherson et al. 2011) suggest that the increase in
$VO_2$peak observed in the present study may be explained by peripheral adaptations with
enhancement of oxidative muscle capacity. According to Macpherson et al. (2011), continuous endurance training (65% of VO$_{2\text{max}}$) induced central adaptations (increase of maximal cardiac output) while SIT (bouts of 30 s with four min of recovery) induced peripheral adaptations, and both kinds of training increased the VO$_{2\text{max}}$ and performance in a 2000 m running time trial. An important aspect to highlight is that the vVO$_{2\text{peak}}$ also depends on anaerobic and neuromuscular characteristics (Paavolainen et al. 2000). In this sense, we found a moderate correlation between ∆PPO$_{\text{CMJ}}$ and ∆vVO$_{2\text{peak}}$, suggesting the importance of the neuromuscular system in aerobic power performance.

Most studies have shown the effect of SIT on maximal aerobic power, but few have reported increases in aerobic capacity, usually represented by submaximal-intensity physiological variables such as vOBLA, maximal lactate steady state and T$_{\text{lim}}$ at submaximal velocities. Burgomaster et al. (2005) examined the effect of cycling SIT with four to seven bouts of 30 s and four min of recovery performed over two weeks and showed that T$_{\text{lim}}$ at 80% of VO$_{2\text{peak}}$ doubled for recreationally active individuals. Additionally, Mckenna et al. (1997) showed that SIT improves not only the VO$_{2\text{max}}$ post training, but also the ventilatory thresholds 1 and 2 at 48% and 72%, respectively, thereby corroborating our findings, once the vOBLA had increased after JIT. The main mechanism that explains the increase of endurance capacity is the increase of mitochondrial potential, which improves respiratory control sensitivity during exercise (Holloszy and Coyle 1984). In addition, it has been suggested that SIT induces increases in lactate transport capacity and H$^+$ release from active muscle (Juel et al. 2004).

No training effect on running economy (RE) was found, since VO$_{2}$ and EC during the submaximal constant-load exercise did not decreased after the training period. This finding is contrary to previous studies (Turner et al. 2003; Spurrs et al. 2003) that suggest RE
improvements after jump training (plyometric) due to the enhancement of the SSC. Improvements in RE may be expected since it has been postulated that plyometric training induces alterations in muscle elastic properties, such as stiffness (Spurss et al. 2003; Fouré et al. 2010), that play an important role in muscle efficiency control during running. One possible explanation for non-improvement on RE is that musculotendinous stiffness may have not improved with training; however, this variable was not measured here. Moreover, the type of exercise performed during JIT may not have been the most properly for RE improvements; perhaps using a short squat movement (like two-legged hopping with short ground contact time), an improvement on stiffness could be expected.

As a limitation of present study, is highlighted the intensity of running training. The major of experimental studies have been using different physiological indices to define the training intensity and equalize the groups for comparison, such as the percentage of $VO_2\max$, $vVO_2\max$ and $vOBLA$ (Billat et al. 1999). In the current study, we used the percentage of $vVO_2\text{peak}$ as reference thinking in the practical application for training prescription. However, as a consequence the EG received a higher cardiorespiratory impact of running protocol (trained at $vOBLA$) than the CG (trained slightly below of $vOBLA$), despite the lack of statistical difference of $vVO_2\text{peak}$ between groups before training. Thus, this aspect could have influenced our results.

In conclusion, four weeks of JIT included in continuous endurance training induces neuromuscular and physiological adaptations. This evidence was indicated by a moderate-to-large effect on vertical jump height, power output, explosive strength, anaerobic power and capacity, and aerobic power and capacity. JIT may be considered not only as a new option to SIT, but a good alternative for improving both physiological and neuromuscular parameters of recreational runners or physically active individuals. It is not possible to say that JIT has a better
effect than cycling or running SIT on neuromuscular and physiological parameters. However, besides being time-efficient, JIT is very practical, because it can be performed in any one square meter of hard surface and does not require any kind of ergometer. Additionally, future studies will indicate whether well-trained endurance athletes might receive benefits from this type of training.
Acknowledgments

We would like to thank all of the participants for their involvement with this study. We would also like to acknowledge all the staff of the Physical Effort Laboratory of the Federal University of Santa Catarina for their support.
Conflict of interest

The authors declare that there are no conflicts of interest.
References


## Table 1. Mean and standard deviation of parameters of CMJ and CJ30.

<table>
<thead>
<tr>
<th></th>
<th>EG (n=9)</th>
<th></th>
<th>CG (n=9)</th>
<th></th>
<th>F&lt;sub&gt;int&lt;/sub&gt; (p)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
<td>Post</td>
<td></td>
</tr>
<tr>
<td>Countermovement jump test (CMJ)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>JH&lt;sub&gt;CMJ&lt;/sub&gt; (cm)</td>
<td>37.74 ± 5.24</td>
<td>39.52 ± 5.06*</td>
<td>40.02 ± 6.52</td>
<td>39.37 ± 6.65</td>
<td>12.01 (0.01)</td>
</tr>
<tr>
<td>PPO&lt;sub&gt;CMJ&lt;/sub&gt; (kW)</td>
<td>2.70 ± 0.59</td>
<td>2.80 ± 0.59*</td>
<td>3.06 ± 0.93</td>
<td>2.99 ± 0.90</td>
<td>8.78 (0.01)</td>
</tr>
<tr>
<td>PMO&lt;sub&gt;CMJ&lt;/sub&gt; (kW)</td>
<td>1.41 ± 0.30</td>
<td>1.46 ± 0.31*</td>
<td>1.60 ± 0.48</td>
<td>1.55 ± 0.46</td>
<td>9.01 (0.01)</td>
</tr>
<tr>
<td>Continuous jump test (CJ30)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NJ</td>
<td>25.44 ± 2.87</td>
<td>23.77 ± 2.43</td>
<td>26.33 ± 2.64</td>
<td>25.66 ± 2.54</td>
<td>14 (0.01)</td>
</tr>
<tr>
<td>JH&lt;sub&gt;INI&lt;/sub&gt; (cm)</td>
<td>34.41 ± 5.92</td>
<td>36.97 ± 4.83*</td>
<td>36.88 ± 6.06</td>
<td>36.38 ± 5.97</td>
<td>8.75 (0.01)</td>
</tr>
<tr>
<td>PPO&lt;sub&gt;INI&lt;/sub&gt; (kW)</td>
<td>2.53 ± 0.61</td>
<td>2.68 ± 0.612*</td>
<td>2.86 ± 0.96</td>
<td>2.85 ± 0.94</td>
<td>5.56 (0.03)</td>
</tr>
<tr>
<td>JH&lt;sub&gt;ALL&lt;/sub&gt; (cm)</td>
<td>30.14 ± 5.69</td>
<td>33.21 ± 4.12*</td>
<td>32.91 ± 5.68</td>
<td>32.51 ± 5.22</td>
<td>10.96 (0.01)</td>
</tr>
<tr>
<td>PPO&lt;sub&gt;ALL&lt;/sub&gt; (kW)</td>
<td>2.19 ± 0.68</td>
<td>2.40 ± 0.67*</td>
<td>2.58 ± 0.89</td>
<td>2.59 ± 0.87</td>
<td>9.28 (0.01)</td>
</tr>
</tbody>
</table>

F<sub>int</sub> = F value of ANOVA interaction (time vs group); JH<sub>ALL</sub> = mean of jump height of all jumps performed in the CJ30; JH<sub>CMJ</sub> = jump height of CMJ; JH<sub>INI</sub> = mean of jump height of the first 20% of jumps performed in the CJ30; MPO<sub>CMJ</sub> = mean power output of CMJ; NJ = number of jumps; PPO<sub>ALL</sub> = mean of peak power output of all jumps performed in the CJ30; PPO<sub>CMJ</sub> = peak power output of CMJ; PPO<sub>INI</sub> = mean of peak power output of the first 20% of jumps performed in the CJ30; *difference between pre- and post-training condition (p ≤ 0.05).
**Table 2.** Central tendency and variability of the knee extensor and flexor variables in isokinetic evaluation.

<table>
<thead>
<tr>
<th></th>
<th>EG (n=9)</th>
<th></th>
<th>CG (n=9)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
<td>Post</td>
</tr>
<tr>
<td>PET&lt;sub&gt;CON&lt;/sub&gt; (N.m)</td>
<td>173.77 ± 39.73</td>
<td>178.97 ± 37.92</td>
<td>180.03 ± 66.28</td>
<td>175.44 ± 66.88</td>
</tr>
<tr>
<td>PET&lt;sub&gt;ECC&lt;/sub&gt; (N.m)#</td>
<td>226.00 ± 86.05</td>
<td>240.60 ± 81.75</td>
<td>230.00 ± 93.65</td>
<td>218.50 ± 67.00</td>
</tr>
<tr>
<td>PFT&lt;sub&gt;CON&lt;/sub&gt; (N.m)</td>
<td>144.84 ± 29.47</td>
<td>153.16 ± 34.07</td>
<td>154.01 ± 48.77</td>
<td>149.96 ± 51.38</td>
</tr>
<tr>
<td>PFT&lt;sub&gt;ECC&lt;/sub&gt; (N.m)</td>
<td>155.10 ± 35.42</td>
<td>160.76 ± 35.76</td>
<td>159.24 ± 48.52</td>
<td>155.92 ± 49.91</td>
</tr>
<tr>
<td>IPT&lt;sub&gt;EXT&lt;/sub&gt; (N.m)</td>
<td>210.45 ± 47.26</td>
<td>218.35 ± 51.13</td>
<td>213.43 ± 60.35</td>
<td>207.75 ± 51.89</td>
</tr>
<tr>
<td>IPT&lt;sub&gt;FLE&lt;/sub&gt; (N.m)#</td>
<td>111.10 ± 54.85</td>
<td>115.30 ± 59.05</td>
<td>93.00 ± 52.10</td>
<td>93.20 ± 59.80</td>
</tr>
<tr>
<td>RTD&lt;sub&gt;EXT&lt;/sub&gt; (Nm.s&lt;sup&gt;1&lt;/sup&gt;)</td>
<td>617.50 ± 250.43</td>
<td>800.50 ± 312.24*</td>
<td>615.12 ± 317.26</td>
<td>634.03 ± 249.28</td>
</tr>
<tr>
<td>RTD&lt;sub&gt;FLE&lt;/sub&gt; (Nm.s&lt;sup&gt;1&lt;/sup&gt;)</td>
<td>303.72 ± 99.48</td>
<td>365.00 ± 125.70</td>
<td>306.36 ± 140.48</td>
<td>341.05 ± 164.76</td>
</tr>
</tbody>
</table>

CON = concentric; ECC = eccentric; EXT = extensors; FLE = flexors; IPT = isometric peak torque; PET = peak extensor torque; PFT = peak flexor torque; RTD = rate of torque development. * Difference between pre- and post-training condition (p ≤ 0.05). # nonnormal data expressed as median and interquartile ranges.
Table 3. Mean and standard deviation of variables during incremental and time to exhaustion test.

<table>
<thead>
<tr>
<th></th>
<th>EG (n=9)</th>
<th></th>
<th>CG (n=9)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
<td>Post</td>
</tr>
<tr>
<td><strong>Progressive maximal exercise test</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>vVO₂peak (km.h⁻¹)</td>
<td>13.68 ± 1.40</td>
<td>14.06 ± 1.57*</td>
<td>14.00 ± 1.33</td>
<td>14.00 ± 1.26</td>
</tr>
<tr>
<td>VO₂peak (L.min⁻¹)</td>
<td>3.17 ± 0.72</td>
<td>3.46 ± 0.70*</td>
<td>3.23 ± 0.73</td>
<td>3.25 ± 0.72</td>
</tr>
<tr>
<td>HRmax (bpm)</td>
<td>197 ± 8</td>
<td>195 ± 8</td>
<td>188 ± 6</td>
<td>191.44 ± 6</td>
</tr>
<tr>
<td>% HRmax</td>
<td>100.62 ± 3.62</td>
<td>99.40 ± 4.31</td>
<td>99.55 ± 5.76</td>
<td>101.08 ± 4.61</td>
</tr>
<tr>
<td>vOBLA (km.h⁻¹)</td>
<td>10.11 ± 1.64</td>
<td>11.09 ± 1.82*</td>
<td>11.39 ± 1.80</td>
<td>11.46 ± 1.77</td>
</tr>
<tr>
<td>LACmax (mmol.L⁻¹)</td>
<td>9.77 ± 0.99</td>
<td>8.74 ± 1.76</td>
<td>8.88 ± 1.45</td>
<td>9.96 ± 1.86</td>
</tr>
<tr>
<td>RER</td>
<td>1.19 ± 0.05</td>
<td>1.15 ± 0.08</td>
<td>1.20 ± 0.11</td>
<td>1.20 ± 0.09</td>
</tr>
</tbody>
</table>

|                      |          |            |          |            |
| **Submaximal constant-load test** |          |            |          |            |
| VO₂ (L.min⁻¹)        | 2.41 ± 0.31 | 2.36 ± 0.37 | 2.39 ± 0.43 | 2.36 ± 0.43 |
| EC (kcal.min⁻¹)      | 12.84 ± 1.61 | 12.57 ± 1.99 | 12.63 ± 2.28 | 12.31 ± 2.23 |
| HR (bpm)             | 159 ± 20 | 156 ± 17 | 149 ± 5 | 145 ± 17 |

%HRmax = percentages of maximal heart; EC = energetic cost; HRmax = maximal heart rate; rate according to age; LACmax = maximum rate of lactate accumulation; RER = respiratory exchange ratio; vOBLA = velocity at onset of blood lactate accumulation; VO₂peak = peak oxygen uptake; vVO₂peak = peak of aerobic velocity. *difference between pre- and post-training condition (p ≤ 0.05).