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original article

# Effects of downhill walking training on aerobic and neuromuscular fitness of young adults

## *Efeitos da caminhada em declive na aptidão aeróbia e neuromuscular em adultos jovens*

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**Abstract** – Eccentric exercise training using low intensity-high volume approach has been performed to improve maximal muscle strength and power. The aim of this study was to compare the effects of short-term downhill walking and level walking training on lower limb strength and maximal oxygen uptake of active individuals. Eighteen young adults were divided into level walking group (n = 9) or downhill walking training group (n = 9). Both groups performed a four-week training program. The level walking group performed seven level walking sessions per week, while the downhill walking group walked downhill (-16%) in the same weekly frequency. One week before and one week after the training protocol, maximal oxygen uptake, muscle-bone cross-sectional area and isometric peak torque of knee extensors and plantar flexors were assessed for both groups. A significant group vs. time interaction was found only for cross sectional area of plantar flexors (PF), showing increases for the downhill walking group (112.6 ± 28.9 $cm^2$ vs. 115.9 ± 29 $cm^2$) but not for the level walking group (94.9 ± 23.3 $cm^2$vs. 94.6 ± 228 $cm^2$). Maximal oxygen uptake remained unaltered after training for both groups and IPT was increased after training for both groups. It was concluded that short-term downhill walking training does not seem to be efficient in promoting improvements in cardiorrespiratory fitness of young adults. However, it seems to promote gains in some variables related to neuromuscular fitness.

**Key words**: Muscle strength; Physical endurance; Physical fitness.

**Resumo** – *O treinamento excêntrico de baixa intensidade e alto volume vem sendo adotado para desenvolver a força e a potência muscular. O objetivo deste estudo foi comparar os efeitos do treinamento de caminhada em declive e em plano, em parâmetros de força de membros inferiores e consumo máximo de oxigênio de indivíduos ativos. Dezoito adultos foram separados em grupos de treinamento em plano (GTP - n = 9) em declive (GTD - n = 9). Ambos realizaram um programa de treinamento de 4 semanas. O GTP realizou sete sessões semanais de caminhada no plano, enquanto o GTD caminhou em declive (-16%). Uma semana antes e uma semana após o treinamento, foram medidos o consumo máximo de oxigênio, área de secção transversa músculo-óssea e o pico de torque isométrico dos extensores do joelho e flexores plantares dos participantes. Interação significante grupo-tempo foi identificada apenas para a área de secção transversa dos flexores plantares, demonstrando aumentos para o grupo GTD (112,6 ± 28,9* $cm^2$*vs. 115,9 ± 29* $cm^2$*), mas não para o GTP (94,9 ± 23,3* $cm^2$*vs. 94,6 ± 228* $cm^2$*). O consumo máximo de oxigênio permaneceu inalterado após o treinamento para ambos os grupos e o pico de torque isométrico aumentou significantemente após o treinamento para ambos os grupos. Concluímos, então, que um treinamento de caminhada em declive de curto prazo parece não ser eficiente na promoção de melhoras significativas de parâmetros cardiorrespiratórios de adultos jovens, embora seja efetivo no incremento de algumas variáveis relacionadas à aptidão neuromuscular.*

**Palavras-chave**: *Aptidão física; Força muscular; Resistência física.*

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# INTRODUCTION

Regular exercise helps to improve health-related components of physical fitness such as aerobic power, exercise economy and muscular strength. Adaptations promoted by physical exercise are highly specific[1-3]. Endurance training improves aerobic-related indexes [e.g., maximal oxygen uptake ($VO_2$max)] with little effect on muscle mass. On the other hand, resistance exercise increases strength, power, and lean body mass, without changes in $VO_2$max. Thus, in an attempt to improve simultaneously all health-related components, strength and endurance training have been performed concurrently (i.e., concurrent training)[4,5]. Two major problems, at least, arise from this training model. Firstly, when endurance and strength training are performed simultaneously, there are fewer gains of both strength and skeletal muscle mass[6,7]. Moreover, a greater training volume in each session and/or a higher weekly frequency is necessary to perform endurance and strength training concurrently[4].

Downhill running could be considered a viable alternative to concurrent training, since it stimulates both the neuromuscular system, via increased loads of eccentric contractions used to decelerate and to absorb energy due to declination[8], and the cardiorespiratory system, to sustain the activity for relatively long periods[9]. However, great magnitudes of exercise-induced muscle damage (EIMD) are elicited by this exercise modality, since a considerable number of eccentric contractions are performed[10,11]. EIMD is known to cause strength loss, soreness, edema and impaired exercise economy. Since these symptoms usually return to baseline only 5-7 days after the damaging bout[12], proper weekly frequency to determine training adaptations would not be achieved on this modality. Even though a protective phenomenon known as repeated bout effect is obtained after the occurrence of EIMD, blunting the damaging response after other sessions, compliance to training sessions that elicit high magnitude of EIMD is low[13].

Recent studies have shown that downhill walking (DW) can be considered an alternative to downhill running[14-17]. Indeed, Lima et al.[17] demonstrated that a 4-week periodized DW training program induced moderate magnitudes of EIMD, suggesting that DW can be adopted as training stimulus without impairing further sessions. In Parkinson's disease patients, Yang et al.[14]found that the isometric peak torque (IPT) of knee extensors was increased after 4 weeks of DW training. Similarly, Gault & Willems[16]showed that IPT and torque steadiness were also improved after 12 weeks of DW training in older individuals. Interestingly, Hahn et al.[18]found significant increases in the total content of citrate synthase enzyme after 6 weeks of downhill running training in mice, while Ahmadi et al.[19]reported acute increases in vascularization and muscle oxygenation after a DW session in mice. These data, associated with the classical finding of Saltinet al.[20]and Wagner[21], which showed that peripheral adaptations play an important role in increasing aerobic power, indicate that DW training could improve aerobic fitness. However, to the best of our knowledge, there are no studies investigating the beneficial effects of DW training on health-related components of physical fitness of healthy young adults.

Therefore, the aim of the present study was to compare the effects of DW and level walking training on strength-related variables of the lower limbs and aerobic power in young active individuals. We hypothesized that DW training would lead to improvements in strength-related variables of knee extensors and ankle flexors and increase aerobic power when compared to level walking training.

## METHODOLOGICAL PROCEDURES

### Participants

Eighteen healthy active individuals volunteered for the study. Participants' mean age, body mass, height and body mass index were 22.9 ± 4.6 years, 76.6 ± 14.7 kg, 1.74 ± 0.07 m and 25.0 ± 3.9 kg/$m^2$, respectively. None of them had prior experience with strength or endurance training during the 6 months that preceded the study and had no medical history regarding articular and/or muscular injuries. They were also instructed to maintain their regular eating habits and drink plenty of water. All procedures adopted in the present study were conducted in accordance with the declaration of Helsinki for the use of humans as research subjects. The study was analyzed and approved by the Ethics Research Committee of the São Paulo State University (Biosciences Institute - Rio Claro) under protocol number 3310 (approval number: 097/2011).

### Experimental design

The volunteers were randomly assigned into two groups: downhill walking training (DWG; n = 9) and level walking training (LWG; n = 9). All participants visited the laboratory on two different occasions (Visits 1 and 2) before the start of the experiment in order to become familiarized with the equipment used and signed the informed consent form. One week before and one week after the training protocol, criterion measures related to strength and aerobic fitness were assessed for both groups. All assessments were conducted in a climate-controlled environment, at the same time of the day and by the same examiner to avoid external interference in results. The experimental design is represented in Figure 1.

### Training

Both groups performed 4 weeks of training with 7 sessions per week. Subjects only trained from Monday to Friday; therefore, they trained twice at Tuesdays and Thursdays. Each training session consisted of 20 min walking. DWG performed walking at a -16% slope, while LWG performed level walking (0% slope), both on a treadmill (h/p/cosmos pulsar – 3P, Nussdorf-Traunstein, Germany). The training protocol started at a walking speed of 5.0 km/h for DWG and 4.5 km/h for LWG, with increments of 0.5 km/h every week. The initial speeds were not similar between groups due to dif-

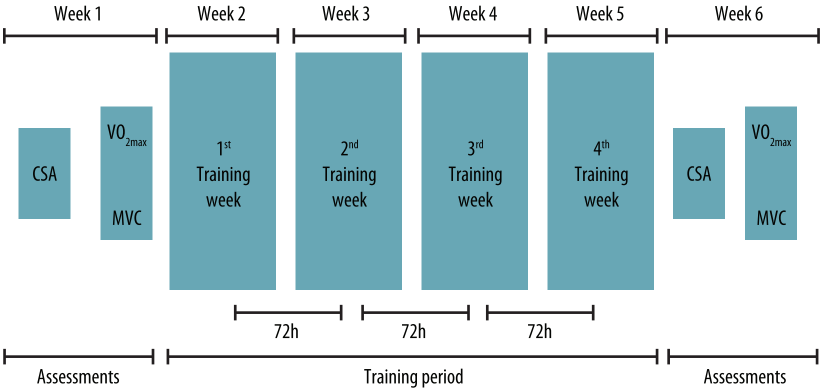

**Figure 1.** Timeline representing the study design. CSA: Muscle-bone cross sectional area; VO2max: Maximal oxygen uptake; MVC: Maximal voluntary contraction.

ferences in the metabolic requirements for level and downhill walking[17], and were set based on a pilot study. Oxygen uptake was continuously assessed during the final training session of each week for both groups using a pulmonary gas exchange analyzer (Cosmed Quart PFTergo, Rome, Italy).

## Dependent variables

- **Isometric Peak Torque (IPT)**

Two 5-second maximal voluntary contractions (MVC) were performed on an isokinetic dynamometer (Biodex System 3, Biodex Medical Systems, Shirley, N.Y.) with a 180-second rest interval between them. For knee extensors (KE), a fixed knee joint position of 70° (0 = full extension) was used, and for plantar flexors (PF), the position adopted was neutral (i.e., 90° between leg and tarsus). These tests were performed in random order using only the dominant (preferred kicking) limb. Volunteers were instructed to perform the MVC “as hard and as fast as possible” and to hold until they were instructed otherwise. Examiners gave strong verbal encouragement during all MVC. MVC with the highest isometric peak torque value for each muscle group was selected for analysis.

- **Cross-sectional area (CSA)**

Muscle-bone cross sectional area (CSA) of the dominant thigh and leg was assessed using circumferences (CIR) and adipose tissues (AT). CIR and AT were measured following protocol proposed by Abe et al.[22]. CIR was measured with Gullick tape at the halfway point between the *trocanter majoris* and the lateral condyle of the femur (for thigh) and at the halfway point between the lateral condyle of the tibia and the lateral malleolus (for leg). AT was determined by ultrasonography (Voluson E8, GE Health Care, USA) at the same spot where CIR was measured. Volunteers were lying down and completely relaxed. Water-based gel was used to promote acoustic contact between skin and the transducer, which was positioned perpendicularly to the limb. Excessive pressure on the skin was avoided. Measurements were performed three times by an experienced professional, who was blinded for the group distribution, and the mean value of the three trials was considered for analyses. AT was calculated as the mean of the anterior and posterior adipose tissues [(anterior+posterior)/2] of the segment.CSA was then calculated using the following equation:

$$CSA = \pi \cdot (R\text{-}AT)^2$$

where CSA is the cross sectional area, R is the radius of CIR, and AT is the adipose tissue thickness.

- **Maximal oxygen uptake**

Maximal oxygen uptake ($VO_2max$) was measured using an incremental protocol performed on motorized treadmill (h/p/ comos pulsar – 3P,Nussdorf-Traunstein, Germany) with gradient set at 1%. The exercise protocol began with 3 minutes of warm-up exercise at 7 km/h. Thereafter, speed was incremented 1 km/h every 1-min, until voluntary exhaustion. Pulmonary gas exchange was continuously measured using breath-by-breath analyzer (Cosmed Quark PFTergo, Rome, Italy). Before each test, $O_2$ and $CO_2$ analysis systems were calibrated using ambient air and gas of known $O_2$ and $CO_2$ concentration according to manufacturer's instructions, while the gas analyzer turbine flowmeter was calibrated using 3-L syringe. Heart rate (HR) was also monitored throughout the tests (Polar, Kempele, Finland).  $VO_2max$ was defined as the highest average 15-s $VO_2$ value recorded during the incremental test.

### Statistical analyses

Data normality was tested using the Shapiro-Wilk test, and all normal data are expressed as mean ± SD. Changes in the main parameters were evaluated with analyses of variance using the mixed model procedure (group *vs.* time). Paired t-tests were then used to determine within-group differences between pre- and post-training measures. Significance levels were set at $p \leq 0.05$, and all tests were conducted using SPSS 21.0.

## RESULTS

Oxygen uptake values for the last training session of every week for LWG and DWG are expressed as percentage of their pre-training $VO_2max$ shown in Table 1. The 0.5 km/h increases performed every week resulted in very small increases in oxygen consumption on the second week (DWG: 0.8%; LWG: 1.4%). In the third week, the increases in this variable were substantially higher for both groups (DWG: 11%; LWG: 14.7%). There was also an increase in oxygen uptake in the fourth week (DWG: 7.7%; LWG: 15%). Increases in oxygen uptake, when comparing the first and last weeks of training, were 20.5% for DWG and 33.9% for LWG.

IPT values for KE and PF are represented in Figure 3. No significant group *vs.* time interaction was identified for IPT of both KE ($F = 0.47$; $p = 0.45$) and PF ($F = 0.52$; $p = 0.47$). A significant time effect ($F = 4.69$; $p = 0.04$) was identified for IPT of KE. No significant time effect ($F = 1.29$; $p = 0.27$) was observed for IPT of PF.

**Table 1.** Oxygen uptake values of training sessions of level (LWG) and downhill (DWG) groups along the training protocol. $VO_2max$ = Maximal oxygen uptake.

| | Oxygen uptake (%$VO_2$max) | | | |
|---|---|---|---|---|
| | Week 1 | Week 2 | Week 3 | Week 4 |
| LWG[#] | 28.0 ± 5.6 | 28.4 ± 2.6 | 32.6 ± 2.9* | 37.5 ± 3.1** |
| DWG | 24.3 ± 2 | 24.5 ± 3 | 27.2 ± 5 | 29.3 ± 5* |

# Main effect of group; * $p < 0.05$ in relation to Week 1; ** $p < 0.05$ in relation to Weeks 1, 2 and 3.

No significant group *vs*. time interaction (F = 0.88; p = 0.36) was found for $VO_2$max, and no significant effect was found for group (F = 1.17; p = 0.29) and time (F = 0.5; p = 0.48) (Figure 2).

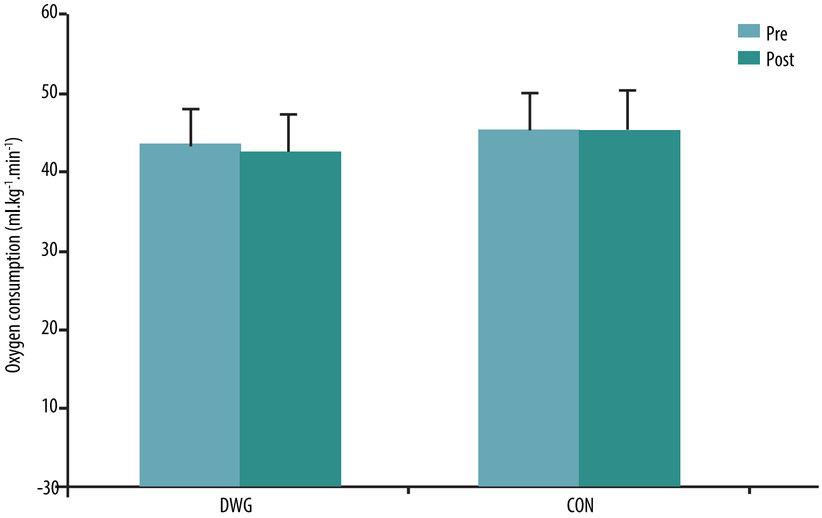

**Figure 2.** Maximal oxygen uptake ($VO_2$max) values for level (LWG) and downhill (DWG) groups before (Pre) and after (Post) the training period.

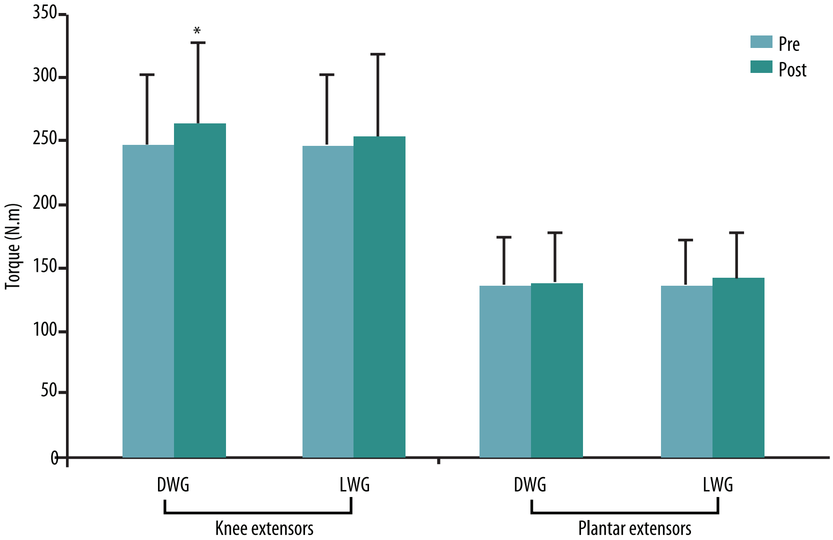

**Figure 3.** Isometric peak torque (IPT) values for knee extensors and plantar flexors for level (LWG) and downhill (DWG) groups before (Pre) and after (Post) the training period. * Main effect of time.

Significant group *vs*. time interaction was identified for CSA of leg (F = 10.64; p < 0.01). Paired comparisons revealed that CSA of leg increased in DWG (+2.9%; p < 0.001), but were unchanged in LWG. No significant group *vs.* time interaction (F = 0.7; p = 0.41) was found for the CSA of subjects' thighs and no significant effect was found for group (F = 2.27; p = 0.15) and time (F = 1.63; p = 0.22) (Figure 4).

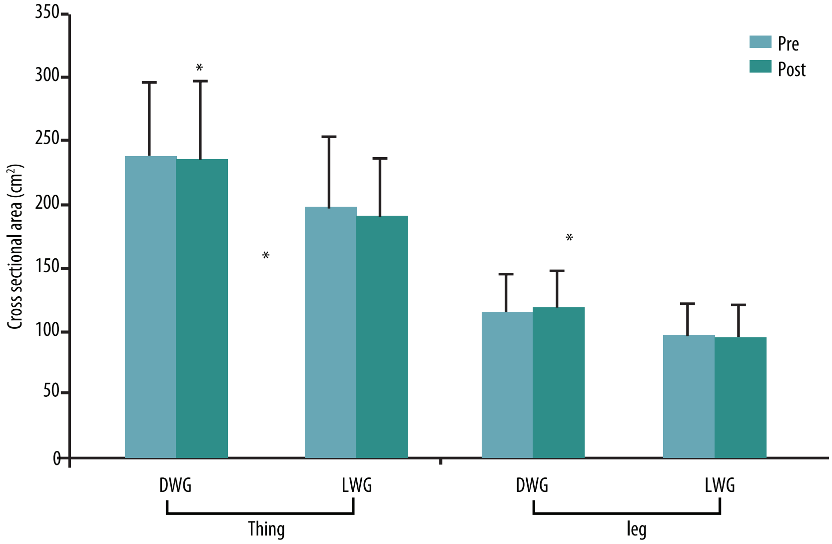

**Figure 4.** Cross sectional area (CSA) values of leg and thigh for level (LWG) and downhill (DWG) groups before (Pre) and after (Post) the training period. * p< 0.05 in relation to pre.

## DISCUSSION

The aim of the present study was to investigate if a 4-week periodized DW training protocol performed by young healthy adults would lead to greater adaptations in neuromuscular and cardiorespiratory markers compared to level walking training. It has been demonstrated for the first time that downhill walking induced greater increases in CSA of leg compared with level walking. Moreover, similarly to that found for elderly[16]and Parkinsons' disease patients[14], downhill walking training induced increases in IPT, as so did level walking training. However, no significant improvements in maximal oxygen uptake were found. Thus, although successful in increasing maximal lower limb strength, downhill walking training does not seem to be efficient in promoting improvements in cardiorrespiratory fitness of young adults.

In the 2011 position stand[9], the American College of Sports Medicine (ACSM) suggested that, in order to enhance aerobic fitness, healthy adults should expend an average of 1000 Kcal per week (~ 150 min.week$^{-1}$). This weekly exercise volume can be distributed in ≥5 days.week$^{-1}$ with 20-30 minutes.day$^{-1}$ of moderate-intensity exercise (≥ 40% $VO_2$max). In the present study, a protocol in which subjects performed 7 DW sessions per week (140 min.week$^{-1}$) was adopted, as recommended by the ACSM. However, the exercise intensity performed in all sessions (Table 1) was insufficient to achieve significant enhancements in aerobic power[9]. Thus, it was expected that the LWG group would not present any alterations in aerobic fitness. Based on evidences obtained in animal models[18,19], we hypothesized that DW could represent an additional stress in relation to walking level, considering the oxidative adaptations provided by downhill walking and running[18,19], to improve aerobic power. Hahn and colleagues[18] identified an increase in the total content of citrate synthase enzyme, a key regulatory enzyme in assessing oxidative capacity, after 6 weeks of downhill running training in mice. There is also evidence pointing to acutely increased vascularization and oxygenation of the muscle tissue of mice after a single bout of DW[19]. However, our DW training protocol did not improve aerobic power of young individuals. Thus, the additional stress imposed by DW is apparently insufficient to stimulate the circulatory and respiratory systems to improve aerobic power in young individuals. A faster walking speed (> 7 km/h) has been adopted in our protocol, aiming to increase exercise intensity (i.e., > % $VO_2$max), in which subjects would enter a transition phase between walking and running. It has been well established that downhill running leads to EIMD on lower limbs, causing strength loss, delayed onset of muscle soreness and other symptoms that could compromise further stimuli administration during the training period[8,10,23].

Several lines of evidence have indicated that eccentric training is more effective for improving strength, when assessed under concentric or eccentric conditions[24,25]. Unlike results found during classical eccentric-concentric training, in which neural adaptations are predominant during initial training phase (6-8 weeks)[26], short-term eccentric training (e.g., 4 weeks) can improve muscle mass[27]. In the present study, it was demonstrated for the first time that CSA of legs was improved by DW training. This increase in muscle mass of legs can be explained by the repeated number of eccentric contractions of dorsi flexors accompanied by co-contraction of plantar flexors during DW[8]. These characteristics can promote both hypertrophic response and swelling of the assessed area, which could have lasted up to the post-training CSA assessment. The mean muscle hypertrophy per session (~ 0.3%) found in the present study is very similar to that found in untrained individuals after high intensity-low volume isokinetic eccentric training (~0.3%)[28]. After low intensity-high volume training modality (i.e., eccentric cycle ergometer training), LaStayo et al.[29] found a 52% increase of muscle fiber cross-sectional area after 32 eccentric training sessions performed within 8 wk. A higher training workload (20-30 min at 54%-65% peak heart rate) performed during eccentric cycle ergometer training can explain the greater muscle hypertrophy found by LaStayoet al.[29].

Although it was found that CSA of leg was significantly increased, IPT of PF was not enhanced in DWG. In patients with Parkinson's disease, Yang et al.[14] identified significant increases in IPT of KE after a training protocol consisting of 4 weeks of DW. Similar data were obtained after 12 weeks of DW training performed by elderly individuals[16]. The weekly frequency (3 sessions per week), volume (4 and 12 weeks) and exercise intensity (self-selected walking speed with ~ -8.5 and -10 slopes) in studies conducted by Yang et al.[14]and Gault & Willems[16], respectively, were substantially lower than those performed by our volunteers. Our DW protocol promoted increases in IPT of KE. However, these increases were also identified in the LWG group. This strength gain in both groups can be justified by the high trainability of volunteers, which did not perform any type of training for at least 6 months before participation in the study. However, in an overall view, it seems that DW training might not be a good alternative to concurrent training, since it does not promote increases in aerobic power and strength gains promoted by it are similar to those promoted by level walking training. The only advantage conferred by DW training, when compared to level walking training, seems to be a relatively small increase in the CSA of legs. Therefore, it is reasonable to state that DW training does not provide additional advantages when compared to traditional level walking training in active young adults.

It was considered that the short-term characteristic of the training protocol can be considered as a limitation of this study, as well as the small sample size, which could have led to a type II error in the statistical analyses. Moreover, the addition of a passive control group would be useful to help identifying the magnitude of adaptations provided by level and DW training.

## CONCLUSIONS

It was concluded that the DW training protocol adopted in the present study did not promote significant improvements in aerobic power of young adults, and promotes strength gains similar to those promoted by level walking training. However, DW training led to significant increases in CSA of subjects' legs. We believe that this adaptation has occurred due to great levels of stress provided by repeated eccentric contractions of plantar extensors during DW, which were not present in LWG and might have led to a hypertrophic response. Future studies should investigate if longer training periods would lead to more pronounced enhancements in the fitness parameters of young adults.

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