THE TIME COURSE OF OXYGEN UPTAKE, AEROBIC CAPACITY AND EMG DURING TWO MONTHS OF MODERATE INTERVAL ENDURANCE TRAINING (A CASE STUDY)

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ABSTRACT

Research background and hypothesis. The low-moderate-intensity continuous endurance training improved body composition, aerobic capacity and overall health-related parameters in healthy persons. However, we could not find publications about the effect of moderate interval aerobic endurance training (IET) on body composition, $\dot{V}O_2$ kinetics, aerobic capacity and EMG parameters.

Research aim. The main purpose of this study was to examine the effect of interval endurance training (IET) on oxygen uptake kinetics, aerobic capacity, body composition and EMG parameters.

Research methods. A 26-year-old, sedentary obese female (stature – 1.80 m; weight – 99.2 kg; VO_2max – 37.2 ml/kg^{-1}/min^{-1}) was involved in two-month moderate interval endurance training (IET). The subject performed three training sessions a week separated by one or two days of rest. The initial intensity of training was 90% of the first ventilation threshold (VT1). The VT1 and second ventilation threshold (VT2) ware estimated after completion of incremental running test until exhaustion on a LE 200 CE treadmill (VIASYS, Germany).

Research results. We determined that after two months IET subject' body mass decreased by 10%, the training had an effect on aerobic capacity parameters as well. The running speed at VT1 and VT2 increased by 8.1% and 10.2% respectively after the two-month IET programme. The heart rate (165.9 beats/min^{-1}) and oxygen uptake (2.583 l/min^{-1}) significantly decreased respectively (150.4 beats/min^{-1}) (2.285 l/min^{-1}) after IET period compared with pre-training testing. To indicate the total muscle activity we measured integrated EMG (iEMG) and root mean square (RMS). We also determined changes on EMG parameters after four, six and eight weeks IET.

Discussion and conclusions. Two-month moderate interval endurance training has significant effect on aerobic capacity, anthropometrics, EMG parameters and VO_2 kinetics.

Keywords: ventilatory thresholds, maximal oxygen uptake, EMG root mean square.

INTRODUCTION

It is well established that low-to-moderate-intensity continuous endurance training has been the most common type of exercise recommended to improve body composition, aerobic capacity and overall health-related parameters in healthy (Donnelly et al., 2009) and obese people (McInnis et al., 2003). Several studies showed that endurance and high intensity training induced similar metabolic, cardiorespiratory system and skeletal muscle molecular adaptations in healthy humans (Burgomaster et al., 2008; Rakobowchuk et al., 2008) and in obese children (Corte et al., 2012). Also, M. J. Gibala et al. (2006) observed that two-week endurance training improved exercise performance and maximal activity. The oxygen uptake (VO_2) at the ventilatory thresholds and maximal oxygen uptake (VO_2max) led to significant improvement after combined (consisting of continuous and interval load) endurance training (Carter et al., 2000).

I. E. Schjerve et al. (2008) demonstrated that high intensity aerobic interval training had a higher effect on VO_2max than moderate intensity training.

Previous studies examining the effect of training on VO_2 kinetics typically used a more "traditional" exercise training regime (i. e. continuous endurance exercise at – 60–65% VO_2max, for 30–120 min) (Philips et al., 1995; Carter et al., 2000). However, different training has various effects on VO_2 kinetics. It was determined that endurance exercise training (4–6 wk.) had an effect on VO_2 kinetics during the transition to moderate intensity exercise, a significant reduction in time constants for VO_2 (tVO_2) was reported after only 4 days of training (Phillips et al., 1995).

The VO_2max, VO_2 kinetics parameters are related to electrical activity of skeletal muscles. The surface electromyography (EMG) signals such as amplitude (integrated EMG (iEMG), root mean square or (RMS)) and power spectrum (mean power frequency (MPF)) are commonly used to assess the level of muscle fatigue or changes in motor units during static and dynamic exercises (Farina et al., 2004). It is already known that the amplitude of iEMG increases and it means that fast-twitch fibres are gradually recruited during exhausting exercises and constant-load exercise (Shinohara, Moritani, 1992). It is likely that both type I and II fibres are recruited at the onset of exercise, and that as intense exercise progresses, a greater proportion of type II fibres are recruited as type I fibres become fatigued (Krustrup et al., 2004 b).

There are several studies which try to explain the effect of different training on aerobic capacity, VO_2 kinetics. For the first time we are trying to explain the effect of moderate intensity interval training on cardiorespiratory system and EMG parameters in **sedentary obese women.** We hypothesized that a two-month interval endurance training would have a positive effect on body composition, VO_2 kinetics, aerobic capacity and EMG parameters in sedentary **obese** subject. Therefore, the purpose of this study was to examine the effect of IET on body composition, oxygen uptake kinetics, aerobic capacity and EMG parameters.

RESEARCH METHODS

Participant. A 26-year-old untrained female (stature – 1.80 m; weight – 99.1 kg; VO_2max – 37.2 $ml/kg^{-1}/min^{-1}$) was involved in 8-week moderate interval endurance training (IET). The experimental protocol was approved by the Lithuanian Ethics Committee of Kaunas University of Medicine (No. BE-2-68).

Training Programmes. The two-month IET session consisted of 8 repetitions of the following intervals: 4 min running of constant moderate intensity followed by 2 min walking (at 5 km/h) and 2 min rest periods. The participant performed 3 trainings sessions a week separated by 1–2 days of rest. The intensity of IRT was 90% of the first ventilation threshold (VT1).

Incremental running test. The participant performed incremental running test (IRT) until exhaustion on a LE 200 CE treadmill (VIASYS, Germany). The subject was standing on the sides of treadmill 2 minutes till the speed increased to 7 km/h^{-1}, then she constantly ran for 4 minutes (7 km/h^{-1}), at the end of this period the load was increased incrementally (0.1 km/h^{-1}per 6 s) to maximum 20 km/h^{-1}speed, then the slope was raised (0.05% per 6 s) until the subject stopped the treadmill due to fatigue.

Pulmonary gas exchange date collection. Pulmonary gas exchange parameters (VO_2; VCO_2 Ve) were measured breath-by-breath throughout all IET and IRT using wireless portable spirometry system "Oxycon mobile" (VIASYS Healthcare; California, USA). Prior to each test, the portable spirometry system was calibrated. The first and second (VT2) ventilation thresholds and VO_2max were evaluated during the IRT on a LE 200 CE treadmill (VIASYS, Germany). The average value of VO_2 over the last 15 s of running was referred to as VO_2max.

Determination of ventilatory thresholds. VT1 ir VT2 were established according to the dependence of pulmonary ventilation as well as ventilation equivalents of oxygen (Ve/VO_2) and carbon dioxide (Ve/VCO_2) at the end of expiration on the work intensity performing IRT. VT1 was considered to be the intensity of the work load when the Ve increase accelerated for the first time, and the Ve/VO_2 started increasing without any changes in the Ve/VCO_2. VT2 was the intensity of the work load when the Ve increase accelerated for the second time, and the Ve/VCO_2 started increasing even faster with the increase in the Ve/VO_2.

Blood lactate concentration. Blood sample (25μl) for the measurement of blood lactate concentration ([La]) (Accutrend Portable Lactate Analyser, Roche, Germany) was taken from fingertips.

Heart rate (HR) was continuously recorded every 5 s using a wireless Polar monitoring system (S810 Polar, Finland) during IET and IRT.

Anthropometric data. The subject's body composition components (body mass, free fat mass and fat mass) were measured using body composition analyser (*Tanita*, Japan).

EMG recording. Bipolar Ag-AgCI surface electrodes were used for surface electromyography (sEMG) recordings (silver bar electrodes, diameter 10 mm, centre-to-centre distance 20 mm) of right leg *m. vastus lateralis* (m. VL), *m. vastus medialis* (m. M) and *m. gastrus lateralis* (m. GL), *m. gastrus medialis* (m. GM) (DataLog type No. P3X8 USB, Biometrics Ltd, Gwent, Uk.). The skin at the electrode site was shaved and cleaned with alcohol wipes. To be sure that electrode was precisely at the same place for each IET, the electrode location was marked on the skin with an indelible marker. The electrodes were placed $2/3^{-1}$ on m. VL and 80% way on m. VM. Respectively m. GL were placed $1/3^{-1}$ of the line between the head of the fibula and the heel and m. GM on the most prominent bulge of the muscle. The ground electrode was positioned on the wrist of the left hand. The EMG parameters integrated electromyogram (iEMG), root mean square (RMS) of sEMG values were consistently taken during the course of IET.

Experimental protocol. The participant was familiarized with the research and signed informed consent to participate in it, she was tested under the same conditions. The participant performed three IRT on a treadmill – a control test, after 1 and 2 months of IET periods. The participant was included in a 2-month IET programme. The training frequency was 3 times per week, separated by 1–2 days of rest. The blood lactate concentration was measured on the 5^{th} and 20^{th} minutes of rest after IRT. VO_2, HR parameters were measured during all tests (IRT, IET). The EMG parameters of right leg muscles and anthropometric parameters (body mass, free fat mass and fat mass) were measured every two weeks.

Statistical analysis. Descriptive data were expressed as mean values and standard deviations (SD). Comparisons between the four tests were made by nonparametric statistics and significant results were further analysed using Friedman ANOVA and Kendall's Concorde test. Statistical significance was accepted when $p < 0.05$.

RESEARCH RESULTS

Anthropometric data. After two months of IET the subject's body mass, fat mass (kg), free fat mass (FFM) (kg) decreased respectively by 8.5, 17.2 and 3.5%, compared to the first testing (Table 1).

Table 2 shows the effect of the two-month IET on the aerobic capacity that was measured during IRT. The maximal running speed, relative VO_2max, HRmax increased respectively by 7.0, 9.4 and 4.9% after IET compared to control testing. The alteration of aerobic capacity parameters at the VT1 and VT2 were different. The speed of running at VT1 and VT2 increased respectively by 8.1 and 10.2% after a two-month IET programme. HR at the VT1 increased by 7.8% and at the VT2 – by 6.3% after one month of IET, but it decreased respectively by 1.7 and 2.1% after two months of IET programme compared to middle testing.

The steady state of VO_2 decreased significantly during the running sessions after two months IET (Figure 1), but the steady state of relative VO_2 was unchanged (Figure 2). Heart rate significantly decreased after IET programmes compared to pre-training testing (Figure 3).

Table 2 shows the changes in EMG parameters during IET sessions every 2 weeks. The iEMG of *m. vastus lateralis* and *m. vastus medialis* during running intervals of training sessions significantly

Table 1. **Changes in the subject's anthropometric parameters during IET period**

Parameters	Pre-training	After 2 weeks	After 4 weeks	After 6 weeks	After 8 weeks	Change of percentages
Weight, kg	99.1	96.4	92.4	90.3	89.6	9.6↓
BMI	30.6	29.8	28.5	27.9	27.7	9.5↓
Fat mass, %	44.7	43.4	41.8	40.8	40.9	8.5↓
Fat mass, kg	44.3	41.8	38.6	36.8	36.7	17.2↓
Free fat mass, kg	54.8	54.6	53.8	53.5	52.9	3.5↓
TBW, kg	40.1	40	39.4	39.2	38.7	3.5↓

Note. ↓ – parameters' percentage decreased after two months of IET compared to Pre-training. BMI – the body mass index; TBW – the total body water.

increased after 6 and 8 weeks, and *m. gastrus medialis* significantly increased after 2, 6 and 8 weeks; *m. gastrus lateralis* significantly chances was determined after 4 weeks compeered with testing after 2 weeks IET. The following significant changes in RMS of EMG during the running intervals of the training session were observed: increase after 6, 8 weeks of *m. vastus lateralis* and *m. vastus medialis*, after 2, 6 and 8 weeks of *m. gastrus medialis* and decrease after 4, 6 and 8 weeks of *m. gastrus lateralis*.

VO_2 kinetics parameters: baseline VO_2; oxygen uptake amplitude (AVO_2) and oxygen uptake time constant (tVO_2) are given in Figure 4. The baseline VO_2 (Figure 4A) significantly decreased after 2–8 weeks of IET compeered to pre-training testing. The AVO_2 (Figure 4 B) significantly increased after 5 weeks, but it decreased after 7–8 weeks of IET compared to pre-training testing. There were no significant differences in tVO_2 under different testing conditions (Figure 4 C).

Table 2. **Aerobic capacity parameters during incremental running test**

	Control testing	After one month	After two months
Data at the first ventilation threshold (VT1)			
Running speed at VT1, km/h^{-1}	8.7	9.2	9.4
Heart rate at VT1, beats/min^{-1}	165	178	175
VO_2 at VT1, l/min^{-1}	2.778	2.820	2.594
Data at the second ventilation threshold (VT2)			
Running speed at VT2, km/h^{-1}	10.8	11.7	11.9
Heart rate at VT2, beats/min^{-1}	176	187	183
VO_2 at VT2, l/min^{-1}	3.233	3.356	3.292
Maximal data			
Maximal running speed, km/h^{-1}	12.8	13.5	13.7
Absolute VO_2max, l/min^{-1}	3.683	3.731	3.644
Relative VO_2max, ml/kg/min^{-1}	37.2	40.4	40.7
Heart rate max, beats/min^{-1}	184	192	193
TDmax, l	2.984	2.624	2.758
VEmax, l/min^{-1}	137.3	136.0	136.0

Note. VT1 – first ventilation threshold; VO_2 – oxygen uptake; VT2 – second ventilation threshold; VO_2max – maximal oxygen uptake; TD – tidal volume; VEmax – maximal ventilation.

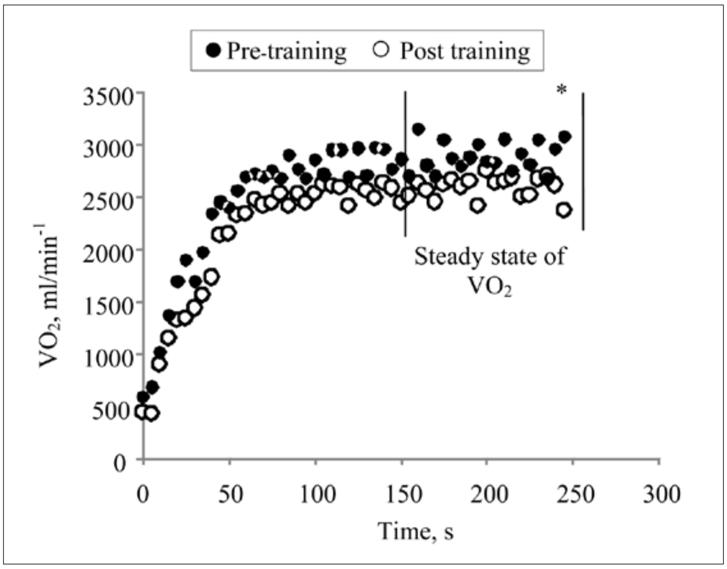
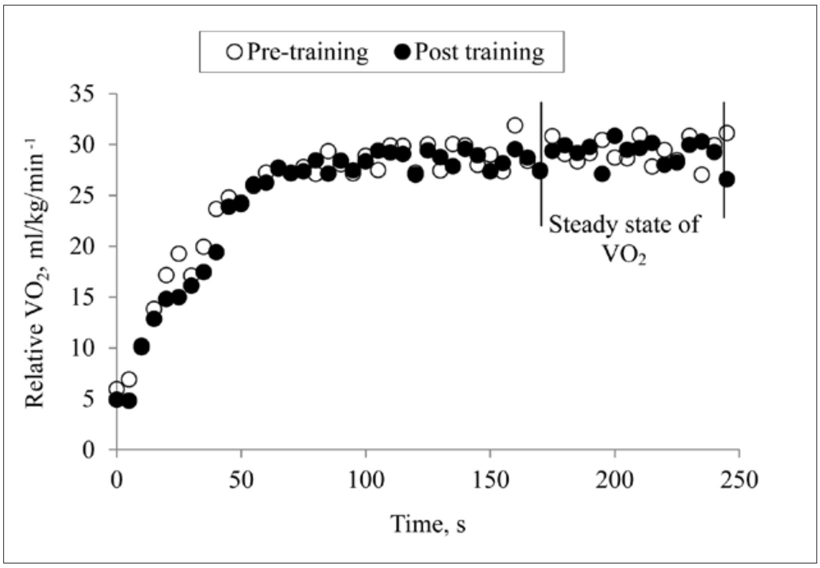


Figure 1. **Oxygen uptake average during 8 repetitions of 4 min running sessions before (●) and after (○) the training period**

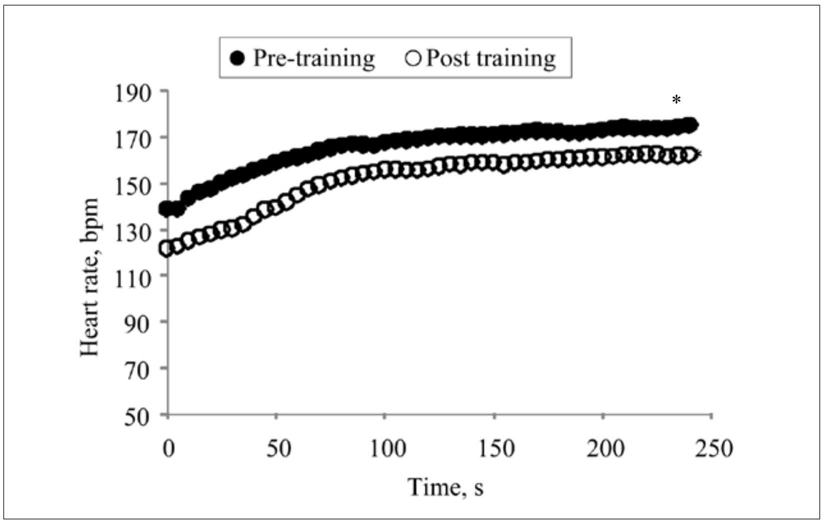
Note. * – significant difference compared to pre-training; VO_2 – oxygen uptake.

Figure 2. **Relative oxygen uptake average during 8 repetitions of 4 min running sessions before (●) and after (○) the training period**



Note. VO_2 – oxygen uptake.

Figure 3. **Heart rate 5 s interval average during 8 repetitions of 4 min running sessions before (●) and after (○) the training period**

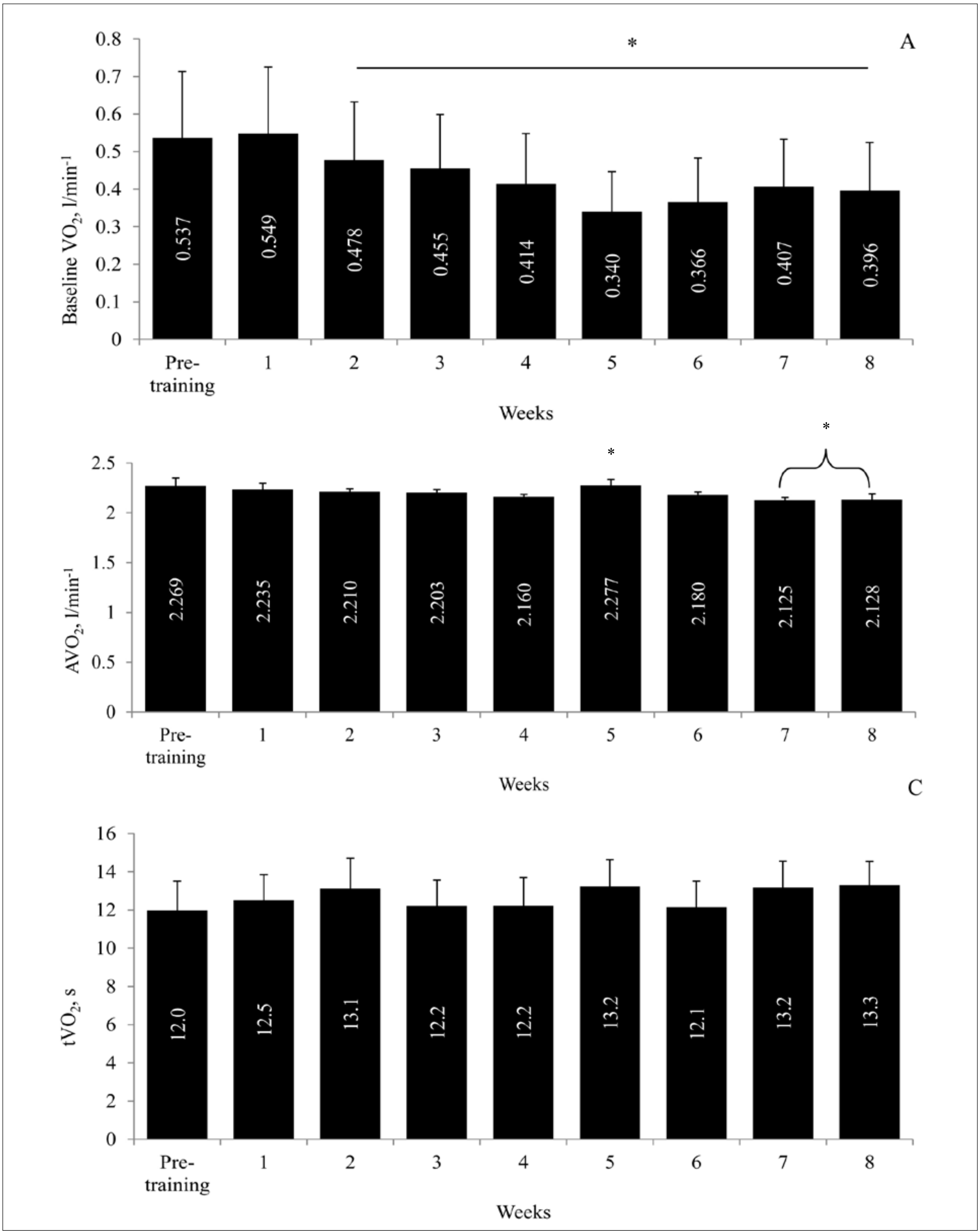


Note. * – significant difference compared to pre-training.

Table 3. **The EMG parameters during interval endurance training every two weeks**

	iEMG, mV/s-1					RMS, mV				
Muscles	**Pre-training**	**After 2 weeks**	**After 4 weeks**	**After 6 weeks**	**After 8 weeks**	**Pre-training**	**After 2 weeks**	**After 4 weeks**	**After 6 weeks**	**After 8 weeks**
Vastus lateralis	0.021 (0.001)	0.021 (0.001)	0.021 (0.001)	0.026 (0.001)*	0.028 (0.001)*	0.079 (0.004)	0.080 (0.005)	0.078 (0.003)	0.094 (0.006)*	0.092 (0.013)*
Vastus medialis	0.028 (0.001)	0.027 (0.001)	0.028 (0.001)	0.034 (0.001)*	0.042 (0.005)*	0.107 (0.007)	0.106 (0.008)	0.099 (0.003)	0.124 (0.006)*	0.137 (0.013)*
Gastrus lateralis	0.026 (0.035)	0.027 (0.001)	0.023 (0.001)#	0.025 (0.002)	0.026 (0.005)	0.095 (0.005)	0.097 (0.002)	0.082 (0.005)*	0.087 (0.005)*	0.079 (0.013)*
Gastrus medialis	0.034 (0.001)	0.040 (0.001)*	0.036 (0.001)	0.041 (0.001)*	0.051 (0.001)*	0.141 (0.006)	0.158 (0.008)*	0.141 (0.007)*	0.159 (0.005)*	0.163 (0.021)*

Note. Values presented are means ± SD. Integrate electromyogram values (iEMG); Root mean square values (RMS). * – significant difference compared to pre-training; # – significant difference compared to 2 weeks of IET.



Note. Oxygen uptake amplitude (AVO_2) and time constant of oxygen uptake (tVO_2); * – significant difference compared to pre-training.

Figure 4. **Baseline oxygen uptake (A), amplitude of oxygen uptake (B) and time constant of oxygen uptake (C) mean values every week during interval endurance training**

DISCUSSION

The main focus of this study was to determine the effects of IET on cardiorespiratory system parameters in sedentary obesity subject. We demonstrated that the two months of IET were equally effective in improving anthropometric, aerobic capacity and EMG parameters.

Different training programmes have various effects on anthropometric parameters. I. E. Schjerve and colleagues (2008) determined that aerobic training regimens had significant effect on body weight; moreover, high intensity sprint and continuous endurance training improved metabolic parameters, BMI and aerobic capacity in children. It was established that aerobic interval training and continuous moderate training led to slight reduction of 3 and 4%, respectively, in body weight (Tjonna et al., 2008). In our study we established that IET had an important effect on the anthropometric parameters (weight, BMI, fat mass, free fat mass). However, the optimal type of training capable of eliciting the most important health benefits and improve the aerobic capacity in untrained people remains debatable. A. Corte de Araujo et al. (2012) affirmed that endurance and sprint training improved aerobic capacity (VO_2max, time to exhaustion) in youth. B. R. McKay and colleagues (2009) suggested that endurance training failed to increase the absolute VO_2max, although the relative VO_2max increased by a small, but significant, amount: 2–3ml/kg^{-1}/min^{-1}. In healthy populations, high intensity training has been shown to improve VO_2max (McManus et al., 2005), maximal velocity in the incremental test, high-intensity intermittent performance, peak and submaximal oxygen pulse, and resting pulmonary function and ventilatory response to exercise. Our results are consistent with previous studies; we also determined decreases in relative VO_2max and time to exhaustion after two months of IET. These changes could be related with a decrease in body mass (McKay et al., 2009). We mentioned earlier that high intensity aerobic interval training had a higher effect on VO_2max than moderate intensity training, but our results showed that IET also improved VO_2max after 2 months. However, several short training studies (i. e. 1–3 weeks), demonstrated an increase in endurance performance and oxidative capacity without significant increases in VO_2max.

In a previous study, S. M. Phillips and colleagues (1995) reported that VO_2 kinetics became faster only after 4 days of continuous endurance training. The phase II $_tVO_2$ was reduced by ~22% after 4 days of training (i. e. from 37 to 29 s), which was similar to the ~30% high intensity training and ~17% endurance training in the present study. However, in the present study, there was a significant reduction in $_tVO_2$ after only 2 training days (~17–20% for both high intensity and endurance training. Our results differ from previous studies, we did not determine significant decrease in $_tVO_2$ after interval endurance training intervention, though baseline VO_2 decreased after 2 weeks and the amplitude of VO_2 – after 7–8 weeks of IET. H. Carter and colleagues (2000) determined that high intensity endurance training program had no effect on the kinetics of the VO_2 response to moderate exercise but it became faster during intense exercise. This tends to support the idea that VO_2 kinetics speed depends on oxygen delivery and muscle mitochondrial density with training. Another explanation is that $_tVO_2$ depends on endurance training intensity. It should be higher than 90% of VT1. Nonetheless this IET intensity is enough to improve aerobic capacity, anthropometric parameters and has effect on muscle electrical activity.

Many researchers explain the increase in EMG amplitude and iEMG as evidence of additional recruitment of motor units in order to compensate the force loss of working muscle fibres (Gandevia, 2001). EMG studies with surface electrodes during dynamic muscle contractions are rarer than those under static conditions (Enoka, Stuart, 1992). There is much disagreement about the effect of fatigue on the EMG parameters during dynamic exercise. EMG activity has been studied in conjunction with investigations of the VO_2 slow component to determine whether there is an increase in iEMG or in MPF (Perrey et al., 2001). The increase in iEMG might reflect greater total muscle fibre recruitment (Shinohara, Moritani, 1992) as fibre fatigue. During exercise, such as running, that involves eccentric and concentric muscle actions, it appears that the magnitude of the VO_2 slow component is reduced when the proportion of concentric exercise is reduced (Jones, McConnell, 1998). J. Mizrahi and colleagues (2000) determined that during 30 min running on treadmill the load was above anaerobic thresholds. In the *tibialis anterior* the average iEMG and the

MPF significantly decreased from the beginning to the end of running. In the *gastrocnemius* iEMG did not change, while MPF increased during the course of running. In the present study, iEMG and RMS significantly increased after six weeks during the IET running period in all muscles except for *m. gastrus lateralis*. The iEMG and RMS of *m. gastrus lateralis* significantly decreased respectively after four, six and eight weeks of IET.

CONCLUSION AND PERSPECTIVES

In conclusion, two months of interval endurance training has a positive effect on anthropometric parameters and aerobic capacity, though VO_2 kinetics parameters have not changed considerably. This training also influences muscle activity, iEMG and RMS significantly increased after four, six and eight weeks.

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DVIEJŲ MĖNĖSIŲ VIDUTINIO INTENSYVUMO INTERVALINIŲ IŠTVERMĖS PRATYBŲ POVEIKIS DEGUONIES KINETINĖMS YPATYBĖMS, AEROBINIAM PAJĖGUMUI IR EMG RODIKLIAMS (ATVEJO TYRIMAS)

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SANTRAUKA

Tyrimo pagrindimas ir hipotezė. Vidutinio ar mažo nenutrūkstamo intensyvumo ištvermės krūvis pagerina nesportuojančių asmenų kūno kompozicijos, aerobinio pajėgumo ar kitus su sveikata susijusius rodiklius. Visgi nėra atlikta tyrimų, kokį poveikį dviejų mėnesių vidutinio intensyvumo intervalinės ištvermės pratybos (IIT) turėtų aerobiniam pajėgumui, deguonies kinetinėms ypatybėms (VO_2), antropometriniams rodikliams ir raumenų aktyvumui.

Tikslas – įvertinti dviejų mėnesių IIT poveikį aerobiniam pajėgumui, deguonies kinetinėms ypatybėms, EMG ir kūno kompozicijos rodikliams.

Metodai. Buvo tiriama 26 metų nesportuojanti, turinti antsvorio moteris (ūgis – 180 cm; svoris – 99,1 kg; VO_2max – 37,2 ml/kg/min). Ji buvo įtraukta į dviejų mėnesių IIT ciklą. Tiriamoji turėjo trejas pratybas per savaitę, tarp kurių būdavo viena arba dvi dienos poilsio. Pratybų intensyvumas 90% nuo pirmo ventiliacinio slenksčio. Slenksčiai buvo nustatomi atliekant nuosekliai didinamą krūvį iki visiško nuovargio bėgtakiu LE 200 (VIASYS, Vokietija).

Rezultatai. Tiriamosios kūno masė po dviejų mėnesių IIT sumažėjo 10%, greitis ties pirmu ir antru ventiliaciniu slenksčiu padidėjo atitinkamai 8,1 ir 10,2%. Širdies susitraukimų dažnis (165.9 tv./min) ir absoliutus VO_2 (2.583 l/ min), užfiksuotas pirmos IIT metu, atitinkamai reikšmingai sumažėjo po pratybų ciklo (150.4 tv./min; 2.285 l/min). Reikšmingi EMG pokyčiai nustatyti po keturių, šešių ir aštuonių savaičių IIT pratybų šiuose raumenyse: šlaunies šoninio ir vidinio plačiojo, blauzdos dvilypio raumens vidinės ir šoninės galvos.

Aptarimas ir išvados. Dviejų mėnesių trukmės IIT reikšmingai paveikia aerobinį pajėgumą, kūno kompoziciją ir EMG rodiklius, tačiau tokio intensyvumo pratybos mažiau veikia deguonies kinetines ypatybes.

Raktažodžiai: ventiliaciniai slenksčiai, EMG amplitudės vidutinė kvadratinė reikšmė, maksimalusis deguonies suvartojimas.

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