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Oxygen Uptake Off-Transient Kinetics Responses to Exercises

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Abstract

The kinetics of oxygen uptake during recovery is defined off-transient kinetics (Sousa et al., 2015). The purpose of this study was to compare the VO_2 off-transient kinetics response of physical education students and also compare the different exercise intensities. Physical education students were grouped as males (n = 10) and females (n = 10). Subjects performed an incremental exercise test for the determination of cardiorespiratory responses. Subjects also performed below threshold exercise on different day. Oxygen uptake was tested via CPX Oxygen analyzer. Off-transient kinetics were modelled via mono-exponential model. The group mean of time to exhaustion was shown statistically significant difference 13±0.6 min for woman and 15±1 min for men and also, the group mean of ventilation at peak was shown statistically significant difference 88±10 L min^{-1} for woman and 127±35 L min^{-1} for men according to cardiorespiratory responses at peak exercise. Absolute VO_{2peak} (L min^{-1}), VO_{2peak} (ml min^{-1}), relative VO_{2peak} (ml kg^{-1} min^{-1}), HR_{max} (bpm), RER at exhaustion was shown no statistically significant difference between gender. The group mean of VO_{2off} (ml kg^{-1} min^{-1}) was shown statistically significant difference 36±6 for woman and 49±4 for men to the off-transient responses to peak exercise. But time constant of the off-transient response was shown no statistically significant difference (141±20 sec for woman and 127±27 sec for men) between gender. The group mean of VO_{2off} (ml kg^{-1} min^{-1}) and time constant of the off transient response was shown no statistically significant difference between gender (25±4 ml kg^{-1} min^{-1} for woman and 30±3 ml kg^{-1} min^{-1} for men; 153±29 sec for woman and 150±30 sec for men) to the off-transient responses to moderate intensity exercise. The group mean of VO_{2off} (ml kg^{-1} min^{-1}) at maximal exercise was found higher than moderate intensity exercise (p = .040) (43±8 ml kg^{-1} min^{-1} at maximal exercise and 27±4 ml kg^{-1} min^{-1} at moderate intensity exercise). The group mean of time constant of the off-transient response at maximal exercise was lower than moderate intensity exercise (p = .015) (134±24 sec at maximal exercise, 151±28 sec at moderate intensity exercise). But time constant of the off transient response was shown no statistically significant difference (141±20 sec for woman and 127±27 sec for men) between gender. The group mean of VO_{2off} (ml kg^{-1} min^{-1}) and time constant of the off transient response was shown no statistically significant difference between gender (25±4 ml kg^{-1} min^{-1} for woman and 30±3 ml kg^{-1} min^{-1} for men; 153±29 sec for woman and 150±30 sec for men) to the off-transient responses to moderate intensity exercise. The group mean of VO_{2off} (ml kg^{-1} min^{-1}) at maximal exercise was higher than moderate intensity exercise ($p = .040$) (43±8 ml kg^{-1} min^{-1} at maximal exercise and 27±4 ml kg^{-1} min^{-1} at moderate intensity exercise). The group mean of time constant of the off transient response at maximal exercise was lower than moderate intensity exercise ($p = .015$) (134±24 sec at maximal exercise, 151±28 sec at moderate intensity exercise). These findings indicate that gender and exercise intensities effect the recovery speed by speeding the rate of adjustment of oxidative phosphorylation.

Keywords: Oxygen uptake, VO_2 kinetics, Off-transient, Physical education

1. Introduction

Cardiorespiratory exercise performance was traditionally explained with VO_{2max}, exercise economy, lactate threshold, critical power (Burnley & Jones, 2007). Oxygen uptake kinetics reflects the cardiorespiratory and metabolic response to exercise (Zacca et al., 2019). Recovery period is defined as a process of returning the body to its pre-exercise state after exercise. Exercise is a stress for the human body and cause a disruption of homeostasis and with this more energy is needed during rest (Romero et al., 2017). Recovery period depends on so many factors like gender, age, height, fat free mass, hearth rate, training status, exercise intensity, and time (Romero et al., 2017).

VO_2 kinetics reflect an intramuscular signal for oxidative metabolism (Rossiter et al., 2002). The kinetics of oxygen uptake (VO_2) during recovery is defined off-transient kinetics (Sousa et al., 2015). After exercise, VO_2 remains high for metabolic process to return to resting conditions. The off-transient VO_2 responses to exercise show functionally curvi-linear fashion (Rossiter et al., 2002). Faster oxygen uptake off-transient responses were found related with repeated sprint ability (Dupont et al., 2010). Time constant reflects the speed of oxygen uptake kinetics. Acceleration of the time constant decreases the dependence on anaerobic energy sources and consequently increases tolerance to exercise by less disruption of intracellular homeostasis (Mattioni Maturana et al., 2018). Two component mono-exponential model fitted throughout the moderate exercise and recovery (Bell et al., 2001; Sousa et al., 2011). Recovery speed can be calculated via modelling mono-exponentially oxygen uptake responses data during the 5 min recovery period (Onarici Güngör et al., 2019). Oxygen uptake off-transient kinetics has been shown to consist of two components. Fast VO_2 decline phase was the definition of alactacid phase. Fosfocreatin resynthesis take place in fast phase. Blood lactate concentration does not reduce in fast phase (Margaria et al., 1933). Fast VO_2 decline found correlated with VO_{2max} (Sousa et al., 2011).

Longitudinal and cross-sectional studies were carried out about off-transient VO_2 response in recent years (Billat et al., 2002; Rossiter et al., 2002; Sousa et al., 2015). Longitudinal studies were focus on training effects on off-transient kinetics (Billat et al., 2002). Seven physical education students were tested at 90% and 95% VO_{2max} for determination of the pulmonary off-transient oxygen uptake after 4 weeks intensive interval training. Performance time, ventilation threshold time extended and time constant shortened after training (Billat et al., 2002). In another cross-sectional study six healthy subjects recruited cycle exercise test on cycle ergometer for determination off-transient response to exercise. On-transient oxygen uptake kinetics of subjects were analyzed by double-exponential and off-transient kinetics were analyzed by mono-exponential function (Ozyener et al., 2001). Oxygen uptake kinetics of eight elite swimmers were modelled via mono-exponential (Sousa et al., 2011). Off-transient kinetics was evaluated among swimmers, rowers, runners and cyclists. They found different oxygen uptake kinetic responses among different sports because of the mechanical differences of sports nature (Sousa et al., 2015). Warm-up exercises effects on oxygen uptake kinetic responses was evaluated on 10 adult cyclists (Mattioni Maturana et al., 2018).

Researches show that off-transient VO_2 kinetics were affected by training, cycling intensity, 200 m swimming effort, different exercise modes and warm up exercises of cyclists (swimmers, rowers, runners, cyclists) (Billat et al., 2002; Ozyener et al., 2001; Sousa et al., 2011; Sousa et al., 2015; Mattioni Maturana et al., 2018). According to the literature review there is no study about the off- transient kinetics of physical education students for different exercise intensities in running. The purpose of this study was to compare the VO_2 off-transient kinetics between male and female physical education students during maximal and moderate intensity treadmill running. It was hypothesized that the gender, exercise intensity would affect the VO_2 off-transient kinetics.

2. Method

2.1 Participants

Twenty Physical Education students, whose main physical characteristics (means±SD) are presented in Table 1, voluntarily participated in this study. Descriptive characteristics of physical education students were tested statistically via independent sample T test and no difference found. All participants were informed written consent before data collection.

All subjects avoided high intensity exercise in the 24 h before each test, and were well hydrated and informed not consumed food, coffee and alcohol 3 hour before testing. The protocols were applied at the same time of the day for subjects and 24-hour break was applied between tests. The Ethical Board of the Eskisehir Technical University, Faculty of Sport, approved the study design, and study carried out the Declaration of Helsinki.

Table 1. Descriptive characteristics of study subject

	Woman (n = 10)	Men (n = 10)	*t*-test p-value
Age (years)	21±2	20±2	.882
Height (cm)	167±5	178±7	.615
Body mass (kg)	61±9	71±6	.527
BMI (kg m^{-2})	22±3	22±1	.239

Note. Values are means±standard deviation. BMI: body mass index.

2.2 Experimental Design

2.2.1 Testing Procedures

Participants were tested at Human Performance laboratory two different days. In the first day VO_{2max} tests were applied and the second day constant load aerobic tests were applied.

Bruce protocol was applied for the determination of cardiorespiratory responses of participants. Constant load aerobic exercise tests were performed at 80% VO_2 at TVE work load (Sousa et al., 2015). During the first visit, height and body mass of participants were measured and body mass index was calculated as the body mass divided by the height (m) squared (Amankwaa et al., 2022).

2.2.2 Assessment of Cardiorespiratory Responses

Graded exercise tests were conducted on motorized treadmill indoors in Human Performance laboratory. Oxygen consumption was measured by indirect calorimetry (Masterscreen Cardiopulmonary Exercise Testing, USA) and calibration of device, gas analysis calibration processes are completed according to manufacturer's instructions before each test. The gas analyzer was calibrated before each test with gases of known concentration (16% O_2 and 5% CO_2). Hearth rate data were obtained by ear clip of device. Baseline hearth rate, VO_2, RER, VCO_2 data were checked and saved before test. Graded exercise test was applied until maximal performance. Participants applied Bruce graded treadmill protocol until volitional exhaustion.

2.2.3 Moderate Intensity Exercise Tests

Constant-load moderate intensity exercise tests were performed on subsequent visits to the laboratory. Exercise began with an intensity corresponding to aVO_2 of approximately 80% of the VO_2 at TVE for 30 min. After exercise competition 5 min recovery VO_2 data was recorded for analyses.

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2.3 Off-Transient VO_2 Data Analyses

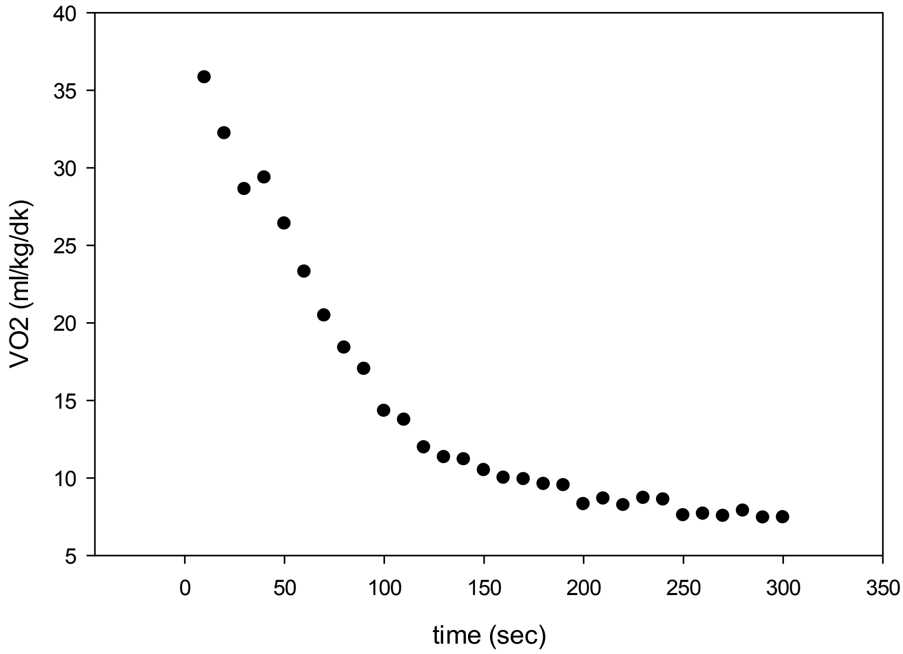

Figure 1. Scatter plot of the woman average off-transient VO_2 to maximal exercise

Scatter diagram plots of the off transient VO_2 data to maximal exercise and moderate intensity exercise for women and men were drawn individually (20 person × 2 exercise).

Scatter plot of the off-transient VO_2 to maximal exercise of woman average was shown at Figure 1 as an example.

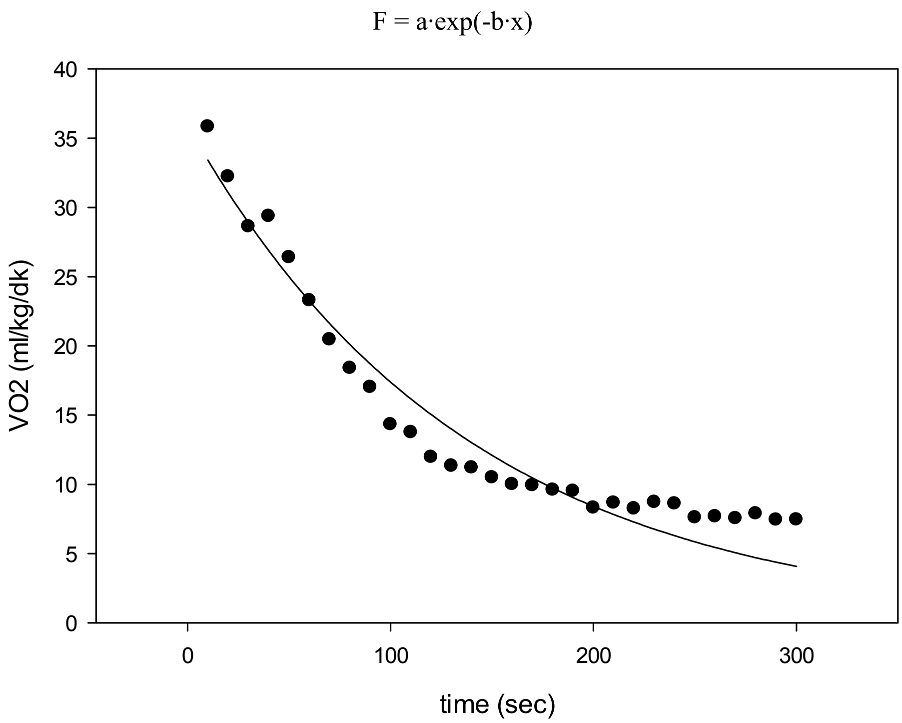

Figure 2. Exponential decay curve fitting of VO_2 response after maximal exercise

As it will be seen at Figure 2 mono-exponential decay equation model was used to fit off-transient VO_2 data. As a result of non-linear regression dynamic fitting, individually statistical data was checked from 'results for the overall Best-Fit solution'. VO_2 and time constant values were recorded according to analysis results.

2.4 Statistical Analysis

Values are presented as mean and standard deviation (SD). Shapiro-Wilk test was used to determination of normality. Individual VO_2 data was modelled mono-exponential decay function. According to results for the overall best-fit solution 'r^2' and p values were checked and then saved as a personal VO_2 off-transient kinetics data.

Independent sample T test was used for male and female descriptive statistics. Independent Sample T test was used for the gender specific analysis of the individual cardiorespiratory responses at peak exercise test and off-transient VO_2 data. Dependent sample T test was used for the comparison of different exercise intensity effects on the off-transient VO_2 response. Statistical analyses of gender differences and exercise intensity differences were performed using SPSS (version 24; SPSS). Statistical significance was set at $p < 0.05$.

3. Results

Cardiorespiratory responses at peak exercise was shown in Table 2. The group mean of time to exhaustion was shown statistically significant difference 13±0.6 min for women and 15±1 min for men. Also, the group mean of ventilation at peak was shown statistically significant difference 88±10 L min^{-1} for women and 127±35 L min^{-1} sec for men.

Other cardiorespiratory response parameters; absolute VO_{2peak} (L min^{-1}), VO_{2peak} (mL min^{-1}), relative VO_{2peak} (ml kg^{-1} min^{-1}), HR_{max} (bpm), RER at exhaustion was shown no statistically significant difference between gender.

Table 2. Cardiorespiratory responses at peak exercise

	Women (n = 10)	Men (n = 10)	*t*-test p-value
Time to exhaustion (min)	13±0.6	15±1	.025
VO_{2peak} (L min^{-1})	2.1±0.3	3.3±0.4	.260
VO_{2peak} (ml kg^{-1} min^{-1})	35±3	46±4	.081
VO_{2peak} (mL min^{-1})	2096±304	3281±420	.238
HR_{max} (bpm)	174±6	186±15	.086
VE_{peak} (L min^{-1})	88±10	127±35	.005
RER at exhaustion	1.09±0.7	1.02±0.9	.690

Note. Values are means±standard deviation; HR_{max}: hearth rate maximal; bpm: beat per minute; VE: ventilation; RER: respiratory exchange ratio.

Off-transient responses to peak exercise was shown in Table 3. The group mean of VO_{2off} (ml kg^{-1} min^{-1}) was shown statistically significant difference 36±6 for women and 49±4 for men. But time constant of the off transient response was shown no statistically significant difference (141±20 for woman and 127±27 for men) between gender.

Table 3. Comparison of the off-transient responses to peak exercise between woman and men

	Women (n = 10)	Men (n = 10)	*t*-test p-value
VO_{2off} (ml kg^{-1} min^{-1})	36±6	49±4	.000
Tau (sec)	141±20	127±27	.217

Note. Values are means±standard deviation; VO_{2off}: off transient response of VO_2 to peak exercise; Tau: time constant of the off transient response.

Off-transient responses to moderate intensity exercise was shown in Table 4. The group mean of VO_{2off} (ml kg^{-1} min^{-1}) and time constant of the off transient response was shown no statistically significant difference between gender (25±4 ml kg^{-1} min^{-1} for women and 30±3 ml kg^{-1} min^{-1} for men; 153±29 sec for woman and 150±30 sec for men).

Table 4. Comparison of the off-transient responses to moderate intensity exercise between women and men

	Women (n = 10)	Men (n = 10)	*t*-test p-value
VO_{2off} (ml kg^{-1} min^{-1})	25±4	30±3	.007
Tau (sec)	153±29	150±30	.797

Note. Values are means±standard deviation; VO_{2off}: off transient response of VO_2 to peak exercise; Tau: time constant of the off transient response.

Off-transient responses to different exercise intensities was shown in Table 5. The group mean of VO_{2off} (ml kg^{-1} min^{-1}) at maximal exercise was higher than moderate intensity exercise (p = .040) (43±8 ml kg^{-1} min^{-1} at maximal exercise and 27±4 ml kg^{-1} min^{-1} at moderate intensity exercise). The group mean of time constant of the off transient response at maximal exercise was lower than moderate intensity exercise (p = .015) (134±24 sec at maximal exercise and 151±28 sec at moderate intensity exercise).

Table 5. Comparison of the off-transient VO_2 responses to different exercise intensities

	Maximal Exercise (n = 20)	Moderate Intensity Exercise (n = 20)	t	*t*-test p-value
VO_{2off} (ml kg^{-1} min^{-1})	43±8	27±4	9.432	.040
Tau (sec)	134±24	151±28	-3.012	.015

Note. Values are means±standard deviation; VO_{2off}: off transient response of VO_2 exercises; Tau: time constant of the off transient response.

4. Discussion

Hypothesis of the gender, exercise intensity would affect the VO_2 off-transient kinetics in physical education students was supported with the results of this study. This study also compared the cardiorespiratory responses at peak exercise and off-transient VO_2 responses of 20 physical education students (men and woman).

4.1 Cardiorespiratory Responses at Peak Exercise

The mean baseline characteristics of subjects are shown in Table 1 and cardiorespiratory responses at peak exercise are shown in Table 2. Gender may differ in acute physiological response to peak exercise because of the genetic, endocrine and body composition features. However detailed physiological mechanisms remain unknown. Body size and composition is known more important factors than gender when explaining differences in cardiac dimensions between genders (Bassareo & Crisafulli, 2020). So VO_2 responses were shown also relative to body weight in this study. Absolute VO_{2peak} (L min^{-1}), VO_{2peak} (mL min^{-1}), relative VO_{2peak} (ml kg^{-1} min^{-1}), HR_{max} (bpm), RER at exhaustion was shown no statistically significant difference between gender in this study. Even though there is no statistically differences relative VO_{2peak} (ml kg^{-1} min^{-1}) of men was found % 32 higher than woman (35±3 for woman and 46±4 for men). According to literature reference values for cardiorespiratory responses on treadmill for Caucasian (n = 37) 20-29 age group VO_{2peak} (ml kg^{-1} min^{-1}) was found lower statistically significant 40.3±7.1 for woman and 48.6±9.6 for men (Edvardsen et al., 2013). Peak oxygen uptake responses of Irish students in another study on cycle (n = 24) 18-28 age group VO_{2peak} (ml kg^{-1} min^{-1}) was found lower statistically significant 32±2.0 for woman and 42.0±1.2 for men (Kilbride et al., 2003). As it was shown previous research VO_{2peak} determined by Bruce at treadmill was higher than cycling test (VO_{2peak} measured by Bruce protocol at treadmill; 56±7; VO_{2peak} measured by cycle ergometer; 48±8) (Hanson et al., 2016). That can be the reason of VO_{2max} differences between Kilbride et al. (2003) and this study. The VO_{2peak} (ml kg^{-1} min^{-1}) responses of physical education students was shown consistent with the similar age groups data in previous researches (Edvardsen et al., 2013; Killbride et al., 2003). Absolute VO_{2peak} (L min^{-1}) responses (2.1±0.3 for woman; 3.3±0.4 for men) were also shown consistent with the previous research (2.6±0.4 for woman; 3.9±0.7 for men) (Edvardsen et al., 2013). HR_{max} (bpm) responses (174±6 for woman; 186±15 for men) were found lower than the previous research conducted with Caucasian (190±7 for woman; 194±8 for men) (Edvardsen et al., 2013). But HR_{max} (bpm) responses shown similarity with Irish students (172±4 for woman; 181±4 for men) (Kilbride et al., 2003). As a cardiovascular adaptation to exercise training; trained women showing smaller cardiac volume and wall thickness than male athletes (Bassareo & Crisafulli, 2020). That can be the reason of higher HR_{max} responses of men than woman. RER at exhaustion (VCO_2/VO_2) (1.09±0.7 for woman; 1.02±0.9 for men) were found lower than the previous research (1.22±0.1 for woman; 1.23±0.1 for men) (Edvardsen et al., 2013). Gender differences of HR_{max} (bpm) and RER at exhaustion (VCO_2/VO_2) was found no statistically significant similarly (Edvardsen et al., 2013). VE_{peak} (L min^{-1}) responses of (88±10 for woman; 127±35 for men; 44% differences) were found lower than the previous research (98±15 for woman; 139±21 for men; 34% differences). But gender differences were found statistically significant similarly (Edvardsen et al., 2013). Time to exhaustion of men was found statistically significantly higher than woman (15±1 for men; 13±0.6 for women) in this study. Even though time to exhaustion of men was found higher (18.5±5.1), time to exhaustion of women was found similar values in previous prospective study of cardiorespiratory responses of 14343 individuals (Sui et al., 2009).

4.2 The Off-Transient VO_2 Responses at Peak Exercise

Graded maximal exercise elicited a maximal VO_2 at the end of exercise. The average off-transient VO_2 responses of 20 physical education students to peak exercise (men and woman) was analyzed two component mono exponential function and shown in Table 3. Asymptotic amplitudes for the exponential term was shown as VO_{2off} (ml kg^{-1} min^{-1}). VO_{2off} (ml kg^{-1} min^{-1}) of men was found higher than woman ($p = 0.000$). Although the difference is not statistically significant, as a representor of oxygen uptake off-transient kinetics speed; time constant of man, was found shorter than women. As it was shown previous research chronic adaptation to 4 weeks interval training is the acceleration in the off-transient phase of VO_2 (Billat et al., 2002). So, it means better cardiorespiratory responses results the shorter time constant. As it will be seen at Table 1, according to the cardiorespiratory responses at peak exercise (ventilation and performance time) of men is higher than women. So that can be the reason of the better off-transient VO kinetics response of men than women. Acceleration of the VO_2 off-transient kinetics response explained by better recovery period. So as a result of this study it can be said that recovery period is faster in men than woman.

4.3 The Off-Transient VO_2 Responses at Moderate Intensity Exercise

Moderate exercise elicited a steady state VO_2, HR, ventilation (Bell et al., 2001). As it was shown in Table 4, the average off-transient VO_2 responses of students to moderate exercise was shown no differences between gender. The reason of the similar off-transient VO_2 responses is thought to be the exercise intensity. Ten male and ten women physical education students tested in this study. Similarly, with the subject group active but non-endurance trained seven male physical education students off-transient VO_2 kinetics tested after 4 weeks training. They found the faster VO_2 off-transient response to maximal exercise (Billat et al., 2002). It can be considered that moderate exercise does not have a predictive intensity in determining off-transient VO_2 kinetics.

4.4 The Influence of Exercise Intensity on the Off-Transient VO_2 Responses

As it was shown at Table 5, the off-transient responses [VO_{2off} (ml kg^{-1} min^{-1}) and tau (sec)] to different exercise intensities was shown statistically significant differences between maximal and moderate intensity running's in this study. Effect of exercise intensity on the off-transient kinetics on 6 healthy males on cycling (aged between 22-58) was determined via mono-exponential model for heavy and moderate exercise similar with this study (Ozyener et al., 2001). Although the modelling of VO_2 data was shown similarity, subjects of the studies [(Ozyener's subjects; 6 males (22-58 aged); this study's subjects 20 physical education students (21±2 aged 20 women and 20±2 aged 20 men)] and exercises (cycling, running) were different between Ozyener's study and this study. In another research about the influence of exercise intensity on the off-transient response shows similar results with this study. Similarity of the performance of the subjects (n = 14) of Simões et al., 2013's study (VO_{2max} = 36±5) and this study (VO_{2max} = 35±3) can be the reason of similar off-transient responses.

The off-transient VO_2 kinetics speed between woman and men shows similar results of this study. But it is known that gender is less important than body size and composition (Bassareo & Crisafulli, 2020). So, body size, composition also performance effects on the off-transient VO_2 kinetics should be investigated.

In conclusion, this study shows that the off-transient VO_2 kinetics at recovery phase in physical education students would change via exercise intensity.

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