

MUSCLE OXYGENATION DURING EXERCISE IN PHYSICALLY ACTIVE AND OVERWEIGHT 6–19-YEAR-OLD CHILDREN

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ABSTRACT

Background. The purpose of our study was to compare muscle oxygenation during walking exercise in physically active, non-physically active normal weight and overweight 6–19-year-old children.

Methods. Twenty four normal weight, physically non-active (NPA), 27 normal weight physically active (PA) and 17 overweight (OW) 6–19-year-old children participated in this study. Muscle oxygenation was recorded by near infrared spectroscopy during constant (6 min, 6 km/h, 4% grade) and increasing walking exercise (modified Balke test). Heart rate was recorded using Polar system.

Results. Overweight children of all age groups demonstrated slower time constant of muscle oxygenation during constant walking exercise (37.2 ± 3 (6–10-year-old); 29.7 ± 2 (11–15-yr old), 33.4 ± 5.1 (16–19-year-old)) and lower threshold of oxygenation (TO) (84.3 ± 10.1 , 104.5 ± 17.1 , 188.5 ± 69.4 respectively) during increasing walking exercise as compared NPA (111.8 ± 13.7 , 124.4 ± 29.8 , 192.6 ± 84 respectively) and PA (106.2 ± 35.2 ; 122 ± 13.3 ; 340.8 ± 44.2 respectively) peers. The time constant of Deoxy-Hb during constant walking exercise was the shortest in PA (16.7 ± 2.3 , 16.9 ± 2 , 15.5 ± 4.7 respectively) in all age groups. The TO was higher in PA as compared to NW only in 16–19 years of age.

Conclusion. Muscle oxygenation during constant or increasing exercise is dependent on both body weight and physical activity status in 6–19-year-old children.

Keywords: muscle oxygenation, children, physical activity, overweight.

INTRODUCTION

More favorable biological cardiovascular disease risk-factor, such as low blood pressure, has association with psychological health, such as higher levels of self-esteem, and lower levels of anxiety and stress have associations with physical activity in young age. In childhood, physical activity maintains an appropriate bone strength, and it contributes to normal skeletal development (Van der Hors, Paw, Twisk, & Van Mechelen, 2007). Physical activity has positive influence on VO₂ max and blood cholesterol (Dobbins, Husson, DeCorby, & LaRocca, 2013). Children display a faster exponential rise in the phase II pVO₂ kinetics, which can be the rise in muscle O₂ consumption during different intensity

exercises (Armstrong, Tomkinson, & Ekelund, 2011). Fawcner, Armstrong, Potter, and Welsman (2002) reported faster VO₂ kinetics in children than adults. Some studies showed no difference in kinetics (Hebestreit, Kriemler, Hughson, & Bar-Or, 1998).

Even 49% of children are less physically active that 60 min per day nowadays (Harrison et al., 2017). Since physical activity is decreasing, overweight and obesity among adults and children are increasing. Pediatric obesity can harm multiple body systems: respiratory system, including pulmonary function, exercise intolerance, gas exchange, and airway musculature (Durbin et al., 2017). Maximum oxygen uptake ($\dot{V}O_{2max}$) may

not be achieved due to reduced motivation and peripheral fatigue among overweight and obese children (Dias et al., 2017). Ventilatory anaerobic threshold and maximal oxygen uptake related to body weight are lower in the obese than in normal weight 9–14-year-old children (Zanconato et al., 1989). The pulmonary oxygen uptake response is deleteriously influenced by obesity in prepubertal children (McNarry, Lambrick, Westrupp, & Faulkner, 2015). Obese children demonstrate significantly slower VO_2 kinetics compared to normal weight children during moderate- and heavy intensity exercise (Lambrick, Faulkner, Westrupp, & McNarry 2013).

Near-infrared spectroscopy (NIRS) has been used to determine the concentration of light-absorbing chromophores (Ferreira, Hueber, & Barstow, 2007). NIRS is a noninvasive and direct method to determine oxygenation in tissue (Van Beekvelt, Colier, Wevers, & Van Engelen, 2001). Respiratory muscles deoxygenate during incremental exercise and ventilatory threshold can be determined by NIRS in children (Moalla, Dupont, Berthoin, & Ahmaidi, 2005).

The mean time response for muscle tissue deoxygenation is significantly faster in children than adults at the onset of high intensity exercise (Willcokes, Williams, Barker, Fulford, & Armstrong, 2010). 13–17-year-old boys demonstrate significant changes in absolute hemoglobin concentrations and oxygenation in the exercising muscle during incremental cycling and post-exercise recovery (Ganesan et al., 2016). 9-year-old girls demonstrate an earlier change in [HHb] compared with same age boys during ramp incremental exercise (McNarry et al., 2015). Also, prepubertal, pubertal, postpubertal trained girls demonstrate a significant rightward shift in the sigmoidal response of [HHb] compared with untrained girls (McNarry et al., 2010). The muscle oxygenation and blood volume curves decreased immediately at the beginning of maximal voluntary isometric exercise among 12-year-old untrained children (Moalla, Merzouk, Costes, Tabka, & Ahmaidi, 2006). Also, Vandekerckhove, Coomans, Moerman, De Wolf, and Boone (2016) assessed muscle oxygenation responses and found that they undergo significant changes as work rate increases at high intensity and are strongly interrelated and associated with changes in pulmonary gas exchange.

Training-induced adaptation in aerobic fitness and muscle oxygenation among adults is carefully analyzed, but findings in children still are not clear. Muscle oxygenation in separate children age groups during different exercise load were investigated. No research investigating muscle oxygenation in 6–19-year-old physically active and overweight children was found.

The purpose of our study was to compare muscle oxygenation during treadmill exercise in physically active, non-physically active normal weight and overweight 6–19-year-old children.

METHODS

Participants. Twenty-four normal weight, physically non-active (NPA) 6–19-year-old, 27 normal weight physically active (PA) 6–19-year-old and 17 overweight (OW) 6–19-year-old children participated in this study. OW status was established using age, height and weight. Written informed consent was obtained from the parents and written assent – from the participants. The children were screened using international physical activity questionnaire (IPAQ). The causes which eliminate participants from research were: heart disease, diabetes, epilepsy, musculoskeletal problems.

Ethical approval for the research was obtained from Kaunas regional Ethics Committee.

Measurements. Participants height was measured using stadiometer to the nearest 0.01 m. Body mass was measured using body composition analyzer “TBF-300” (Japanese) to the nearest 0.1 kg beam. BMI was calculated body mass (kg) dividing by height squared (m^2).

Heart rate (HR) was measured with “Polar” system.

Muscles oxygenation was measured using a tissue near infrared spectrometer (NIRS) (Standard System Model 325, Hutchinson Technology). The detector for recording of infrared signal was placed on the left leg (m. vastus lateralis). Before applying the probes, the skin under the probes was shaved if it was necessary. The NIRS detector was fixed to the leg with black rubber holders and adhesive tape to minimize incidental movement. The muscle oxygenation measurements (oxygenated, deoxygenated and total hemoglobin) were collected continuously every 3–5 s throughout the entire protocol. The sample rate was set to 1Hz.

Table 1. Participants' characteristics

Years	NPA			PA			OW		
	6–10	11–15	16–19	6–10	11–15	16–19	6–10	11–15	16–19
Age (yr)	8.3 ± 1.96	11.16 ± 0.4	18.66 ± 0.89	9.37 ± 1.14	12 ± 1	19 ± 1	9 ± 0.6	13 ± 0.71	17.83 ± 1.47
Height (cm)	134.3 ± 24.1	150.83 ± 2.79	179.83 ± 12.9	142.25 ± 10.57	152.6 ± 6.1	184.66 ± 4.32	145.3 ± 8.1	164 ± 5.48	178.66 ± 4.97
Weight (kg)	34.3 ± 7.15	41.86 ± 5.06	69.74 ± 15.25	37.39 ± 7.02	42.8 ± 3.9	76.33 ± 7.12	46.16 ± 6.4	72.4 ± 7.54	91.5 ± 9.85
BMI (kg/m ²)	18.94 ± 1.2	17.75 ± 0.68	21.5 ± 1.02	18.35 ± 1.3	18.5 ± 1.56	22.4 ± 0.7	26.1 ± 1.44	26.7 ± 1.6	28.7 ± 1.25

Constant walking exercise. It was 6 min walking at 6 km/h speed and a 4% grade treadmill test. During each session StO₂ data were collected at subject's rest and during walking (at 6 km/h and a 4% grade treadmill) for 6 minutes. The testing protocol was then started as follows: 1min baseline with participants standing on the treadmill; 3-min unloaded warm-up, participants slowly walked on treadmill (at 3 km/h, 0% grade); brake for 1 min (treadmill lifts up till 4% upgrade, speed increase till 6km/h, participants were standing on the sides of treadmill); participants were walking 6 min (at 6 km/h and 4% grade treadmill); participants were resting for 5 min in lying down position.

Increasing walking exercise. It was modified Balke test. Following a 1 min period of standing gas exchange, subjects began a step transition into a 3-minute stage at 3 km/h speed and 0% grade. The progressive protocol continued with a 4-min stage at 6 km/h and grade of treadmill was increased to 2, 4, 6, 8, 10% and so far till subject can continue. Subjects were verbally encouraged to give maximal effort during the test until volitional exhaustion was achieved. StO₂ data were collected at subjects during test and in resting.

Study design. Participants started the experimental procedure at least intense exercise for 24 h before testing. Participants had to come to laboratory 2 times.

Two consecutive walking exercises sessions (separated by 45 min) were performed on the first arrival.

Increasing walking exercise – Balke – was performed the next week after consecutive walking exercise (the second arrival time). Participants were walking on the treadmill at 6km/h speed, every minute treadmill angle was raising up 2 degrees during high intensity test. Subjects continued walking till exhaustion.

Data analysis. The kinetics deoxygenized hemoglobin (Deoxy-Hb) was assessed applying monoexponential equation $\text{Deoxy-Hb}(t) = \text{Deoxy-Hb}(b) + A(1 - e^{-t/\tau})$, where Deoxy-Hb (t) is the Deoxy-Hb at any time point; Deoxy-Hb (b) is the baseline Deoxy-Hb at rest (standing); A is the amplitude of Deoxy-HB response, and $(1 - e^{-t/\tau})$ is the exponential function describing the rate at which Deoxy-Hb is rising towards the amplitude. In the exponential function, t is time; τ is the time constant.

Threshold of muscle oxygenation (TO) was calculated analysing relationship between Deoxy-Hb and walking power during increasing walking exercise. The power at which Deoxy-Hb started to decrease was considered as TO.

Statistical analysis. All statistical analyses were performed using SPSS version 22.0. All values were expressed as mean ± standard deviation. Comparison of threshold of oxygenation, muscle oxygenation time constant and HR were analyzed by nonparametric data analyze Mann - Whitney Test. Significance was accepted at $p < .05$.

RESULTS

Time constant kinetics of Deoxy-Hb during constant walking exercise was significantly different ($p < .05$) among all age groups: 6–10-year-old group PA (16.7 ± 2.3), NPA (21.7 ± 1.5), OW (37.2 ± 3.1); 11–15-year-old group PA (16.9 ± 2), NPA (20.2 ± 1.3), OW (29.7 ± 2.8), 16–19-year-old group PA (15.5 ± 4.7), NPA (19.9 ± 2.3), OW (33.4 ± 5.1) (Figure 1).

TO during increasing walking exercise was significantly different between 6–10-year-old PA (106.2 ± 35.2) and OW (84.3 ± 10.1) groups and between NPA (111.8 ± 13.7) and OW (84.3 ± 10.1) groups ($p < .05$), between 11–15-year-old PA ($122 \pm$

13.3) and OW (104.5 ± 17.1) groups and between NPA (124.4 ± 29.8) and OW (104.5 ± 17.1) groups ($p < .05$), between 16–19-year-old PA (340.8 ± 44.2) and OW (188.5 ± 69.4) groups and PA (340.8 ± 44.2) and NPA (192.6 ± 84) groups ($p < .05$). There were no significant differences in TO between 6–10-year-old PA (106.2 ± 35.2) and NPA (111.8 ± 13.7) groups, 11–15-year-old PA (122 ± 13.3) and NPA (124.4 ± 29.8) and 16–19-year-old OW (188.5 ± 69.4) and NPA (192.6 ± 84) groups ($p > .05$) (Figure 2).

Relative threshold of muscle oxygenation (RTO) during increasing walking exercise was significant different ($p < .05$) between NPA (3.25 ± 0.7) and

OW (1.49 ± 0.45), PA (2.84 ± 0.56) and OW (1.49 ± 0.45) in 6–10-year-old group, between NPA (2.97 ± 0.54) and OW (1.82 ± 0.45), PA (3.06 ± 0.23) and OW (1.82 ± 0.45) in 11–15-year-old group, between NPA (2.76 ± 0.65) and OW (2.06 ± 0.43), PA (4.46 ± 0.75) and OW (2.06 ± 0.43), NPA (2.76 ± 0.65) and PA (4.46 ± 0.75) in 16–19-year-old group. There was no significant difference ($p > .05$) between NPA (3.25 ± 0.7) and PA (2.84 ± 0.56) in 6–10-year-old group, between NPA (2.97 ± 0.54) and PA (3.06 ± 0.23) in 11–15-year-old group (Figure 3).

Heart rates during increasing walking exercise in NPA, PA and OW groups were not significantly different ($p > .05$) (Figure 4).

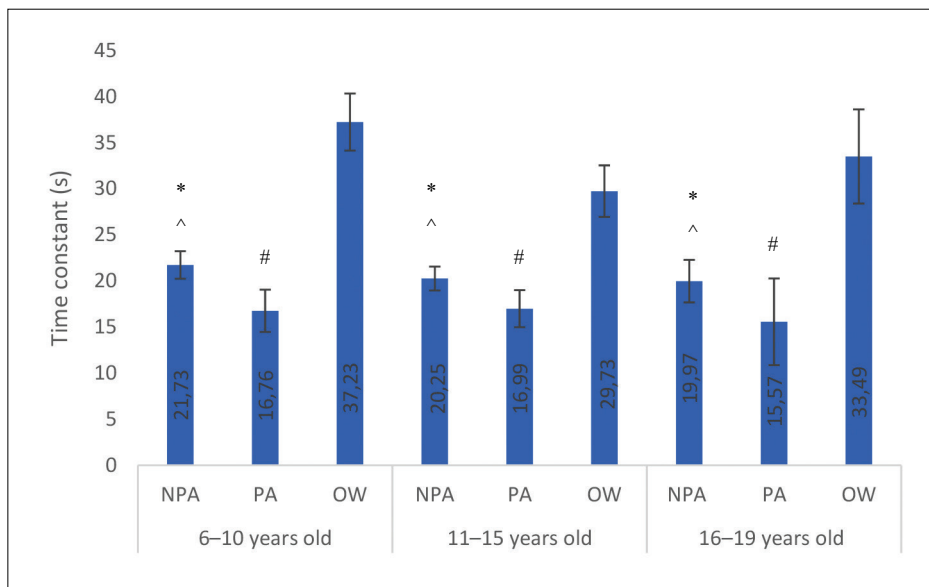


Figure 1. Time constant of muscle oxygenation kinetics during constant walking exercise in non-physically active (NPA), physically active (PA) and overweight (OW) 6–19-year-old children

Note. * significant difference between NPA and OW ($p < .05$), # significant difference between PA and OW ($p < .05$), ^ significant difference between NPA and PA ($p < .05$).

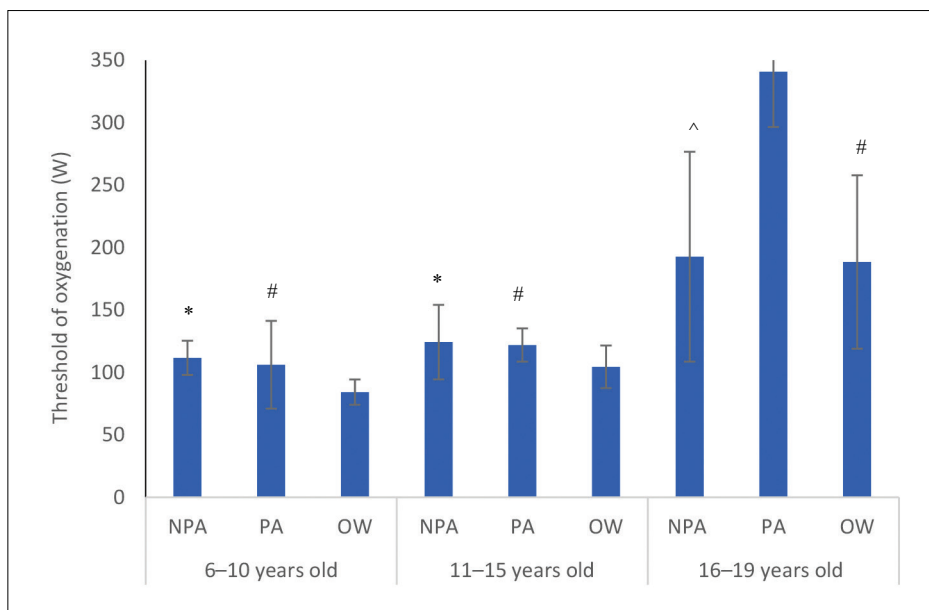
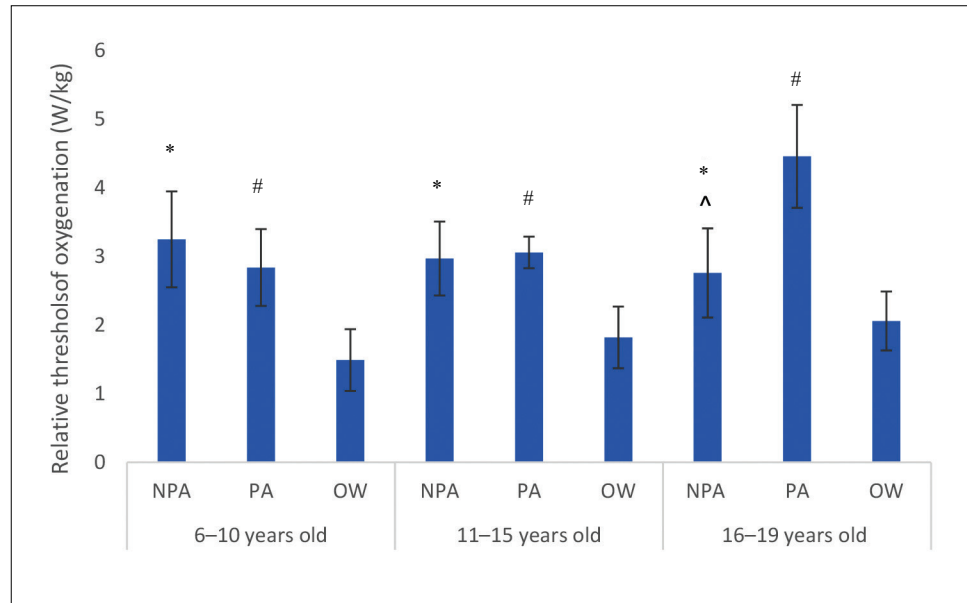


Figure 2. Threshold of muscle oxygenation during increasing walking exercise in non-physically active (NPA), physically active (PA) and overweight (OW) 6–19-year-old children

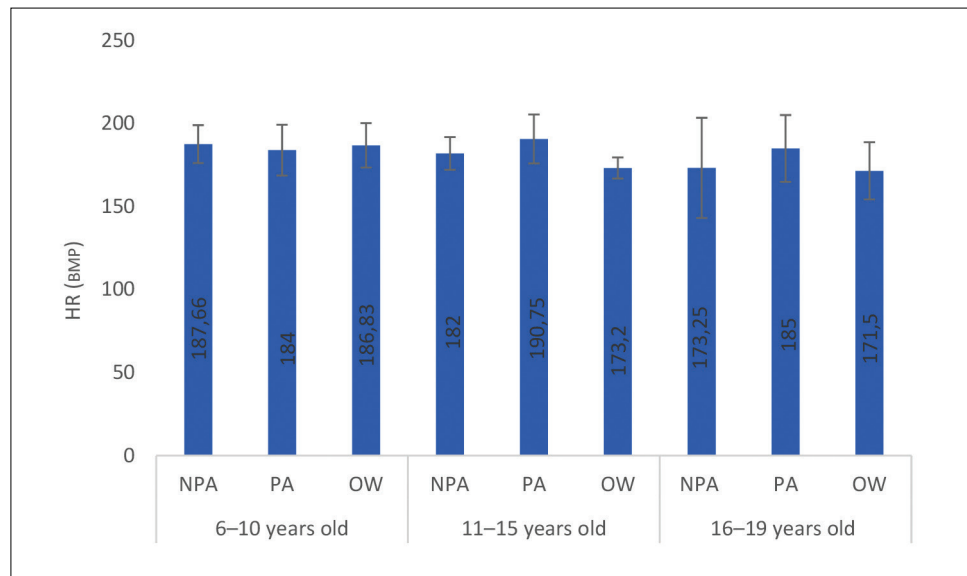
Note. * significant difference between NPA and OW ($p < .05$), # significant difference between PA and OW ($p < .05$), ^ significant difference between NPA and PA ($p < .05$).

Figure 3. **Relative threshold of muscle oxygenation during increasing walking exercise among non-physically active (NPA), physically active (PA) and overweight (OW) 6–19-year-old children.**



Note. * significant difference between NPA and OW ($p < .05$), # significant difference between PA and OW ($p < .05$), ^ significant difference between NPA and PA ($p < .05$).

Figure 4. **Heart rates during increasing walking exercise in non-physically active (NPA), physically active (PA) and overweight (OW) 6–19-year-old children**



DISCUSSION

Our findings confirm slower muscle oxygenation and faster peripheral fatigue among overweight and non-physically active children of 6–19-year-olds compared with physically active children of the same age. Similar findings were detected by other researchers: Breese with coworkers (2010) found that high – intensity exercises have influence not only on slower phase II τ and a greater pVO_2 slower component but also hypothesized about age dependent change in muscles and mitochondrial oxidation and differences in muscle fiber recruitment patterns. It is

known that trained adults and children have more developed muscles. This leads to the bigger number of mitochondrias, therefore physically active children demonstrate slower peripheral fatigue compared with non-physically active children. Our findings demonstrate faster changes in [HHb] among 6–19-year-old physically active children compared with same age non-physically active children and overweight children.

Since the capacity of sustainable exercise depends on supplying the contrasting muscle with O_2 in proportion to their metabolic requirements

(Okushima et al., 2015), physically active children demonstrate better endurance compared with overweight or physically non-active children.

Our research involved children of various ages (6–19 years old), some results might be and are influenced by puberty. The peak VO_2 increases with age and maturation. The responses of the components of aerobic fitness vary in relation to age and maturation during youth. Physically active children demonstrate higher peak VO_2 , a faster primary time constant at the same relative exercise intensity compared with same age physically non-active and overweight peers. Our findings are in agreement with those of Armstrong et al. (2011) and McNarry et al. (2012).

Since we did not find any research in muscle oxygenation changes among overweight or obese children and it is confirmed that NIRS significantly positively correlate with peak VO_2 , so we can compare our findings with those of other researchers who evaluated oxygen uptake differences among overweight children. Overweight children demonstrated the worst muscle oxygenation in all age groups compared with physically active and non-physically active children. Since ventilatory threshold could be determined by NIRS (Moalla et al., 2005) our findings are supported by Lambrick and colleagues' (2013) findings that pre-pubertal obese children during moderate and high intensity treadmill exercise demonstrated significantly worse results. During moderate intensity exercise, the phase II τ , mean response time, phase II gain and oxygen deficit were significantly higher in the obese children. During high intensity exercise, the τ and phase II gains were similarly higher in the obese children.

Ratel and Blazeovich (2017) state that prepubertal children were metabolically comparable to well-trained adult endurance athletes because of faster contribution of energy delivery from aerobic metabolism in working out muscle and reduced susceptibility to muscular fatigue. The results of our research support Ratel and Blazeovich (2017), there were no significantly different results in muscle oxygenation among 6–10-year-old non-physically active and 6–10-year-old physically active children, as well as among 11–15-year-old non-physically active and 11–15-year-old physically active children.

Heart rate was not significantly different among physically active, non-physically active

and overweight children of 6–19-year-olds. Mean of heart rate was similar in all groups. It might be because overweight children got tired very fast, physically active children completed high intensity treadmill test, but did not reach the maximal heart rate. Our findings agree with those of Cheatham, Mahon, Brown, and Bolster (2000) who found out that responses of cardiovascular system were similar among boys (10–13 yr) and men (18–25 yr). We did not find research to confirm or deny our findings in children population, but Gayda et al. (2017) found that obese adults have a lower VO_2 peak and muscle oxygenation, higher systolic blood pressure compared to non-obese peers during maximal cardiopulmonary exercise testing on ergo cycle. The reason of lower VO_2 and muscle oxygenation possibly is a lower mitochondrial density/function, oxygen transport capacity and to endothelial dysfunction. These findings demonstrate risks that overweight, obesity and physical inactivity can have consequences for overweight and non-physically children and adolescents in the future.

Time constant was significantly different among children of different age and fitness. Physically active participants demonstrated faster mean response time of muscle deoxyhemoglobin compared with physically non-active and overweight children. Our findings agree with those of Marwood, Roche, Garrard, & Unnithan (2011), who assessed trained and untrained 15-year-old young males. Researchers found that trained subjects demonstrated faster mean response time of muscle deoxygenation compared with untrained individuals in exercise at a workload equivalent to 80% lactate threshold (trained 24.2 ± 9.2 s vs. untrained 34 ± 13 s). Our findings demonstrate that in all age groups (6–10, 11–15, 16–19 yr) the slowest mean response time of muscle deoxygenation was in overweight children groups. Obesity and overweight can affect respiratory system by several mechanisms: direct effect of fat in the chest wall, abdomen reduces lung volume, particularly expiratory reserve volume and causes structural changes (Brazzale, Pretto, & Schachter, 2015).

CONCLUSION

Muscle oxygenation during constant or increasing exercise is dependent on both body weight and physical activity status in 6–19-year-old children.

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