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Monitoring pulmonary VO_2 on-kinetics during a 3-year period in youth elite-cyclists

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Abstract: Pulmonary oxygen uptake on-kinetics provide insights into the processes underlying the increase in O_2 flux from ambient air to muscle mitochondria following the onset of exercise. It is well known that aging from childhood to adulthood has a detrimental effect on the oxygen uptake on-kinetic response. Therefore, the aim of this study was to investigate the effects of aging on pulmonary oxygen uptake on-kinetics in nine youth elite-cyclists throughout a period of ~3 years. Participants visited the laboratory twice on three occasions within ~3 years. Anthropometric measures, a graded ramp-exercise test and two square-wave transitions from baseline to a constant work-rate within the moderate and heavy intensity exercise domain, respectively were conducted during these visits. The parameter estimates of the oxygen uptake on-kinetic response were resolved by least-squares non-linear regression. A repeated measures ANOVA was used for statistical analyses and the level of statistical significance was set at $P < 0.05$. During moderate and heavy intensity exercise, the time constant and the amplitude of the primary phase improved over time ($P < 0.01$). However, the slow component evident during heavy intensity exercise was not significantly affected by time ($P > 0.05$). These results suggest that regularly performed endurance training of elite youth-cyclists augments the potential for oxidative phosphorylation and reduces the impairments normally observed with aging.

Keywords: VO_2 kinetics, endurance performance, youth athletes, oxidative phosphorylation, longitudinal monitoring

1. Introduction

Pulmonary oxygen uptake (VO_2) on-kinetics provide insights into the processes underlying the increase in O_2 flux from ambient air to muscle mitochondria following the onset of exercise. Therefore, the VO_2 on-kinetic response is related to the O_2 debt and ultimately exercise tolerance (Poole & Jones, 2012; Whipp & Wasserman, 1972).

A detrimental effect of aging (i.e. from childhood to adulthood) on the primary VO_2 on-kinetic response and slow component has been shown consistently by a number of longitudinal and cross-sectional studies (Breese et al., 2010; Cooper et al., 1985; Fawkner & Armstrong, 2004; Fawkner et al., 2002; Leclair et al., 2013; McNarry, 2019; Williams et al., 2001).

Therefore, the purpose of this study was to investigate the effects of aging on pulmonary VO_2 on-kinetics during moderate and heavy intensity exercise in youth elite-cyclists throughout a period of ~3 years.

2. Materials and Methods

Nine trained youth elite-cyclists participated in this investigation. Prior to the study, the athletes and their legal guardians were informed of the experimental procedures and gave written informed consent to participate. The study was conducted in accordance with the Declaration of Helsinki and approved by the institutional review board.

Participants visited the laboratory twice on three occasions within a period of ~3 years (Feb-2017, May-2018, Sep-2019). Anthropometric measures and a graded ramp-exercise test (GXT, 20 $W.min^{-1}$) to determine peak oxygen uptake (VO_{2peak}), maximal power (W_{max}), ventilatory threshold (VT) and the intensity corresponding to 50% between VT and W_{max} (Δ50%) were conducted during the first visit (see table 1 for participant characteristics). On a subsequent visit, participants performed two square-wave transitions from a 3-min baseline at 40 W to a work-rate corresponding to 90% VT (moderate intensity) and Δ50% (heavy intensity), respectively. All tests were conducted on the participants own road bikes mounted on a Cyclus 2 ergometer (RBM Electronics, Leipzig, Germany). Gas exchange and pulmonary ventilation were measured continuously during the GXT and breath-by-breath during the square-wave transitions with a portable gas analyzer (MetaMax 3B, Cortex Biophysik, Leipzig, Germany).

To determine VO_2 kinetic parameters, breath-by-breath data were filtered, linearly interpolated at 1-second intervals and time aligned to the onset of exercise. To account for the cardio-dynamic phase the first 20 s of each square-wave transition were excluded from further analyses. The parameter estimates of the exponential primary phase (i.e. time constant (τ), amplitude) were resolved by least-squares regression (GraphPad Prism 8.4.3, GraphPad Software Inc., San Diego, CA, USA). The VO_2 slow component evident during heavy intensity exercise was calculated as the difference between end-exercise VO_2 and the amplitude.

Descriptive data are presented as mean ± standard deviation (SD). A repeated measures ANOVA was used for statistical analyses. Tukey's post-hoc test was used for multiple pairwise comparisons. The level of statistical significance was set at $P < 0.05$ two tailed for all tests.

Table 1. Participants anthropometric characteristics and results of the graded ramp-exercise test as mean ± SD (n = 9).

	Feb 2017	May 2018	Sep 2019
Age (years)	14.5 ± 1.1	15.7 ± 1.0	16.7 ± 1.2
Stature (cm)	165 ± 13	171 ± 11	175 ± 11
Body mass (kg)	53.9 ± 12.7	59.1 ± 11.7	64.0 ± 11.1
WR[1] 90% VT[2] (W)	127 ± 27	135 ± 30	170 ± 34
WR[1] Δ50% (W)	218 ± 44	243 ± 48	279 ± 5
VO_{2peak}[3] ($mL \cdot min^{-1} \cdot kg^{-1}$)	62.6 ± 4.2	61.1 ± 4.6	68.4 ± 7.6
W_{max}[4] (W)	296 ± 58	332 ± 65	371 ± 65

[1] work-rate, [2] ventilatory threshold, [3] peak oxygen consumption, [4] maximal power.

3. Results

The parameter estimates of the primary phase VO_2 response for both square-wave transitions throughout the study are shown in figure 1. During moderate and heavy intensity exercise, τ significantly improved (i.e. was reduced) over time (90% VT: $F_{2,16} = 7.18$, $P = 0.006$; Δ50%: $F_{2,16} = 14.70$, $P < 0.001$). As a result of the increased work rate during moderate and heavy intensity exercise, the amplitude significantly increased over time (90% VT: $F_{2,16} = 27.40$, $P < 0.001$; Δ50%: $F_{2,16} = 23.41$, $P < 0.001$). For multiple pairwise comparisons see figure 1.

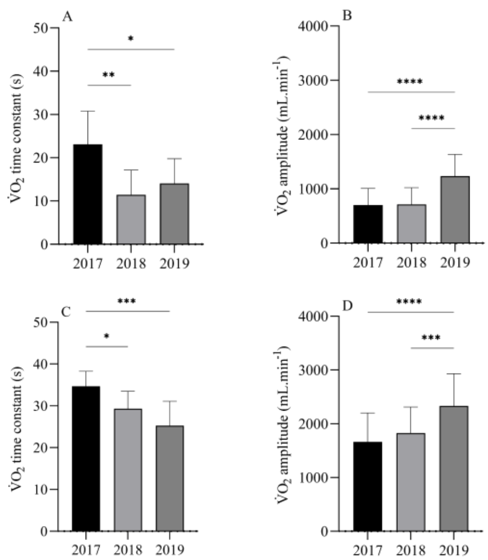

Figure 1. Primary phase VO_2 time constant (Panel A: 90% VT, Panel C: Δ50%) and amplitude (Panel B: 90% VT, Panel D: Δ50%) throughout the study duration. Tukey's post-hoc test: * P < 0.05. ** P < 0.01. *** P < 0.001. **** P < 0.0001. VT = ventilatory threshold.

The VO_2 slow component was not significantly affected by time (absolute: $F_{2,16}$ = 3.34, P = 0.061, relative: $F_{2,16}$ = 0.76, P = 0.456, see figure 2).

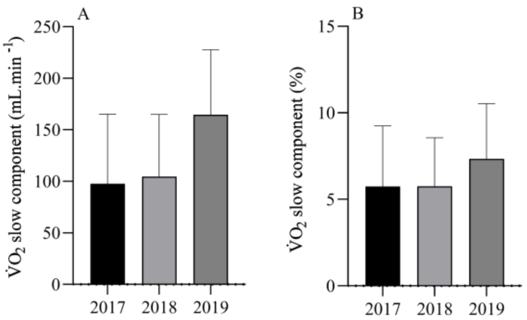

Figure 2. Heavy intensity exercise VO_2 slow component absolute (Panel A) and relative to the amplitude (Panel B) throughout the study duration.

4. Discussion

The findings of this study are not in line with previous longitudinal and cross-sectional studies showing increases of the moderate and/or heavy intensity exercise primary phase τ and the VO_2 slow component in untrained individuals with age (i.e. from childhood to adulthood). These previous findings suggest that aging (i.e. from childhood to adulthood) is related with a slowing and augmentation of the primary phase τ and the VO_2 slow component, respectively and therefore reduces the potential for oxidative phosphorylation at the onset of exercise (Armstrong & Barker, 2009; Breese et al., 2010; Cooper et al., 1985; Fawkner & Armstrong, 2003; Fawkner & Armstrong, 2004; Fawkner et al., 2002; Leclair et al., 2013; McNarry, 2019; Williams et al., 2001). In contrast, the results of the current investigation suggest that regularly performed endurance training of elite youth-cyclists augments the potential for oxidative phosphorylation and reduces the impairments normally observed with aging. However, these results must be interpreted with caution due to the lack of a control group.

5. Practical Applications

Monitoring the pulmonary VO_2 on-kinetics may yield important information about the potential for oxidative phosphorylation at the onset of exercise during the long-term athletic development of youth elite-cyclists.

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