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The higher fraction of $\dot{V}O_{2max}$ during interval training, the greater gains in performance

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1. Introduction

Exercising at intensities near the body's maximal oxygen consumption (VO_{2max}) is argued to stress the oxygen delivery and utilization system, hence providing an effective physiological stimulus for enhancing VO_{2max} (Buchheit & Laursen, 2013; Midgley et al., 2006). The favorable muscular adaptations facilitated by exercising at this intensity, i.e. capillary growth and improvements in mitochondrial functions (Granata et al., 2018; Liu et al., 2022), are also associated with improvements in fractional utilization of VO_{2max} (Coyle, 1995). High-intensity interval training (HIT) is therefore considered an highly effective training modality for improving endurance performance (Buchheit & Laursen, 2013).

The fraction of VO_{2max} achieved during a HIT session and the time it is sustained ≥ 90% of VO_{2max} have been suggested as good criterions for judging the effectiveness of the session (Thevenet et al., 2007). However, scientific findings supporting this assumption are surprisingly still unavailable (Midgley et al., 2006; Turnes et al., 2016). No study has continuously measured the oxygen consumption (VO_2) during exercise training sessions throughout an entire exercise training intervention, and subsequently related the elicited VO_2 to the magnitude of exercise training adaptations.

Thus, the present study aimed to investigate the importance of average fraction of VO_{2max} achieved during HIT sessions (%VO_{2max}HIT) throughout a nine-weeks exercise training intervention on changes in endurance performance and physiological determinants of endurance performance in cyclists.

2. Materials and Methods

Participants and experimental design. Twenty-two participants (average VO_{2max}, 67.1 ± 6.4 mL·min^{-1}·kg^{-1}; ♀, 3 and ♂, 19) performed a nine-weeks exercise training intervention including 20.6 ± 0.8 sessions consisting of 5x8-min intervals at an average power output (PO) corresponding to the individual participants´ 40-min maximal PO. VO_2 was measured continuously during all 8-min work-periods in each HIT session throughout the exercise training intervention (average %VO_{2max}HIT, 83.0 ± 5.0%; range %VO_{2max}HIT, 74.2-90.8%). Physiological tests, including a blood lactate profile, a VO_{2max}-test, and a 15-min time trial, were performed before and after the intervention.

Statistical Analysis. All descriptive data are presented as means with standard deviations (mean ± SD). A performance index (arbitrary unit) was calculated based on the endurance performance tests, i.e., maximal 1-min PO achieved during the VO_{2max}-test (W_{max}), PO corresponding to 4 mmol·L^{-1} blood lactate concentration ([La$^-$]; $PO_{@4mmol}$),

and 15-min maximal PO ($PO_{@15min}$). The index was calculated as the average of the given performance indicators after normalization ($x_i \cdot \max(x)^{-1}$ where x_i is a single observation from one performance indicator). The relationships between $\%VO_{2max}HIT$ and training adaptations were investigated using multiple linear regression models fitted with absolute changes for the variable of interest as the dependent variable, $\%VO_{2max}HIT$ as the explanatory variable, and pre-test values, change in body mass, and sex as covariates. For statistically significant results ($p \leq 0.05$), $R^2_{adjusted}$ and estimated scores with 95% confidence intervals are reported.

3. Results

There was a positive relationship between $\%VO_{2max}HIT$ and change in W_{max} ($p = 0.009$; $R^2_{adjusted} = 0.44$; Figure 1a), $PO_{@4mmol}$ ($p = 0.035$, $R^2_{adjusted} = 0.25$), and the performance index ($p = 0.013$; $R^2_{adjusted} = 0.36$). The estimated scores per %-point increase in $\%VO_{2max}HIT$ were 0.04 $W \cdot kg^{-1}$ [0.01, 0.06] for W_{max}, 0.02 $W \cdot kg^{-1}$ [0.00, 0.04] for $PO_{@4mmol}$, and 0.004 AU [0.001, 0.007] for the performance index. This means, theoretically, that by increasing the $\%VO_{2max}HIT$ from 80 to 90 % during a similar nine-weeks intervention, W_{max} will increase by additional 0.4 $W \cdot kg^{-1}$, $PO_{@4mmol}$ by additional 0.2 $W \cdot kg^{-1}$, and the performance index by additional 0.04 AU. Notably, $\%VO_{2max}HIT$ and change in $PO_{@15min}$ was not related to each other ($p = 0.215$).

We also observed a positive relationship between $\%VO_{2max}HIT$ and change in VO_{2max} ($p = 0.029$; $R^2_{adjusted} = 0.54$; Figure 1b). The estimated score per %-point increase in $\%VO_{2max}HIT$ was 0.25 $mL \cdot min^{-1} \cdot kg^{-1}$ [0.03, 0.48]. Theoretically, by increasing the $\%VO_{2max}HIT$ from 80 to 90 % during a similar nine-weeks intervention, VO_{2max} will increase by additional 2.5 $mL \cdot min^{-1} \cdot kg^{-1}$. There was a tendency to a positive relationship between $\%VO_{2max}HIT$ and fractional utilization of VO_{2max} at 4 $mmol \cdot L^{-1}$ [La^-] ($p = 0.085$; $R^2_{adjusted} = 0.41$). $\%VO_{2max}HIT$ and change in gross efficiency at 175 watts was not related to each other ($p = 0.706$).

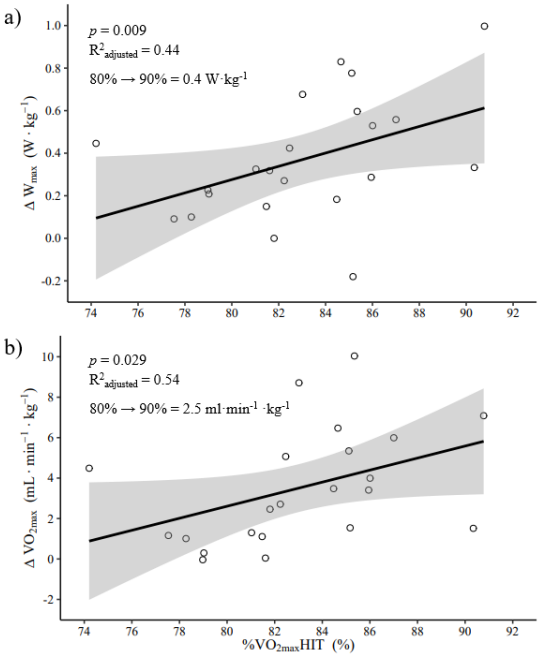

Figure 1. *Average fraction of maximal oxygen consumption elicited during HIT sessions ($\%VO_{2max}HIT$) related to absolute change in a) 1-min maximal power output (W_{max}), and b) VO_{2max}. Datapoints for the individual participants (white dots), and regressions slopes (solid lines) with 95% confidence limits (light grey areas) are shown.*

4. Discussion

To our knowledge, the present study is the first who continuously measured VO_2 during all HIT sessions throughout an entire exercise training intervention. Although several studies have supported the notion of greater training effects of exercising at or near VO_{2max} (Buchheit & Laursen, 2013; Midgley et al., 2006; Turnes et al., 2016), this is the first study actually providing scientific findings supporting this assumption. Our finding that higher $\%VO_{2max}HIT$ translates into greater improvement in endurance performance covers a great gap in the existing literature of applied exercise physiology.

5. Practical Applications.

As we observed that $\%VO_{2max}HIT$ during an exercise training intervention was positively related to improvements in W_{max}, $PO_{@4mmol}$, the performance index, and VO_{2max}, performing HIT sessions optimized to elicit a high $\%VO_{2max}HIT$ appears to be a good training strategy for improving endurance performance in cyclists.

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Conflicts of Interest: The authors declare no conflict of interest.

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