

## Influences on Pulmonary and Muscular $\dot{V}O_2$ -Kinetics

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### Introduction

Muscular and respiratory  $\dot{V}O_2$ -kinetics are influenced by many factors. At cellular level muscular  $\dot{V}O_2$  ( $\dot{V}O_{2\text{musc}}$ ) is affected by  $O_2$ -delivery and  $O_2$ -consumption. Further, these factors can be divided into muscle perfusion, capillary density, enzyme activity, mitochondrial proliferation, muscle fiber composition and some more.

Focusing on the difference between  $\dot{V}O_{2\text{resp}}$  and  $\dot{V}O_{2\text{musc}}$  the venous blood volume, the venous  $O_2$ -stores and the dynamics of cardiac output can be identified as influences. These influences result in a time delay and a distortion of  $\dot{V}O_{2\text{resp}}$ . Usually exercise step responses are used for estimating  $\dot{V}O_{2\text{resp}}$ -kinetics. But it has to be recognized, that  $\dot{V}O_{2\text{resp}}$  may be influenced by the cardio-respiratory system during the transition phases, so that the calculated time constants using an exponential data fitting method could lead to incorrect estimations. In succession, discrepancies to static or dynamic linearity as well as asymmetries in on- and off-kinetics may be observed.

To avoid these possibly wrong estimations a backward calculation model considering the influences of the cardio-respiratory system can be applied for calculating  $\dot{V}O_{2\text{musc}}$ -kinetics (Fig. 1). Furthermore, the combination of the backward calculation model and the time-series analysis describes an alternative approach for the kinetic analysis. In addition, only a single exercise test for this approach has to be performed for estimating the kinetic responses.

### Methods

11 volunteers (Age:  $30 \pm 8$  years; Height:  $175 \pm 7$  cm; Weight:  $72 \pm 10$  kg; BMI:  $23 \pm 2$  kg·m<sup>-2</sup>;  $\dot{V}O_{2\text{peak}}$ :  $4 \pm 1$  L·min<sup>-1</sup>;  $\text{rel}\dot{V}O_{2\text{peak}}$ :  $54 \pm 5$  ml·min<sup>-1</sup>·kg<sup>-1</sup>) were subjected to dynamic workload (WL) changes between 30 and 80 Watt. Gas exchange was assessed breath-by-breath and heart rate (HR) was estimated by applying ECG.

For modeling of  $\dot{V}O_{2\text{musc}}$  a two compartment model representing the exercising and the non-exercising segments of the body was used. The model accounts for a muscular venous blood volume ( $V_{\text{vmusc}}$ ) and a constant blood flow to the non-exercising segments ( $Q'_{\text{rem}}$ ). Pseudo random binary workload changes (PRBS) between 30 and 80 W were used as workload protocol and as a prerequisite for the time-series analysis. For adjustment of  $V_{\text{vmusc}}$  and  $Q'_{\text{rem}}$  auto- and cross-correlation functions (ACF, CCF) of workload and calculated  $\dot{V}O_{2\text{musc}}$  as well as  $\dot{V}O_{2\text{resp}}$  were applied. Higher CCF peaks indicate faster system responses.

The following criteria were utilized for estimating  $V_{\text{vmusc}}$  and  $Q'_{\text{rem}}$ :

- 1) Arterio-venous  $O_2$ -content difference for the muscle and the remaining compartment was preset to 200 ml·L<sup>-1</sup>.
- 2) Fluctuations in the CCF (Workload/ $\dot{V}O_{2\text{musc}}$ ) course were minimized in the range of initial increase.

- 3) On the decreasing part the course of the CCF (Workload/ $\dot{V}O_{2\text{musc}}$ ) had to be as smooth as possible, indicating no or small deflections.

## Results

$\dot{V}_{\text{vmusc}}$  and  $Q'_{\text{rem}}$  were calculated as  $2.9 \pm 0.5$  L and  $3.6 \pm 1.6$  L · min<sup>-1</sup>, respectively. By focusing the kinetic responses respiratory ( $0.33 \pm 0.09$ ; equal to a time constant of 41 s) are slower than muscular ( $0.39 \pm 0.07$ ; 32 s)  $\dot{V}O_2$ -kinetics (Fig. 2). The fastest kinetics can be observed for this population in HR ( $0.44 \pm 0.10$ ; 26 s).

## Conclusion

- 1)  $\dot{V}_{\text{vmusc}}$ , venous O<sub>2</sub>-stores and the dynamics of cardiac output may be responsible for the time delays and the distortion between  $\dot{V}O_{2\text{resp}}$ - and  $\dot{V}O_{2\text{musc}}$ -kinetics.
- 2) The approach of using a PRBS workload protocol in combination with time-series analysis can be applied for estimating  $\dot{V}O_{2\text{musc}}$ -kinetics by a single exercise test at moderate exercise intensity.
- 3) It has to be noticed, that  $\dot{V}O_{2\text{resp}}$  with this kind of analysis rely on the complete distorted and time delayed response measured at the mouth, so that differences with the estimation of the kinetic responses using exponential fitting procedures are evidently in the time-series analysis.

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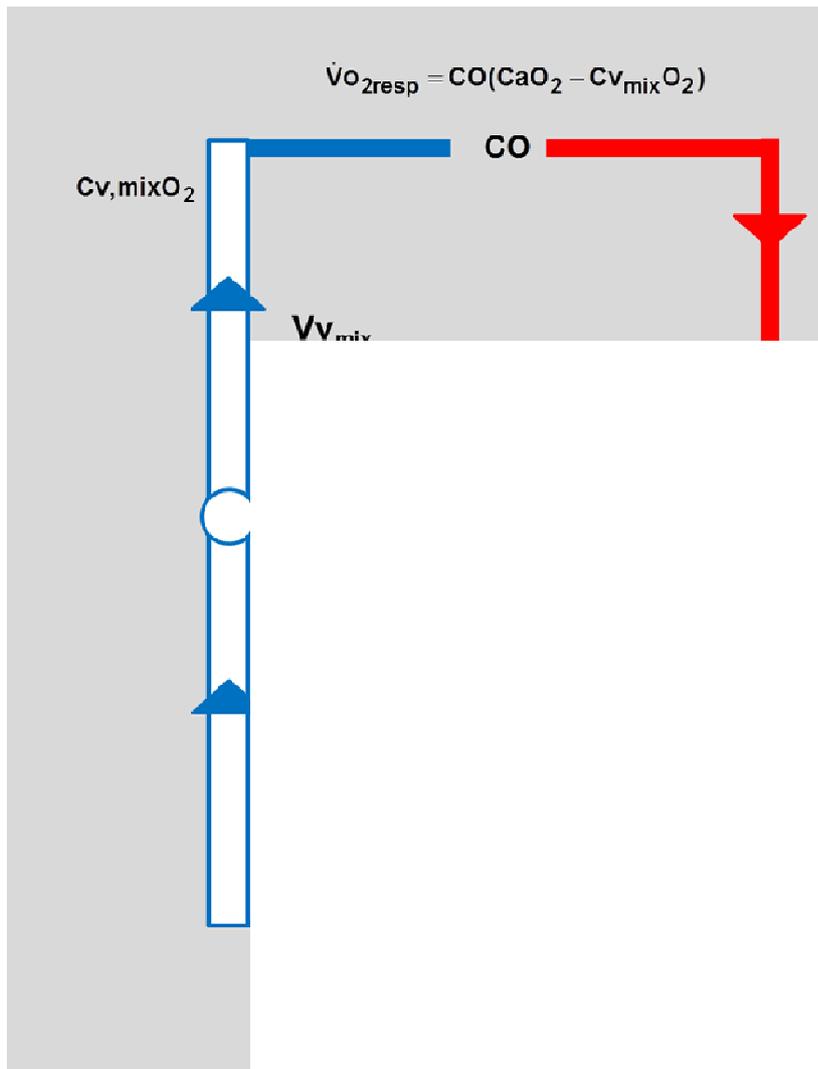


Figure 1: *Backward calculation model. See Table 1 for abbreviations*

Table1: Abbreviations in the backward calculation model.

$V'O_2\text{resp}$	Respiratory oxygen uptake
$V'O_2\text{musc}$	Muscular oxygen uptake
$V'O_2\text{rem}$	Oxygen uptake of the non-exercising compartment
CO	Cardiac Output
$Q'\text{rem}$	Perfusion rate of the non-exercising compartment
$Q'\text{musc}$	Perfusion rate of the exercising compartment
$V\text{vmusc}$	Muscular venous blood volume
$V\text{vmix}$	Venous blood volume between confluence point and the lungs
$CaO_2$	Arterial $O_2$ -concentration
$Cv.\text{mix}O_2$	Mixed venous $O_2$ -concentration
$Cv\text{rem}O_2$	Venous $O_2$ -concentration of the non-exercising compartment
$Cv\text{musc}O_2$	Venous $O_2$ -concentration of the exercising compartment

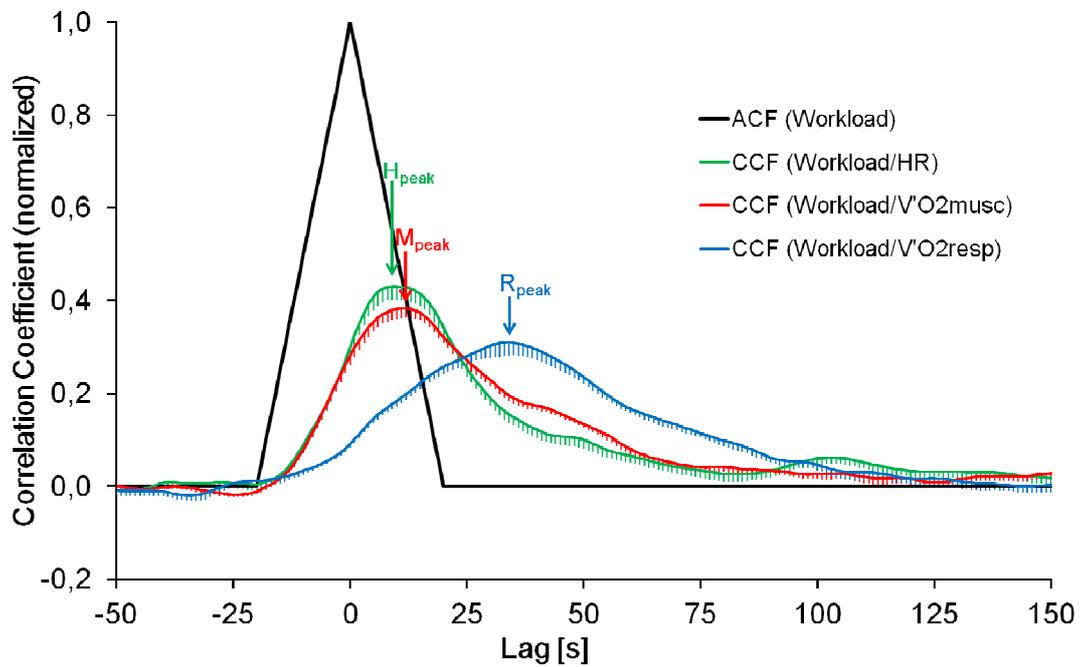


Figure 2: Time series-analysis.  $H_{peak}$ ,  $R_{peak}$  and  $M_{peak}$  indicate the kinetic responses of HR,  $V'O_2\text{resp}$  and  $V'O_2\text{musc}$ , respectively.