Communications

KINETICS OF CARDIORESPIRATORY FUNCTION AT THE ONSET OF EXERCISE

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The kinetics of oxygen uptake \( (\dot{V}O_2) \), heart rate (HR), stroke volume (SV) and cardiac output (\( \dot{Q} \)) were examined at the onset of exercise. The increasing rate of each parameter from rest to exercise was evaluated with the time constant. The time constants of \( \dot{V}O_2 \), HR, SV and \( \dot{Q} \) were 40, 7, 23 and 14, respectively.

Following the start of light exercise, oxygen uptake increases for the initial 2–3 min and then remains at a steady state. The increasing rate of oxygen uptake at the onset of exercise is generally expressed in time constants (LINNARSSON, 1974; HUGHSON and MORRISSEY, 1983; YANO, 1985). HUGHSON and MORRISSEY (1983) measured the time constants of oxygen uptake and heart rate at the onset of exercise to examine the relationship between the oxygen transport system and oxygen uptake, and found these time constants to be identical. It is also known that the oxygen uptake at the steady state increases in proportion to the increase in the cardiac output (ÅSTRAND et al., 1964). From these results, it has been interpreted that the oxygen transport system controls the kinetics of oxygen uptake not only at the steady state but also at the onset of exercise (HUGHSON and MORRISSEY, 1983). However, CERRETELLI et al. (1966) reported that the time constant of cardiac output at the onset of exercise was faster than that of oxygen uptake. This result disagrees with the above-mentioned result. The purpose of the present study was, therefore, to reexamine the kinetics of oxygen uptake \( (\dot{V}O_2) \), heart rate (HR), stroke volume (SV) and cardiac output (\( \dot{Q} \)) at the onset of exercise.

METHODS

The subjects in the present study were twelve healthy males (20–31 years old, weighing 53–75 kg and 165–180 cm in height). At rest the \( \dot{V}O_2 \) was determined

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by the Douglas bag method and the SV by the impedance method (Kubicec et al., 1966). Thereafter, work was performed for a short duration (20–70 sec) by means of a bicycle ergometer (Monark) driven at 450 kpm/min (1.5 kp, 50 rpm). The work was repeated 4 times at intervals of 3 min to determine the SV (Fig. 1). After the series of short work, the subjects rested for 6 min and started a 6-min period of work to determine the \( \dot{V}O_2 \). After collecting the expired air up to 5 min during the 6-min work period, the SV was determined again.

The oxygen and carbon dioxide concentrations in the Douglas bag were measured with a mass spectrometer (Perkin-Elmer MGA-1100). The thorax impedance was measured with an impedance cardiograph (IMF Model-400). The measured thorax impedance was used for the calculation of SV in the formula proposed by Kubicec et al. (1966).

The means for \( \dot{V}O_2 \), SV, HR and \( \dot{Q} \) were approximated by the following equation:

\[
Y(t) - Y_r = (Y_{ss} - Y_r)(1 - e^{-t/\tau}),
\]

where \( Y(t) \): values at a given time, \( Y_{ss} \): values at the steady state, \( Y_r \): values at rest, \( t \): time and \( \tau \): time constant. The SV, HR and \( \dot{Q} \) at 1 min and the \( \dot{V}O_2 \) at 5 min were used as the values at the steady state.

**RESULTS**

The time constant of \( \dot{V}O_2 \) was 40 sec. The time constant of \( \dot{Q} \) was 14 sec which was faster than that of \( \dot{V}O_2 \). The time constant of HR was 7 sec. The HR at 6 min was significantly higher than that at 1 min \( (p<0.001) \). The time
constant of SV was 23 sec. The SV at 6 min was significantly lower than that at 1 min ($p<0.001$).

**DISCUSSION**

The HR at 6 min was found to be higher than that at 1 min. This may have derived from the repeated work since the oxygen debt caused by the previous exercise might not have been recovered perfectly. It is known, however, that in light exercise an alactic oxygen debt alone is produced which can be repaid within 2 min during the recovery phase (MARGARIA, 1976). Since the recovery phase lasted at least for 3 min in the present study, there should be another reason for the higher HR at 6 min. LINNARSSON (1974) reported the change in HR in a continuous light exercise (HR at steady state: 100 beats/min). In his study, the change in HR could be expressed in two exponential terms ($\tau_1=11$, $\tau_2=367$ sec). Accordingly, HR at the onset of exercise sharply increased within 1 min and thereafter there was a continuous increase in the HR. It also appeared in the
present study that this increase of HR at 6 min corresponded to the decrease of SV and that these changes at the steady state were so controlled that the \( \dot{Q} \) might be maintained constant. To study the HR at the onset of exercise, therefore, at least two time constants should be applied to the analysis even if the exercise is light.

To examine the factors controlling the kinetics of \( \dot{V}O_2 \), HUGHSON and MORRISSEY (1983) measured the \( \dot{V}O_2 \) and HR at the onset of exercise, and found that the time constant of HR was almost identical with that of \( \dot{V}O_2 \). In their study, however, one exponential term was used as the approximate equation for the HR change. Since they neglected the continuous increase in the HR after its sharp increase, their time constant of HR might have been wrong. Furthermore, to evaluate the oxygen transport system at the onset of exercise, the time constant of \( \dot{Q} \) should have been determined rather than that of HR. The difference between the time constants of \( \dot{Q} \) and HR was also found in the present study. Although CERRETELLI et al. (1966) have already reported the faster response of \( \dot{Q} \) at the onset of exercise than that of \( \dot{V}O_2 \), Kim’s method they used to measure \( \dot{Q} \) has been criticized (FARHI et al., 1976). Therefore, this faster response of \( \dot{Q} \) was confirmed in the present study.

A new finding in the present study was that there was a time delay in the increase of SV at the onset of exercise. STEINGART et al. (1984) suggested that the SV in light exercise was mainly increased by the increase of the venous return that was caused by the start of muscle pump. Therefore, the time delay in the increase of SV due to the start of muscle exercise may be related to transport from muscle to heart.

REFERENCES


