Change in Double Product during Stepwise Incremental Exercise

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Abstract The purpose of this study was to observe the change in double product with increases in the intensity of bicycle exercise. Eleven young male adults participated in this study. The subjects performed graded bicycling exercise increasing 20 watts every 2 min from 0 watts until the heart rate (HR) reached 170 beats · min⁻¹. During exercise systolic blood pressure (SBP) and HR were continuously measured. Initially SBP gradually increased with the increase in workload, but when the intensity of exercise became even higher, the rate of increase slowed. On the other hand, the increase in HR was very small during the initial 5 min of exercise and when the intensity of exercise increased, the rate of increase became higher. The polygonal regression analyses on the relation of double product to elapsed time revealed clear break-points. On average, the break-point of double product was 6.6 min (56 watts). These results clearly showed that the break-point of double product with an increase in workload appeared even though the workload was relatively low. J Physiol Anthropol 22 (3): 143–147, 2003 http://www.jstage.jst.go.jp/en/

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Introduction

With the advances in devices used for sphygmomanometry, it has become easy to measure blood pressure during exercise (Griffin et al., 1997). Therefore, the number of studies on variations in blood pressure during exercise, especially systolic blood pressure (SBP), has recently been increasing rapidly (Blum et al., 1997; Dagianti et al., 1998; Ferguson and Brown, 1997; O’Connor and Cook, 1998; Smolander et al., 1998; Sugimoto et al., 1998). In addition, one of the things noticed about SBP is the double product (DP) that is obtained by multiplying SBP by HR. DP is used as an index indicating the level of oxygen consumption for a cardiac muscle (Jorgensen et al., 1973; Kitamura et al., 1972). There have been many studies on DP during exercise, including individuals with coronary artery disease during training (May and Nagle, 1984), work load (Hui et al., 2000), and kind of exercise (Bohien et al., 1984; Chaney, 1981; MacMasters et al., 1987). DP has also been evaluated in terms of its relation to other physiological functions during exercise (Kiyonaga et al., 1985; Obara et al., 1997; Riley et al., 1997; Tanaka et al., 1997). Tanaka et al. (1997) performed an experiment on the supposition that there was a relationship between DP and the lactic threshold. Their results showed that the DP increased rapidly around the lactic threshold. In contrast to this result, it has also been reported that DP continued to increase when HR was between 80 and 190 beats · min⁻¹ and a definite DP increase was not observed when DP was around the lactic threshold level (Obara et al., 1997). However, the pattern of DP increase during incremental exercise has not been definitively established.

The purpose of this study, therefore, was to ascertain what kind of variation DP shows with an increase in the intensity of exercise. For this purpose, polygon regression analysis was applied to SBP, HR and DP. In this study, because blood pressure varies with every beat of the heart, the average blood pressure for each defined time period was obtained by continuous measurement at each beat, with the subsequent analyses being performed using these values.

Methods

Subjects

Eleven healthy adult males [mean age (SD); 21.8 (1.8) years, height; 1.73 (3.6) m and body weight; 62.5 (6.3) kg] volunteered to participate in this study. All volunteers were in good health and free from cardiovascular or renal diseases. The experiment was performed from 2 p.m. to 3 p.m. and the subjects were asked to refrain from eating and drinking and to keep themselves in a state of rest for at least two hours before the experiment started. The subjects wore T-shirts and...
sweatpants. The purpose, content, and procedures of the experiment were explained to the subjects in detail and their consent to be subjects in this experiment was obtained.

**Experimental Procedures**

The subjects kept themselves in a state of rest on a cycle ergometer for at least thirty minutes immediately after they entered the laboratory. During this time they wore electrodes for an electrocardiogram, a sphygmomanometry sensor and a gas mask. An electrically controlled cycle ergometer (Aerobike 710, Combi) was used for the exercise. The subjects were instructed to try to keep the number of revolutions at 50 rpm and the workload level, starting at 0 watts, was increased by 20 watts per 2 min. The exercise was continued until HR reached 170 beats·min⁻¹ or the subjects could no longer maintain the prescribed rate of wheel revolutions due to fatigue. Most subjects performed the exercise until HR reached 170 beats·min⁻¹. The room temperature was 20–24°C and the relative humidity was 50–60%.

**Physiological measurements**

HR and SBP were measured continuously for 5 min of rest and during exercise. HR was obtained from an electrocardiograph with the precordial lead in the CM5 position throughout the experiment. SBP was measured noninvasively with each heart beat using Finapres (2300, Omeda, CO). This device for sphygmomanometry measures blood pressure from the change in the capacity of an artery of the finger using a light emitting diode, and its accuracy was previously confirmed at rest, during laboratory maneuvers (Campbell et al., 1990; Christen et al., 1990; Egmond et al., 1985; Omboni et al., 1993) and during prolonged heavy exercise (MacDonald et al., 2000a; 2000b). Sphygmomanometry was performed using the middle, index, or ring finger to which an appropriately sized finger-cuff was fitted, as pointed out by Griffin et al. (1997). During the measurement period the arms were positioned so that the fingers were as high as the heart. The SBP measurements were sent to a computer on-line and the pulse wave was simultaneously monitored, with blood pressure values being calculated by means of MacLab/4e (ADInstruments Pty Ltd.).

**Statistics**

SBP, which was measured at each beat, was obtained as a mean value for every 30 second period. With regard to the change in SBP, HR and DP with elapsed time, polygon regression analysis was performed on the results from each subject. Then, the time when it started to rise rapidly during exercise was obtained from the intersection of two linear curve fits.

**Results**

Figure 1 shows the continuously measured SBP of one subject. As this figure shows, blood pressure fluctuated throughout the experiment, and there was a tendency that the more intense the exercise became, the greater the fluctuation. At first, blood pressure gradually increased after the start of exercise, and continued to increase to about 1,000 beats. After this, however, although the fluctuation at each beat increased, there was no tendency for blood pressure to increase overall, with blood pressure remaining at almost the same level. In other subjects, a similar pattern of increase to that in Figure 1
was also observed.

Figure 2 illustrates the change in the value of all subjects’ SBP (top), HR (middle) and DP (bottom) with elapsed time. Initially, SBP increased linearly with the increase in work load, although with even greater intensity of exercise, the rate of increase slowed. On the other hand, the change in HR with elapsed time showed an pattern of increase forming a clear sigmoidal shape. HR within 5 min after the start of exercise (when the workload was about 0 watts or 20 watts) varied little and almost no rise was observed. At an elapsed time of about 5 min (40 watts) HR started to increase rapidly and at an elapsed time of about 18 min (about 160 watts) the rate of increase decreased.

The bottom of Figure 2 shows the change in DP with elapsed exercise time. The pattern of increase of DP was similar to that of HR shown in the middle of Figure 2. Although the variation was small at low workloads, it began to increase rapidly at workloads greater than 40 watts (5 min). The time at which the rapid rise in DP occurred in each subject was examined. Polygon regression analysis was applied to each subject’s measurements and the examples are presented in Figure 3. Subject E is an example of a subject whose DP showed a rapid rise at a relatively early time; the time was 4.6 min and the workload was 40 watts at the break-point. On the other hand, subject G’s DP showed a rapid rise only after the workload reached 100 watts; the time was 11.2 min (100 watts) at the break-point. Table 1 shows the time and workload at the break-point of DP which were calculated for each subject. On average, the time at the break-point was 6.6 min (56 watts) for DP.

As with DP, the time at the break-point of SBP and HR was calculated for each subject. Although the break-point of SBP was found in only three subjects, that of HR was clearly noticed in all subjects. Figure 4 shows the relation between the time of the break-point in DP to that in HR. This relationship was found to be linear and significant (*P<0.05).

**Discussion**

The variation in SBP at each beat during exercise was not small, as shown in Figure 1. Therefore, there are many potential problems in utilizing only one blood pressure reading measured at one beat as the measurement value for blood pressure during a time period. Compared with other physiological functions, it is quite important to measure blood pressure at each beat and obtain the mean value during a period of time.

In the present study, it was found that the increase in SBP was low at low workloads and then became high with greater workloads. Furthermore, with even greater workloads it became lower. Therefore, the increase in SBP with elapsed time formed sigmoidal like curve. These results were in good agreement with those reported previously by Andersen et al. (1985) and Obara et al. (1997). On the other hand, the relation between HR and time could be adapted to a clearer sigmoidal shape than SBP. For the first 5 min after the beginning of the exercise, the HR almost remained constant. After that, the HR increased with elapsed time.

The responses of SBP and HR during increment exercise suggested sympathetic or parasympathetic nervous system
change according to the intensity of workload. It is generally accepted that sympathetic activity increases progressively and parasympathetic activity decreases gradually with increases in exercise intensity (Ekblom et al., 1972; Robinson et al., 1966). When the workload becomes greater, the excessive increase in blood pressure excites a baroreceptor that controls sympathetic nerve activity, and a further rise in blood pressure does not occur (Strange et al., 1990). Therefore, the sympathetic nervous system is activated at a relatively low workload and inhibited at a much greater workload.

Since the rate of increase of HR was low when the load was light and then started to increase when the workload increased to a certain level, the break-point in DP appeared when the load intensity was still low. However, these results were different from those reported by Tanaka et al. (1997) who suggested that the intensity of exercise at the break-point in DP usually accorded with the lactic threshold. In the present study, polygon regression analysis was used, while in the case of Tanaka et al. (1997), the method was to analyze the data by dividing DP beforehand into two at the point of the lactic threshold. Therefore, using the method of Tanaka et al. (1997), if there was any change point where the intensity of workload was low, it could have been missed.

Taking all the subjects’ findings into consideration, the change in DP with elapsed time increased with its curve loosely conforming to a sigmoidal shape. The bottom of Figure 2 clearly shows that when elapsed time was short, in other words when the intensity of exercise was low, the rise in DP was low and then afterwards the rate of increase increased. This result suggests that there is a break-point in DP when the workload is light (Kiyonaga et al., 1985; Obara et al., 1997).

The break-point in HR also appeared at a low work load with polygon regression analysis. The relation of the time of the break-point in DP to that in HR was found to be significant. In contrast, the break-point in SBP was not clear compared to HR and DP. Therefore, these results indicated that the HR contributed greatly to the appearance of the break-point in DP at low workload intensity.

In conclusion, there existed a break-point such that DP increased abruptly during stepwise incremental exercise, and it appeared at a lower work load (56 watts). The break-point in DP at low intensity was closely associated with the pattern of increase of HR during exercise.

References


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