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Fat-free Mass and Excess Post-exercise Oxygen Consumption in the 40 Minutes after Short-duration Exhaustive Exercise in Young Male Japanese Athletes

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Abstract The relationship between fat-free mass (FFM) and excess post-exercise oxygen consumption (EPOC) has not been well researched because of the relatively small number of subjects studied. This study investigated the effects of FFM on EPOC and EPOC/maximum oxygen consumption. 250 Japanese male athletes between 16 and 21 years old from Nagasaki prefecture had their EPOC measured up to 40 minutes after short-duration exhaustive exercise. The value was named as $EPOC_{40\,min}$. The proportions of EPOC up to 1, 3, 6, 10, and 25 minutes to $EPOC_{40\,min}$ were calculated and named as P1, P3, P6, P10, and P25, respectively. Body size and composition, VO_2max and resting metabolic rate (RMR) were also measured. Mean $EPOC_{40\,min}$ was 9.04 L or 158 ml/kg FFM. $EPOC_{40\,min}$ was related to FFM ($r=0.55$, $p<0.001$) and VO_2max ($r=0.37$, $p<0.001$). The ratio of $EPOC_{40\,min}$ to VO_2max was related to FFM ($r=0.28$, $p<0.001$). P1, P3, P6, P10, and P25 were negatively related to $EPOC_{40\,min}$/FFM, $EPOC_{40\,min}/VO_2$max, and FFM. Athletes who had larger FFM had larger $EPOC40_{40\,min}$ and $EPOC40_{40\,min}/VO_2$max, and smaller P1, P3, P10, and P25. *J Physiol Anthropol 27(3): 139–143, 2008* http://www.jstage.jst.go.jp/browse/jpa2
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Keywords: body composition, fat-free mass, excess post-exercise oxygen consumption (EPOC), maximum oxygen consumption (VO_2max), Japanese

Introduction

The total amount of oxygen consumed during recovery after exercise was originally defined as "oxygen debt" by Hill and Lupton (1923; Green and Dawson, 1993). The theory of oxygen debt developed by previous investigators (Hill et al., 1924; Furusawa et al., 1924) was based on oxygen consumption being greater during rest after exercise than during rest before exercise (Lukin and Ralston, 1962). Oxygen debt after short exhaustive exercise has been used as an index for anaerobic work capacity to indicate a person's ability to perform exhaustive exercise of short duration (Hermansen, 1969). Margaria (1933) elaborated the theory by distinguishing between the initial fast (alactacid) and second slow (lactacid) oxygen debt curve components. However, studies in the 1980s found that the original lactic acid explanation of the oxygen debt was too simplistic. Gaesser and Brooks (1984) recommended the use of the term excess post-exercise oxygen consumption (EPOC) instead of oxygen debt to avoid the implication of causality in describing the elevation in metabolic rate above resting levels after exercise. The current consensus is that the oxygen debt is not a valid measure of anaerobic capacity (Green and Dawson, 1993). Many factors are related to EPOC, but the mechanisms that produce EPOC have remained unclear.

In the present study, we measured the EPOC of 250 Japanese male athletes in order to gain understanding of their sporting performance. We also measured their fat-free mass, resting oxygen consumption (RMR), and maximum oxygen intake (VO_2max), simultaneously. Compared to previous studies, the number of subjects was larger, and the data were analyzed to determine the relation of EPOC with other measurements. Although body size and composition are supposed to relate with EPOC, this relationship has not been well studied, especially for Japanese.

Subjects and Methods

Subjects

This study was conducted between 1987 and 1994 in Nagasaki City. We measured 679 Japanese athletes between 14 and 35 years old of both sexes. They were top-level athletes of Nagasaki prefecture, Japan. The purpose and procedures of the study were explained to the subjects and a signed consent form was obtained from each subject. Data from the 250 young male athletes between 16 and 21 years old were used for this analysis. The mean age was 17.6 with a standard deviation of 1.1 years. The athletes consisted of 88 football players, 48 long-distance runners, 43 canoeists, 37 cyclists, 19 rugby players, 10 swimmers, and 5 volleyball players.

Methods

The Douglas bag method was used to measure RMR, EPOC, and VO_2max (STPD). This measurement was carried out in this order in one day for each subject. RMR was measured after at least 30 minutes of resting on a chair and more than 3 hours after the previous meal. Heart rate was monitored and RMR was measured after confirming resting condition. Oxygen consumption was measured for 40 minutes after exhaustive anaerobic exercise consisting of 45–105 seconds of 5-degree slope treadmill running, and RMR was subtracted from oxygen consumption and this value was used for analyses as $EPOC_{40min}$. EPOC up to 1, 3, 6, 10, and 25 minutes after exercise was also measured, and the proportions to $EPOC_{40min}$ (P1, P3, P6, P10, and P25, respectively) were calculated. VO_2max was measured by using the 5-degree slope treadmill running. The speed was increased every two minutes (Kuroda et al., 1973) and all the subjects reached exhaustion after 6–13 minutes of running.

All the anthropometric measurements were carried out using standard techniques (Lohman et al., 1988; Tahara et al., 2002). Height (HT) was measured to the nearest mm (Shirai [Japan] stadiometer) and weight to the nearest gram (Sauter [Germany] scale). Body weight (BW) was calculated after subtracting the weight of the bathing suit. The body mass index [BMI, weight in kg/(height in m)^2] was calculated. Body density was measured by underwater weighing densitometry using a cylindrical stainless steel tank (Tahara et al., 2002). A force transducer (Kyowa-LU20KSB34, maximum capacity of 20 kg), amplifier (model RM-45, Nihon-Koden, Tokyo), and recorder (Rikadenki WE-21) were used for the underwater weight measurement. All subjects had their last meal at least two hours before the underwater weighing measurement, and were asked to defecate and urinate just before the measurement. One of the authors (YT) performed all the measurements of underwater weighing. Residual lung volume was calculated by a helium spirometer (model COMF100, Fukuda) outside the tank after each underwater trial. The formula of Brozek et al. (1963) was used to estimate percentage fat (%Fat) from body density. Fat mass (FM) and fat-free mass (FFM) were calculated accordingly. All measurements were conducted at Nagasaki University.

Table 1 Age, body size, density, and composition of the subjects

Variables	Mean	SD	Minimum	Maximum
Age (years old)	17.5	1.1	16.0	21.0
Height (HT, cm)	171.7	5.0	159.4	185.7
Weight (BW, kg)	63.3	7.4	43.7	99.7
Body Mass Index (BMI, kg/m^2)	21.5	2.1	16.6	31.0
Body density (g/ml)	1.0777	0.0087	1.0417	1.0988
Percentage fat (FAT%, %)	9.9	3.5	1.7	24.5
Fat mass (FM, kg)	6.3	2.8	1.0	21.8
Fat-free mass (FFM, kg)	57.0	6.1	41.4	79.1

1. 250 male Japanese athletes
2. SD: standard deviation

The relationship of FFM and $EPOC_{40min}$, and their relations to VO_2max, RMR, and P1, P3, P6, P10, and P25 were analyzed using Pearson product-moment correlation coefficients. SPSS software (version 13.1, Chicago, IL) was used for all analyses.

Results

Subjects were, on average, 171.7 cm tall weighed 63.3 kg, and had a BMI of 21.5 kg/m^2, 57.0 FFM, 6.3 kg FM, and 9.9% of %Fat (Table 1). Mean $EPOC_{40min}$ was 9.04 L, or 143 ml/kg BW, or 158 ml/kg FFM. Mean VO_2max was 3.82 L/min, or 60.7 ml/kg BW/min, or 67.3 ml/kg FFM/min. Mean RMR was 0.259 L/min, or 4.11 ml/kg BW/min, or 4.56 ml/kg FFM/min. $EPOC_{40min}$ was 88% of RMR for 40 minutes and 240% of VO_2max (Table 2).

On average, 23.2% of $EPOC_{40min}$ was consumed within one minute after the exercise, and 63.3% was consumed within 10 minutes after the exercise. Figure 1 shows the cumulative proportion of excess oxygen consumption up to 40 minutes after exercise. As shown in Figure 2, excess oxygen consumption per minute decreased with time after exercise. On average, EPOC was 7.9 times that of RMR in the first minute, and 2.8 times that of RMR in the next two minutes. EPOC was 33% of RMR after 25 minutes of exercise.

Table 3 shows that $EPOC_{40min}$ was significantly correlated with FFM, BW, BMI, HT (all, $p<0.001$), and FM ($p<0.05$). VO_2max and RMR were significantly correlated with FFM (both, $p<0.001$). $EPOC_{40min}$, VO_2max, and RMR showed some inter-correlations; $EPOC_{40min}$ showed a correlation with VO_2max and with RMR (both, $p<0.001$). However, $EPOC_{40min}$/FFM did not significantly correlate with VO_2max/FFM ($r=0.12$, $p=0.069$) or with RMR/FFM ($r=-0.09$, $p=0.149$).

$EPOC_{40min}$, $EPOC_{40min}$/RMR, $EPOC_{40min}/VO_2max$, and $EPOC_{40min}$/FFM were all negatively correlated with P1, P3, P6, P10, P15, and P25 (Table 3). FFM was negatively correlated with P1, P3, P6, P10, and P15. These correlations indicate that those subjects who had larger $EPOC_{40min}$, or larger FFM, or larger $EPOC_{40min}$ values relative to RMR, VO_2max, and FFM consumed smaller proportions of excess oxygen (of

Table 2 Maximum oxygen consumption, capacity of excess post-exercise oxygen consumption, and resting oxygen consumption

Variables	Mean	SD	Minimum	Maximum
capacity of excess post-exercise oxygen consumption ($EPOC_{40\,min}$) (l/40 min)	9.04	2.02	5.18	15.76
$EPOC_{40\,min}$/weight (ml/kg)	142.7	27.4	84.4	224.6
$EPOC_{40\,min}$/FFM (ml/kg)	158.3	29.6	90.2	250.8
Maximal oxygen consumption (VO_2max, l/min)	3.82	0.46	2.49	5.12
VO_2max/weight (ml/kg/min)	60.7	7.1	37.1	78.1
VO_2max/FFM (ml/kg/min)	67.3	7.7	45.7	85.5
Resting oxygen consumption (RMR, l/min)	0.259	0.033	0.200	0.367
RMR/weight (ml/kg)	4.11	0.49	2.95	5.74
RMR/FFM (ml/kg)	4.56	0.54	3.24	6.52
Percentage to $EPOC_{40\,min}$				
First 1 minute (P1, %)	23.2	4.6	13.0	39.2
First 3 minute (P3, %)	39.4	6.3	25.6	57.6
First 6 minute (P6, %)	52.5	7.3	70.6	33.5
First 10 minutes (P10, %)	63.3	7.0	42.3	81.4
First 15 minutes (P15, %)	72.6	6.5	53.1	88.9
First 25 minutes (P25,%)	86.1	4.9	72.3	99.8
$EPOC_{40\,min}$/RMR/40min	0.88	0.20	0.42	1.45
$EPOC_{40\,min}$/VO_2max	2.4	0.5	1.3	4.6

1. 250 male Japanese athletes
2. SD: standard deviation
3. FFM: fat-free mass

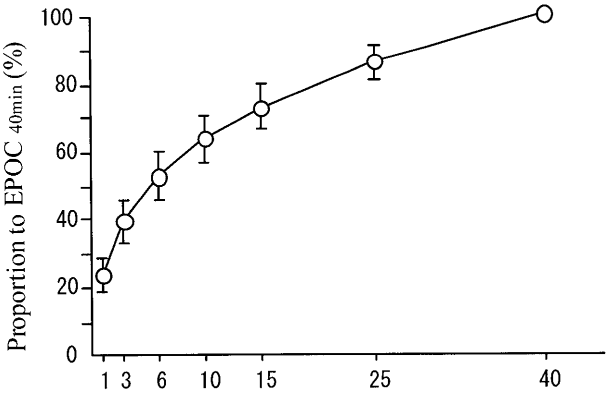

Fig. 1 The cumulative proportion of excess oxygen consumption up to 40 minutes after exercise (Mean values with standard deviation).

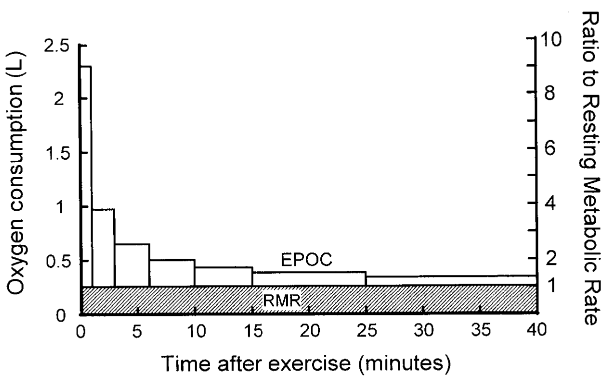

Fig. 2 Mean oxygen consumption of 250 male athletes during recovery for 40 minutes. Mean values of excess post-exercise oxygen consumption (EPOC) and resting metabolic rate (RMR) are shown. Left vertical axis: Oxygen consumption (L), Right vertical axis: ratio to RMR (RMR is presented as 1.0).

$EPOC_{40\,min}$) within 1, 3, 6, 10, 15 minutes after exercise. The correlations were stronger for P1 and P3 than P25. Figure 3 shows this relation by comparing the values of P1 to P25 between upper and lower quartiles of $EPOC_{40\,min}$.

Discussion

Measurements of EPOC vary largely from one study to another. There are two major factors other than the influence of atmospheric pressure: body temperature and catecholamines (Roth et al., 1988). First, the type of exercise used to induce EPOC varies in terms of intensity, duration, and event of workload among the studies, and these variations affect the value of EPOC (Hill, 1924; Knuttgen et al., 1970; Bahr and Sejersted, 1991; Bielinski and Jequir, 1985; Di Prampero et al., 1973; Margaria et al., 1964; Withers et al., 1991; Katch, 1973; Bahr, 1992a; Bahr et al., 1992b; Sedlock, 1991). Bahr (1992a) found that EPOC is influenced by the intensity of exercise rather than the duration of exercise. Secondly, in previous studies, the duration used to measure EPOC after exercise

Table 3 Correlation Coefficients and p values between oxygen consumption and body composition (250 men)

Variables	HT	BW	BMI	%Fat	FM	FFM	P1	P3	P10	P15	P25
$EPOC_{40\,min}$ (ml)	0.34 0.001	0.51 0.001	0.40 0.001	−0.01 0.830	0.15 0.016	0.55 0.001	−0.63 0.001	−0.60 0.001	−0.55 0.001	−0.49 0.001	−0.40 0.001
VO_2max (ml)	0.36 0.001	0.44 0.001	0.32 0.001	−0.02 0.709	0.11 0.095	0.49 0.001	0.06 0.376	0.05 0.460	0.07 0.304	0.03 0.628	0.07 0.267
RMR	0.23 0.001	0.49 0.001	0.45 0.001	0.14 0.025	0.27 0.001	0.47 0.001	0.03 0.594	0.10 0.104	0.20 0.001	0.21 0.001	0.23 0.001
$EPOC_{40\,min}$ per RMR	0.20 0.002	0.22 0.001	0.14 0.032	−0.08 0.226	0.00 0.960	0.26 0.001	−0.61 0.001	−0.64 0.001	−0.64 0.001	−0.59 0.001	−0.50 0.001
VO_2max per RMR	0.11 0.093	−0.05 0.439	−0.12 0.057	−0.13 0.048	−0.13 0.036	0.00 0.983	0.01 0.823	−0.06 0.349	−0.13 0.034	−0.17 0.006	−0.15 0.021
$EPOC_{40\,min}$ per VO_2max	0.15 0.019	0.27 0.001	0.23 0.001	0.01 0.888	0.10 0.109	0.28 0.001	−0.70 0.001	−0.67 0.001	−0.62 0.001	−0.53 0.001	−0.46 0.001
$EPOC_{40\,min}$ per FFM (ml/kg)	0.06 0.319	0.06 0.338	0.03 0.610	−0.02 0.732	0.00 0.978	0.07 0.249	−0.62 0.001	−0.62 0.001	−0.57 0.001	−0.49 0.001	−0.41 0.001
FFM (kg)	0.59 0.001	0.93 0.001	0.76 0.001	0.00 0.964	0.30 0.001	1.000 0.001	−0.22 0.001	−0.19 0.003	−0.15 0.020	−0.16 0.011	−0.12 0.050

1. Upper: correlation coefficients, Lower: p values
2. EPOC: capacity of excess post-exercise oxygen consumption
3. VO_2max: maximal oxygen consumption
4. FFM: fat-free mass
5. RMR: resting oxygen consumption

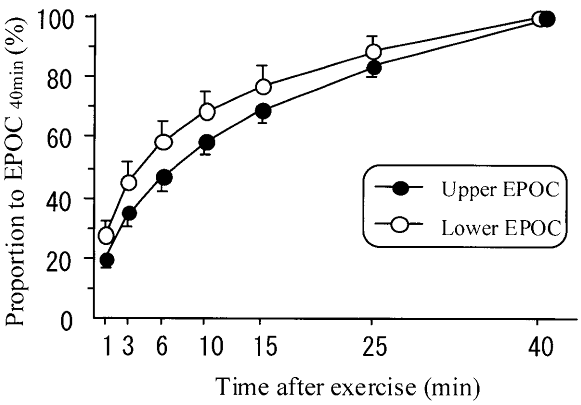

Fig. 3 The cumulative proportion of excess oxygen consumption up to 40 minutes after exercise by the upper and lower quartiles of EPOC (Mean values with standard deviation, Total $n=250$, upper EPOC $n=62$, lower EPOC $n=62$)

varied between 15 minutes (Katch, 1973; Hagberg et al., 1980) to 24 hours (Bielinski et al., 1985). As EPOC per minute reduces quickly after exercise (as shown in Fig. 2), values of different duration cannot be easily compared. EPOC was primarily measured to quantify anaerobic capacity before the 1980s, and intensive exhaustive exercises were applied and EPOC was measured for a relatively short recovery period after exercise. Recently, EPOC during a relatively long recovery period after long and mild exercise has been studied in relation to preventing obesity. The importance of the long-lasting ultraslow component of EPOC for more than two hours after exercise had been stressed (Bahr, 1992b).

The present study aimed to compare the EPOC of athletes in Nagasaki prefecture with top national athletes of Japan (Kuroda, 1973). We measured a relatively large number of subjects with simultaneous measurement of fat-free mass and VO_2max. We found that FFM was strongly related with $EPOC_{40\,min}$ as well as with VO_2max and RMR. Secondly, although $EPOC_{40\,min}$ was related with VO_2max and RMR, there was no significant relationship after correcting for FFM. Thirdly, FFM was related to $EPOC_{40\,min}/VO_2$max and $EPOC_{40\,min}$/RMR. Large $EPOC_{40\,min}$ relative to VO_2max and to RMR was related to FFM. These findings suggest a large effect of FFM on EPOC and EPOC/VO_2max.

A lager FFM would be associated with a lager volume of myoglobin. The oxygen binding myoglobin plays an important role in the re-synthesis of ATP with a shortage of oxygen during exercise. Furthermore, short period of high intensity training, which strengthen muscle power, would increase the enzymic activity of glycolysis. Thus, a person with a larger FFM would have a high EPOC and anaerobic capacity for exercise.

In conclusion, athletes with a larger FFM have a larger capacity of EPOC, and a larger capacity of EPOC for VO_2max and for RMR.

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