Plasma β-endorphin and lactate to marathon running in male fun runners

～a positive aspect responding to endurance exercise～

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Abstract

The concentration of beta-endorphin (B-EP) was measured in 12 male recreational runners before and after marathon running. All subjects could finish 42 km distance and their mean time for finishing was 3 hr and 50 min (3 hr 6 min－4 hr 22 min). Plasma B-EP significantly ($P<0.0001$) increased to about 9.8-fold above base line, from 9.1± 0.8 (SE) to 88.9±17.0 pg/ml. In addition, B-EP remained above baseline at 30 min and 60 min after the marathon race (43.9 ± 12.7 pg/ml; $P<0.0001$ and 33.6±6.6 pg/ml; $P<0.001$, respectively) and dropped to baseline 24 hr following the race. Lactate concentration also significantly ($P<0.0001$) increased during the marathon race (from 11.8±0.12 to 2.33±0.18 mmol/L). This value was far below anaerobic threshold levels, 4 mmol/L, and was equivalent to approximately 60-65% VO_2max of our subjects. Previous studies have reported that the peripheral B-EP responses may be intensity dependent and that an exercise intensity of at least 70% VO_2max for 15 min is needed to increase plasma B-EP. Since our subjects performed extremely over-duration exercise and were exhausted after the race, therefore, the undue physical stress might affect the increase in B-EP. In conclusion, plasma B-EP responses may be both intensity and duration dependent.

INTRODUCTION

Programs of regular exercise have long been recommended for stress reduction[1]. Although details remain unclear, the discovery of endogeneous opiates[2] and their release during stress[3] has provided the basis for an attractive hypothesis. This hypothesis suggests that opiates released during physical activity mediate the relaxing effects of exercise. After the discovery of endogeneous opioids, which demonstrated that beta-endorphin (B-EP) particularly revealed potent morphine-like activity, in several subsequent studies the dependence of exercise-induced B-EP-increases upon exercise intensity was investigated. Exercise-induced increases in circulating levels of B-EP are mostly a reflection of secretion by the anterior pituitary and are indicative of stress. It has widely documented that high intensity cycling and treadmill running elicits elevated B-EP, corticotropin and cortisol concentrations[4, 5, 6]; whereas lower intensities do not[4, 7]. Previous investigators[8, 9] using 1 hr of running and incremental graded bicycle-exercise, have stated that the exercise of which intensity is below the anaerobic threshold did not affect peripheral B-EP concentrations, but exercise above the anaerobic threshold significantly elevated the endogeneous opioid. However, there is an evidence that lactate alone does not produce increases in B-EP concentrations during submaximal exercise[10]. It is still debatable whether the exercise-induced increase in B-EP is related to the intensity of the exercise.

It seems to the authors that exercise effects on volume of distribution have been overlooked. Many runners have experienced good feeling, natural high or good mood after the completion of marathon race although at the same time they experienced muscle soreness. The purpose of this study was to describe the response to marathon running of circulating beta-endorphin.

METHODS

Subjects. Twelve healthy recreational male runners participated in this study. Anthropometric data, physiological and performance characteristics of the subjects are presented in Table 1. After a brief information session, all runners gave their written informed consent. Fluids were available to subjects during marathon race, and they drank ad libitum. The distance of the race is 42.195 km.

Laboratory tests. The following two tests were conducted at the laboratory three weeks prior to a marathon race. A maximal exercise test was carried out on a motor driven treadmill (Quinton, Seattle, WA) employing the Bruce protocol. During the test subjects wore a mask connected to an automated gas analyzer (MetaMax 3B, Cortex, Leipzig, Germany).

Three submaximal treadmill tests were completed within one week of the VO_2max test. The tests were separated with at least one day between tests. After a 5-min warm-up the workload to the treadmill was adjusted to 40, 60 or 80% of VO_2max based on the VO_2max data.

The body fat (%) was measured using a body impedance technique (Weight Manager System, Clinton, MI).

Samples and analyses. At the laboratory blood was obtained at 5 min of recovery after each three submaximal and maximal tests by venipuncture. Then the blood samples were analyzed for lactate determination using a 1500 Sport Lactate (Yellow Springs Instrument Co., Yellow Springs, OH).

Early morning 4 hr prior to marathon race blood samples were collected at a medical clinic with subjects at rest and in at least 8-hr postabsorptive state (pre-race values). The second blood samples were obtained within 5 min after finishing the race (post race); and three more samples were collected 30, 60 min and 1440 min (24 hr) following the race. The blood samples were used for determination of plasma B-EP and lactate

concentrations. Plasma levels of B-EP were measured using commercially available reagents. The B-EP assay (Incstar) first concentrated the B-EP in one ml of plasma using anti B-EP coupled to sepharose. B-EP was then eluted from the affinity gel column and the eluate was used for duplicate analysis in a second antibody RIA procedure. Lactate was determined with aforementioned lactate analyzer. Hematocrit (Hct) was determined by microcentrifugation to estimate hemoconcentration/dilution following the race.

Statistical analyses. Data were evaluated by descriptive statistics with calculation of the mean values and SEM. Further statistical analyses were performed by a variance analysis for repeated measurements and the Student's t-test for paired data. All post-race values were compared with baseline values. For all statistical analyses, the level of significance was set at $P<0.05$.

RESULTS

The running time for the marathon race was 3 hr and 50 min (range: 3 hr 06 min−4 hr 49 min) and corresponding to an average speed of 183 m min^{-1}.

The Hct immediately after the race increased significantly by 1.0% following the race. The 1% increase indicates that the race reduced plasma volume of 3.6%. This indicates that post-race plasma concentrations are overestimated by this amount.

Figure 1 depicts that a steep increase in B-EP was measured within 5 min after the race ($P<0.0001$), increasing to about 9.8-

Table 1. Anthoropometric data and VO_2max in 12 subjects.

Age (yr)	Height (cm)	Body mass (kg)	BMI	Body fat (%)	VO_2max (ml/kh/min)
42.9 (2.8)	168.8 (1.4)	60.5 (1.5)	21.2 (0.4)	17.8 (0.7)	54.7 (1.6)

Values are mean (SE)

fold above base line (from pre-race: 9.1±0.8 to post race: 88.9± 17.0 pg/ml). It remained above baseline at 30 min and 60 min after the run (43.9±12.7 pg/ml; $P<0.0001$ and 33.6±6.6 pg/ml; $P<0.001$, respectively) and dropped to baseline (8.9±0.8 pg/ml).

Lactate concentration (Fig. 2) also significantly ($P<0.0001$) increased during the marathon (from 1.18±0.12 to 2.33±0.18 mmol • l^{-1}), and remained significantly in higher levels (1.83± 0.14 mmol • l^{-1}) at the time point of 30 min following the race ($P<0.0001$). In addition, changes in lactate concentration during submaximal and maximal exercises were presented in Fig. 3. As illustrated in the figure, lactate begins to accumulate markedly in the blood when the exercise intensity exceeds 80% VO_2max. The lactate concentration values of 2.33 mmol/L after marathon running in this study is equivalent to approximately 65% VO_2max.

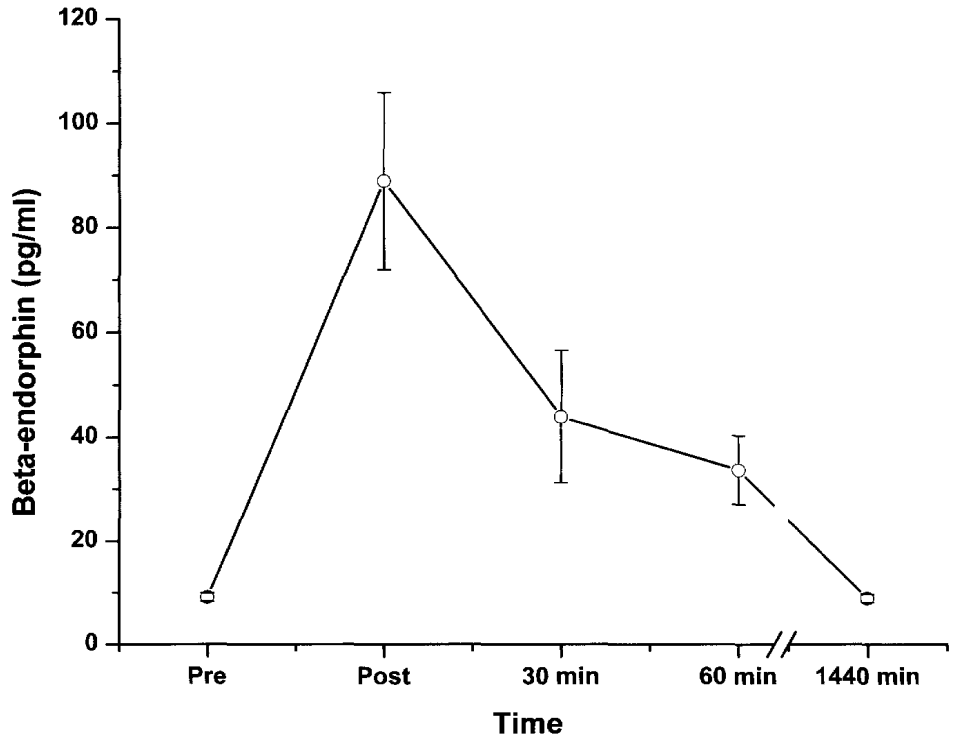

Figure 1. Beta-endorphin responses to marathon running in male runners.
Values are mean±SEM.

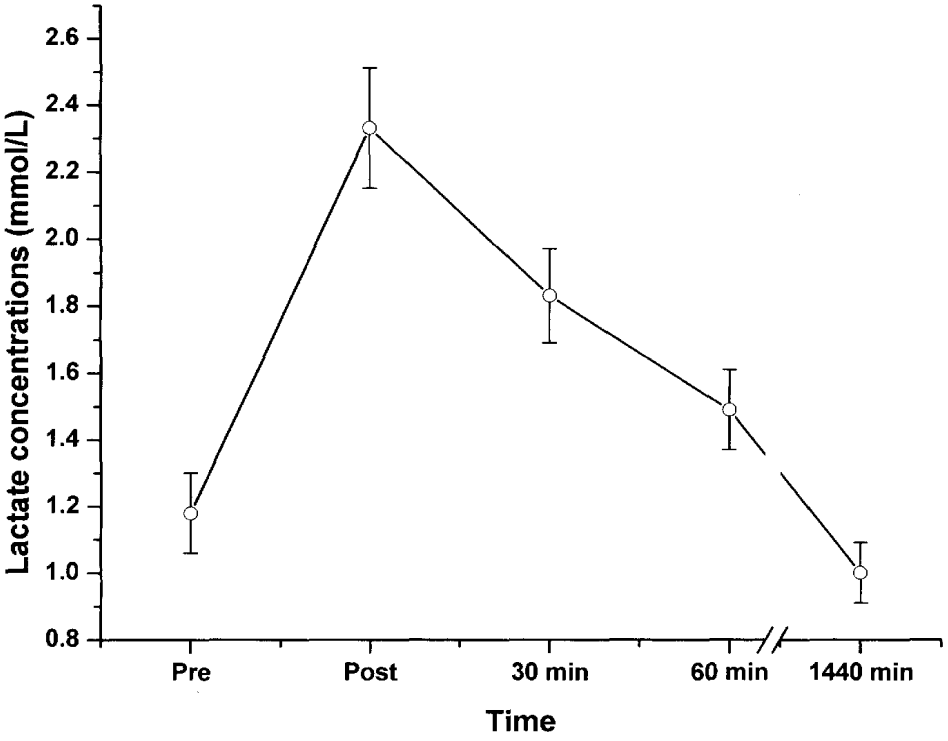

Figure 2. Lactate responses to marathon running in male runners. Values are mean±SEM.

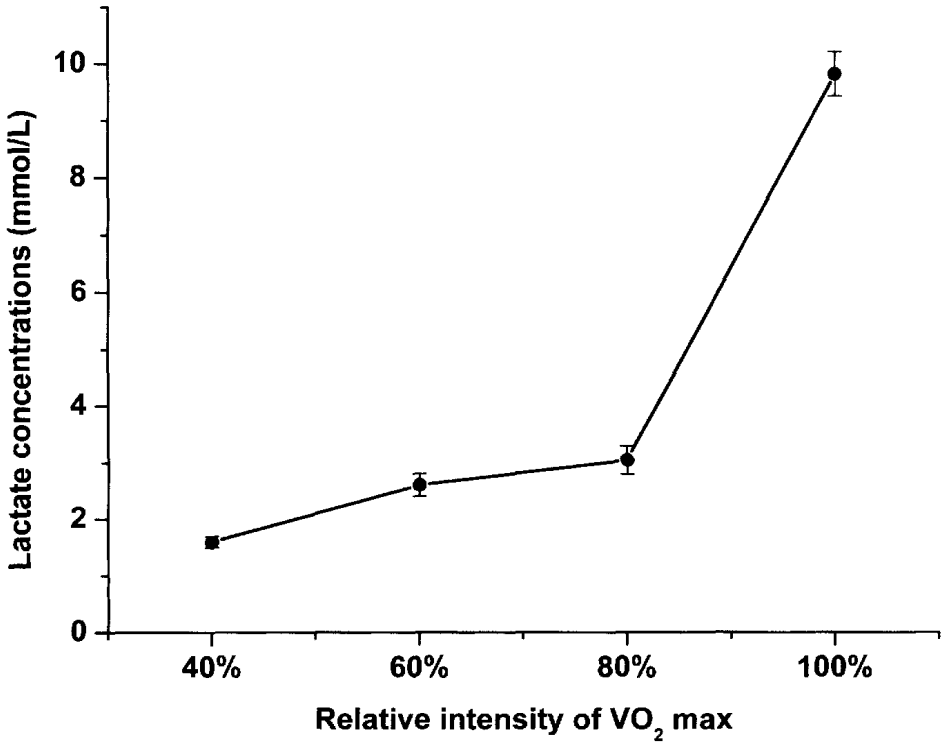

Figure 3. Lactate responses to submaximal exercises (40%, 60% and 80% VO_2max) and maximal exercise.
Values are mean±SEM.

DISCUSSION

The present study was conducted to determine the effects of 42-km marathon race on plasma B-EP and peripheral lactate concentrations. The primary aim of the present study was to evaluate the magnitude of changes of B-EN concentrations.

A steep increase in B-EP was measured at post race ($P<0.0001$), increasing to about 9.8-fold above baseline. This magnitude is greater than the findings of previous studies[11, 12] in which 6.9- and 4.6-folds, respectively were reported in male runners. This disparity might be due to different fitness levels and training levels. In contrast to our recreational runners whose mean finishing time was 3 hr and 50 min, runners in these previous studies were sub-three runners and runners whose finishing times were close to sub-3 hr. Schwarz and Kindermann[13] summarized in their review article that B-EP levels do not increase until exercise duration exceeds approximately 1 hour, with the increase being exponential thereafter.

Lactate concentration immediately after the race showed 2.33 mmol/L that is below anaerobic threshold levels of 4 mmol/L. This value of lactate concentration is equivalent to approximately 65% VO_2max (Fig 3). Early study by Colt et al.[14] suggested that the peripheral B-EP response might be intensity dependent. Goldfarb et al.[5] reported that the intensity of 60% VO_2max during a 30-min bicycle exercise did not elevate B-EP, but the intensities of 70 and 80% VO_2max did increase B-EP content (5-fold the resting level at 80% VO_2max). The researchers concluded that an exercise intensity of at least 70% VO_2max for 15 min is needed to increase plasma B-EP. Considering the relationship of the anaerobic threshold to plasma B-EP, McMurray et al.[15] also found that 20 min of exercise on a bicycle ergometer at 40-60% VO_2max which resulted in lactate levels less than the 4 mmol/L, did not affect B-EP concentrations but exercise above the anaerobic threshold (80% VO_2max) significantly

elevated the endogenous opioid. In summary of these studies, the authors concluded that the stimulation of β-endorphin during exercise was related to metabolic acidosis and that base excess was the best indicator of β-endorphin release. These findings conflict with reports that markedly improved mood status were predominantly found in long-lasting endurance exercise.

However, it is debatable whether the exercise induced increase in B-EP is related to the intensity of exercise. Some studies[16, 17] refuted such a correlation. In addition, endurance exercise of longer duration than 30 min and of sufficient intensity has been reported to produce increase in β-endorphin but not necessarily high lactate levels; or that lactate levels were not related to β-endorphin levels[11, 18]. In the present study even though running intensity was at 65% VO_2max or below, marathon running resulted in a significant increase in plasma B-EP without high levels of lactate concentrations. Furthermore, the levels of B-EP concentrations were remained above resting levels for at least 1 hr after the race. The postulated half-life of B-EP of 20 min must have been extended by slowed degradation processes, a possible reason for runner's high or for the continuing feeling of well being after a long period of endurance exercise. Such results might be affected by extremely over-duration of exercise (mean finishing time was 3 hr. and 50 min). The most of our runners were exhausted after the race; therefore, the undue physical stress might affect the increase in B-EP. Therefore, it is conceivable that the rate of perceived exertion is related to the release of B-EP. This may be supported by Schwarz and Kindermann[13]. They stated that aggravating external conditions (increased ambient temperature, change in humidity) led to a significantly higher increase of B-EP. We must point out that in all previous studies, the duration of exercise was limited to 60 min, so that an increase of β-endorphin levels in exhaustive endurance exercise could not be excluded. Apart from the

influence of the intensity of exercise, it may be considered that duration of exercise also influenced the changes of B-EP. Schwarz and Kindermann[9] reported that endurance exercise did not lead to an increase in B-EP until approximately 60 min of exercise had been exceeded and concluded that the behaviour of β-endorphin apparently depended both on intensity, defined as an increase in anaerobic metabolism, and on the duration of exercise. Furthermore, exercise duration, independent of intensity is known to influence the response of several hormones in the hypothalamic-pituitary-adrenal axis[19]. Using low-volume but high-intensity resistive exercise, Kraemer et al.[20] found that lactate concentrations rose significantly to peak at 8.54 mmol/L without altering B-EP concentrations.

In summary, a 42 km marathon running in male recreational runners resulted in an increase in β-endorphin, which is known to have effects on the changes of mood state. The results of this investigation suggest that apart from the influence of the intensity of exercise, it may be considered that a stimulation by extremely long duration of exercise also influences the changes of B-EP.

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マラソンランニングにともなう血漿βエンドルフィンと乳酸濃度

～持久運動のポジテイブ応答～

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要約

目的

ジョギングやランニング後に感じられる爽快感，いわゆる「ランナーズハイ」をもたらす因子として血中内因性モルヒネ様物質のβエンドルフィンが知られている。運動とこのβエンドルフィンの分泌に関してこれまでに多くの研究報告がなされているが，その多くはβエンドルフィンの分泌は無酸素性の高強度の運動が強く関与するとしている。すなわち，血中分泌乳酸濃度に関係する。しかし，持続時間が著しく長い運動後の「ハイ」とよばれる気分は多くのランナーが体験することである。そこで本研究において，運動持続時間が著しく長くなることでβエンドルフィン分泌を誘う運動強度になるのではないかということを検討することにした。

研究方法

被験者：12名の男子健康ランナー（平均年齢，身長，体重，BMI，%体脂肪，最大酸素摂取量がそれぞれ42.9歳，168.8cm，60.5kg，21.2，17.8%，54.7ml/kg/分）が本研究の被検者として参加した。全員がマラソンレースを完走し，その平均タイムは3時間50分であった。

マラソン走以前の測定：トレッドミル走による最大酸素摂取量の測定を行った。その際，最大運動終了5分後にプリックによる指先からの採血を行って乳酸濃度を求めた。その数値を100% VO_2max値とし，さらに運動強度が40%，60%，80% VO_2maxに設定されたトレッドミル上の10分走後の血液サンプルからそれぞれの乳酸濃度を求めた。

マラソン走当日の測定：肘静脈からの採血がマラソンスタート4時間前

（ベースラインデータ），マラソン完走後5分以内，30分後，60分後，24時間後に行われて血中のβエンドルフィンと乳酸濃度の測定に当てられた。マラソン走中の水分補給には制約を与えなかった。

結果

マラソン完走後のβエンドルフィン濃度は88.9pg/mlで安静時値の8.9倍を示した。βエンドルフィン濃度は以後60分までの測定において安静時値より有意に高いレベルにとどまったが，24時間後では安静値レベルに戻った。他方，乳酸濃度もマラソン完走後に安静値水準から有意に上昇した（2.33mmol/L）。この値は60～65% VO_2max に相当するものであった。

考察

βエンドルフィン分泌への運動強度として，これまでの多くの研究は乳酸値が4mmol/Lを超える強度の無酸素性運動をあげ，運動の持続時間は影響因子ではないと報告している。しかし，それらの研究はほとんどが研究室での漸増負荷運動の結果によるものか，持続運動であってもほとんどが60分以内であって，持続運動後にアスリートが体験する高揚感（ランナーズハイ）はβエンドルフィンに起因するのではないかという考えと異なる。本研究における運動持続時間は平均値が3時間を越す長いものであって，マラソンランニング完走直後のβエンドルフィン濃度はランニング前値の約9倍にも上昇した。これまでに高温，高湿などの外部環境要因によってβエンドルフィン分泌が促進されることが報告さている。したがって，3時間以上走り続けるといった感覚的強度がエンドルフィン分泌の刺激作用因子になったものと考えられる。以上のことから，ムードを好転させる内因性物質のβエンドルフィンの分泌は運動の強度（70～80% VO_2max）の他に持続時間が1時間を越え著しい疲労をともなうような運動によっても影響されると言えよう。

（受理日　平成15年7月9日）