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Effects of training on iron status in cross-country skiers

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Summary. Haematological changes were studied in cross-country skiers during a 33-week training season (7 h a week). The daily amounts of training were calculated from the duration and the intensity of the exercise and then used to estimate training responses associated with a first order transfer function. The profile of system training responses (STR) was determined by convolution between the amounts of training and a first-order transfer function. Linear regressions were used to determine correlation coefficients between STR and iron status indices. Among the values for the time constants of decay, the one giving the best fit between STR and iron status indices was chosen. A relationship was noted between on the one hand STR and changes in serum ferritin concentration ([FERR]) and on the other hand STR and change in mean cell volume (MCV). The [FERR] was decreased and MCV was increased by training. It is suggested that a decrease in [FERR] could have been related to a decrease in total body iron stores. However, large and rapid changes in [FERR] could not have been a reflection of changes in total body iron stores. Equilibrium between [FERR] and total body iron stores could have been temporarily altered by the effects of training. Moreover, iron stores did not seem to have been sufficiently depleted to restrict erythropoiesis. The MCV increased slightly in response to intense training suggesting that training enhances the proportion of young erythrocytes.

Key words: Endurance training – System model – Iron status – Cross-country skier

Introduction

Endurance activities have been found to induce alterations in iron metabolism (Clement and Sawchuk 1984; Ehn et al. 1980; Magnusson et al. 1984; Newhouse and Clement 1988). Although documented mainly in runners (Miller 1990), and obviously more frequently among runners than other athletes (Dufaux et al. 1981; Dickson et al. 1982), these alterations would not appear to be specific to running. Diehl et al. (1986) have observed a decrease in serum ferritin concentration ([FERR]) in female players during the hockey season, compared to controls. Magazanik et al. (1988) have measured, in a group of men and women, a 50% decrease in [FERR] within 4 weeks of an intensive training programme including various physical activities. Cross-country skiing has been found to induce iron status alterations as well. Haymes et al. (1986) have reported that out of the 19 members (both men and women) of the US ski team, 6 had [FERR] below 28 $\mu g \cdot l^{-1}$, irrespective of their iron intake. Moreover, the [FERR] measured in the female members of that ski team were similar to those reported for Canadian women runners. Recently, Pattini et al. (1990) have reported the early changes in [FERR] measured after cross-country and roller-ski endurance races to be similar to those observed by Dickson et al. (1982) in runners after ultra-marathon races.

Although it has been clearly demonstrated that depletion of body iron stores does not inhibit oxidative metabolism (Celsing et al. 1987), and that a decrease in [FERR] does not necessarily reflect a depletion of athletes' iron stores (Magnusson et al. 1984), haematological and blood iron parameters, mainly [FERR] and haemoglobin, are still used in clinical sports medicine as suggested indices of overtraining. However, very few studies have been conducted to determine the relationship between haematological parameters and the amount of training or competition. Pattini et al. (1990) have pointed out that the magnitude of the early increase in [FERR] following ski endurance races, was related to the duration of the competitions. The only longitudinal study taking into account the whole data of a training and competition season was completed by Banister and Hamilton (1985), on five female long distance runners. These authors have suggested that the percentage transferrin saturation was positively related to the

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Table 1. Subject data

Subject	Age (year)	Sex	Mass (kg)	Height (cm)	$\dot{V}O_{2max}$ ($ml \cdot min^{-1} \cdot kg^{-1}$)	Training[a] (year)	Training[b] ($h \cdot week^{-1}$)		Training[b] ($number \cdot week^{-1}$)	
							mean	SD	mean	SD
1	17	F	52	162	60.2	6	7.4	4.0	5.0	1.6
2	26	M	64	170	69.1	10	7.3	4.1	5.9	1.4
3	21	M	62	172	70.2	4	5.3	5.1	3.5	1.7

F, female; M, male; [a] training background; [b] training during the period studied

level of fatigue, as derived from the amount of training and performances using a system model of training. However, this relationship was mainly based on a comparison of the shapes of curves from two subjects (i.e. 18 biological measurements) and did not include any statistical data.

The purpose of the present study was to investigate whether haematological parameters or iron status indices are quantitatively related to training amounts. These relationships were researched using a statistical method derived from system theory. The parameters needed for quantifying the amount of training were computed during the whole period studied. This programme was completed in only three subjects. Biological indices were regularly measured in cross-country skiers over a whole season.

Methods

Subjects. Three subjects, two men, one woman, aged 17–26 years, volunteered to take part in this study. These subjects were well-established athletes: one was selected for the national team at the end of the study, the other two obtained the titles of Low-Lander World Champion. Their physical and physiological characteristics are listed in Table 1. During the 33-week period of this study, they were training an average $7\ h \cdot week^{-1}$. Training included skiing (81%), roller skiing (15%) and running (4%). All the subjects were nonsmokers; they were not taking iron supplements. The woman was amenorrhoeal and not using contraceptive pills.

Quantification of training. To quantify the amount of training, the duration of exercise and the heart rate (f_c) were monitored with a heart rate recorder (Sport Tester PE 3000, Pragmat, Paris). From these data, amounts of training [($W(t)$) expressed in arbitrary units] were calculated according to the method of Banister and Hamilton (1985):

$$W(t) = X \cdot D \cdot k \quad (1)$$

where X is $(f_{cExercise} - f_{cBasal}) \cdot (f_{cMax} - f_{cBasal})^{-1}$ and D is duration of exercise (min), k is $0.86 \cdot e^{1.67X}$ for female subjects and k is $0.64 \cdot e^{1.92X}$ for male subjects.

X was estimated from the average f_c recorded during the training session. When the training session was composed of exercises of differing intensities, the session was divided into different units and the total amount of training was estimated as the sum of individual exercises. The multiplying factor k, weighting $W(t)$, emphasized the high intensity of training undertaken during a training session. Banister and Hamilton (1985) have used an exponential function for the factor k, in accordance with the exponential increase in blood lactate with exercise intensity observed by Green et al. (1983).

System training response. The amounts of training were used to estimate training responses, which were associated with first order transfer functions. The mathematical form of the time impulse response of a first order transfer function is $e^{-t/\tau}$, where τ is a decay time constant. The profile of the system training response (STR) was determined by the convolution product of the amounts of training and the time impulse response as:

$$STR(t) = W(t) * e^{-t/\tau} \quad (2)$$

The convolution product is defined by

$$STR(t) = \int_0^t W(t') e^{-(t-t')/\tau} dt' \quad (3)$$

The discretisation of this equation results in:

$$STR(i\Delta t) = \sum_{j=1}^{i-1} W(i\Delta t) e^{-j/\tau} \quad (4)$$

where t is $i\Delta t$. The value of Δt was 1 day. Thus, the level of STR at the day number i was estimated from the previous training loads, i.e. observed for the days numbered $j = 1$ to $i - 1$. The profiles of STR were calculated with a decay time constant varying from 1 to 50 days. An example of such recursive variations is given in Fig. 1.

Iron status indices. An 8-ml venous blood sample was collected at 8.30 a.m. every 2 weeks during the training period. Haemoglobin (Hb), red blood cell count (RBC), mean corpuscular volume (MCV), and packed cell volume (PCV) were determined using a counter model system 9000 Baker (Baker Instruments, Paris, France). Serum iron concentration was analysed with a Hitachi 704 (Boehringer Mannheim, Meylan, France), using the ferrozine method. Total iron binding capacity (TIBC) was determined with Nor-Partigen plates (Behring Diagnostic, Rueil Malmaison, France). The [FERR] was analysed using the Elisa method with a ES 22 Boehringer (Boehringer Mannheim).

Statistics. Means and standard deviations of iron status indices were calculated. Linear regressions were used to determine correlation coefficients between STR and iron status indices. The value of the decay time constants giving the best fit between STR and iron status indices was adopted.

Results

Iron status indices

During the training period, changes of large amplitude were observed in the serum iron concentration, transferrin percentage saturation (% SA), and ([FERR]; Table 2). In subjects 2 and 3 [FERR] decreased to a value below $15\ \mu g \cdot l^{-1}$ and 15 days after, increased to reach normal range (Fig. 2). Small amplitude changes were observed in RBC, Hb, PCV, MCV, mean cell haemoglobin and mean cell haemoglobin concentration (Table 2).

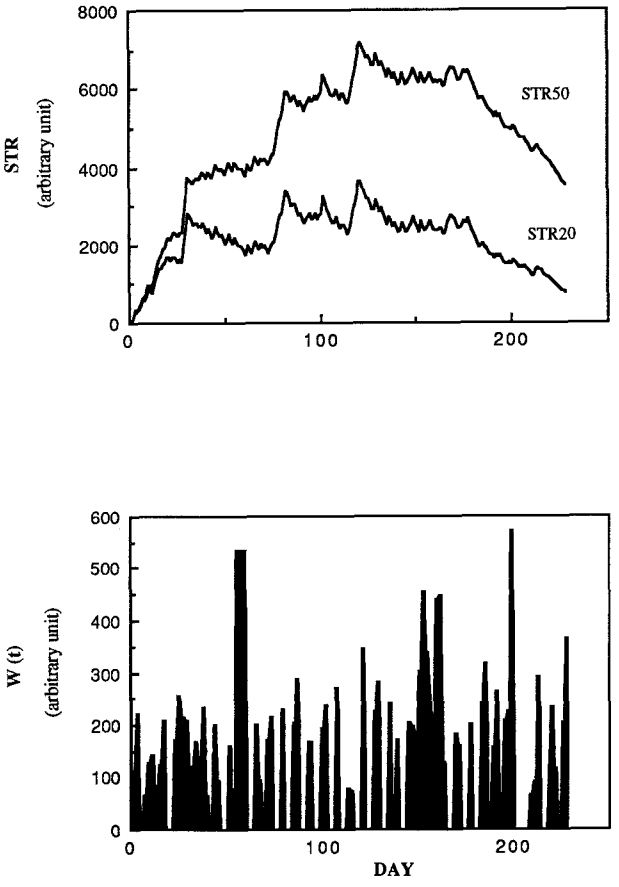

Fig. 1. An example of two different system training responses (*STR*) with two decay time constants (20 and 50 days) derived from the training of subject 1. *W*(t), amounts of training

Table 2. Haematological parameters and iron status indices of the subjects, during the 33 weeks of the period studied

Variables	Subject 1 ($n=11$)		Subject 2 ($n=12$)		Subject 3 ($n=12$)	
	mean	SD	mean	SD	mean	SD
Serum iron ($\mu g \cdot 100\,ml^{-1}$)[a]	81.9	40.0	96.0	22.9	143.5	56.3
Total iron binding capacity ($\mu g \cdot 100\,ml^{-1}$)	313.0	37.5	303.0	25.8	292.1	38.7
Saturation (%)[a]	26.9	14.5	31.9	8.1	48.7	16.2
Ferritin ($\mu g \cdot l^{-1}$)	27.4	9.2	37.7	14.8	60.1	25.6
Red blood cell ($10^{12} \cdot l^{-1}$)	4.5	0.4	5.3	0.2	5.4	0.2
Packed cell volume (%)	42.0	2.3	45.5	1.8	49.1	1.9
Haemoglobin ($g \cdot 100\,ml^{-1}$)	14.0	0.8	15.6	0.6	16.8	0.8
MCV (μm^3)	92.4	0.8	85.3	0.6	91.4	0.7
MCH (pg)	30.8	0.6	29.2	0.7	31.2	0.5
MCHC ($g \cdot dl^{-1}$)	33.3	0.8	34.4	0.8	34.1	0.5

[a] One measurement was missing; MCV, mean cell volume; MCH, mean cell haemoglobin; MCHC, mean cell haemoglobin concentration

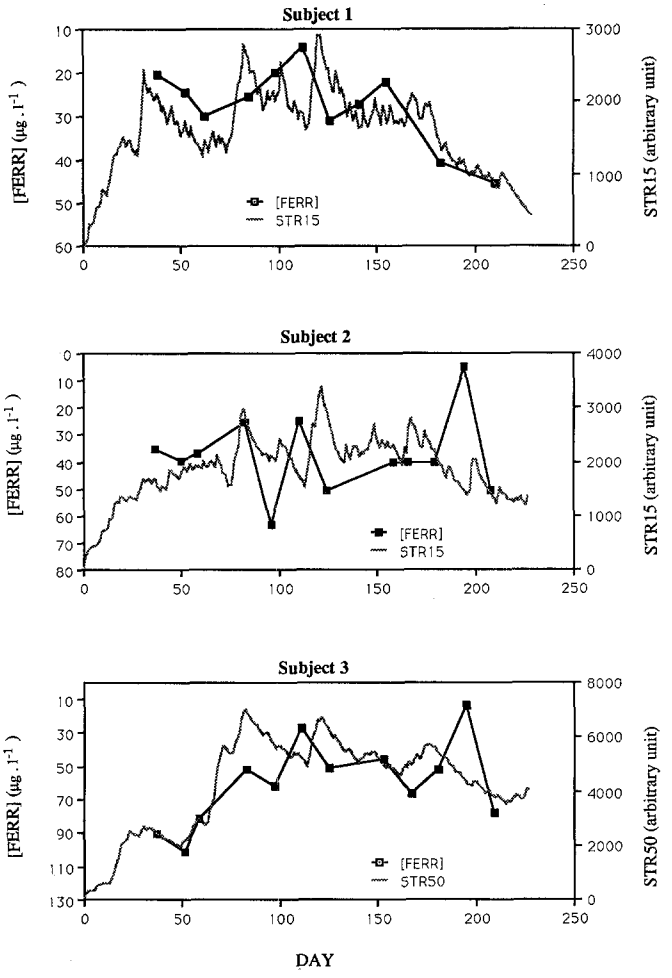

Fig. 2. The relationship between system training responses (*STR*) in individuals and serum ferritin concentration ([*FERR*]; decreasing scale). A negative and significant correlation was found between *STR* and [*FERR*], $r=-0.68$ ($P<0.05$), and $r=-0.63$ ($P<0.05$), in subject 1 and 3, respectively. No correlation between these two parameters was observed in subject 2. 15, 15, 50, decay time constants (days)

Relationships between STR and iron status indices

A relationship has been noted between STR and change in [FERR] (Fig. 2). Moreover, a negative and significant correlation was found between STR and [FERR], $r=-0.68$ ($P<0.05$), and $r=-0.63$ ($P<0.05$) in subjects 1 and 3, respectively. No correlation between these two parameters was observed in subject 2. The decay time constants were 15, 15 and 50 days for subjects 1, 2 and 3, respectively. For the whole group, a negative and significant correlation was found, $r=-0.63$ ($P<0.001$).

A relationship was noted between STR and change in MCV. Moreover, a positive and significant correlation was found between STR and MCV, $r=0.72$ ($P<0.02$), $r=0.57$ ($P=0.05$), and $r=0.63$ ($P<0.05$) for subjects 1, 2, and 3, respectively (Fig. 3). Decay time constants were 20, 15 and 50 days for subjects 1, 2 and 3, respectively. For the whole group, a positive and significant correlation was found, $r=0.59$ ($P<0.001$).

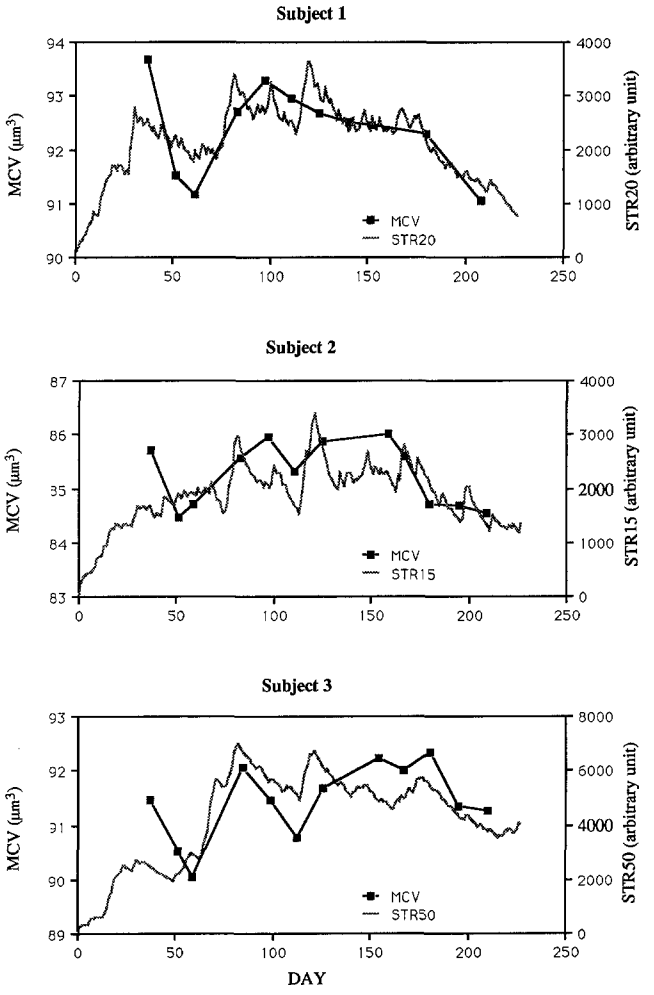

Fig. 3. The individual relationship between system training responses (*STR*) and mean corpuscular volume (*MCV*). A positive and significant correlation was found between *STR* and *MCV*, $r=0.72$ ($P<0.02$), $r=0.57$ ($P=0.05$), and $r=0.63$ ($P<0.05$), for subject 1, 2, and 3, respectively; for other definitions see Fig. 2

A negative and significant correlation, $r=-0.72$ ($P<0.02$), was found between STR and %SA for subject 3. No significant correlation between these two parameters was observed in either of the other two subjects, or in the whole group.

Relationships between iron status indices

No significant correlation between [FERR] and MCV was found in any subject.

Discussion

The major finding of the present study was that training was related to changes in [FERR] and MCV, in the cross-country skiers studied.

The relationships between amounts of training and biological changes were supported by first-order transfer functions. Previous studies relating to modelling of training similarly have used first order transfer functions to describe training responses, i.e. fatigue and fitness (Banister et al. 1975; Banister and Hamilton 1985; Busso et al. 1990; Busso et al. in press; Calvert et al. 1976; Morton et al. 1990). The decay time constant was determined by fitting the model performances estimated as the difference between fatigue and fitness, to the recorded ones. Significant relationships were observed between changes in serum testosterone concentrations and the modelled responses, i.e. fatigue and fitness (Busso et al. 1990). In the present study, the relationships between training and biological indices were directly examined by researching the transfer function which related them. The decay time constants were obtained by determining those providing the best correlation between STR and the biological parameters. The statistical significance of the correlation allowed us to verify the validity of the relationship obtained between amounts of training and biological parameters. The STR was not associated with either fatigue or fitness.

The statistical approach used in this study showed the relationships between amount of training and parameters related to iron metabolism more clearly than direct observation could do, since exercise sessions have been found to induce early iron metabolism index changes in the opposite direction to that of their long-term consequences (Dickson et al. 1982; Gimenez et al. 1988; Pattini et al. 1990). These oppositely directed changes could have been responsible in part for the low correlation coefficients obtained with training for the variables studied. The relationships between training and biological changes were not evident by comparing the amounts of training directly with the biological changes. The cumulative effect of successive training sessions and the delay in response obscure these relationships. In a general sense, differences in training programmes and sensitivity among athletes interfere with the investigation of relationships between training and biological changes. In the present study, which allowed analysis of individuals, it was possible to observe differences in sensitivity to training stimuli; also differences in durability of training effects on iron status were observed. The longer the training effect was, the more the amounts of training accumulated, and the greater was the time constant of the STR values describing the velocity of response decay (Fig. 1). The time constants were different among the subjects. The functional significance of these differences was probably included in the training history of these athletes: for instance, for subject 3, the training effects on [FERR] and MCV lasted longer compared to the other subjects and this was probably linked to the fact that his training background was less than the other subjects (Table 1). He was more affected by training because he was not used to intense training. The opposite was the case for subject 2, for whom the training effects on [FERR] and MCV lasted for a shorter time compared to the other subjects and this was associated with the fact that he had been used to intense training for many years (Table 1).

Generally, studies relating to biological changes due to training consist of research into the significant differences between before and after training period. These

studies need a great number of subjects. In the present study, the purpose was different – it was to determine relationships in individuals between training and biological changes. In this case, the number of biological measurements was more important than the number of subjects. Thus, despite the small number of subjects, the relationships between training and changes in [FERR] and MCV provided an opportunity to speculate on the functional significance of the observed changes. The changes in [FERR] were significantly related to training in two subjects (subjects 1 and 3) among the three athletes studied. A weaker sensitivity to training, or a training stimulus that was too small, could explain the lack of quantitative relationship evidenced between [FERR] and training in subject 2. Indeed, subject 2 had a longer background in training than the others (Table 1); therefore he could have been less affected by training during the period studied.

The significant relationship observed in the other subjects between [FERR] and training agrees with other reports (Diehl et al. 1986; Magazanik et al. 1988). These studied have shown a decrease in [FERR] during training. Based on the closed relationship between [FERR] and total body iron stores (Bothwell et al. 1983), a decrease in [FERR] could be related to a decrease in total body iron stores. However, in the present study, equilibrium between [FERR] and total body iron stores seems to have been temporarily altered by training. Indeed, subjects 2 and 3 (Fig. 2) demonstrated a rapid and large decrease following by a rapid and large increase in [FERR]. These changes are too large and rapid to be a reflection of changes in total body iron stores because the body's capacity to excrete and absorb iron is extremely limited (McCance and Widdowson 1937).

Three possible explanations for the decrease of [FERR] in endurance athletes have been advanced:

1. Intravascular haemolysis and bleeding (Miller 1990).
2. Increased iron losses in sweat, these losses being enhanced by the increased iron plasma concentrations that results from intravascular haemolysis (Magnusson et al. 1984).
3. Banister and Hamilton (1985) have proposed, as an alternative explanation, that fatigue could inhibit iron delivery from transferrin to bone marrow, thus progressively inducing anaemia. According to this hypothesis, increasing iron intakes would be of no value if the athletes were still suffering from fatigue. On the one hand, the assumption of Banister and Hamilton (1985) was not based on any statistical evaluation. On the other hand many unsuccessful attempts have been made to demonstrate that % SA might control iron absorption (Schade et al. 1969). Moreover, there is some evidence that the endurance athlete's [FERR] is sensitive to iron intake (Haymes and Spillman 1989; Magazanik et al. 1991; Newhouse et al. 1989). The present study did not show any positive relationship between amounts of training and percentage transferrin saturation or with TIBC either; moreover, a negative and significant correlation ($r = 0.72$ and $P < 0.02$) was obtained for subject 1. Our findings did not support the hypothesis of Banister and Hamilton (1985).

In the present study, [FERR] decreased in response to intense training in two subjects, however, iron stores were not depleted enough to restrict erythropoiesis: the RBC and Hb did not decrease (Table 2) – moreover, MCV increased slightly in response to intense training. This increase in MCV may have been related to a higher proportion of young erythrocytes. Radomski et al. (1980) have shown that during recovery after a 6-day period of military walking, there was an increased proportion of young erythrocytes. This was in line with the observation of Brodthagen et al. (1985) who have reported an increased proportion of young erythrocytes in runners.

The same decay time constant (15 and 50, for the subjects 2 and 3, respectively) has been found in the relationships [FERR]-SRT and MCV-STR suggesting a possible relationship between [FERR] and MCV. However, no significant correlation was observed between these two parameters in subjects 1, 2 and 3. Thus, no interpretation can be given for the similarity among the decay time constants.

In conclusion, the statistical method used in this study made it possible to link biological changes to training. The changes in [FERR] were quantitatively related to training in two subjects. However iron stores did not seem to be sufficiently depleted to restrict erythropoiesis. The MCV increased slightly in response to heavy training, suggesting that training may enhance the proportion of young erythrocytes.

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