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CLINICAL INVESTIGATIONS

Sex, sport, and body-size dependency of hematology in highly trained athletes

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ABSTRACT

TELFORD, R. D. and R. B. CUNNINGHAM. Sex, sport, and body-size dependency of hematology in highly trained athletes. *Med. Sci. Sports Exerc.*, Vol. 23, No. 7, pp. 788–794, 1991. Blood hemoglobin concentration, hematocrit, red cell count, white cell count (WBC), and plasma ferritin concentration were measured on 1604 occasions from 706 nationally ranked athletes in 12 sports. The blood samples were taken from a forearm vein amidst periods of moderate to intense training but at least 6 h after a training session. A multiple regression model, accounting for correlations between variables and incorporating the categorical variables of sex and sport revealed the following. Each blood variable was found to be dependent on body mass index, (mass/height^2, BMI), with the exception of WBC in the males. As BMI increased so did the magnitude of these blood variables ($P < 0.01$). Each blood variable was also dependent on the sport ($P < 0.01$), significant differences being observed between several sports in each case. Furthermore, as has been previously reported, the magnitude of the blood variables was dependent on the sex of the athlete, each being significantly greater in males ($P < 0.01$), with the exception of the WBC, which was greater in females ($P < 0.01$). These data indicate that the rationality of interpreting the hematology in highly trained athletes may be increased by taking BMI and sport into account, as well as gender.

HEMOGLOBIN, HEMATOCRIT, RED CELLS, WHITE CELLS, FERRITIN, TRAINING, BODY MASS INDEX, EXERCISE

Hematology is a well-accepted form of investigation of the health and fitness of the intensely training athlete. It is usual to compare the athlete's results with a reference value or range during the diagnostic procedure. These values may include the individual's previous record and/or the values obtained from the literature. There has been considerable research to develop reference ranges in the so-called "normal" populations in many countries (10–12,18,21), Australia being no exception (5,6,26). Athletes have also been studied quite extensively for their hematological status (3,7,8,10,16,19,29,32,35,36).

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During routine assessment of athletes the authors had noticed trends in hematological data that suggested certain blood concentrations and cell counts were related to the sport and size of the athlete as well as the sex. Should these trends be real, then specific reference values could facilitate more accurate interpretation of the presenting athlete's blood profile.

In support of the premise that the hematology may be sport-dependent is the suggestion that blood hemoglobin concentrations of athletes in endurance-related events may differ from those in the power-related events (32).

In some support of a body-size dependent hematology in the athlete are the findings that red cell mass is related to lean body mass (20) and also to height and weight (24) and that red cell volume was found to be correlated significantly with lean body mass as well as fat mass (13). However, there does not appear to be any literature relating anthropometry to blood concentrations, although it has been documented that hemoglobin concentration and red cell count are dependent on gender (2,15) as well as age (15).

The purpose of this study was to investigate the relationships of five routine hematological measures (red cell count, hemoglobin concentration, hematocrit, white cell count, and plasma ferritin concentration) with height, mass, and the particular sport for which the athlete was trained.

SUBJECTS AND METHODS

Subjects. Data were recorded from 706 athletes as part of the monitoring services to athletes and their coaches. As many athletes were sampled on several occasions, a total of 1604 observations were obtained. All athletes gave written consent to methods used in

this study which were approved by the Institute's Ethics Committee.

Athletes were either resident at the Australian Institute of Sport or visiting as part of a training camp scheme. All athletes therefore belonged to national training squads and most of the sports involved Australia's best senior athletes. Exceptions were soccer, basketball, and tennis, where most of the data were obtained from highly nationally ranked junior athletes under the age of 20 years. The age, height, and mass data for each sport is listed in Tables 1 and 2. Only subjects in apparent good health were used in the current analysis.

Procedures. Venous blood samples were collected from a forearm vein with the athlete in the lying position. They were usually taken in the morning before the athlete had commenced training. However, on a few occasions samples were drawn in the afternoon, in which case the athletes had not trained for at least 6 hr, if at all that day.

Methods. Hemoglobin concentration (HGB), hematocrit (HCT), red blood cell count (RBC), and white blood cell count (WBC) were performed using a Coulter Counter M430 (Coulter Electronics, Hialeah, FL). Plasma ferritins (F) were assayed using either a solid phase enzyme immunoassay (EIA) method (ferrizyme, Abbott Australasia, Sydney, Australia) or for samples toward the end of the study a radioimmunoassay (RIA) method (Ciba Corning Magic Ferritin, Australian Diagnostics, Melbourne, Australia). The EIA absorbance measurements were performed on a Pye Unicam SP6-550 UV/VIS Spectro-photometer (Philips Scientific and Industrial, Sydney, Australia) and the RIA measurements were performed on a Corning 4000 Multiwell Gamma Counter (Australian Diagnostics).

TABLE 1. Age, height, mass, and BMI of the male athletes.

Sport	*N*	Age (yr)	Height (cm)	Mass (kg)	BMI (kg cm^{-2} × 10^3)
Basketball	26	18.4	187.5	81.9	2.32
		0.81	4.95	5.1	0.18
Cycling	36	21.5	178.1	73.3	2.28
		2.3	4.31	7.0	0.15
Gymnastics	20	21.3	166.3	62.0	2.24
		3.0	6.04	7.5	0.18
Kayak	13	22.5	180.4	80.4	2.45
		2.4	4.35	3.7	0.12
Rowing	44	21.9	186.8	81.7	2.41
		2.00	6.22	9.7	0.13
Soccer	27	18.0	178.2	71.8	2.26
		0.84	6.10	5.9	0.14
Swimming	57	19.6	182.4	77.4	2.31
		1.6	6.27	6.2	0.11
Tennis	11	17.8	180.4	69.6	2.17
		0.60	4.23	6.5	0.16
Track (m)	26	21.2	180.0	75.4	2.34
100–400		2.2	5.73	7.0	0.10
	53	23.4	175.8	63.4	2.05
>400		2.4	5.31	4.5	0.12
Field	9	22.5	185.3	79.2	2.24
		2.6	5.89	8.1	0.12
Waterpolo	27	19.1	182.6	76.3	2.27
		2.6	5.62	8.8	0.23
Weightlifting	19	20.2	172.5	74.2	2.51
		2.3	7.90	9.3	0.02

Values are means and standard deviations.

TABLE 2. Age, height, mass, and BMI of the female athletes.

Sport	*N*	Age (yr)	Height (cm)	Mass (kg)	BMI (kg cm^{-2} × 10^3)
Basketball	27	18.3	179.0	69.7	2.17
		1.1	6.91	7.6	0.15
Gymnastics	29	17.7	160.8	52.3	2.00
		0.74	1.59	1.5	0.10
Netball	48	19.1	173.9	67.0	2.22
		1.2	5.49	7.0	0.17
Rowing	26	21.5	175.3	69.7	2.33
		2.3	4.69	6.5	0.16
Swimming	51	18.6	171.3	62.5	2.14
		1.6	5.04	5.0	0.13
Tennis	10	18.1	167.1	61.6	2.18
		1.0	3.95	3.4	0.16
Track (m)	13	20.1	169.9	56.8	2.00
100–400		1.3	6.82	2.6	0.08
	24	20.5	171.1	58.6	2.00
>400		3.1	6.6	4.0	0.09
Field	10	21.3	175.4	71.8	2.15
		2.5	4.46	10.5	0.12

Values are mean and standard deviations.

STATISTICAL ANALYSIS AND RESULTS

Tables 3 and 4 present summaries of the raw data obtained from the athletes' blood samples.

The main aim of the statistical analysis was to determine whether there were any hematological differences, on average, between athletes from the various sports, between the sexes, and whether there was an effect of mass or height. As the ratio of the number of males to females varied considerably among different sports the effects of SEX and SPORT were not independent. Thus, to test the statistical significance of these effects, correlations between the variables had to be considered. Multiple regression analysis provides a method that appropriately adjusts for such effects. Categorical variables such as SEX and SPORT are included in the multiple regression model by defining an appropriate set of dummy variables. In this case the analysis could be alternatively described as a two-way nonorthogonal analysis of covariance.

For all blood variables, intersubject variability was significantly ($P < 0.05$) greater than intrasubject variability. It was therefore necessary to calculate means for each subject and carry out "weighted" regression analyses; the "weights" in each case being the number of observations recorded for each subject. Regression models relating the response variable (blood component) to SPORT, SEX, age, height and mass, and interactions of these variables were considered. Results of these preliminary analyses disclosed that the body mass index (BMI) calculated as the mass divided by the square of the height ($\times 10^3$), correlated more closely with each hematological variable than mass or height

TABLE 3. Raw values of hematological data grouped according to sport for male athletes.

	RBC ($10^{12} \cdot l^{-1}$)	WBC ($\times 10^{9} \cdot l^{-1}$)	HGB $g \cdot dl^{-1}$	HCT (%)	F ($ng \cdot dl^{-1}$)
Basketball	5.20	7.24	15.84	45.58	56.27
	0.33	1.45	0.65	3.05	
Cycling	5.27	6.49	16.00	47.84	98.16
	0.30	1.41	0.88	2.57	
Gymnastics	5.04	6.34	15.63	43.90	44.21
	0.37	1.22	1.01	3.27	
Kayak	5.31	7.04	15.88	47.39	125.50
	0.28	1.62	0.74	2.83	
Rowing	4.99	6.93	15.82	44.26	95.69
	0.34	1.70	0.90	2.74	
Soccer	5.20	7.29	15.97	44.69	48.13
	0.33	1.28	1.01	2.72	
Swimming	5.21	7.29	16.17	46.10	54.30
	0.40	1.79	1.00	3.48	
Tennis	5.28	7.51	15.41	46.08	28.18
	0.46	2.15	0.83	3.42	
Track (m)	5.35	8.24	16.29	46.85	87.61
100–400	0.38	1.92	1.05	3.51	
	5.15	6.76	15.95	45.79	63.26
>400	0.41	1.56	1.10	3.21	
Field	5.29	7.38	16.14	45.85	90.31
	0.37	2.26	0.92	3.21	
Waterpolo	5.15	8.11	15.98	46.19	68.46
	0.27	1.72	1.04	2.40	
Weightlifting	5.54	7.11	16.58	48.84	82.00
	0.32	1.53	0.97	3.29	

Values are means and standard deviations.

TABLE 4. Raw values of hematological data grouped according to sport for female athletes.

	RBC ($10^{12} \cdot l^{-1}$)	WBC ($\times 10^{9} \cdot l^{-1}$)	HGB ($g \cdot dl^{-1}$)	HCT (%)	F ($ng \cdot dl^{-1}$)
Basketball	4.70	7.24	14.27	40.42	23.98
	0.35	1.32	0.90	2.69	
Gymnastics	4.75	7.01	14.38	41.67	31.91
	0.33	1.55	0.89	2.68	
Netball	4.56	7.77	13.89	40.06	33.33
	0.33	1.74	0.95	2.94	
Rowing	4.59	7.86	14.45	40.99	52.56
	0.38	2.01	0.97	2.87	
Swimming	4.66	7.63	14.47	42.21	54.30
	0.32	1.89	0.96	3.45	
Tennis	4.76	6.48	14.32	42.68	28.18
	0.24	1.34	1.02	2.36	
Track (m)	4.71	7.74	14.60	41.99	35.12
100–400	0.35	1.91	1.09	3.74	
	4.55	6.73	14.35	41.24	42.24
>400	0.38	1.82	1.11	3.37	
Field	4.74	7.52	14.70	41.54	46.85
	0.31	1.94	0.93	2.72	

Values are means and standard deviations.

alone or the linear combination of mass and height. Therefore, together with the fact that mass and height themselves were highly correlated, the BMI was preferred as the variable depicting body size in the regression models. The BMI has been used widely by epidemiologists (34).

The final regression models chosen for all blood variables included SPORT, SEX, and BMI as significant explanatory variables. For WBC the SEX-BMI interaction was also significant with further analysis, indicating that the effect of BMI on the WBC for female athletes was not significant (see Fig. 3). A summary of the analysis of variance, including the levels of significance, is presented in Table 5.

It is generally held that most biological data are not symmetrically distributed (14). However, the distribution of RBC, HGB, HCT, and WBC were sufficiently symmetrical to validate application of the analysis of variance. In the case of F the frequency distribution was skewed, but transformation to the natural logarithm normalized the distribution to satisfy the conditions for application of the regression analysis.

Summaries of these regressions in the form of predicted values for SPORT, SEX, and the linear effect of BMI are also presented graphically in Figures 1–3. The graphs show predicted means (adjusted for other effects), and the length of the vertical markers are two SE either side of the mean, which represent the 95% confidence intervals for the mean. These confidence intervals provide an effective measure of uncertainty about the mean. Now, having established that significant differences exist (Table 5), the confidence intervals can also be used to develop a simple but approximate rule for making decisions concerning pairs of means. Any two means are significantly different at $P < 0.01$ (approximately) if the 95% confidence intervals do not overlap. Consequently, it is possible to derive a very good estimation of the significance of differences between any two means in any graphical representation while obviating the need for cumbersome tables of multiple comparisons.

DISCUSSION

The International Committee for Standardization in Haematology (14), in alluding to the importance of providing reliable sets of reference values, pointed out that rational interpretation of hematological results requires special attention to the variation caused by physiological processes, genetic differences, environmental factors, and diseases. Now highly trained and successful athletes are subjected to unusual physiological adaptations and are likely to be at variance genetically from the "normal" population. Further, they interact with their environment in ways not usual for more sedentary human beings. Therefore, it would appear likely that use of the usual "laboratory normal values" or "textbook reference values" may not be the most appropriate data for interpretation of an athlete's hematological results. Some studies support this notion by suggesting differences in the hematology of athletically trained and untrained individuals (25,31,36).

The current study has investigated the hematological differences of athletes in more detail. The relationship

TABLE 5. Summary analysis of variance for regression analyses.

Source of Variation		Variance Ratio					Crticial Values	
(Terms Adjusted for)	*df*	RBC	WBC	HGB	HCT	log(F)	$P = 0.05$	$P = 0.001$
Sport (Sex, BMI)	15	5.8	3.7	4.8	6.9	8.0	1.67	2.52
Sex (Sport, BMI)	1	273.5	4.4	350.0	228.3	88.5	3.86	11.0
BMI (Sport, Sex)	1	6.7	11.2	19.9	10.6	3.9	3.86	11.0
Sex · BMI	1	—	6.0	—	—	—	3.86	11.0
Residual								
Mean Square	445*	0.185	4.35	1.211	12.90	0.487	—	—
R^2 (adjusted)	—	57.6	11.1	65.4	57.8	49.0		

* 345 for variable log (F).

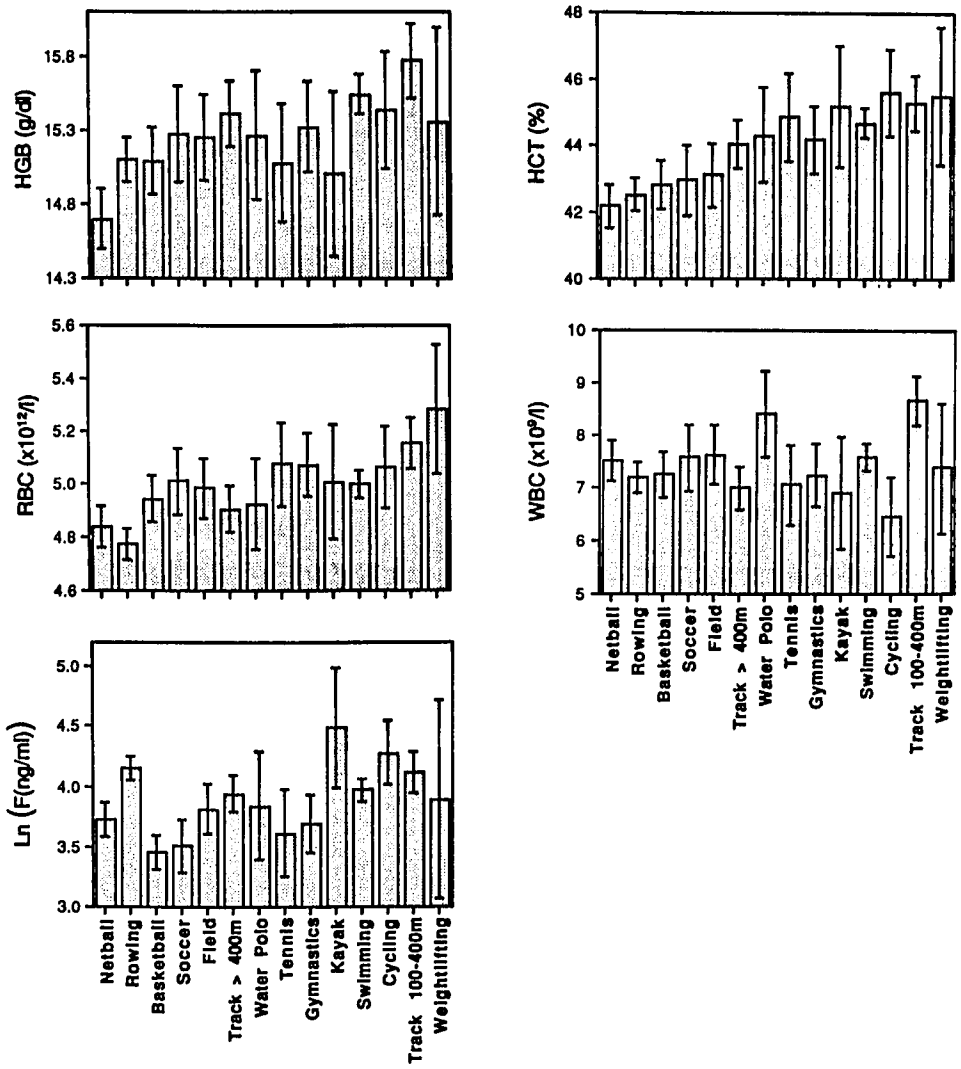

Figure 1—Graphical expression of the effect of SPORT on the hematology of the athlete. The data include both male and female athletes after statistical adjustment to remove the effects of SEX and SPORT. The *column graphs* are means, and the *lines* depict ±2 SE. Significant differences (approximately) at $P < 0.01$ for any two means are indicated when the SE lines do not overlap.

between the hematological variables and BMI suggests that concentration of each of the five blood measures varies with somatotype (white blood cells in the females excepted). Sheldon (30) has defined body types, or somatotypes, as ectomorphic, mesomorphic, or endomorphic. Ectomorphs are lean and long limbed; mesomorphs are well muscled, and endomorphs tend to carry more body fat. The work of Ross and coworkers (28) has highlighted the problems associated with using BMI for the purpose of assessing body composition. However, as expected of nationally representing athletes, those attending the Institute of Sport were in general very lean (33). Therefore, in contrast to a sedentary group where body fat level is more variable, the BMI of the homogeneously lean athletes may be considered to provide a reliable indication of relative ectomorphy or mesomorphy. In practical terms then, before making allowances for SPORT and body size, the shorter, mesomorphic athlete (and consequently high BMI) in good health, is predicted to possess he-

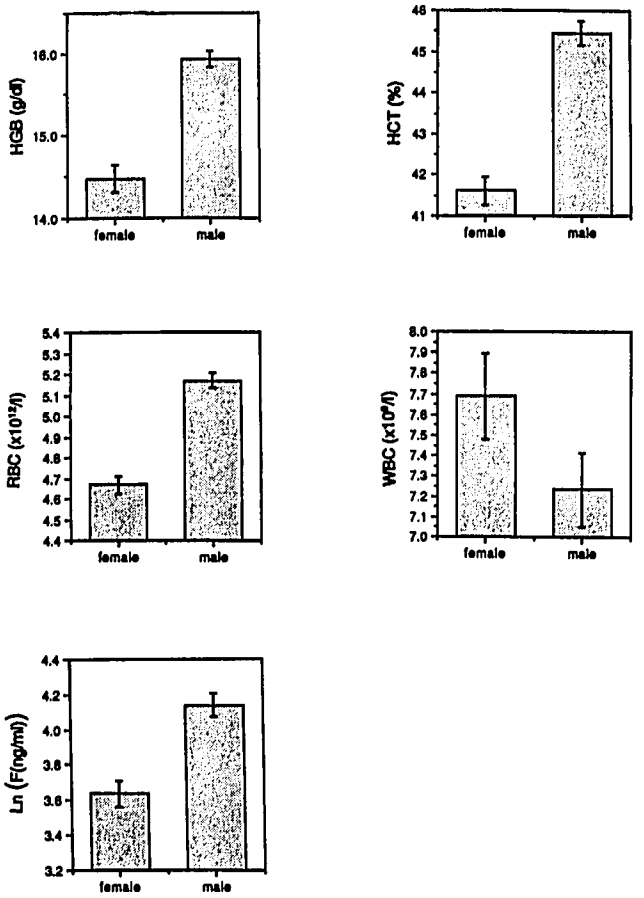

Figure 2—Graphical expression of the effect of SEX on the hematology of the athlete. The *column graphs* are means, and the *lines* depict ±2 SE. Significant differences (approximately) at $P < 0.01$ for any two means are indicated when the SE lines do not overlap.

matological concentrations at the high end of the range. On the other hand, a tall ectomorphic athlete (and so with a low BMI) is predicted to have hematological values at the lower end of the range. Having demonstrated a significant relationship between the blood variables and BMI, it would be of interest to test the suggested relationship between the blood variables and somatotype using direct measures of the latter.

This study has also demonstrated that hematological values vary according to sport. The sets of raw data listed in Tables 1 to 4, representing groups of highly and specifically trained Australian athletes, should provide useful additional information for the clinician when assessing the blood tests of a particular sportsperson, especially for those sports where larger numbers of athletes were measured. So, from a practical viewpoint, clinical assessment might not only take into account the expected sex differences, and the BMI, but also the sport for which the athlete is highly trained.

It is emphasized that the graphs present statistically adjusted data for systematically comparing the effects of each of SEX, BMI, or SPORT in turn on the particular hematological concentration. On the other hand, the tables of raw data are presented for reference purposes, but due to different weightings of BMI and gender in each sport, they cannot be used directly to investigate the relationship of the sport with the hematological measurement.

The significant differences according to sex in HGB, HCT, RBC, and also F have been previously documented (2,4,25,32). Higher cell counts and HGB in males has been suggested to result from the increased circulating testosterone levels, this hormone being hemopoietic in nature (9). A sex difference in WBC has been reported by Allan and Alexander (2), but only in age groups above 30 yr old. The latter finding was at variance with an earlier study in which no evidence for a sex difference in WBC was found (22).

Although not large, there were clear differences in the WBC between the sexes for the athletes in the current study. There appears to be little evidence for a sex hormone effect on WBC, so an explanation was sought in relation to a variation in training between the sexes. Generally males train with more intensity, a major reason being their greater physical work capacities. Exercise is known to demarginate WBC, thus increasing the circulating numbers, and this demargination depends on the intensity and duration of the exercise (27). Consequently higher levels of WBC in the males might have been expected, given their generally greater training loads, so the finding of higher WBC counts in the females is unexplained in these terms.

Having established from the multiple regression model the significant differences in athletes' hematology due to SPORT and BMI, the explanation for such differences is again not obvious. There does not appear to be any clear pattern relating the aerobic power requirements of the sport with those hematological variables associated with oxygen transport. For example, the track sprinters have a higher mean HGB concentration than the middle-distance/distance runners, which might be explained in terms of a hemodilution effect associated with endurance training (23). In contrast, however, the size and SEX-adjusted mean value for swimming, a sport involving extensive endurance training, is higher than the size and SEX-adjusted mean value for the less endurance-oriented sport of basketball. In any case one might expect total body hemoglobin rather than HGB concentration to correlate more closely with the aerobic demands of a sport. Also worthy of consideration in investigating reasons for the SPORT differences in the hematology is the relationship between training stress and testosterone production. For example, while exercise has been shown to raise serum testosterone levels in the short term, stressful training has been shown to lower circulating testosterone (1,17). Therefore, varying levels of training stress could be a

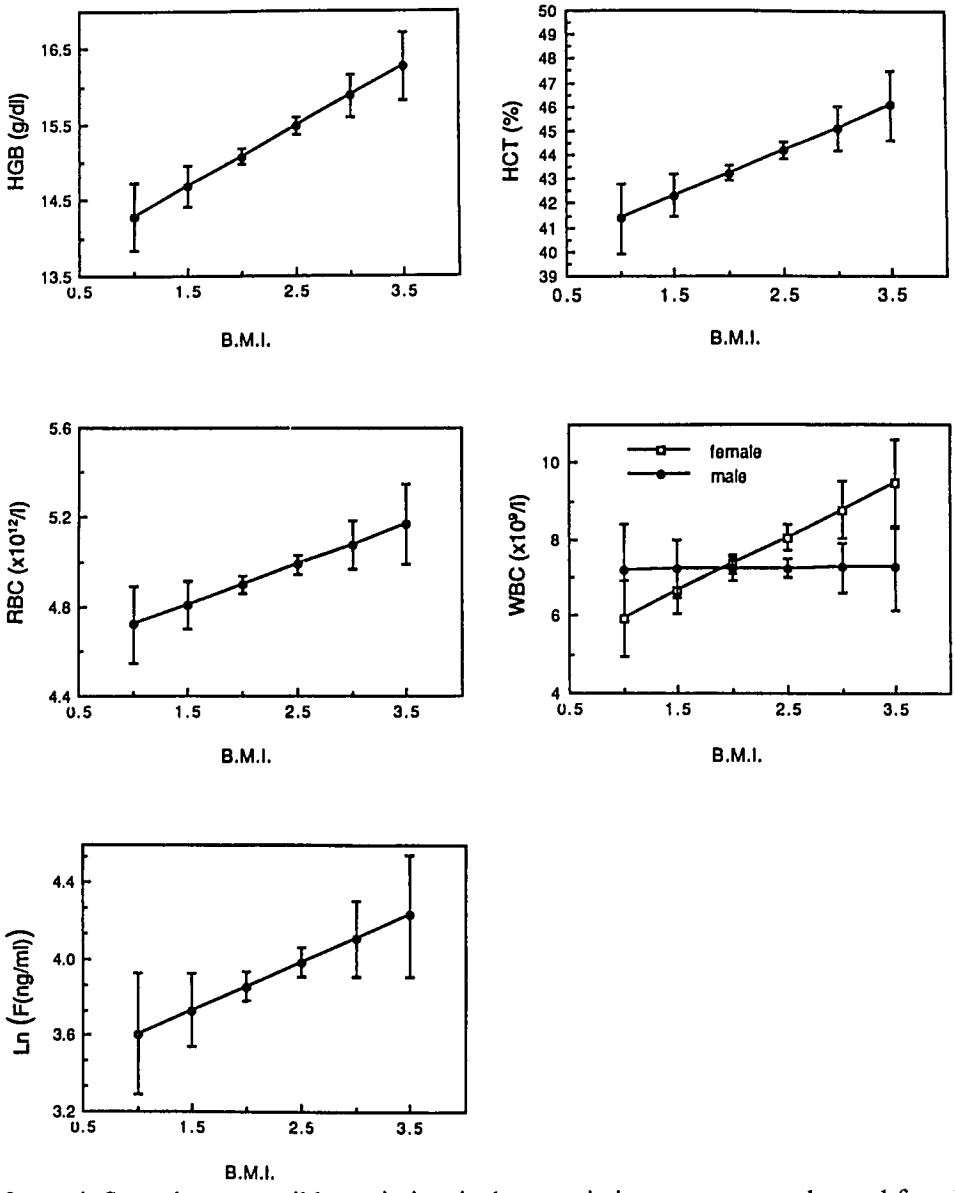

Figure 3—Graphical expression of the relationship between BMI ($\times 10^3$) and hematology of the athlete. The data include all athletes and have been statistically adjusted to remove the effects of SPORT and SEX. Values are means, and the *vertical lines* depict ± 2 SE. Significant differences (approximately) at $P < 0.01$ for any two means are indicated when the SE lines do not overlap.

factor influencing a possible variation in hemopoietic activity of athletes training in different sports. The SPORT difference in WBC might be explained at least in part by the previously discussed influences on demargination of WBC. Such demargination might be in response to tissue damage incurred during physical exercise, a factor likely to vary according to the physical demand of the sport and its training methods. It is also possible that the particular phase of training in which the athletes' WBC were measured, these phases varying in intensity and volume, may have been a factor involved in the significant differences between the sports.

The significant effect of BMI (after statistical adjustment to remove the effects of SEX and SPORT) on the hematological variables is no less difficult to explain but may also tentatively be speculated to be related to the androgenic action of testosterone. It is generally accepted that differences in muscular development between males and females are due partly at least, to the variation in testosterone production. As previously discussed, for homogeneously lean athletes the BMI is effectively an index of mesomorphy or muscularity. If testosterone is related to mesomorphy irrespective of sex, then this may account in part for the relationship between BMI and blood concentrations. However, the authors could not locate any studies investigating the relationship between somatotype and testosterone production.

In conclusion, this study, incorporating a multiple regression model, has indicated that in highly trained athletes blood concentrations of HGB, RBC, HCT, WBC, and F vary according to the BMI, the particular sport, as well as with the gender of the athlete. The rationality of blood-test interpretation in athletes may be increased by taking these characteristics into account.

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