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ORIGINAL ARTICLE

Lower white blood cell counts in elite athletes training for highly aerobic sports

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Abstract White cell counts at rest might be lower in athletes participating in selected endurance-type sports. Here, we analysed blood tests of elite athletes collected over a 10-year period. Reference ranges were established for 14 female and 14 male sports involving 3,679 samples from 937 females and 4,654 samples from 1,310 males. Total white blood cell counts and counts of neutrophils, lymphocytes and monocytes were quantified. Each sport was scaled (1–5) for its perceived metabolic stress (aerobic–anaerobic) and mechanical stress (concentric–eccentric) by 13 sports physiologists. Substantially lower total white cell and neutrophil counts were observed in aerobic sports of cycling and triathlon (~16% of test results below the normal reference range) compared with team or skill-based sports such as water polo, cricket and volleyball. Mechanical stress of sports had less effect on the distribution of cell counts. The lower white cell counts in athletes in aerobic sports probably represent an adaptive response, not underlying pathology.

Keywords Elite athletes · WBC counts · Sports · Inflammation · Neutropaenia

Introduction

Most interest in the haematology of athletes focuses on the number, size and haemoglobin content of their red blood cells. Given the central role in oxygen delivery to the tissues and ultimately exercise performance, this interest is understandable. However, as the body's defenders against infection, white blood cells (WBC) also contribute indirectly to performance by keeping athletes well enough (infection free) to maintain their training programmes. Information about WBC numbers in elite athletes has received little attention, even though in many cases, this information is derived at the same time and from the same blood sample as the red cell information. Previous studies of WBCs in athlete populations have considered only total WBCs (Telford and Cunningham 1991), only one of the five types of WBCs (Parisotto et al. 2003), or WBCs in only one sport (Bain et al. 2000; Lesesve et al. 2000; Watson and Meiklejohn 2001).

For more than 10 years, a haematology database has been maintained in the Sports Science and Sports Medicine Centre at the Australian Institute of Sport. Some of these haematology data have been part of medical–clinical investigations on unwell athletes, but the majority have been collected on healthy, elite athletes across a range of sports for routine monitoring or research studies. Haematological analyses in the database are linked with additional information such as the athletes' age (at date of collection), sex and their sport. Our interest is in how exercise itself, in the absence of any underlying inflammatory or immunological responses, affects changes in WBC numbers. Such changes

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might reflect adaptation to the metabolic and mechanical stressors evident in individual and team sports (Pyne 1994), rather than an underlying pathological response. Our aim was therefore to establish sport-specific WBC reference ranges and compare WBC values between sports against standard clinical reference values.

Methods

Experimental approach

We retrospectively examined blood test results of rested, healthy elite athletes (presenting without illness) collected over a 10-year period in a haematology database that was linked to demographic information on age, sex and sport. All samples were from national scholarship holders thereby defining their elite status at the Australian level. The mean (±SD) age for athletes in different sports ranged from 16 ± 1 years for female gymnasts to 26 ± 4 years for male cyclists.

Haematological data

Names of all athletes were removed from the analysis to preserve the anonymity. We then removed spurious and/or suspicious data as well as eliminating data that we suspected had been collected as part of medical–clinical investigations on unwell athletes. The elimination of these results was based upon whether the requesting officer was one of the Institutes' medical practitioners, if the sample was accompanied by a request for pathology, or had 'unwell' written into the comment section on the request form. Although our database did not identify the ethnicity of the athletes, the overwhelming proportion was Caucasian. This study was approved by the Ethics Committee of the Australian Institute of Sport (approval number 2007-1011).

If more than one sample was collected on a single day from an individual athlete, we included only the first sample of the day in our analysis. This step was undertaken to ensure that the collection was an overnight 'at rest' sample and not taken post-exercise. We also removed from the dataset, all samples from athletes identified as disabled, less than 14 or over 60 years of age. Our sport-specific retrospective study meant that the athlete groups were relatively homogeneous: we included in our analysis only the sports in which the number of different individual athlete observations was greater than 20. Data presented are from 14 female and 14 male sports, and 11 of these sports were common to both sexes. Rugby, canoeing and boxing only had sufficient numbers of male participants, whereas gymnastics, netball and cricket only had sufficient female participants for inclusion in our analysis.

Classification of sports by metabolic and mechanical stress

To understand what aspects of different sports might be influencing the WBC counts, we surveyed a sample of sports physiologists at the Australian Institute of Sport. For each of the 14 sports (for each sex), we asked physiologists to quantify (using a 5 point Likert scale) the relative contribution of the nature of each sport (during competition and in training) in relation to perceived major metabolic energy system used in a given sport (from dominantly aerobic to dominantly anaerobic). We also asked each physiologist to quantify (using another 5 point Likert scale) the relative contribution of the mechanical nature of those sports from purely concentric muscle demands to dominantly eccentric muscle demands.

Analytical equipment

During the first 4 years of the 10-year data collection period, haematology results were generated on an H3 Technicon auto-analyzer (Bayer, Tarrytown, NY). The majority of haematology results were gathered on an ADVIA-120 Hematology analyzer (Bayer Health Care Diagnostics, Tarrytown, NY). Across the entire 10 years, only two technical operators had primary responsibility for equipment calibration, maintenance, data entry and monthly QC assessments for WBC totals and differential counts. Selected haematology values were also routinely submitted to the quality assurance programme of the Royal College of Pathology, Australasia.

Statistical analysis

Values for total WBC, neutrophils, lymphocytes, monocytes, eosinophils and basophils were log transformed before analysis with a mixed linear model using SAS software (Statistical Analysis System, Version 9.1, SAS Institute, Cary, NC). The fixed effects in the model were the identity of the sport (nominal) and age of the athlete (quadratic). The random effects were the identity of the athlete and the residual, which represents error between repeated measurements on a given athlete. A different residual was specified for each sport. Outliers were identified as observations with a standardised residual >5.0; these observations, which represented typically 0.15% of the total were deleted and the analysis was repeated. Separate analyses were performed for the total WBC and individual cell types, as well as for females and males. Some athletes were sampled several times but these repeated measures were accounted for in the mixed modelling analysis.

The mean values of the cell counts for each sport are the back-transformed means adjusted to the mean age of all athletes. The magnitude of an effect on mean cell count was assessed by standardization: the difference in the count was divided by the between-subject standard deviation, which was derived by taking the square root of the sum of the variances for the athlete and mean residual. The resulting standardised effect was compared to thresholds of 0.20, 0.60 and 1.20 for small, moderate and large (Hopkins et al. 2009). These values are also compared to published reference intervals found in the literature including the definitions of what were considered to be lowered cell counts. For example, a threshold of $<2.0 \times 10^9$/L was set to define neutropenia.

Alpha reliabilities of the 13 completed sport surveys comparing relative aerobic to anaerobic and relative concentric to eccentric nature of the 14 sports were calculated with the Statistical Analysis System (Version 9.1, SAS Institute, Cary, NC). Pearson's correlation coefficients were used to characterise the degree of association of cell counts with mean aerobic–anaerobic and concentric–eccentric scores; magnitudes were interpreted using thresholds of 0.10, 0.30 and 0.50 for small, moderate and large effects (Hopkins et al. 2009).

Results

Cell counts

Tables 1 and 2 present WBC findings (total and sub-types) from male and female sports, respectively, along with sport specific and clinical reference ranges. The highest mean WBC counts were for the male team sports of rugby and water polo, and cricket and water polo for female sports. The lowest total WBC counts in both males and females were the individual sports of cycling and triathlon.

Neutrophil counts generally mirrored total WBC counts with the lowest neutrophil counts for both male and female sports being cycling and triathlon. Differences in neutrophil counts between these team and individual sports were generally small to moderate in magnitude. Neutropenia (defined as $<2 \times 10^9$/L) was seen in 5% of samples across all our sports and in 17% of cycling and 16% of triathlon samples (Table 3). Approximately 11% of athletes had at least one episode of neutropenia but athletes in the sports like swimming, triathlon and cycling experienced more than twice that percentage of episodes.

Male and female swimmers had moderately higher lymphocyte counts than other sports (yet still within the clinical reference range), whereas the lowest lymphocytes counts were noted in male canoeists and the female team sports of cricket and volleyball. Lymphopenia (defined as $<1.0 \times 10^9$/L) was seen across 2.4% of all samples from all sports (Table 3): overall 5.1% of athletes experienced at least one episode of lymphopenia.

The lowest mean monocyte values for both sexes were seen in cycling and triathlon. Monocytopenia (defined as $<0.2 \times 10^9$/L) was noted in 2.4% of all samples and 6.4% of athletes experienced at least one episode (Table 3). Female eosinophil values were consistently lower than

Table 1 White blood cell counts in male athletes

Sport	*n*	Total white blood cell count, 10^9/L		Neutrophil count, 10^9/L		Lymphocyte count, 10^9/L		Monocyte count, 10^9/L	
		Mean	95% Reference range	Mean	95% Reference range	Mean	95% Reference range	Mean	95% Reference range
Archery	21	6.7	4.1–10.9	3.7	1.8–7.6	1.9	1.1–3.3	0.42	0.22–0.83
Athletics	113	6.3	3.9–10.2	3.5	1.7–7.1	1.9	1.2–3.1	0.39	0.22–0.70
Basketball	101	6.6	4.3–10.3	3.7	1.9–7.2	1.9	1.1–3.2	0.41	0.22–0.74
Boxing	59	7.2	4.5–11.6	4.0	2.0–8.2	2.1	1.3–3.4	0.47	0.26–0.84
Canoeing	25	6.2	3.7–10.2	3.5	1.7–7.2	1.7	1.0–3.0	0.45	0.24–0.85
Cycling	173	5.7	3.7–8.8	2.8	1.5–5.5	2.0	1.2–3.3	0.36	0.20–0.65
Rowing	195	6.1	3.7–10.1	3.4	1.6–6.9	1.9	1.1–3.2	0.39	0.22–0.71
Rugby Union, AFL	150	7.4	4.7–11.6	4.2	2.3–7.9	2.1	1.3–3.2	0.45	0.26–0.79
Swimming	127	6.7	4.3–10.3	3.4	1.8–6.5	2.2	1.4–3.7	0.44	0.24–0.79
Soccer	165	6.9	4.1–11.7	3.7	1.7–8.0	2.0	1.1–3.5	0.42	0.23–0.75
Triathlon	48	5.9	3.5–9.9	2.9	1.3–6.4	2.0	1.2–3.5	0.35	0.18–0.69
Volleyball	50	6.9	4.2–11.4	4.0	1.9–8.1	1.9	1.2–3.1	0.43	0.22–0.87
Winter sports	32	6.4	4.2–9.8	3.5	1.7–7.0	1.9	1.0–3.5	0.37	0.21–0.66
Water polo	51	7.4	4.3–12.5	4.3	1.9–9.4	2.0	1.1–3.6	0.43	0.21–0.87
All sports	1,310	6.6	3.9–11.1	3.6	1.7–7.7	2.0	1.1–3.5	0.41	0.21–0.81
Normal reference range			4.5–11.0		2.0–8.0		1.0–4.8		0.2–0.78

Table 2 White blood cell counts in female athletes

Sport	n	Total white blood cell count, 10^9/L		Neutrophil count, 10^9/L		Lymphocyte count, 10^9/L		Monocyte count, 10^9/L	
		Mean	95% Reference range	Mean	95% Reference range	Mean	95% Reference range	Mean	95% Reference range
Archery	21	7.0	4.0–12.3	4.1	1.8–9.4	2.0	1.0–3.8	0.36	0.15–0.81
Athletics	66	6.2	3.8–10.1	3.5	1.6–7.6	1.9	1.1–3.0	0.33	0.18–0.62
Basketball	99	6.5	3.9–10.7	3.6	1.7–7.4	1.9	1.2–3.2	0.37	0.20–0.69
Cricket	41	7.1	4.0–12.5	4.3	1.8–10.4	1.7	1.1–2.8	0.40	0.19–0.81
Cycling	101	5.9	3.5–9.8	2.9	1.3–6.5	2.0	1.1–3.6	0.33	0.18–0.63
Gymnastics	40	6.7	3.9–11.5	3.9	1.8–8.4	1.8	1.1–3.0	0.36	0.18–0.69
Netball	122	6.8	4.2–11.1	4.0	1.9–8.2	1.9	1.1–3.3	0.38	0.20–0.71
Rowing	108	6.4	4.0–10.3	3.6	1.8–7.1	2.0	1.2–3.3	0.36	0.20–0.66
Swimming	114	6.5	4.2–10.2	3.2	1.6–6.3	2.4	1.4–4.0	0.35	0.19–0.66
Soccer	80	6.3	3.9–10.4	3.6	1.8–7.2	1.9	1.1–3.2	0.39	0.22–0.71
Triathlon	33	5.9	3.8–9.2	2.9	1.5–5.4	2.1	1.3–3.3	0.33	0.18–0.60
Volleyball	38	6.8	4.2–10.9	4.2	2.0–8.6	1.7	1.1–2.6	0.36	0.21–0.63
Winter sports	38	6.4	4.2–9.8	3.6	2.0–6.6	1.9	1.1–3.4	0.34	0.18–0.63
Water polo	35	7.3	4.1–13.0	4.6	2.0–10.5	1.8	1.1–3.0	0.36	0.18–0.70
All sports	937	6.5	3.8–11.2	3.7	1.7–8.1	1.9	1.1–3.4	0.36	0.18–0.72
Normal reference range			4.5–11.0		2.0–8.0		1.0–4.8		0.2–0.78

Table 3 Sports with low white blood cell sub-types counts

	Neutrophils <2.0 × 10^9/L	Lymphocytes <1.0 × 10^9/L	Monocytes <0.2 × 10^9/L
Across all samples	5%	2%	2%
Two sports with most samples having low cell counts (% with low counts)	Cycling, 17% Triathlon, 16%	Archery, 5% Canoeing, 5%	Gymnastics, 5% Triathlon, 5%

male eosinophil values and swimmers had the highest mean values across all sports. Female swimmers and male boxers had the highest mean basophil counts.

Effects of sport-related metabolic and mechanical stresses

The alpha reliability for the Likert ratings of sports on the aerobic–anaerobic scale, were 0.88 and 0.90 for females and males, respectively; on the concentric–eccentric scale, the corresponding alphas were 0.96 and 0.95. Mean aerobic–anaerobic scores ranged from lows of 1.2 and 1.4 for female and male triathlon through to highs of 4.2 for volleyball (both sexes). The range for the concentric–eccentric scores was 1.5 for cycling (both sexes) to 4.0 for volleyball (both sexes). There was a large correlation between the two scores for the females (0.57; 90% confidence limits ±0.34) and the males (0.58; ±0.34).

The aerobic–anaerobic score had large positive correlations with neutrophil and WBC counts for females and males (0.52–0.70), a large positive correlation for monocytes in males (0.53), a moderate positive correlation for monocytes in females (0.34), a trivial correlation for lymphocytes in males (0.08) and a large negative correlation for lymphocytes in females (−0.56). The correlations between cell counts and the concentric–eccentric score were generally trivial to small, with the exception of moderate correlations for neutrophils and WBC in males (0.36 and 0.31) and a large negative correlation for lymphocytes in females (−0.56). The confidence limits for these correlations ranged from ±0.26 to ±0.46 for the large through to the small correlations, respectively (Fig. 1).

Discussion

This study has expanded the available published information of normal WBC values for elite athletes by investigating a wide range of sports and detailing counts of specific WBC types. The mean total WBC count across all sports is similar to that for elite athletes in the existing literature.

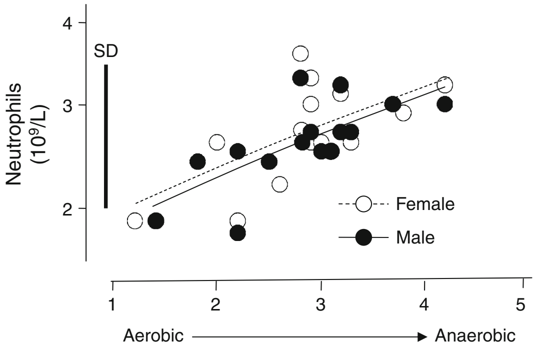

Fig. 1 Relationship between neutrophil cell count (log scale) and the aerobic–anaerobic rating of the sport. Each *point* represents means for a sport. *SD bar* is the within-sport, between-athlete standard deviation in the neutrophil counts averaged over all the sports. Regression lines are shown

A number of other studies have also noted lower WBC numbers in endurance-type sports compared with team-based sports (Parisotto et al. 2003; Telford and Cunningham 1991). Here, we have shown that more aerobically oriented sports tend to have lower WBC and neutrophil counts. This observation has implications for sports physicians or others involved in haematological assessment of healthy athletes in regular training.

A finding in common across studies of WBC values in high-level athletes is the observation of low neutrophil counts (neutropenia). Several studies have reported neutropenia in different groups of athletes including marathon runners, cyclists, professional footballers and cyclists (Bain et al. 2000; Lesesve et al. 2000; Parisotto et al. 2003; Watson and Meiklejohn 2001). Our finding of 5.3% neutropenia compares with a 35% incidence of neutropenia observed in professional footballers (Watson and Meiklejohn 2001). Other studies of cyclists reported 16, 29 and 38% neutropenia amongst male track, road and mountain bikers, respectively (Parisotto et al. 2003) and an 11% incidence in male and 20% in female cyclists (Lesesve et al. 2000). The latter differential cell counts were done manually on stained blood-film preparations and the 20% figure they reported among their female athletes is based on only five individuals. Neutropenia, then, seems to occur relatively commonly amongst athletes, especially in endurance athletes compared to clinical reference samples. Our finding is lower than other data reported but presents a more comprehensive estimate of WBC in athletic populations given the large numbers of sports and athletes in our analysis.

The observation of neutropenia is of clinical interest because, in general, neutropenic individuals have increased susceptibility to bacterial infections. Given the presence of multidrug-resistant bacteria in the community (including the sporting community), athletes must be vigilant with personal hygiene and pay attention to even seemingly trivial skin wounds (Buss et al. 2009; Redziniak et al. 2009; Saunders 2009). As the low total neutrophil counts reported in our studies are from active healthy people at rest, we consider these findings most likely reflect a training-induced adaptive anti-inflammatory response operating within broader homeostatic limits. We presume that the exclusion of unwell individuals minimised the likelihood that immune cells had compromised functional activity. The reasons for the exercise-induced low neutrophil counts are unclear, but could include decreased cell production by bone marrow stem-cell precursors, increased cell destruction, increased transit rate into tissues, increased endothelial adhesion, or a mix of these mechanisms (Barreda et al. 2004).

Neutrophils are short-lived circulating cells, so they must be constantly replaced through actions of growth factors such as granulocyte colony-stimulating factor (G-CSF) which stimulates bone marrow hematopoietic progenitor\stem cells (HPCs). Exercise elevates levels of G-CSF (Bonsignore et al. 2002; Yamada et al. 2002) and our elite athletes would be routinely experiencing such pulsatile increases of G-CSF. The observation of low circulating neutrophil counts was therefore unexpected. If transiently elevated levels of G-CSF do not result in increased numbers of neutrophils, the observed neutropenia could be associated with low numbers of HPC, the G-CSF target population. A study of 30 elite triathletes reported lower numbers of HPC than in 38 sedentary controls (Philip and Bermon 2003). In contrast, another study found levels of HPC were higher in runners compared with controls (Bonsignore et al. 2002). A third study of HPC numbers showed little difference between trained and untrained individuals (Wardyn et al. 2008). These conflicting findings reflect the challenges in defining and enumerating HPC counts in peripheral blood. Overall though, information on the exercise-associated pulsing of G-CSF along with normal or elevated target HPC numbers is at odds with the observed neutropenia in our highly trained endurance athletes. Stated another way, reduced neutrophil production does not seem to be the explanation for our observed elite athlete neutropenia.

Could the observed elite athlete neutropenia be associated with decreased neutrophil lifespan in the blood? Circulating neutrophils can undergo apoptotic cell death and exercise-induced WBC and neutrophil apoptosis gene expression pathways have been investigated (Radom-Aizik et al. 2008). In this study, the Jak/STAT pathway, known to inhibit apoptosis, was significantly activated by 30 min of aerobic exercise, but another 14 genes were altered in a way that was likely to accelerate neutrophil apoptosis. Additionally, exercise affected WBC gene expression in a dose-dependent manner and genes for stress (heat shock) proteins were substantially altered by a treadmill running protocol (Buttner et al. 2007). Unfortunately, the investigators did not include specific apoptosis genes in their screening procedures. Exercise-induced neutrophil apoptosis could thus be an explanation for the observed neutropenia by decreasing overall neutrophil life span.

A final consideration to explain the low neutrophil counts in cyclists and triathletes is the possibility of plasma volume expansion. Expansion of plasma volume has long been acknowledged as an adaptation to thermal and non-thermal aspects of endurance exercise. A comprehensive review of 11 experimental studies of short and long-term endurance exercise (Convertino 1991) reported that the mean percentage increase in plasma volume was less than 10% (from pre-exercise values). In comparison, our low-end neutrophil counts (cyclists and triathletes) were more than 20% lower than the mean neutrophil counts across all sports. For example, the neutrophil counts in female cyclists were 29% lower than the mean for all females. Given that the magnitude of cell-count differences in cycling and triathlon were larger than the typical change in plasma volume, we feel that plasma volume expansion is unlikely to fully account for the observed differences.

We defined low lymphocyte counts (lymphopenia) by a cut off of $<1.0.10^9$/L. The only other published study reporting on athlete lymphopenia, defined as $1–1.5.10^9$/L (Lesesve et al. 2000), observed 27% among male cyclists and 20% among female cyclists. As with these authors' neutropenia data, this latter figure is based only on five individuals. In our study, lymphopenia was seen most often in archery and canoeing; these sports have not previously been included in published WBC findings. We have no clinical records to suggest that these low counts were associated with a clinical history of increased illnesses.

Compared to neutrophils, lymphocytes are relatively long-lived cells (some surviving for months), but factors regulating normal circulating numbers are not well understood. Two published studies have reported on the influence of exercise on gene expression of peripheral blood mononuclear cells (PBMCs) which would consist predominately of lymphocytes. One study had 15 healthy men run for 30 min at ~80% of their peak VO_2 (Connolly et al. 2004). PBMCs were collected, RNA isolated, cRNA prepared and then hybridized to microarrays. Circulating lymphocyte numbers in their participants increased threefold after exercise, and 311 genes were differentially regulated. Up-regulated genes were noted in several categories including immune, inflammatory (more pro-inflammatory than anti-inflammatory) and stress (heat shock proteins and hypoxia-inducible factor-1, HIF). A more recent paper (Radom-Aizik et al. 2009) used 20 young female participants, and found altered expression of 622 genes in 11 different gene pathways. Significant gene pathway changes were related to inflammation, stress (heat shock protein-70) and apoptosis (fas ligand) pathways. Indeed, lymphocyte apoptosis has been specifically documented post-exercise (Mars et al. 1998; Mooren et al. 2002), albeit not in the sports (archery and canoeing) in which we noted increased incidence of lymphopenia. Exercise-induced lymphocyte apoptosis then could be part of an explanation of the observed low lymphocyte counts in athletes.

Monocytes are potent innate defence cells that produce many (and mostly) pro-inflammatory proteins. Early studies of monocytes and exercise (Bieger et al. 1980; Rivier et al. 1994) not only quantified the transient, exercise-induced monocytosis but also the functional alterations to these cells provoked by exercise (phagocytic activity and cytokine production). More recently, Timmerman et al. (2008) reported that exercise training lowered blood monocyte percentages as well as the LPS-stimulated monocyte TNF-α production in 65–80-year-old subjects. As these studies did not report circulating blood cell numbers, it is not possible to compare them directly to our younger population where we saw 2% low monocytes counts (defined by a cut off of < 0.2.0.109/L), but both sets of results are consistent with exercise having generally anti-inflammatory influences, including lowering WBC cell counts (Mathur and Pedersen 2009). In general, low monocyte counts were seen in the same sports that had low neutrophil counts. This is consistent with exercise having an influence on their common precursor cell in the bone marrow.

Eosinophil values across all sports were within the clinical reference interval with male and female swimmers having the highest eosinophil counts. Swimming is often recommended as the sport of choice for asthmatics and high eosinophil counts are frequently seen with asthma. More than a decade ago, Helenius et al. (1998) reported that eosinophils were overrepresented in sputum of elite swimmers (as was heightened bronchial responsiveness), but by limiting our survey to well athletes, we hopefully excluded athletes experiencing acute asthmatic symptoms and so do not account for these findings in swimmers with a disease situation. Furthermore, a recent overview of the association between asthma and blood eosinophils presents a more complex association than was previously appreciated (Wenzel 2009).

In an effort to partly explain the range of normal resting white blood cell values, we characterised the association between the physical\mechanical and biochemical\metabolic differences and cell counts across the range of sports. We observed a substantial relationship between the perceived aerobic content of a sport and the total WBC and subclass cell counts: the more aerobic the sport, the lower the total WBC, neutrophil and monocyte counts (for males). There were few substantial relationships between the concentric\eccentric mechanical nature of different sports and the WBC. We expected a substantial relationship between them, as many researchers interested in linkages between WBC and exercise consider that eccentric muscle damage initiates the recruitment of WBC (and especially neutrophils and monocytes) to facilitate the subsequent repair and healing processes. These cells are present in eccentrically damaged tissues (Malm et al. 2000) but apparently recruitment to damaged muscle is not reflected in diminished counts of these cells in blood. In contrast, there was a large negative correlation (−0.56) between female lymphocyte counts for both aerobic\anaerobic and concentric\eccentric Likert scores. This latter result is somewhat unexpected as lymphocytes are not typically associated with eccentric muscle damage.

Limitations to this study include the absence of detailed training and medical histories (both short and long term) of our athletes. Nevertheless, to achieve elite status (and be a national level scholarship holder), generally, requires years of rigorous training and ongoing commitment to a sport. In practice, physicians are likely to interpret results of haematological assessment in view of individual patient (athlete) presentation including medical and training history, and a physical examination.

In summary, WBC counts can be lower in elite athletes, particularly those participating in aerobic endurance sports. The lower counts probably represent a training-induced adaptive response in healthy athletes rather than an underlying pathological response, and are likely the result of similar anti-inflammatory influences seen across even non-elite physically active\exercising populations. Prospective longitudinal studies are needed to assess the relationships between cell counts in different sports, the effects of training type/load, and changes in inflammatory control processes. Sports physicians need to be aware that some athletes in highly aerobic sports will routinely present with lower WBC, especially neutrophil counts. Our sport-specific reference-range intervals for WBC values should assist physicians in interpreting haematological test results for athletes in diagnostic and screening settings.

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