

- Snow, D. H. and Rose, R. J. (1981). Hormonal changes associated with long distance exercise. *Equine Vet. J.* **13**, 195–197.
- Snow, D. H., Kerr, M. G., Nimmo, M. A. and Abbott, E. M. (1982). Alterations in blood, sweat, urine and muscle composition during prolonged exercise in the horse. *Vet. Rec.* **110**, 377–384.
- Soliman, M. K. and Nadim, M. A. (1967). Calcium, sodium and potassium levels in the serum and sweat of horses after strenuous exercise. *Zentbl. Vet. Med.* **14**, 53–55.
- Stewart, G. A., Riddle, C. A. and Salmon, P. W. (1977). Hematology of the racehorse – a recent study of Thoroughbreds in Victoria. *Aust. Vet. J.* **53**, 353–359.
- Streter, F. A. (1959). The effect of systemic training on plasma electrolytes, haematocrit value, and blood sugar in Thoroughbred race horses. *Can. J. Biochem. Physiol.* **37**, 273–283.
- Tasker, J. B. (1967). Fluid and electrolyte studies in the horse. III. Intake and output of water, sodium, and potassium in normal horses. *Cornell Vet.* **57**, 649–657.
- Taylor, C. R. (1980). Response of large animals to heat and exercise. In: *Environmental Physiology: Aging, Heat and Altitude*. Horvath, S. M. and Yousef, M. K. (eds.). Elsevier North Holland, New York.
- Taylor, C. R. and Heglund, N. C. (1982). Energetics and mechanics of terrestrial locomotion. *Ann. Rev. Physiol.* **44**, 97–107.
- Taylor, C. R., Heglund, N. C. and Maloig, G. M. O. (1982). Energetics and mechanics of terrestrial locomotion. I. Metabolic energy consumption as a function of speed and body size in birds and mammals. *J. Exp. Biol.* **97**, 21–31.
- Thomas, D. P., Fregin, G. F., Gerber, N. H. and Ailes, N. B. (1980). Cardiorespiratory adjustments to tethered-swimming in the horse. *Pflügers Arch.* **385**, 65–70.
- Thomas, D. P. and Fregin, G. F. (1981). Cardiorespiratory and metabolic responses to treadmill exercise in the horse. *J. Appl. Physiol.* **50**, 864–868.
- Van Beaumont, W., Strand, J. C., Petrofsky, J. S., Hipskind, S. G. and Greenleaf, J. E. (1973). Changes in total plasma content of electrolytes and protein with maximal exercise. *J. Appl. Physiol.* **34**, 102–106.
- Warner, A. and Mayhew, I. J. (1982). Equine anhidrosis: A survey of affected horses in Florida. *J. Am. Vet. Med. Ass.* **180**, 619–632.
- White, K. K., Lesser, F. R., Hintz, H. F. and Lowe, J. E. (1978). The value of dietary fat for working horses. II. Physical evaluation. *J. Equine Med. Surg.* **2**, 525–530.
- Williamson, H. M. (1974). Normal and abnormal electrolyte levels in the racing horse and their effect on performance. *J. S. Afr. Vet. Ass.* **45**, 335–340.
- Wyndham, C. H., Benade, A. J. H., Williams, G. G., Styrdom, N. B., Goldin, A. and Heyns, A. J. A. (1968). Changes in central circulation and body fluid spaces during acclimatization to heat. *J. Appl. Physiol.* **25**, 586–593.

Investigations on Sodium Metabolism in Exercised Shetland Ponies Fed a Diet Marginal in Sodium*

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Summary

During a 75-day trial period, three ponies were fed an adequate sodium diet (25 mg Na/kg bwt), and three were fed a marginal sodium diet (5 mg Na/kg bwt). The changes in sodium metabolism as well as water balance were investigated. In the study, a 30-day exercise period was included. After euthanasia, sodium, potassium and water distribution were determined in the different body compartments. During the last third of the trial, clinical signs associated with a decreased ECF volume developed. A fall in faecal and renal sodium excretion occurred in the marginal group. During the exercise period, sweat production in the marginal sodium group progressively decreased to 55% of that in the control group. In the marginal sodium group, there was also a reduction in sweat sodium concentration. Plasma sodium concentration decreased, whilst plasma potassium concentration increased in the marginal sodium group by the end of the trial period. Immediately after exercise, a significantly greater decrease in plasma volume occurred in the marginal sodium group compared with the control group. At the end of the trial, there was an overall 22% reduction in total body sodium content in the marginal sodium group, the biggest contribution being from gastrointestinal contents and the skeleton. There was only a moderate decrease in total body water in the marginal sodium group, as blood and skin decreased, whilst the organs and muscle had an increased water content.

Introduction

A considerable sodium exchange normally takes place in the digestive tract. In horses fed mixed rations of hay and concentrates, about 250 g sodium enter the large intestine per day, where more than 95% is absorbed (Meyer 1980).

In practice, the horses' sodium intake is often very low. During exercise-induced sweating, horses may lose large amounts of sodium within a relative short time (Carlson and Ocen, 1979). The following investigation was therefore undertaken to evaluate the influence of low sodium intake in exercising horses on sweat production and composition and on the function of the gastrointestinal tract. The effects of sodium losses after heavy

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sweating on the sodium content of the different compartments of the body were also studied.

Materials and Methods

Six male Shetland ponies (98 to 180 kg bwt) aged between three and eight years were used. The ponies were divided into two equal groups, marginal sodium and control. The ponies were fed a semisynthetic low sodium diet (hay, oats, sugar, minerals and vitamins) with a sodium content of 0.2 g/kg dry matter. The feed of the control group was supplemented with NaCl (2.5 g Na/kg dry matter). The intake per day of the marginal and control groups was less than 5 mg and more than 25 mg Na/kg bwt, respectively.

The experimental protocol consisted of two 5-day sodium balance studies (periods A₁ and A₂) followed by a 30-day exercise period (B) (described by Meyer *et al.*, 1979), and two final 5-day balance studies (C₁ and C₂). During the exercise period, the ponies were run on a treadmill (each pony on ten occasions for two hours every third day at 10 km/h, a 5% gradient and an environmental temperature of 25° to 30°C).

Sweat was collected with weighed filter pads placed beneath a special cover on the saddle area (Lindner 1983). Total sweat production was calculated by multiplying the amount collected under the pads by the body surface of the animal (Brody 1964). Sodium and potassium were recovered from the sweat-soaked filter pads by rinsing them with known volumes of boiling 10% nitric acid solution. This ensured complete sodium recovery.

At the end of the trial, the animals were euthanized by exsanguination. The various organs, including the liver, spleen, kidney, lung, heart as well as the gastrointestinal tract and its content, were weighed and samples taken for sodium, potassium and dry matter analysis. Samples of skin, blood, bones and muscles were also collected for analysis, their respective total weights being calculated from the figures quoted by Webb and Weaver (1979).

The volume of different body water compartments was measured by marker dilution techniques. The plasma volume was determined using Evans blue dye (0.4 mg/kg bwt, 1% solution; sampling at 15, 90, 180, 270 and 360 minutes after IV injection) as described by Chinard (1951), and the extracellular fluid (ECF) was measured using sodium thiocyanate (20 mg/kg bwt of a 10% solution IV; sampling at 90, 180, 270 and 360 minutes post injection) as reported by Eder (1951). In addition, total body water (TBW) was calculated after desiccation of all tissues and organs. Total sodium, potassium and water content in each animal were calculated from the weight of the organs, blood, gastrointestinal tract and its content, bones, skin and muscles.

The sodium and potassium concentrations of the sweat solution, plasma and ash solutions (wet ashing) of faeces, urine, organs, tissues and gastrointestinal contents were measured by flame emission spectrography (Schuhknecht and Schinkel, 1963). Osmolarity was measured in fresh plasma (Knauer Halbmikroosmometer).

Statistical analysis of the results was performed by Student's *t* test comparing the values of the control with those of the marginal sodium group (mean \pm standard deviation). Because of the small number of animals, the 90% probability was taken into account ($p < 0.1 = (x)$; $p < 0.05 = x$; $p < 0.01 = xx$; $p < 0.001 = xxx$).

Results

Clinical manifestations in the sodium-deficient group appeared only during the last third of the exercise period. The ponies were restless and licking all the time, and the cutaneous turgor was decreased.

At the end of the exercise period, feed and water consumption of the marginal group was reduced by 25%. Faecal output and urine output were reduced by 41% and 35%, respectively. The animals had marked difficulties in swallowing. During the last balance period (C), one of the ponies in the marginal group did not eat at all. The composition of the digestive tract contents was therefore determined from only two animals, one with complete and the other with 80% consumption of the ration.

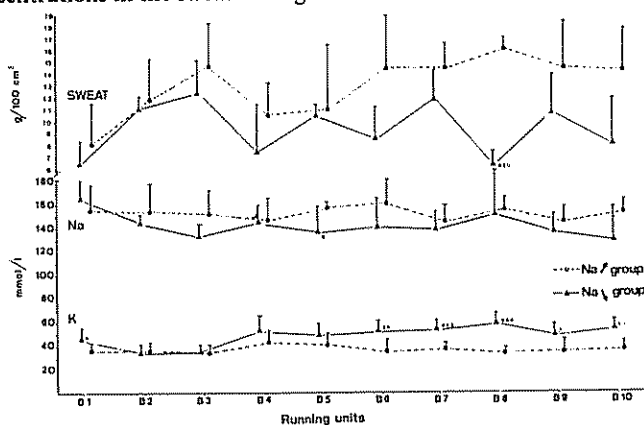
Bodyweight in the marginal group decreased from the fifth running unit until the end of the trial by an average of 6%, in contrast to a 3% increase in the control group.

The mean increase in heart rate and body temperature during exercise was not significantly different between the marginal sodium group (46.4 beats/min. and 1.7°C) and the control group (55.8 beats/min. and 1.2°C). However, there was a significant difference ($p < 0.01$) in the increase in mean respiratory rate which was 75.8/min. in the marginal sodium group and 124/min. in the control group.

Faecal and renal sodium excretion dropped markedly in the marginal group. This occurred to such an extent that, despite a daily sodium intake of 1.6 mg/kg bwt, they were still in a positive sodium balance, considering only faecal and renal losses (0.5 and 0.25 mg/kg bwt/day renal and faecal sodium excretion), at the end of the trial.

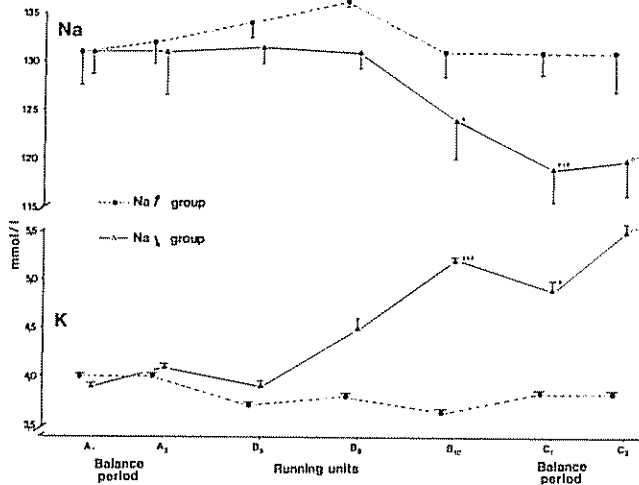
At the beginning of the exercise period, sweat production was similar in both groups (Fig. 1), whilst during the last three exercise sets, sweat production was 55% lower in the marginal sodium group than in the control group. In the marginal sodium group, there was a change in sweat composition when the first two exercise units were compared with the last two; a significant drop in sodium ($p < 0.01$) and increase in potassium ($p < 0.01$) concentrations occurred. Concentrations of sodium (152 mmol/l) and potassium (36 mmol/l) remained unchanged in the control group (Fig. 1). It was calculated that over the entire exercise period the average sodium loss was 57 g/100 kg bwt in the marginal sodium group and 74 g/100 kg bwt in the control group.

FIGURE 1. Sweat production in the saddle back area ($\text{g}/100 \text{ cm}^2$) and sodium and potassium concentrations in the sweat during exercise units.



During the period of investigation, plasma sodium concentration decreased to below 120 mmol/l in the marginal sodium group, whilst plasma potassium concentration increased to 5.5 mmol/l (Fig. 2). The decrease in plasma sodium concentration during each two-hour running set was small (0–3.0 mmol/l) and similar in each group.

FIGURE 2. Plasma sodium and potassium concentrations.



In the marginal sodium group, plasma osmolarity fell significantly ($p < 0.001$) from 287 mOsm/l at the beginning of the exercise period to 263 mOsm/l at the end, whilst total plasma protein concentration increased significantly during this period. Blood glucose concentrations were similar in both groups during all phases of the investigation.

The plasma volume, measured immediately after ending the ninth treadmill run, was reduced by 27% and the ECF by 8.4% (Table 1) in the marginal sodium group, while these parameters were reduced by only 8% and 5.6%, respectively, in the control group. Total body water, determined by desiccation at the end of the experiment, was calculated to be 57.4% in the control group and 56.3% in the marginal sodium group.

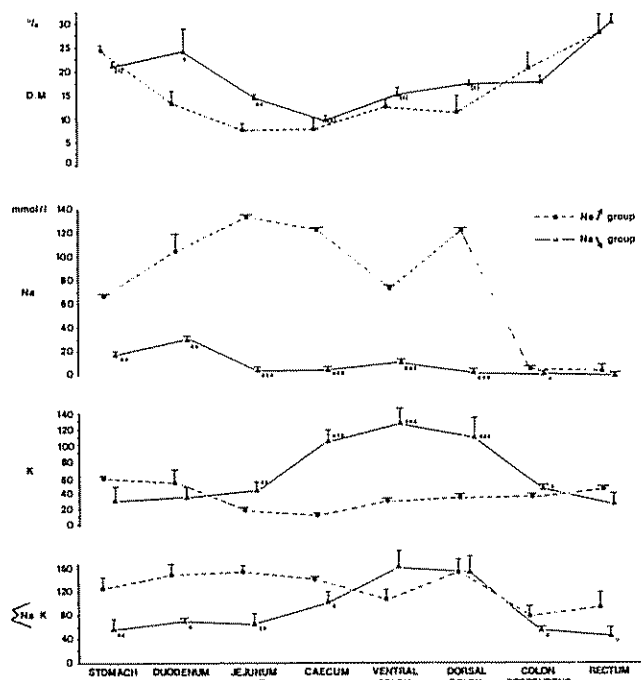
TABLE 1. Body fluid compartments (ml/kg bwt) in control ↗ and marginal sodium ↘ ponies.

	Plasma volume		ECF	
	Na ↗ group	Na ↘ group	Na ↗ group	Na ↘ group
Before exercise period	48.3 ± 1.2	51.3 ± 4.5	240.3 ± 25.0	247.3 ± 35.2
Immediately after the ninth running unit	44.0 ± 4.6	37.3 ± 5.6	227.0 ± 34.0	227.3 ± 35.9
Difference	4.3 ± 5.5	14.0 ± 3.5	13.3 ± 25.0	20.0 ± 1.0
Percentage change	8.8 ± 11.3	27.5 ± 7.8	5.6 ± 10.2	8.4 ± 1.7

*: $p < 0.05$.

Dry matter, sodium and potassium concentrations of the organs and tissues analyzed are shown in Table 2. In the marginal sodium group, dry matter increased significantly in the gastrointestinal contents, blood and skin, whilst water content increased slightly in the skeletal tissue, organs and muscles. Changes in dry matter within the gastrointestinal tract were not uniform in the marginal sodium group, with increases occurring in the small intestine and decreases occurring in the stomach and end of the tract (Fig. 3).

FIGURE 3. Comparison of dry matter (D.M.,%), and sodium and potassium concentration and their sum in the gastrointestinal contents.



In the marginal group, there was a 22% reduction in total sodium concentration which was 1.24 g/kg bwt compared with 1.59 g/kg bwt in the control group. This was reflected in a decrease by varying amounts of sodium concentration in all tissues, except the liver. The largest sodium decrease was throughout the gastrointestinal contents (Fig. 3), representing 44% of the total loss, while skeletal tissue, blood and muscle contributed 24%, 12% and 12%, respectively.

The potassium content in the marginal sodium group increased in the blood (10.6%), the gastrointestinal wall (21.9%) and contents (152%), the skin (20.4%) and the skeleton (1.9%) but decreased in muscle (-7.4%) and in the organs (-1.2%).

Discussion

Even with a very low sodium supply, the ponies are capable of maintaining a positive sodium balance. This is achieved through a large reduction in renal and faecal sodium excretion. However, further loss due to sweating in this study or any loss induced by blood loss, lactation, diuretics, diarrhoea or fistulas (salivary, bile duct, caecum) produces

TABLE 2. Dry matter (%) and sodium and potassium concentrations of the organs and tissues in control and marginal sodium ponies.

	Dry matter (%)		Na concentration (g/kg F.M.)		K concentration (g/kg F.M.)		
	Na group	Na group	Na group	Na group	Na group	Na group	
			Difference (%)	Difference (%)	Difference (%)	Difference (%)	
Bone	86.7	83.9	-3.2 (x)	5.5 ± 0.2	5.0 ± 0.2	0.7 ± 0.1	0.7 ± 0.1
Organs	26.0	24.2	-1.2	1.2 ± 0.3	0.9 ± 0.2	3.1 ± 0.3	3.1 ± 0.2
Skin	36.1	42.7	+18.3 x	1.8 ± 0.1	1.6 ± 0.1	0.9 ± 0.1	0.7 ± 0.2
Muscle	27.7	25.9	-6.5	0.4 ± 0	0.3 ± 0	3.6 ± 0.3	3.9 ± 0.2
Blood	14.7	19.6	+33.3 xx	2.5 ± 0.1	1.8 ± 0.1	0.8 ± 0.1	0.6 ± 0.1
G.I. tract	28.9	29.9	+3.5	1.4 ± 0.4	1.1 ± 0.2	2.7 ± 0.2	2.4 ± 0.1
G.I. contents	12.9	13.9	+7.6	2.3 ± 0.3	0.6 ± 0.3	3.4 ± 0.5	1.1 ± 0.2
Whole body	42.6	43.7	+2.5	1.6 ± 0.1	1.2 ± 0.1	2.2 ± 0.3	2.1 ± 0.0

F.M. = fresh matter.

(x): $p < 0.1$; x: $p < 0.05$; xx: $p < 0.01$; xxx: $p < 0.001$.

a negative sodium balance. From this study, it can be seen that probably the first response after prolonged sodium depletion is that sweat production and its sodium concentration are reduced during exercise.

The primary internal compensatory mechanism is sodium mobilization from the body reservoirs, namely from the gastrointestinal content and the skeleton. In the gastrointestinal tract, sodium was reduced to 25% of its normal content (Table 2). Whether this was due to a decreased production of digestive juices and/or a lowering of their sodium concentration or due to an increased absorption rate in the small intestine, merits further investigation. Alexander (1966) described a drop in sodium concentration in the saliva of parotid fistulated ponies with sodium deficiency. Recent results also indicate a reduced ileocaecal waterflow in sodium-deficient caecum fistulated horses (Lindner *et al.*, 1983). From the skeleton, which contains about 50% of the total body sodium, only 10% was mobilized. This limitation, also observed by McDougall *et al.* (1974) in sheep, could be due to the firm incorporation of the sodium into the bone crystal matrix structure (Nichols and Nichols, 1956).

To preserve tonicity, the continuous sodium loss in the sweat was equilibrated by a reduction in the ECF volume. The reduced sweat production could be attributed to this. Finally, because the sodium content could not be replenished, the tonicity was sacrificed to preserve volume. The fall in plasma osmolarity probably induced an increased uptake of water by the cells. The increase in plasma potassium concentration could also result from mechanisms to conserve the osmolarity. Renal excretion of potassium could also be impaired by the lack of exchangeable sodium ions.

The high potassium content in the large intestine of the marginal sodium group was probably due to secretion into the large intestine (Meyer *et al.*, 1982), as water content was unaltered. This may have been brought about by an increased potential across the intestinal wall, due to increased aldosterone secretion resulting from an attempt to conserve sodium.

The lower respiratory rate seen during exercise in the marginal sodium group may be explained by the recent findings of Meyer *et al.* (1983). These workers reported that a compensated metabolic alkalosis occurred during sodium deficiency, and as shown in goats by Fencl *et al.* (1966), an increased blood pCO₂ depresses breathing.

The clinical symptoms of sodium deficiency correlate with observations from field cases of horses with hyponatraemia (Cosgrove 1968; Williamson 1974). The licking habit may be induced in attempts to obtain sodium wherever possible. Decreased cutaneous turgor, weight reduction, sunken eye-balls and other symptoms of dehydration result from the reduced ECF volume. The reduced feed uptake may result from a decreased production of digestive secretions, while the lowered water uptake may have resulted from the hypoosmolarity (Stricker 1966) as well as from the reduced feed uptake.

References

- Alexander, F. (1966). A study of parotid salivation in the horse. *J. Physiol.* **184**, 646–656.
Brody, S. (1964). *Bioenergetics and Growth*. Hafner, New York.
Carlson, G. P. and Ocen, P. O. (1979). Composition of equine sweat following exercise in high environmental temperatures and in response to intravenous epinephrine administration. *J. Equine Med. Surg.* **3**, 27–32.

- Chinard, F. P. (1951). Estimation of plasma volume by dye dilution method. *Methods in Medical Research* **4**, 38–47.
- Cosgrove, S. (1968). The practical application of haematology. *Equine Vet. J.* **1**, 194–198.
- Eder, H. A. (1951). Determination of thiocyanate space. *Methods in Medical Research* **4**, 48–53.
- Fencl, V., Miller, T. B. and Pappenheimer, J. R. (1966). Studies on the respiratory response to disturbances of acid–base balance, with deductions concerning the ionic composition of cerebral interstitial fluid. *Am. J. Physiol.* **210**, 459–472.
- Lindner, A. (1983). *Untersuchungen über den Na-Stoffwechsel des Pferdes bei marginaler Na-Versorgung und Belastung*. Vet. Diss., Hannover. In preparation.
- Lindner, A., Schmidt, M., Teleb, H. and Meyer, H. (1983). Na-Mangel beim Pferd – Verteilung von Natrium, Kalium und Wasser, intestinaler Na-, K- und Wasserstoffwechsel. *Z. Tierphysiol. Tierernährg. Futtermittelkde.* In preparation.
- McDougall, J. G., Coghlan, J. P., Scoggins, B. A. and Wright, R. D. (1974). Effect of sodium depletion on bone-sodium and total exchangeable sodium in sheep. *Am. J. Vet. Res.* **35**, 923–929.
- Meyer, H. (1980). Na-Stoffwechsel und Na-Bedarf des Pferdes. *Übers. Tierernährg.* **8**, 37–64.
- Meyer, H., Pferdekamp, M. and Huskamp, B. (1979). Untersuchungen über die Verdaulichkeit und Verträglichkeit verschiedener Futtermittel bei typhlektomierten Ponys. *Dtsch. Tierärztl. Wschr.* **86**, 384–390.
- Meyer, H., Muuss, H., Güldenhaupt, V. and Schmidt, M. (1982). Intestinaler Wasser-, Natrium- und Kaliumstoffwechsel beim Pferd. *Fortschr. Tierphysiol. Tierernährg.* **13**, 52–60.
- Meyer, H., Schmidt, M., Lindner, A. and Pferdekamp, M. (1983). Na-Mangel beim Pferd – Na-Bilanz, Schweissbildung und -zusammensetzung, klinisches Verhalten. *Z. Tierphysiol. Tierernährg. Futtermittelkde.* In preparation.
- Nichols, G. Jr. and Nichols, N. (1956). Changes in tissue composition during acute Na-depletion. *Am. J. Physiol.* **186**, 383–392.
- Schuhknecht, W. and Schinkel, H. (1963). Universalschrift für die Bestimmung von Kalium, Natrium und Lithium nebeneinander. *Z. Anal. Chem.* **194**, 176–183.
- Striker, E. M. (1966). Extracellular fluid volume and thirst. *Am. J. Physiol.* **21**, 232–238.
- Webb, A. I. and Weaver, B. M. Q. (1979). Body composition of the horse. *Equine Vet. J.* **11**, 39–47.
- Williamson, H. M. (1974). Normal and abnormal electrolyte levels in the racing horse and their effect on performance. *J. S. Afr. Vet. Ass.* **45**, 335–340.

HAEMATOLOGY

Physiological Factors Affecting Resting Haematology

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Introduction

Blood sampling for haematological examination is frequently carried out by many veterinarians, especially those involved with racing animals, both for assisting in the diagnosis of clinical or subclinical disease and for the possible assessment of fitness. It is its use in this last category that has given rise to considerable controversy, with some veterinarians believing in the usefulness of haemograms and leucograms, whilst many tests are performed because of pressures from trainers and owners. Unfortunately, there is little documentation on the usefulness of routine resting haematological investigation in the assessment of performance. In describing normal haemograms for Thoroughbreds, Stewart and Steel (1974) and Stewart *et al.* (1977) claim that subdivisions within the normal range may be useful in assessing fitness for optimal performance. These workers suggest that a haematocrit greater than one standard deviation below the population mean indicates a horse unlikely to perform well. On the other hand, Laufenstein-Duffy (1971) concluded that wide variations in resting haematocrit occurred in individual horses even when blood was collected under standardized conditions, and that performance was not related to differences in resting haematocrit. Persson (1969, 1975) also found that the reproducibility of haemoglobin concentration at routine sampling at rest was low. The problems of relying on measurement of resting red blood cell numbers or haematocrit when assessing fitness or work capacity have been well documented in a number of studies by Persson. Persson considers that the determination of total blood volume gives a more meaningful result (Persson 1983).

In addition to placing emphasis on resting red blood cell values, trainers now possibly lay even more reliance on an ideal white blood cell count, especially on the neutrophil/lymphocyte ratio. It would appear that at a ratio 1.5:1 (60% neutrophils, 40% lymphocytes) or thereabouts is considered ideal and that many horses are not raced, even in the absence of clinical problems, if the desired ratio is not seen on haematological examination. Unfortunately, examination of the literature reveals no scientific evaluation of the concept of such ratios and of their relationship to fitness. Furthermore, it has recently been shown that there is an alteration in the neutrophil/lymphocyte ratio with age, as the number of circulating lymphocytes decreases in the older, mature horse (Allen *et al.*, 1983).

One of the reasons for the unreliability of examining resting haemograms and leucograms is the number of physiological factors that can readily cause alterations in the

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