equivalent to 4% bwt 90 min before exercise also maintain higher PV during prolonged constant load low intensity exercise, but that this treatment did not assist thermoregulation (*Sosa León* et al. 1995a).

In this study, fluid administration equivalent to 6% bwt prior to exercise, resulted in higher PV expansion throughout exercise than that previously reported with fluid based on 4% bwt. This suggests that the larger the fluid load, the greater the degree of PV expansion. However, the treated horses in this study passed watery faeces, which was not observed with the 4% fluid volume (*Sosa León* et al. 1995a). Therefore, the maximum fluid volume that probably can be administered to maintain the highest level of hyperhydration during exercise without causing diarrhoea lies between 4 and 6% bwt.

Hyperhydration resulted in maintenance of total body fluid. When comparing the bwt changes before treatment with those after exercise between the two groups, the treated group maintained almost the initial bwt while the control group lost about 4% of their bwt. Maintenance of body fluid status at the end of the 2nd day of the 3-day event is critical because horses may enter into the 3rd day of the competition already dehydrated. *Andrews* et al. (1995a) reported that up to 24 h after a 2nd day event competition, horses fail to replenish voluntarily fluid losses.

Hyperhydration did not assist in heat dissipation during exercise. In exercising humans, it is clear that the better hydrated they are the greater is the capacity for heat dissipation (*Nadel* et al. 1980; *Montain* and *Coyle* 1992). In the horse, hyperhydration appears not to overcome the limitations imposed by the higher body mass to surface area ratio with high rates of metabolic heat production. However, these studies were performed in an artificial treadmill environment where the opportunity for evaporative cooling may not be as great as in the field.

The administration of fluid did not improve cardiac responses to exercise. The HR was higher in the treated group contrary to a lower HR which would have been expected with the increases in PV (*Greenleaf* and *Castle* 1971). The increase in HR was not due to an increase in metabolic rate, which was not significantly different between treated and untreated horses.

We have concluded that hyperhydration to 6% bwt does increase PV which is maintained throughout exercise. Hyperhydration also helps maintain bwt but does not assist thermoregulation.

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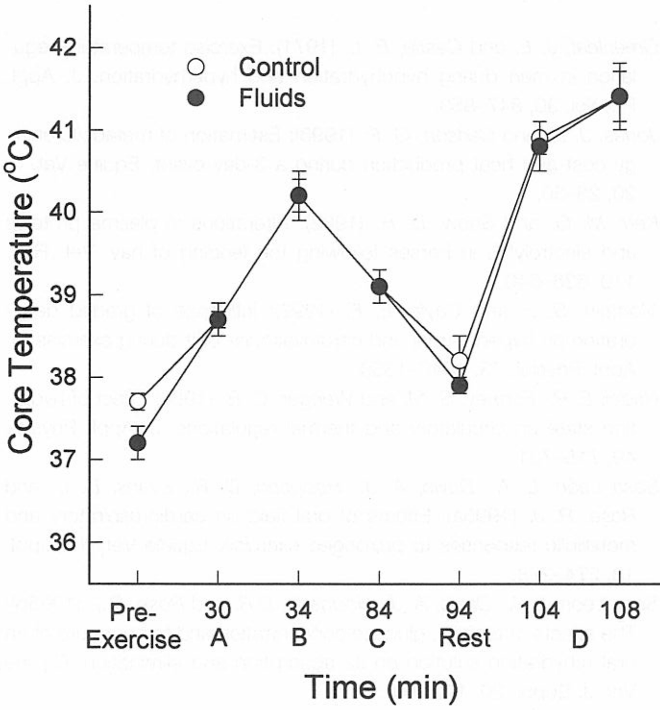

Fig. 2: Core temperature (mean±sem) before and during exercise in hyperhydrated and normohydrated (control) horses.

exercise. Four horses in this group also urinated during the 10 min rest or within few minutes after the end of exercise or both while only one horse in the control group urinated at the end of the test.

Hyperhydration and thermoregulation

Fluid administration prior to exercise resulted in a pre-exercise bwt gain of 21.3±1.2 kg with 3.5±0.8 kg being lost by faeces prior to exercise. Despite the bwt gain, there were no significant differences in TP between groups before exercise. However, throughout exercise TP and PCV were lower ($P<0.05$) in the treated group until the end of the test (Fig. 1).

The total bwt loss at the end of exercise was higher in the treated group (25.7±1.7 vs 17.1±0.9 kg, $p<0.05$) and approximated the total of administered fluid. From the total of bwt loss, 60% was lost up to the 10 min rest, while the remaining weight (40%) was lost during phase D. Most of the fluid loss was accounted for by sweating. Faecal fluid losses up to 10 min rest were 2.7±0.9 and 0.8±0.4 kg and during phase D they were 0.6±0.3 and 0.2±0.1 kg for the fluid treated and control groups, respectively. The percentage of faecal water content in the treated and control groups was 88% and 82%, respectively. The observed urine losses were not measured.

Central blood temperature was similar in both groups throughout the study with no effect of treatment. When compared with resting values, temperature increased ($P<0.05$) at all points of exercise being highest during phases B and D with values +4°C higher than at rest occurring at the end of the test (Fig. 2).

Cardiorespiratory responses

Heart rate was higher ($p<0.05$) in the treated group throughout the study with highest values occurring during phases B and D (Fig. 3). There were no differences in $\dot{Q}$, SV, $\dot{V}O_2$, $\dot{V}CO_2$, and R. As $\dot{V}O_2$ did not differ between treatments, oxygen pulse ($\dot{V}O_2$/HR)

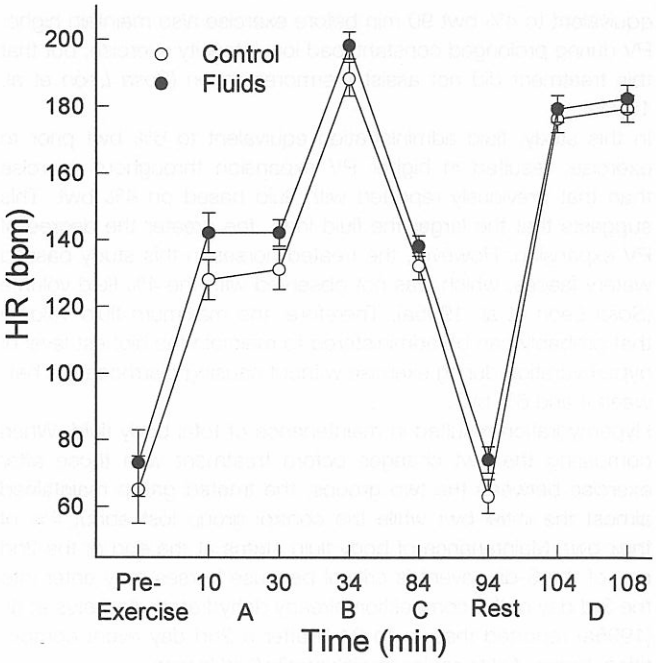

Fig. 3: Heart rate (mean±sem) before and during exercise in hyperhydrated and normohydrated (control) horses.

showed the opposite response to HR, being lower in the treated group throughout the test.

Metabolic responses

Throughout the study, plasma Cl was higher ($p<0.05$) in the treated group and contributed to a lower strong ion difference (SID) which probably caused the lower HCO_3^--concentration observed in this group. Plasma Na, K, lactate and glucose did not differ from values in the control group throughout the study.

Discussion

The aim of this study was to determine whether the provision of fluid prior to exercise could be a practical and beneficial tool to assist the hydration status of horses exercising during a second day of a three-day event. This is because this part of the event demands a considerable metabolic response from the horse (*Jones* and *Carlson* 1995) and dehydration is one of the most common clinical consequences (*Andrews* et al. 1995a). However, there is little opportunity for horses to rehydrate themselves during the event. The only possibility for supplementation of fluid is during the 10 min rest period between phases C and D. However, we have found that fluid absorption occurs after 30 min of its administration and is greatest after 2 h (*Sosa León* et al. 1995b). This implies that fluid given during the 10 min rest will not become part of the cardiovascular volume and will add extra weight to be carried. Thus, the only suitable opportunity to assist the hydration status of horses competing during the second-day of a three-day event is before the start of exercise.

The aim of giving fluid in advance of exercise is to try to maintain a higher PV during exercise in order to enhance cardiovascular and thermoregulatory function. Hyperhydration prior to prolonged exercise in human results in higher PV, lower heart rate and lower blood temperature throughout exercise (*Greenleaf* and *Castle* 1971). We have found that horses treated with hypotonic fluid weeks followed by a similar period of exercise at 50–90% $\dot{V}O_{2\,max}$ for the next two weeks. In a cross-over design, horses were randomly grouped and allocated on the first day to either ≈26 L (6% bodyweight) of isotonic fluid prior to exercise or nothing (control group). One week later, each group received the alternate treatment. One group was tested on each experimental day and there was a separation of at least 1 week between treatments. The fluid was given at room temperature (21°C) via nasogastric tube 2 h prior to the exercise test in 4 equal doses, 20 min apart, with the last dose given 1 h before exercise. The fluid contained 4.9 g/L of each of table salt (NaCl) and Lite salt (NaCl, KCl), (Saxa, Saltpak Pty Ltd, Seven Hills, Australia) and had an electrolyte composition (mmol/L) of Na 123, K 34, and Cl 157.

An exercise test was performed on a treadmill (Mustang 2000, Kagra AG, Fahrwangen, Switzerland) set at a 3% slope. It involved 4 phases (A, B, C and D) with a 10 min rest between C and D. Four days before the study, an incremental exercise test was performed in which horses' maximum heart rates (HR_{max}) were determined. From linear regression analysis the speeds at which each phase of the standardised exercise test was to be performed were determined so that all horses would run at the same percentage of their HR_{max}. The mean speeds and duration of exercise for each of the phases were: 3.7, 8, 3.7, and 7.3 m/s, and 30, 4, 50, and 14 min, respectively. Phases A and C were performed at 20% $\dot{V}O_{2\,max}$ while phases B and D at 60% $\dot{V}O_{2\,max}$. Measurements were performed prior to treatment and exercise and during exercise; every 10 min during phases A and C, at the end of phase B, and at 10 and 14 min during phase D.

Animal preparation and instrumentation

Horses were fed 6 h before the test and were allowed to eat for 1 h, after which food was removed. Only pellets and a commercial sweet-feed mix were given because roughage consumption has been shown to decrease PV (*Kerr* and *Snow* 1982). Water was removed 1 h later. Before fluid administration, blood samples for determination of base line values were taken and the horses weighed. Immediately after the last dose of fluid, the horses were reweighed and preparation for the exercise test commenced. The general preparation such as positioning of catheters, the collection, handling, and storage of samples, as well as the equipment and techniques used for the measurements of samples and data collection have been described elsewhere (*Sosa León* et al. 1995a).

Measurements

Central blood temperature was measured to assess thermoregulation. Bodyweight (bwt) changes were used to assess retention and elimination of fluid. Measurements of haematocrit (PCV), plasma total protein concentration (TP) were used to assess changes in plasma volume (PV) while those of heart rate (HR), cardiac output ($\dot{Q}$) and stroke volume (SV), oxygen uptake ($\dot{V}O_2$) and carbon dioxide production ($\dot{V}CO_2$), were used to evaluate cardiorespiratory responses to exercise. Metabolic responses were evaluated by measurements of respiratory exchange ratio (R), plasma glucose and lactate concentrations. Measurements of venous plasma electrolytes (Na, K, and Cl) and HCO_3^- were also undertaken to determine the interaction of exercise and fluid administration on electrolyte and acid base status. Throughout exercise, faecal samples were collected to determine the fluid loss from this route. The method for determination of faecal fluid content has been previously described (*Sosa León* et al. 1995a).

Statistical analysis

All measurements were analysed by two-factor analysis of variance to assess the effect of treatment with time used as a repeated measures factor. For all analyses, $p<0.05$ was regarded as statistically significant. When appropriate, post hoc comparisons were made using the Tukey Test. Data are expressed as mean±sem unless otherwise indicated.

Results

Exercise test

The exercise test was conducted on both groups under similar environmental conditions. Throughout the study, room temperature and humidity did not differ significantly between groups on either experimental day averaging 24.5±0.0°C and 66.0±0.3%, respectively. All horses completed the 4 phases of the test but some required encouragement to be able to keep pace with the treadmill towards the end of phase D. Prior to exercise, during preparation time, 6 horses in the treated group defecated while none in the control group passed faeces. Passage of watery stool in the treated group was also a common feature during

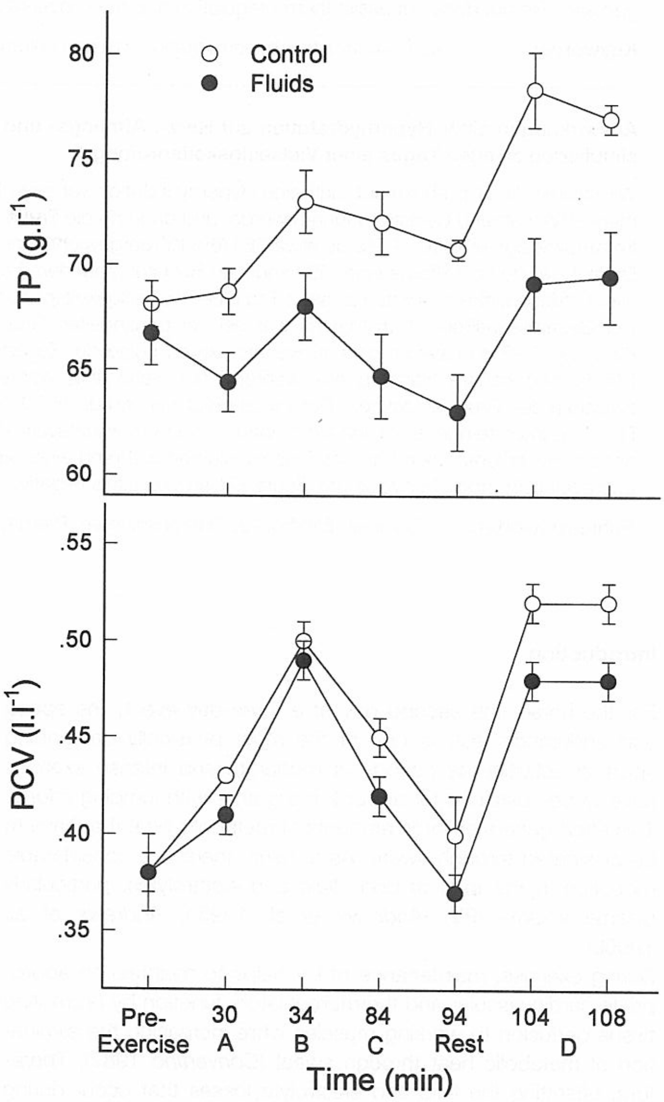

Fig. 1: PCV and TP (mean±sem) before and during exercise in hyperhydrated and normohydrated (control) horses.

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Effects of hyperhydration on cardiorespiratory and metabolic responses to exercise in horses during a simulated 2nd day of the 3-day-event

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Summary

We hypothesised that hyperhydration before prolonged exercise would increase and maintain plasma volume (PV), assisting thermoregulation and cardiorespiratory function. In a cross-over design, 7 horses received ≈26 L (6% bodyweight) of isotonic fluid or nothing (control). Horses undertook 98 min of treadmill exercise at intensities eliciting 20–60% $\dot{V}O_{2\,max}$ (24.5°C and 60% RH) to simulate 2nd day of a 3-day event. Results (mean±sem, P<0.05) at the end of the test in the treated group when compared with control showed: a lower TP (69±2 vs 77±2 g/L) indicating PV expansion; a higher HR but no differences in $\dot{Q}$ and SV; and lower venous pH, HCO_3^-. Core temperature remained unchanged despite higher bodyweight losses (25.7±1.7 vs 17.1±0.9 kg), mainly as sweat. Hyperhydration does maintain PV during prolonged exercise but does not assist thermoregulation and may adversely affect acid-base balance.

Keywords: fluid, electrolytes, hyperhydration, plasma volume, horses.

Auswirkungen einer Hyperhydratation auf Herz-, Atmungs- und Stoffwechselparameter bei Belastung von Pferden während eines simulierten zweiten Tages einer Vielseitigskeitsprüfung

Wir stellten die Hypothese auf, daß eine Hyperhydratation vor einer langen Belastung zu einem Anstieg und zur Erhaltung des Plasmavolumens (PV) während Belastung führen würde, und dadurch die Thermoregulation sowie die Herz- und Atemfunktion unterstützt.
Im Kreuzdesign erhielten 7 Pferde etwa 26 l (6% Körpergewicht) einer isotonischen Flüssigkeit oder keine Flüssigkeit (Kontrolle).
Danach wurden die Pferde einer 98 minütigen Belastung auf dem Laufband unterzogen, bei 20–60% ihrer $\dot{V}O_{2\,max}$ (bei 24,5°C und 60% relativer Luftfeuchtigkeit), um den zweiten Tag einer Vielseitigskeitsprüfung zu simulieren.
Der Gesamteiweißgehalt im Plasma war bei der behandelten Gruppe am Ende des Testes niedriger als bei der Kontrollgruppe (p<0,05; 69±2 vs 77±2 g/l jeweils); dies ist wahrscheinlich Folge der Zunahme des Plasmavolumens gewesen. Außerdem hatten die behandelten Pferde eine höhere Herzfrequenz während der Belastung, während Herzschlagkraft und das Herzschlagvolumen keinen Unterschied zwischen den Gruppen zeigten. Der venöse Blut-pH und die HCO_3^--Konzentration im Plasma waren bei den behandelten Pferden niedriger. Die Körperkerntemperatur blieb trotz höherer Körpergewichtsverluste (25,7±1,7 vs 17,1±0,9 kg), hauptsächlich als Schweißverlust, unverändert. Hyperhydratation hält das Plasmavolumen während einer langen Belastung aufrecht, unterstützt jedoch nicht die Thermoregulation und beeinflußt möglicherweise das Säure-Basen Verhältnis negativ.

Schlüsselworter: Flüssigkeit, Elektrolyte, Plasmavolumen, Pferde, Thermoregulation

Introduction

For the horse, the second day of a three-day event, the speed and endurance test, is one of the most physically demanding sporting activities as periods of moderate and intense exercise have to be sustained for about 2 h together with jumping efforts. This effort generates large amounts of metabolic heat that have to be dissipated through sweat. As a result, there is a considerable reduction in the total of body fluid and electrolytes, particularly plasma volume (PV) (*Andrews* et al. 1995a, *Andrews* et al. 1995b).
During exercise, maintenance of PV helps to maintain an appropriate cardiovascular and thermoregulatory function by promoting tissue perfusion to working muscles while increasing the elimination of metabolic heat through sweat (*Convertino* 1987). Therefore, offsetting the fluid and electrolyte losses that occur during exercise is essential to assist cardiovascular and thermoregulatory function.

Hyperhydration prior to prolonged exercise in humans results in higher plasma volume, enabling better circulatory function and heat dissipation (*Greenleaf* and *Castle* 1971). We therefore hypothesised that horses hyperhydrated prior to a simulated 2nd day of a 3-day event would maintain PV throughout the test maintaining a better cardiovascular and thermoregulatory function than when exercising without fluid.

Materials and methods

Experimental design

Seven clinically normal Standardbred geldings, age 4–6 years and weighing 434±10 kg (mean±sem) were used. Prior to the study, horses undertook a training protocol which consisted of low to moderate intensity exercise; eliciting about 30–70% of the maximal oxygen uptake ($\dot{V}O_{2\,max}$) for 10–30 min, 5 days per week for 4