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Dehydration, stress, and water consumption of horses during long-distance commercial transport[1]

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ABSTRACT: The aim of this study was to characterize progressive dehydration, stress responses, and water consumption patterns of horses transported long distances in hot weather and to estimate recovery time after 30 h of transport. Thirty adult mares and geldings were deprived of access to feed and water for 6 h, blocked by age, sex, breed, and body condition score, and assigned to one of the following treatments: penned, offered water (Penned/Watered, n = 5); penned, no water (Penned, n = 5); transported, offered water (Transported/Watered, two groups of n = 5); or transported, no water (Transported, two groups of n = 5). None of the horses had access to feed while on treatment. A commercial, single-deck, open-top, 15.8-m-long trailer was divided into four compartments to accommodate the two Transported/Watered and two Transported groups at 1.77 m^2 per horse. At 8, 17, 22, 27, 30, and 33 h after initiation of transport, the truck returned and stopped for 1 h to allow for data collection and to give the Transported/Watered and Penned/Watered horses 10 min of access to water in individual buckets. Treatments for the non-watered horses (Penned and Transported) were terminated after 30 h due to dehydration and fatigue, whereas the watered horses (Penned/Watered and Transported/Watered) could continue for another 2 h. Mean weight loss after 30 h was greater in the Penned (57.1 kg, 12.8%) and Transported (52.2 kg, 10.3%) groups than in the Transported/Watered (20.7 kg, 4.0%) and Penned/Watered (17 kg, 3.5%) groups ($P < 0.0001$). Respiration, heart rate, sodium, chloride, total protein, and osmolality were significantly elevated in the non-watered horses ($P < 0.0001$), and sodium, chloride, total protein, and osmolality greatly exceeded normal reference ranges, indicating severe dehydration. Although not statistically significant, the horses penned in full sun, with or without water, had a dehydration response that was slightly greater than that of the transported horses. Plasma cortisol concentrations had a significant time × treatment interaction ($P < 0.0001$), in which the Penned/Watered and Transported/Watered horses remained relatively consistent, whereas the Transported, and especially the Penned, horses' plasma cortisol concentrations greatly increased. Transporting healthy horses for more than 24 h during hot weather and without water will cause severe dehydration; transport for more than 28 h even with periodic access to water will likely be harmful due to increasing fatigue.

Key Words: Blood Protein, Dehydration, Electrolytes, Horses, Transport

Introduction

The "Safe Commercial Transportation of Equine to Slaughter Act" (Sec. 901-905, 1996 Farm Bill) authorized the U. S. Secretary of Agriculture to regulate the commercial transport of slaughter horses. The number of horses slaughtered in the United States has steadily decreased from 245,585 in 1992 to 103,678 in 1996 and to 72,120 in 1998 (USDA, 1993, 1997, 1999). Because of the long distance between slaughter plants, continuous transport for 30 h is common (Stull, 1999), and some trips last for 36 h or longer.

Most prior research conducted on the transportation of horses has been directed toward transport for breeding, showing, racing, or similar purposes. Although the 1996 summer Olympics stimulated a number of studies on horses during periods of strenuous exercise under hot and humid conditions (e.g., Ecker and Lindinger, 1995; Lindinger et al., 1995; McCutcheon et al., 1995), those studies were not very applicable to the transport of slaughter horses. Recent studies do address specific aspects of slaughter horse transport: dehydration and stress responses of horses transported for 24 h (Friend et al., 1998), preferred orientation and the effect of ori-

entation on balancing ability (Gibbs and Friend, 1999), welfare problems of horses arriving at slaughter plants (Grandin, 1999), a survey of nine trailer loads of slaughter horses (Stull, 1999), and the effect of density of horses on falls and injuries (Collins et al., 2000). The previous study conducted by this laboratory (Friend et al., 1998) is limited in its application because trips of 30 h and longer are common and exposure to the hottest period of the day was limited.

The objective of this study was to characterize progressive dehydration, stress responses, and water consumption patterns of horses transported during hot weather for 36 h or until they displayed signs of severe dehydration or fatigue, whichever occurred first. Recovery time was also estimated in a sample of the non-watered horses.

Materials and Methods

Experimental Animals

All procedures were approved by the Texas A&M University Large Animal Care Committee. The horses were carefully monitored so that in the event a horse seemed to become overly dehydrated or stressed, corrective measures could be immediately taken.

Thirty mature, healthy, nonpregnant mares and geldings were used. The horses were assembled and moved to two pastures adjoining the Department of Animal Science Freeman Arena 2 d before the start of the trial. Before the start of the study, the horses were maintained on pastures or lots with access to grass or hay and water. The horses were also fed grain twice daily to maintain their body weight. The trial was conducted at the same facility as our previous study (Friend et. al., 1998) on July 23 to 24, 1997. There were 9 Thoroughbreds, 17 Quarter Horses, and 4 Arabians, and they averaged 11.2 yr of age with a range of 2 to 22 yr of age. The horses were accustomed to being handled and having blood samples taken via jugular venipuncture.

Treatments

The horses were blocked by age, sex, breed, and body condition score and randomly assigned to one of the following treatment groups: 1) five horses were penned and offered water at set intervals (Penned/Watered horses); 2) five horses were penned with no water (Penned horses); 3) two sets of five horses each were transported and offered water at set intervals (Transported/Watered horses); and 4) two sets of 5 horses each were transported with no water (Transported horses).

The schedule of data collection is summarized in Table 1. The same set of data was collected from each horse at each of the eight sampling periods. The only exception was water consumption, which could only be measured after the horses were offered water following completion of the first 8 h of transport and data collec-

tion. Sampling consisted of first measuring heart and respiration rate, followed by jugular venipuncture (a plasma and serum sample), and then weighing. Body temperature (rectal) was taken while the horses were on the scale. Whole blood was used to determine packed cell volume, and plasma samples were used to determine total plasma protein concentration and plasma cortisol concentration. Serum biochemical analyses were performed to determine serum concentrations of electrolytes, total protein, albumin, calcium, phosphorus, glucose, BUN, creatinine, total bilirubin, globulin, and serum osmolality. Serum enzyme activities were determined for alkaline phosphatase, creatine kinase, lactate dehydrogenase, glutamic oxaloacetate transaminase, and gamma glutamyl transferase.

The initial sample was obtained by walking up to each horse while it was relaxed in the pasture. After each horse was sampled, it was individually led to holding pens containing groups of three to four. The horses were then held in those shaded facilities for 5 h without access to feed or water to approximate the amount of time that many horses arriving at an auction the morning of a sale are held before being transported to slaughter. During the 5-h holding period all of the transported and penned horses were individually led through the scales and onto the truck several times to acclimate them to the experimental routine. The penned horses were also led onto the truck to standardize the training for all subjects. The next sampling period commenced at 1100, after which the horses were loaded and the truck departed on the first run at 1200.

The same commercial single-deck, 16-m-long trailer and tractor (16-wheeler) that was used earlier (Friend et al., 1998) was hired to haul all of the Transported/ Watered- and Transported horses simultaneously. The trailer had an open top and was divided into four 3.65- × 2.43-m compartments to accommodate the two sets of Transported/Watered horses and two sets of Transported horses (20 horses total) in alternate compartments. To control for location effects, the compartment assignments rotated with each sampling and watering. Dividing the trailer into four compartments resulted in one replicate of each treatment group. There was adequate room (1.77 m^2/horse) within each compartment for the horses to change their orientation while traveling. Commercial truckers in North America typically put one or two additional horses in each compartment (1.47 to 1.27 m^2 per horse, respectively; Stull, 1999). However, such a high density would have made the watering of our horses within the trailer difficult.

The truck drove on highways as well as rural and urban roads in the vicinity of College Station, Texas, returning to Freeman Arena at specified intervals (Table 1). Initially, the truck drove for 4 h before returning for a 10-min visual check to ensure that the horses were in good condition. As the study progressed, the time between visual checks and sampling periods decreased to parallel expectations from Friend et al. (1998) of when rapid changes might occur in the horses. During

Table 1. Schedule of data collection and other activities in relation to initiation of treatments and time of day (in parentheses)

Time of data collection	Activity
−6 h (0600)	Initial sample obtained in pasture then subjects placed groups of three to four in holding pens. All horses practiced getting weighed and loading on and off the trailer.
−1 h (1100)	Sample. After this sample, the horses were loaded onto the semi-trailer.
0 h (1200)	Hauling commenced
4 h (1600)	Visual check, required 10 min
8 h (2000)	Sample and water
12 h (0100)	Visual check, required 10 min
17 h (0500)	Sample and water
22 h (1000)	Sample and water
25 h (1300)	Visual check, required 10 min
27 h (1500)	Sample and water
30 h (1800)	Sample and water (end of study for non-watered treatments)
33 h (2100)	Sample and water (end of study for watered treatments)
Recovery for Penned (n = 2) and Transported (n = 5) horses	
36 h (2400)	Blood sample
42 h (0600)	Blood sample
48 h (1200)	Blood sample
54 h (1800)	Blood sample

visual checks, the trailer was backed into the shade of Freeman Arena to permit researchers to take a temperature reading of the neck of each horse using a precision-aiming infrared thermometer (Model 39800, Cole Parmer, Vernon Hills, IL). A visual appraisal was also made that included estimating respiration rates. Transport then resumed, provided that all horses seemed to be in reasonable condition.

When the truck returned for the 1-h sampling periods, the trailer was backed up to the unloading dock. A lead rope was attached to the halter of each horse and the horses were led from the trailer. The horses were then led to one of two sets of stations (approximately 50 m from the truck) where heart and respiration rates were measured. A blood sample was taken at the next station, followed by weighing and body temperature determination. The horses were then loosely tied in the arena while the remainder of the horses were unloaded and sampled. The arena was open on three sides and subject to ambient temperature fluctuations. Following the earlier protocol (Friend et al., 1998), as soon as the trailer was empty, rubber water buckets were mounted on the sides of the compartments in which the Transported/Watered horses were to be confined during the next trip. Each bucket was filled with 12 L of water. When the horses in the Transported/ Watered and Transported returned to the trailer, each was loosely tied, and the Transported/Watered horses were offered water for 10 min. When the truck returned for the first sampling period after 8 h, the horses were not expected to consume their entire 12 L of water, based on previous experience (Friend et al., 1998), so preparations were not made to refill their buckets. However, several drank all of their water and would have drunk more, so provisions were made for the buckets

to be refilled with a measured amount of water for all subsequent waterings, including the first watering for the Penned/Watered horses. After 10 min, the buckets were lifted out of the trailer to prevent possible injury to the horses during transport and to allow for depth of the residual water to be measured, and the horses were untied and the lead ropes removed. The volume of water in the buckets was quantified by converting the depth (measured by a meter stick) to volume using a regression equation.

Horses in the Penned/Watered and Penned groups were subjected to the same data collection procedures as the Transported/Watered and Transported horses after the transported horses departed. Although simultaneously collecting data from both the transported and penned horses would have been preferable throughout the study, logistical considerations prevented simultaneous sampling. Thus, the penned horses were placed on treatment and their sampling occurred after that of the transported horses. When the examinations of penned horses were completed and blood samples were obtained, the Penned/Watered and Penned horses were moved to a single portable pen 16 m in diameter that was located adjacent to the holding facilities. The pen was in a graveled parking area and contained no vegetation or feed. Neither the penned nor the transported horses were given any feed during the trials. The pen was in full sunlight to simulate the sunlight exposure of the transported horses.

During the transport phase of the study, data collection on the penned horses commenced immediately after the transported horses were sampled and reloaded and the truck departed for the next run. The penned horses were individually led through the sampling stations and the Penned/Watered horses were tied 10 m

away from the Penned horses in the arena. The Penned/Watered horses were then offered water for 10 min in the same buckets the Transported/Watered horses used. Initially, 12 L of water was placed in their buckets, which were refilled with a known amount of water when necessary. Blood samples were obtained from the jugular vein using evacuated glass tubes with 20-gauge needles.

During the sampling, one 10-mL blood sample from each horse was collected into an evacuated tube containing anticoagulant (0.1 mL of 15% Na-EDTA solution) for use in the determinations of plasma cortisol concentration, packed cell volume, and total plasma protein concentration using a refractometer. A second 10-mL sample of blood was collected without anticoagulant for determination of serum osmolality and serum biochemical profiles.

Most of the horses did not react to venipuncture and, in most instances, both evacuated tubes were filled using the same puncture. The physical and visual examinations provided immediate indicators of dehydration and stress and served as the basis for determining whether the treatments would continue for an additional period. When a horse seemed dehydrated or fatigued, it was removed from its treatment and placed in a shaded stall, and rehydration commenced.

Rehydration

In our earlier study (Friend et al., 1998) signs of colic were not observed when the horses were offered 14 L of water at 30-min intervals after 28 h of water deprivation. Similarly, no colic was observed when horses were allowed 1 h of access to water after being deprived for 72 h (Carlson et. al., 1979). Because it was anticipated that the horses in this study were going to be more dehydrated than those in the study of Friend et al. (1998), the rehydration schedule used in this study was 12 L of water at 30-min intervals. The goal was to rehydrate the horses as quickly as possible to parallel the situation in the industry in which shipments of slaughter horses arriving at slaughter plants or holding facilities are often offered unlimited water in a group situation.

Recovery

In order to obtain an estimate of how long it took for the physiological (i.e., blood) measures of dehydration to return to normal values, a series of four blood samples was obtained from five Transported and two Penned horses. The remaining Transported and Penned horses were not used to characterize recovery because they were part of an additional experiment. The samples were drawn at 6-h intervals commencing at midnight and ending at 1800. That is, the samples were drawn 5 h after the last regular sampling was completed (sampling took almost 1 h and the horses were offered water at the end of the sampling period)

and after the horses were offered and consumed 24 L of water.

Measurements

Horses were scored on body condition following the descriptions of Henneke et al. (1983), packed cell volume was determined by the microhematocrit method (Schalm, 1965), and total plasma protein concentration was determined by a hand-held refractometer (Leica Temperature Compensated Hand-Held Refractometer, Optical Products Division, Buffalo, NY) using the supernatant plasma in the capillary tube. Plasma cortisol concentrations were determined for duplicate samples using an antibody-coated-tube RIA kit (Diagnostic Products, Los Angeles, CA) that was validated by our laboratory for use in horses (Friend et al., 1998). Duplicates that differed by more than 5% were reassayed. The intraassay CV averaged 9.3% and the interassay CV was 12.2%. Specifics of the assay procedure and cross-reactivity were reported earlier (Friend et al., 1998). Serum concentrations of electrolytes and values of biochemical analysis were determined by The Texas Diagnostic Laboratory, College Station, Texas, using a chemistry analyzer, (Coulter DACOS Chemistry Analyzer, Coulter, Miami, FL) and osmolality was measured by vapor pressure (Westcor Osmometer, Westcor, Logan, UT).

Statistical Analysis

A split-plot model accounting for repeated measures (sampling time) using the GLM procedure of SAS (SAS Inst. Inc., Cary, NC) was used to analyze the data. The main effects were treatment, with horse nested within treatment, whereas the split-plot factors were sampling time and treatment × sampling time. The error for horse nested within treatment was used to test for treatment effects, and the error for treatment × sampling time was used to test for sampling time effects. Least squares means were used to identify differences when significant interactions occurred.

Results

General

There were typical diurnal variations in ambient temperature and relative humidity for southeastern Texas at the times when data were obtained (Table 2). There was little cloud cover and no rain.

The horses were very uniform in their response and no individuals had to be removed from any of the treatments prematurely. The horses displayed increasing signs of fatigue (closing their eyes, lower head carriage, less social interaction, and less response to stimuli) during the course of the study, but none attempted to lie down. Although not quantified, there was a striking absence of social interactions, especially threats and

Table 2. Ambient temperature, relative humidity, distance traveled, and water consumption at data collection times

Hours from initiation of transport (time of day)	Temperature, °C	Relative humidity, %	Distance traveled, km	Water consumption, L (± SE)	
				Penned horses	Transported horses
−6 (0600)	24	94	—	—	—
−1 (1100)	32	44	—	—	—
8 (2000)	36	32	448	22.9 ± 1.8	11.1 ± .4
17 (0500)	25	80	392	5.8 ± 1.6	16.3 ± 1.3
22 (1000)	29	70	176[a]	9.0 ± .4	8.7 ± 1.7
27 (1500)	36	39	272	12.6 ± 1.1	12.2 ± 1.8
30 (1800)	37	35	134	2.5 ± .8	9.1 ± 1.4
33 (2100)	31	53	147	0.6 ± 0.6	4.1 ± 1.5

[a]Distance traveled was reduced due to a flat tire. The horses remained on the trailer during repairs.

nipping each other, at the 27th h sampling in both the Transported and Penned horses. After 30 h of transport, the non-watered horses were judged unfit for another 2 h of treatments by a panel of four experienced horse handlers, so the non-watered horses were removed from the study. The handlers' decision was based on the absence of social interactions, a greatly reduced response to stimuli, and the horses' generally depressed appearance. The watered horses remained on treatments for another 2 h of transport and 1 h of sampling, at which time their fatigue resembled that of the non-watered horses, so the trial was terminated. The additional 32-h sample obtained for the watered horses could not be included in the statistical comparisons that were made between treatments because there was no comparable 32-h sample for the Transported and Penned horses, but those samples are shown in the plots of the data.

Although the same basic rehydration schedule was used without incident in the trial reported by Friend et al. (1998), one Transported horse started to develop colic (restlessness, pawing, looking at flank and attempting to roll) 30 min after consuming the first 12 L of water. Another Transported and one Penned horse showed signs of colic soon after the second watering 30 min later. As a precaution, the horses with colic were given 7.5 L of mineral oil and 2,000 mg of flunixin (Banamine, 50 mg/mL, Schering-Plough, Omaha, NE) and were led around the adjacent arena until symptoms resolved. After offering the second 12 L of water, the 30-min rehydration schedule for the non-watered horses was abandoned and the horses were offered much smaller amounts at longer intervals during the rest of the night. The watered horses were given free access to water, but most horses consumed very little because they had just been offered water on the trailer as part of their treatments prior to their ending the study. One Transported/Watered horse, however, showed symptoms of mild colic 3 h after the end of the study and was given 2,000 mg of flunixin as a precaution.

Water Consumption

All of the watered horses readily consumed water at the first opportunity (Table 2). Only two Transported/Watered horses did not consume all of the 12 L offered, but the horse that drank the least consumed 8.3 L. The relatively low initial water consumption of the Transported/Watered horses relative to the Penned/Watered horses was caused by our not being prepared to refill the Transported/Watered horses' buckets when the horses emptied them. The relatively high water consumption of the Transported/Watered horses after 16 h of transport relative to the Penned/Watered horses was compensation for the limited amount of water the Transported/Watered horses could consume at the initial watering. During the study period, each Penned/Watered horse consumed an average total of 53.3 ± 2.3 L of water, whereas each Transported/Watered horse consumed 61.5 ± 3.3 L ($P > 0.14$). There was a strong diurnal effect in watered horses (Table 2), which consumed less water during the cooler sampling times (i.e., 0500, 1800, and 2100). Spillage caused by the horses when playing with the water or the buckets and by researchers moving the buckets was negligible.

Weight Loss

The initial average body weight for the horses in each treatment group were as follows: Penned/Watered, 492 ± 49 kg; Penned, 450 ± 20 kg; Transported/Watered, 520 ± 42 kg; and Transported, 508 ± 21 kg. All of the horses lost body weight during the course of the study (time effect, $P < 0.0001$), and analysis of the time × treatment interaction ($P < 0.0001$) indicated that there was a differential response across treatments (Figure 1). The watered horses consumed enough water to stabilize their weight loss during the latter half of the trial, whereas the non-watered horses continued to lose weight at a relatively steady rate. A slight decrease in the rate at which they lost weight can be seen during the cooler late night and early morning hours. Percentage of
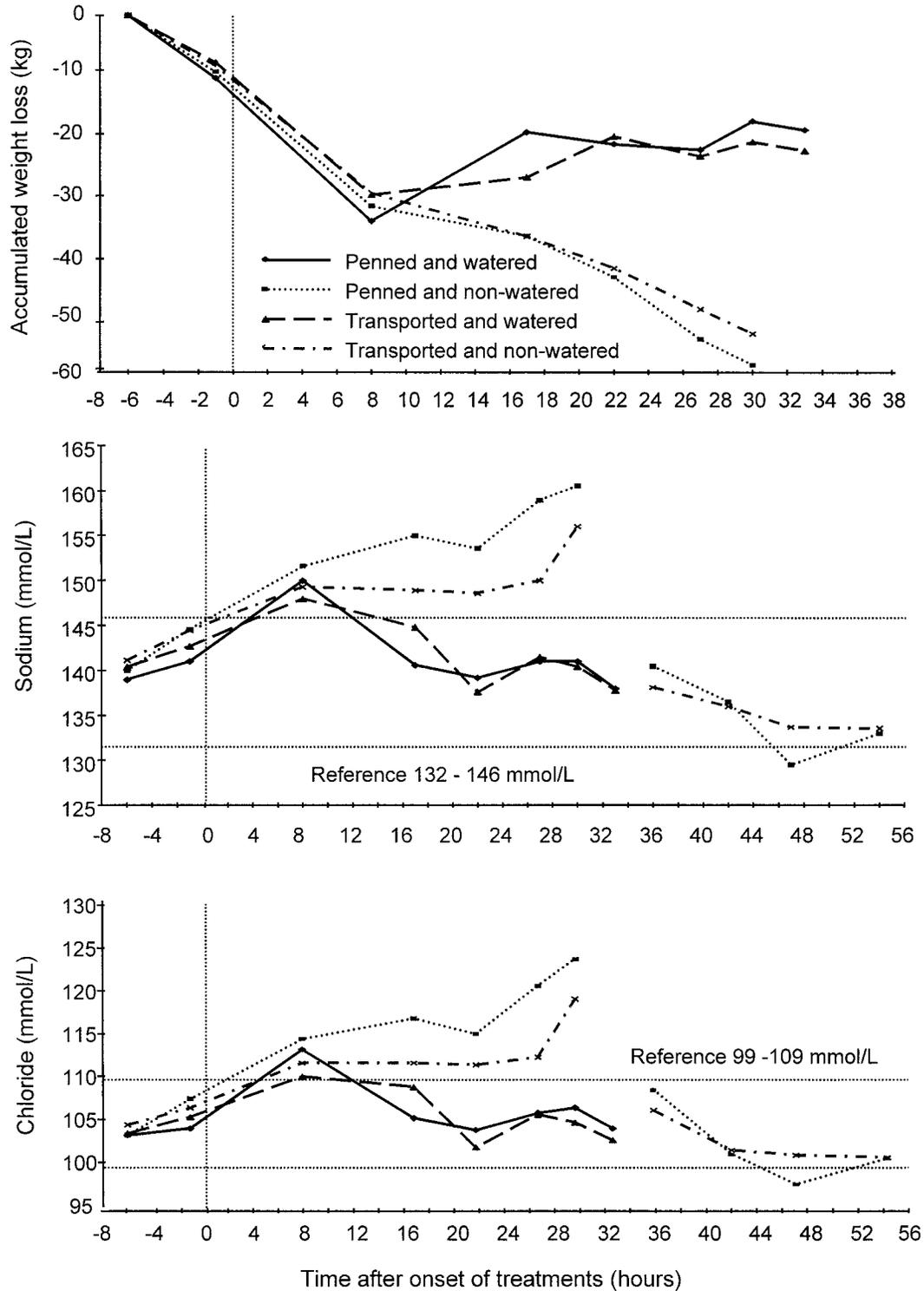
Figure 1. Means of accumulated weight loss and serum sodium and chloride concentrations by treatments before and during treatments and during recovery. Reference (normal) ranges are indicated by the horizontal dotted lines (Boon and Rebar, 1988). Before and during treatments, n = 10 per treatment group for the transported horses and n = 5 per treatment group for the penned horses. During recovery, from 36 to 54 h, n = 5 for the horses and n = 2 for the penned, non-watered horses.

weight loss after 30 h was greater in the Penned (12.8%) and Transported (10.3%) than in the Transported/Watered (4.0%) and Penned/Watered (3.5%) horses.

Electrolytes

Serum sodium concentrations (Figure 1) had a significant time × treatment interaction ($P < 0.0001$). The watered horses were relatively consistent and returned to reference (normal) ranges (Figure 1) after the initial offering of water. Serum sodium concentrations in the Penned and Transported horses, however, increased over time, especially during the hottest part of each day. Serum sodium returned to reference ranges by the time the first recovery blood sample was taken, approximately 4 h after the horses were offered water. Serum chloride concentrations (Figure 1) also had a significant time × treatment interaction ($P < 0.0001$) and followed a pattern similar to that of serum sodium. Serum potassium concentrations had only a slight time × treatment interaction ($P < 0.033$) and remained within reference ranges during the entire experiment.

Serum sodium and chloride concentrations were within normal ranges within 5 h after the non-watered horses started to receive water. The horses had consumed a total of 28 L of water 4 h before the first recovery blood sample was obtained.

Vital Signs

There was a significant ($P < 0.0001$) time × treatment interaction for both respiration and heart rate (Figure 2). The non-watered horses' respiration and heart rates increased during the course of the study and were markedly higher after 30 h of treatments relative to those of the watered horses. There was a diurnal effect on body temperature ($P < 0.0001$) that paralleled changes in ambient (shade) temperature and was not influenced by treatment ($P > 0.94$). Because of the lack of treatment effects on body temperature, body temperature data are not shown.

Cortisol

No circadian rhythms or treatment effects were observed in cortisol concentrations (Figure 2). However, plasma cortisol concentrations had a significant time × treatment interaction ($P < 0.0001$). The watered horses remained relatively consistent, whereas the Transported, and especially the Penned, horses' plasma cortisol concentrations greatly increased (Figure 2).

Packed Cell Volume

All packed cell volumes were within reference range (32 to 53%) (Jain, 1986). Although there was a time × treatment interaction ($P < 0.003$), the trends observed were variable from one sample to the next and seemed to be more a result of the initial values of a particular group of horses than of the actual treatments.

Osmolality and Protein

Osmolality (Figure 3) had a significant time × treatment interaction ($P < 0.0001$). Penned/Watered and Transported/Watered horses were relatively consistent during the course of the study, whereas Penned and Transported values greatly exceeded reference ranges (Figure 3) after 22 h of treatment. During recovery, osmolality tended to be below the reference range.

Values of total plasma protein concentrations (determined by refractometer) had a significant time × treatment interaction ($P < 0.0001$). Penned/Watered and Transported/Watered horses were relatively consistent during the course of the study, whereas Penned and Transported values were above reference ranges and then greatly increased after 28 h of treatment (Figure 3).

Total serum protein concentrations had a significant time × treatment interaction ($P < 0.0001$) and had a response pattern that was almost identical to that of total plasma protein (Figure 3).

Serum Chemistry Profile

Serum albumin, glucose (Figure 4), globulin, and gamma glutamyl transferase had significant time × treatment interactions ($P < 0.0001$) in which Penned horses had the greatest response, closely followed by the Transported horses; the watered horses had a much smaller increase. The non-watered horses were generally well above reference ranges for those items. Serum calcium and phosphorus remained within reference ranges but were significantly ($P < 0.0001$) increased in the watered horses. Serum creatinine, blood urea nitrogen (Figure 4), total bilirubin (Figure 4), alkaline phosphatase, creatine kinase, lactate dehydrogenase, and glutamic oxaloacetate transaminase were influenced ($P < 0.001$) by treatment, but not in a pattern that was consistent with water deprivation. The Penned horses had the greatest increase but the watered horses had the second-highest concentrations, and Transported horses had the lowest.

Discussion

The finding that the Penned horses had greater weight loss (dehydration) than the Transported horses was consistent with our earlier study (Friend et al., 1998). We were originally skeptical that horses that are crowded into a truck, required to continuously expend energy to maintain their balance, and that had a possibly greater radiant heat load because of the reflectivity of the open-topped aluminum trailer would dehydrate more slowly than horses standing in an open pen, but the replication of the same trend 2 yr later is convincing. Perhaps the greater wind speed and convective cooling during transport resulted in less perspiration, and hence reduced water loss. The data from the watered horses, however, do not support that hypothesis. The
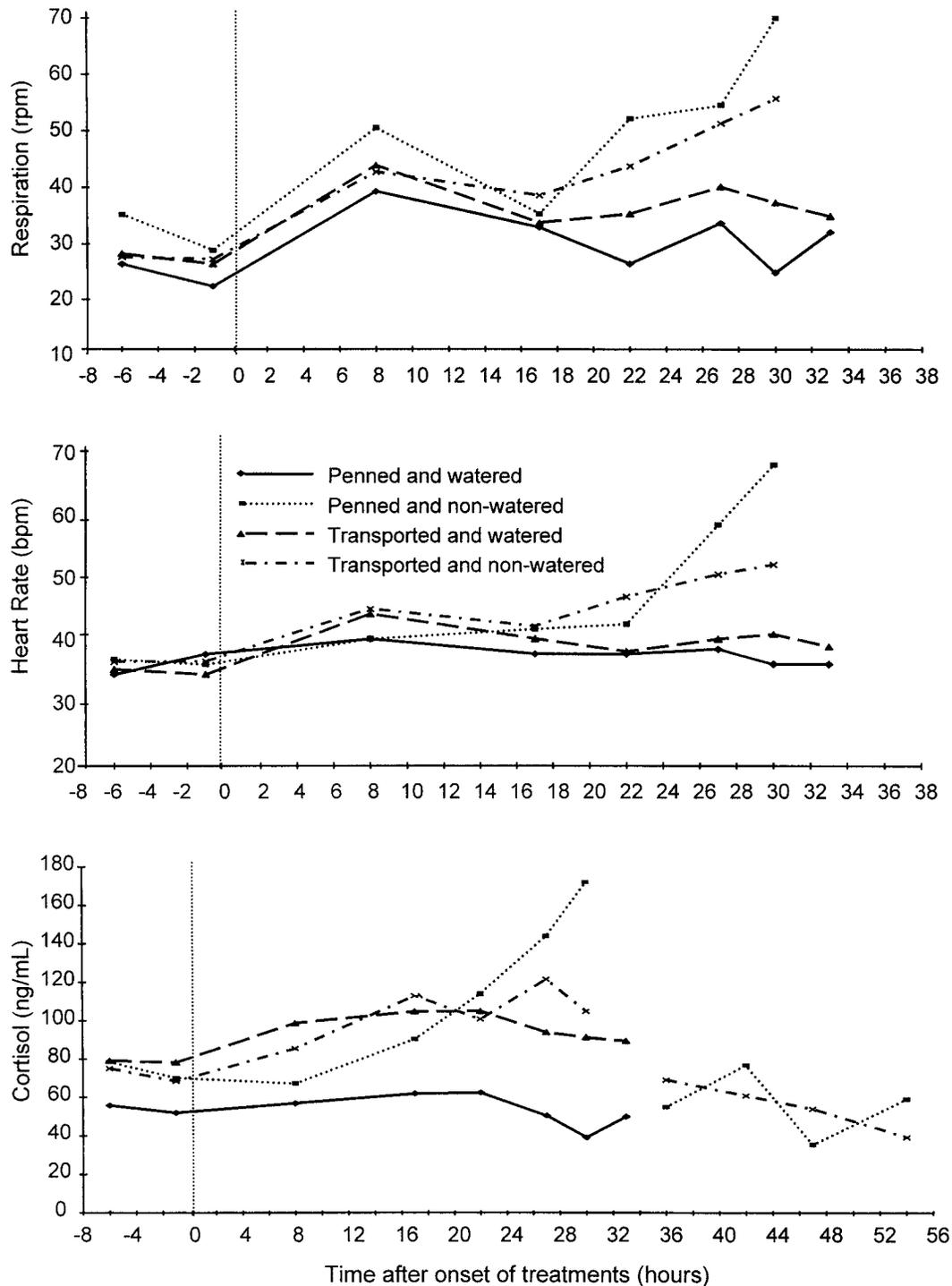
Figure 2. Means of respiration rate, heart rate, and cortisol concentrations by treatments before and during treatments and during recovery (cortisol only). Before and during treatments, n = 10 per treatment group for the transported horses and n = 5 per treatment group for the penned horses. During recovery, from 36 to 54 h, n = 5 for the transported, non-watered horses and n = 2 for the penned, non-watered horses.

Transported/Watered horses lost more weight than the Penned/Watered horses (20.7 vs 17.1 kg, respectively), although the former group of Transported/Watered horses consumed the most water (61.5 vs 53.3 L). If reduced heat load was a major factor in reducing weight loss, one would expect the Transported/Watered horses to have had less weight loss than the Penned/Watered horses, along with an expected lower water consumption, which was not the situation. A differential loss through defecation and urination is not likely, because most urination and defecation would likely occur during the first 8 h on treatments, with the transported horses

urinating and defecating more due to the novelty of the trailer. However, weight loss at 8 h was not consistent with that explanation. More research needs to be conducted to determine the relative heat loads horses experience in different types of trailers.

The report of feral horses voluntarily coming to water sources (Feist and McCullough, 1976) is not directly applicable to situations in which horses are transported in trucks or kept in full sun for extended periods during hot weather. The feral horses were in an environment
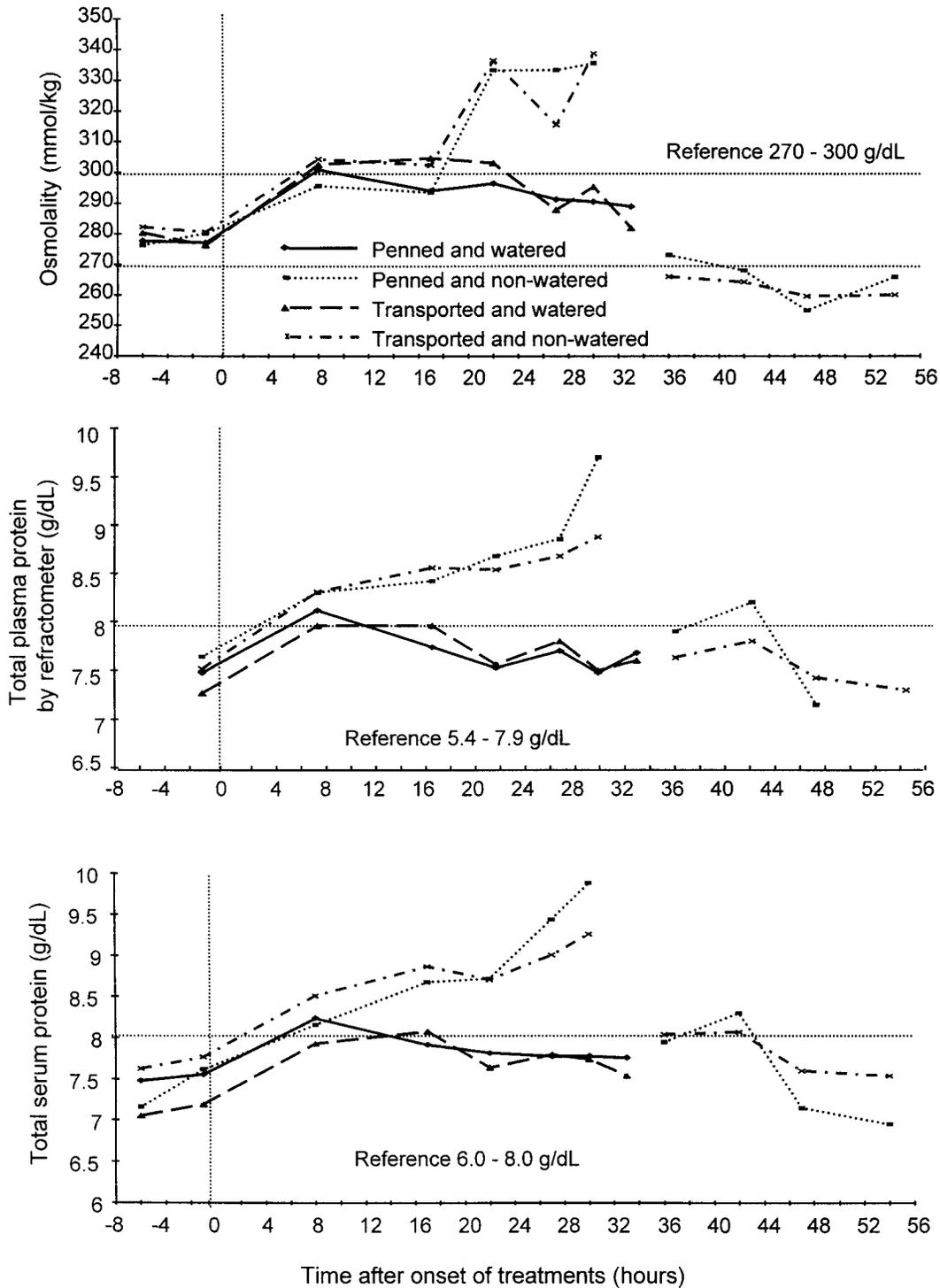

Figure 3. Means of osmolality, plasma protein, and serum protein by treatments before and during treatments and during recovery. Reference (normal) ranges are indicated by the horizontal dotted lines (Boon and Rebar, 1988). Before and during treatments, n = 10 per treatment group for the transported horses and n = 5 per treatment group for the penned horses. During recovery, from 36 to 54 h, n = 5 for the transported, non-watered horses and n = 2 for the penned, non-watered horses.

Figure 4. Means of glucose, blood urea nitrogen, and total bilirubin concentrations by treatments before and during treatments and during recovery. Reference ranges are indicated by the horizontal dotted lines (Boon and Rebar, 1988). Before and during treatments, n = 10 per treatment group for the transported horses and n = 5 per treatment group for the penned horses. During recovery, from 36 to 54 h, n = 5 for the transported, non-watered horses and n = 2 for the penned, non-watered horses.
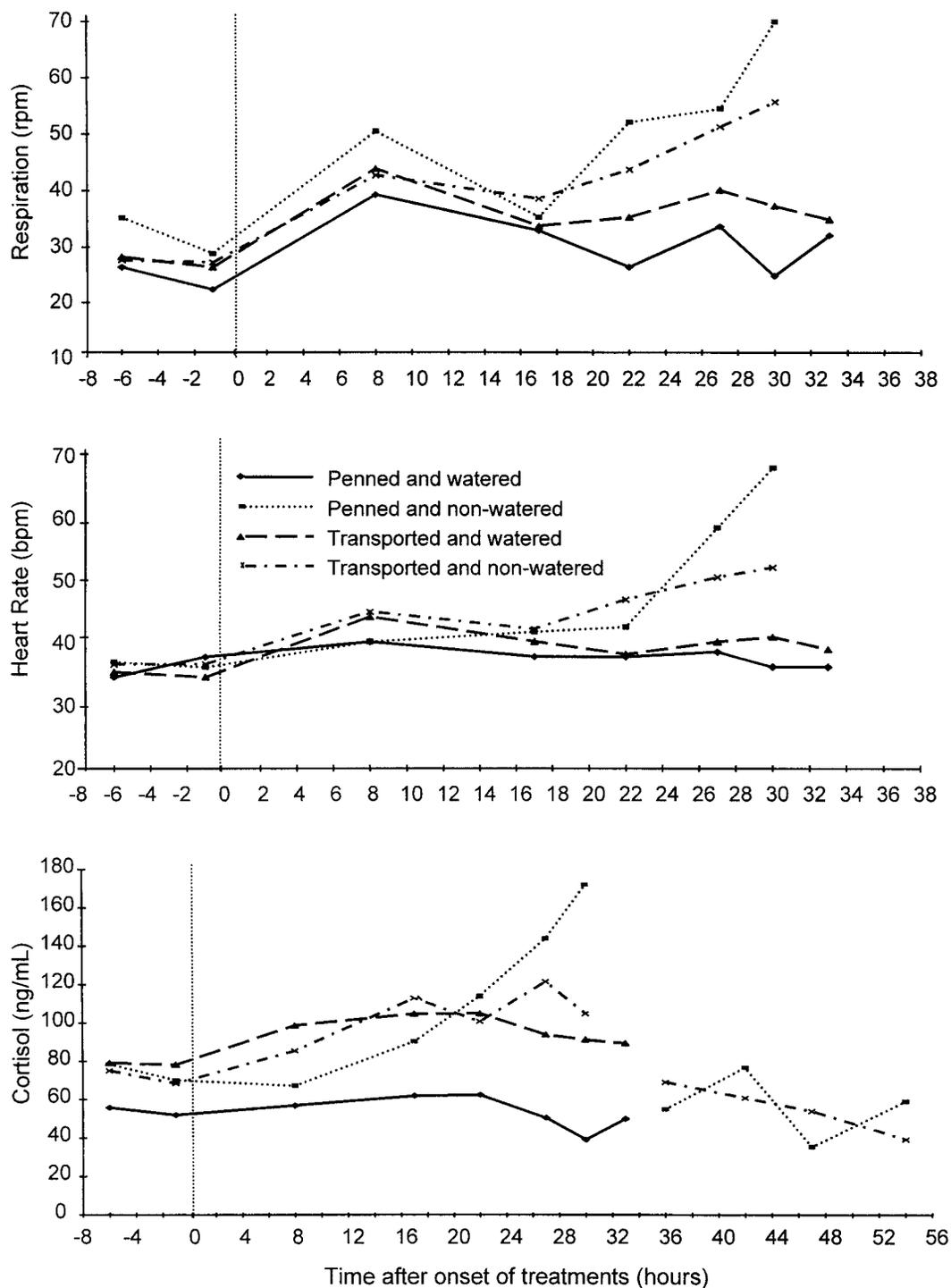
with cool daytime and cold nighttime temperatures, and the horses could have obtained appreciable amounts of water through vegetation. Although the horses in this study seemed to conserve water by reducing urination and defecation (and when a horse did

defecate the feces were noticably much dryer than normal) they expended large volumes of water through sweating.

The 12.8% weight loss observed in the Penned horses after 36 h of water deprivation (6 h before transport

and 30 h of transport) was greater than the 12% weight loss observed by Sneddon et al. (1991) after 72 h of deprivation, the 10.7% weight loss observed by Carlson et al. (1979) after 72 h of deprivation, and the 10% weight loss observed by Tasker (1967) after 6 to 8 d of food and water deprivation. The horses of Sneddon et al. (1991) were stalled and temperatures ranged from 18.7 to 29.9°C. The methodology of Carlson et al. (1979) was roughly equivalent to that used with this study's Penned horses; the horses were individually penned in full sun, but the temperatures ranged from 11.8 to 33.2°C. The temperatures during this study (Table 2) ranged from 24 to 37°C. The horses of Tasker (1967) were kept in stalls with temperatures that ranged from 0 to 20°C. The much higher temperatures, and probably humidity, experienced by the horses in this study created a situation in which the horses had to sweat at a high rate during the day, and probably much of the night, even while standing idle. Such high temperature and humidity patterns are common in the southeastern United States during the summer and can occasionally occur through the Midwest and into Canada. Both Carlson et al. (1979) and Sneddon et al. (1991) measured significant increases in total plasma proteins, sodium, osmolality, and a number of other measures, but their maximum increases were close to the upper reference values presented in this article and were much lower than the most extreme values observed in the horses in this study.

Losing 12.8% of body weight in 36 h seems extreme, especially when considering what has been previously reported (Tasker, 1967; Carlson, et al., 1979; Sneddon et al., 1991). The rapid increase in electrolytes, blood proteins, and osmolality that occurred after 27 and 30 h of transport or penning without water in this study was especially alarming because such concentrations had not been approached by Carlson et al. (1979) or Sneddon et al. (1991). This shows the large effect that high sustained environmental temperatures can have on dehydration rates. At the end of this trial, serum osmolality, serum protein, urea, sodium, and chloride concentrations in the non-watered horses also exceeded those in six critically ill, hypertonic horses (Brownlow and Hutchins, 1982). However, the dehydration in the critically ill horses was caused by underlying disease. Also, the effect of the extreme dehydration in the non-watered horses in this study was probably minimized because it was of short duration.

During the study period, Penned/Watered horses consumed a mean of 53.3 ± 2.3 L of water, whereas Transported/Watered horses consumed 61.5 ± 3.3 L, which was not significantly different ($P > 0.14$). The relative difference between treatment groups can be highly variable; in our earlier study (Friend et al., 1998), the Penned/Watered horses consumed more water (38.2 L) than the Transported/Watered group (20.9 L).

A resting respiration rate of 50 or more per minute may be a very useful measure in determining when horses are at risk from dehydration and heat. Respira-

tion rate could easily be obtained by observing the movement of horses' flanks while they are still loaded on trucks. Although no attempt was made to quantify behavior in this study, casual observation found that the penned and transported horses were still very active behaviorally. The horses continued to nip at or threaten each other, and the penned horses occasionally chased each other around the pen through the 1000 sample on the 2nd d. Most interactive behavior ceased after 24 h, and by 27 h of treatments the horses were noticeably quiet and had the "tucked-up" appearance of the abdomen described by Tasker (1967) as occurring on the 5th d without water. The watered horses were more active and appeared less fatigued (head held up, eyes open, attentive to novel stimuli, etc.) than the non-watered horses; hence, the watered horses continued on the treatments for an additional 3 h.

In our earlier study (Friend et al., 1998), two horses were judged to be questionable or unfit for further transport after 24 h. The horses in this study were much more uniform in their responses. The high initial intake of water in these horses relative to those in the earlier study was probably due to the fact that they were deprived of water earlier in the day and the treatments began at 1200, rather than in the afternoon (1500), so these horses experienced the hottest period of the day in the treatments.

Based on cortisol concentrations, the stress associated with hauling these horses in the trailer seemed not to be significantly greater than what the penned horses experienced (Figure 2), at least during the first 20 h of transport. The large increase in cortisol concentration that occurred at 27 and 30 h for the Penned horses may have in part been due to hemoconcentration.

Consistent with Friend et al. (1998), osmolality increased along with sodium, chloride, serum and plasma protein, and urea. These horses were suffering from water loss in excess of electrolytes. The administration of solutions containing high concentrations of electrolytes could exacerbate the loss of water. Administration of water or low-electrolyte solutions is the suggested treatment (Carlson, et al., 1979; Brownlow and Hutchens, 1982).

The rapid increase in glucose in the Penned horses (Figure 4) during the last hours of transport may be partially due to the gluconeogenic activity of cortisol as well as hemoconcentration. There was a rapid increase in cortisol in the Penned horses during that same time period. Glucose returned to within references ranges approximately 8 h after rehydration.

The failure of creatinine, total bilirubin, alkaline phosphatase, creatine kinase, lactate dehydrogenase, and glutamic oxaloacetate transaminase to be altered in a pattern that was consistent with water deprivation (i.e., a gradual increase in concentrations) could be expected. Creatinine concentrations reflect muscle metabolism, total bilirubin is elevated by starvation, and the other four measures are related to tissue damage. Al-

though the horses were dehydrated and fatigued after 30 h of transport or penning, the extreme muscle tonicity associated with a release of creatine kinase, as occurs during prolonged strenuous exercise (Snow et al., 1982), did not occur.

No incidence of colic was observed during rehydration in the study of Friend et al. (1998). Those horses did not have unrestricted access, but they were limited to 14 L at 30-min intervals. We considered unlimited access to water to be too risky, although Carlson et al. (1979) reported no colic in horses deprived of water for 72 h and allowed 1 h of unlimited access to water. In the present study, the same basic rehydration schedule was initially followed, except that the horses now had access to 12 L of water rather than the 14 L given earlier. Because these horses were more dehydrated than those of Carlson et al. (1979), Sneddon et al. (1991), and Friend et al. (1998), three showed colic after consuming two offerings of 12 L of water at 30-min intervals. The temperature of the water was not likely a factor, because during the periods of extended hot weather the water became tepid, reaching 26°C or higher. The colic was likely due to discomfort from rapid replacement of the gastrointentinal fluid pool, which has been shown to be diminished by 40 to 50%, whereas other body fluid pools were maintained during moderate dehydration (Sneddon et al., 1993). Giving horses as highly dehydrated as the horses in this study unlimited access to water upon arrival at their destination is problematic.

Recovery from dehydration was extremely quick. Sodium, chloride, and osmolality returned to normal ranges (Figures 1 and 3) by the time the first blood sample was taken (4 h after consuming two offerings of 12 L of water). Sodium, chloride, and osmolality had returned to normal ranges in the Carlson et al. (1979) horses within 1 h. Total plasma or serum protein, however, took 12 h or more to return to normal ranges in these horses (Figure 3), which is also consistent with prior studies (Tasker, 1967; Carlson, et al., 1979).

Providing horses with water on trucks seems to be a useful means of delaying severe dehydration and reducing colic due to rapid water consumption upon arrival, provided the horses will drink. All of the horses used in this study readily drank. However, water consumption in our previous study (Friend et al., 1998) was highly variable, and one horse did not drink until after 24 h of transport. That horse had a fever of 40.6°C. Additional studies are needed to determine whether less-tame or more-stressed horses will be more reluctant to drink if providing water on board trucks is to be considered an efficacious method of reducing dehydration. Untamed cattle were observed to readily drink in railcars while the train was moving over rough track; however, those cattle were relatively dehydrated when they were loaded onto the railcar (Friend et al., 1981). Trials are currently being conducted in this laboratory evaluating the use of truck-mounted collapsible water troughs. There are no published data available on the

duration that horses need to have access to the troughs, optimum density, or whether horses will drink from the troughs.

Implications

Results of this study indicate that 28 h is the longest period of time healthy horses should be transported without being provided water under hot conditions if they may have been deprived of access to water for less than 6 h prior to transportation. A 28-h maximum is too long if their water intake may have been restricted for longer than 6 h prior to transport, if there was considerable aggression between the horses during transport, if they were loaded at too high a density, or if they were geriatric, not healthy, or otherwise fit for such a trip. It is important to realize that the horses used in this project were in good to excellent condition at the start of the trial, accustomed to handling, and were familiar with each other, conditions not typical of slaughter horses.

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