Trailer microclimate and calf welfare during fall-run transportation of beef calves in Alberta\textsuperscript{1,2}

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ABSTRACT: Twenty-four commercial loads of beef calves (BW 300 ± 52 kg, mean ± SD) were evaluated for associations among transportation factors, in-transit microclimate, and calf welfare. Transport factors evaluated included vehicle speed, space allowance, compartment within trailer, and transit duration. Calves were transported for 7 h 44 min ± 4 h 15 min, with space allowances ranging from 0.56 to 1.17 m\textsuperscript{2}/animal. Compartment within trailer, space allowance, and vehicle speed did not affect the difference between compartment ceiling-level and ambient temperatures during a 30-min period of steady-state microclimate. During the steady-state period, a 1°C increase in ambient temperature above the mean of 5.6°C was associated with a 0.62°C decrease in the difference between ceiling-level and ambient temperature (\(P < 0.01\)). Ceiling-level temperature and humidity during the first 400 min of transport could be predicted by ambient conditions and vehicle speed (pseudo-\(r^2\) of 0.91 and 0.82 for temperature and humidity ratio; \(P < 0.01\)). Events when animal-level temperature–humidity index (THI) was classified as above the “danger” level lasted for 10.2 ± 4.1 consecutive minutes. Ambient and ceiling-level THI values were not classified as above “danger” for 90.0 and 84.9% of animal-level events. Ambient and ceiling-level THI were 5.0 ± 2.1 and 4.7 ± 2.0°C higher than animal-level THI during periods of disagreement, respectively. The majority of calves arrived in good condition and biochemical indicators of calf welfare were within reference ranges for healthy cattle. Within the study population, high pre-transport cortisol and hematocrit were associated with elevated post-transport values (\(P < 0.01\)). A 1% increase in shrink during the weaning to loading interval (24 or 48 h) decreased transportation shrink by 0.26 ± 0.04% when average animal-level temperature was greater than 5°C and decreased transportation shrink by 0.11 ± 0.04% when average animal-level temperature was less than 5°C (\(P < 0.01\)). We inferred that the study results support future investigation of the extension of in-transit microclimate as a risk factor for post-transport treatment for disease. The study also provided correction factors for estimating in-transit microclimate that could assist in evaluation of transportation management and decisions affecting profitability and calf welfare.

Key words: animal welfare, beef, calves, cattle, microclimate, transportation

INTRODUCTION

Road transportation is integral to North American beef production but has been associated with negative effects on animal welfare. The association between transportation and poor calf welfare is confounded by factors commonly surrounding transportation (e.g., weaning and feed and water withdrawal) as well as a concentration of issues following transportation, particularly weight loss and respiratory disease (Trunkfield and Broom, 1990). There are obvious implications for
the calf but also for the industry through economic losses from reduced performance (Cernicchiaro et al., 2013) and influences on the political and social aspects of beef production (Harris, 2001; WSPCA, 2010).

Managing transportation to ensure good welfare is challenging due to inaccessibility of animals within trailers and a multitude of concurrent stressors. Knowledge of pre- and post-transport risk factors can assist in implementation of strategies to mitigate poor welfare outcomes (Wildman et al., 2008; Nickell and White, 2010; Babcock et al., 2013). There is recent evidence that in-transit factors such as location within trailer, duration of transport, and weather conditions influence indicators of calf welfare measured immediately or within the first few weeks after transport (White et al., 2009; Cernicchiaro et al., 2012a; González et al., 2012a,b). However, there is a lack of understanding of how transportation factors influence the in-transit environment relative to known risk factors for poor welfare, such as temperature and humidity, and individual animal response to transportation. The objectives of the current study were to assess the relationship between transportation factors (e.g., microclimate, location within trailer, and space allowance), trailer microclimate, and indicators of calf welfare during commercial transportation in transportation of beef calves in the fall.

**MATERIALS AND METHODS**

All procedures associated with research were approved by the Animal Care and Use Committee of the Lethbridge Research Center, according to guidelines of the Canadian Council on Animal Care (2009).

From September 2010 to November 2012, 38 commercial loads of beef calves (BW 300 ± 52 kg, mean ± SD) delivered to from auctions (n = 32) or single sources (n = 6) to 4 feedlots were used for data collection. Of the 38 loads, 12 were removed due to equipment failure resulting from journeys occurring when logger memory was full, 1 due to the receiving feedlot withdrawing participation, and 1 due to less than 1 h duration, resulting in 24 loads in the final dataset (18 auction sourced and 6 single source) and a total of 2,238 calves. Monthly distribution of loads is presented in Table 1. Trailers used were Merrit tri-axels, Merrit quad-axels, Wilson quad-axels (n = 2 loads) before shipment, traveled the same route, and were delivered to the same feedlot. Two trailers were delayed 1 d due to a winter storm, causing all samples and transport to occur 48 h after weaning. Hay and water were available during the interval between weaning and transport for all loads. The loads occurred over 2010 to 2012, allowing for 3 sets of paired loads. All trailers within this subset of the study were Merrit tri-axels, with space allowance in the deck and belly manipulated such that each pair had 1 trailer loaded at a high space allowance (greater than 0.67 m²/animal) and 1 loaded at a low space allowance (less than or equal to 0.67 m²/animal). The 0.67 m²/animal threshold represents an allometric constant value of 0.015 based on the average weight of calves in the current study. Allometric constants of 0.015 or lower have been shown to indicate insufficient space for standing (Petherick and Phillips, 2009) and have been associated with increased struggling, falling, and bruising in transport of mature cattle (Tarrant et al., 1988).

**Microclimate Variables**

Each trailer was fitted with temperature and humidity data loggers (Hygrochron iButtons, temperature DS1923; Dallas Semiconductor Corp., Dallas, TX) affixed to the compartment ceiling and the driver’s and passenger’s mirrors outside of the tractors. Loggers at the ambient locations were covered by opaque plastic shields with small ventilations holes to reduce the influence of solar radiation. All loggers were synchronized before placement and set to record at 1-min intervals. The nose compartment (Fig. 1) was not outfitted, due to constraints of logger placement at a consistent height above animals and the variable use of decking in the trailers during nonresearch activities. Therefore, microclimate results are presented for only the deck, doghouse, belly, and back compartments (Fig. 1). The loggers were affixed approximately 3 to 5 cm below the ceiling of the compartments to prevent contact with the aluminum

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**Table 1. Monthly distribution of 24 loads of beef calves used for data collection**

<table>
<thead>
<tr>
<th>Month</th>
<th>Percent of total loads</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sept.</td>
<td>8.3</td>
</tr>
<tr>
<td>Oct.</td>
<td>54.2</td>
</tr>
<tr>
<td>Nov.</td>
<td>20.8</td>
</tr>
<tr>
<td>Dec.</td>
<td>16.7</td>
</tr>
</tbody>
</table>
surface of the trailer and animals within the compartments. According to manufacturer specifications, the trailers used in this study had a total compartment height of approximately 174.9, 146.0, and 169.1 cm in the deck, doghouse, and back and belly, respectively, leaving approximately 170, 141, and 165 cm of free vertical space below loggers in these locations. For all journeys, compartment size to data logger ratio was held constant. Consequently, 10 data loggers were placed in the deck and belly of quad-axel trailers, 8 data loggers were placed in the deck and belly of tri-axel trailers, and 4 sensors were placed in both the back and doghouse compartments for all trailers.

The subset of 6 loads were used to measure animal-level temperature and humidity in the deck and belly compartments, as these carry the majority of calves in a load and are most likely to be overstocked during commercial transport (González et al., 2012c). Calves in these compartments received an ear tag (Allflex Feedlot Tags; Allflex Canada, St. Hyacinthe, QC, Canada) with a logger attached to the tag such that the tag itself prevented direct contact between the logger and the skin. Ear tags were affixed to the ear using previous ear tag holes whenever possible.

Each tractor was fitted with a global positioning system (GPS; Q Starz BT1000 Platinum; Qstarz International Co., Ltd, Ming Chuan, Taiwan) to track the location of each load over the course of the journey. The GPS units were programmed to record the time, speed, and coordinates at 1-min intervals, in sync with the temperature and humidity loggers. The timestamp from the GPS unit was used to match GPS records with records from the temperature and humidity loggers as well as events recorded in the driver log. On the same sheet as recording calf condition (see below for description of conditions recorded), drivers documented the number of cattle in each compartment, departure and arrival times, and reasons for and durations of stationary periods. The start of the journey was defined as the time when the trailer exited the origin. The end of each trip was defined as the point when each trailer entered the unloading area of the receiving feedlot.

Animal Variables

All loads monitored were commercial loads of cattle. The availability of equipment, such as scales for weighing cattle or appropriate handling facilities for collection biological samples, varied with participants and prevented collection of all variables from all loads. Drivers maintained a log of the condition of the calves before loading, at any stops when calves were checked, and at unloading at the destination feedlot. Drivers recorded if calves were considered to be in good condition or if there were any calves that were dead, recumbent and unable to stand, or severely lame. Upon arrival, calves were managed according to the commercial management plan in place and experienced animal health personnel monitored the calves and diagnosed animals for health disorders according to lot-specific treatment protocols under supervision of the attending veterinarian. Single-sourced calves did not receive metaphylactic treatment at arrival, while auction-sourced calves received metaphylactic treatment according to lot-specific protocols. Feedlot records of the diagnoses of health disorders, treatments, and mortalities for calves were gathered from 14 loads (6 single source and 8 auction sourced, representing 1,245 calves) for the first 30 d on feed after arrival (DOF; Day 0 = day of arrival). Single-sourced calves were all placed in the same feedlot, whereas auction-sourced calves were placed in 1 of 3 feedlots (Feedlot 1 = 6 loads and 517 calves, Feedlot 2 = 1 load and 95 calves, and Feedlot 3 = 1 load and 110 calves).

In the subset of 6 loads of single-source calves, shrink, cortisol, and hematocrit was collected at the individual animal level. Cattle were weighed individually in a chute scale immediately before loading at the origin and again immediately following unloading. Shrink was calculated as the percentage of original weight lost: \[(\text{BW}_{\text{initial}} - \text{BW}_{\text{final}})/\text{BW}_{\text{initial}}\] × 100%. Saliva and blood samples were taken immediately before loading and immediately after unloading. Saliva samples were taken using a cotton swab to collect saliva. The swabs were stored on ice immediately after sampling and stored at −20°C until analyzed for cortisol concentration using the Salimetrics ELISA kits (Salimetrics LLC, Carlsbad, CA) as described by Cook and Schaefer (2002). Intra-assay coefficient of variation was 11.5%. Blood was collected into a BD Vacutainer collection tube (BD Canada, Mississauga, ON, Canada) containing 10.8 mg of K₂ EDTA and analyzed within 24 h of collection for hematocrit using a commercial blood analyzer (HESKA HemaTrue Veterinary Hematology Analyzer; Heska Co., Loveland, CO).

Statistical Analysis

All data analyses were done with SAS version 9.1 (SAS Inst. Inc., Cary, NC). To remove the dependency of relative humidity on temperature, all analyses of...
humidity were conducted on the humidity ratio, which is the mass of water vapor per mass unit of dry air, and was calculated as described by Albright (1990). Aberrant values in temperature and humidity data may arise from animals licking or mouthing sensors or failure of sensors in transit. Aberrant values were identified by load and compartment as values more than 1.5 times the interquartile range (Hoaglin et al., 1986) and removed from the dataset after visual confirmation that the values were uncharacteristic relative to data from the specific logger at that point in time and the data from other loggers within the same load and compartment at the same point in time. Aberrant values were not clustered within any load or logger and represented 4.8 and 0.8% of humidity and temperature observations, respectively. All analyses were done on the edited dataset. Manufacturer specifications were used as estimates of systematic error in measurements of temperature and humidity (±0.5°C and ±5% relative humidity; Dallas Semiconductor Corp., Dallas, TX). In accordance with standard methods for uncertainty analysis (NASA, 2010), the root sum square (RSS) method was used to combine random and systematic errors to estimate total uncertainty in a measured value and to propagate the total uncertainty through all calculations.

Under commercial conditions, similar loads (e.g., similar space allowances, compartments, etc.) with different ambient conditions can be combined for comparison of transportation factors on microclimate through comparison of the difference between ceiling-level and ambient temperature and humidity ratio during steady-state periods (Brown et al., 2011; Burlinguette et al., 2012). The interval of 30 to 60 min after leaving the origin location was selected to evaluate the effect of transportation factors on in-transit microclimate as it represented a period of time when all loads were traveling, had been loaded for approximately the same interval, and were most likely to have steady-state conditions based on less than 5°C deviation in temperature within locations and less than 5°C change in the difference between inside and outside of the trailer. The methods of identifying steady-state periods are similar to methods used in evaluation of microclimate during commercial transport of poultry (Burlinguette et al., 2012) and swine (Brown et al., 2011). At each minute within the interval of 30 to 60 min after leaving the origin, the temperature and humidity ratio mean was taken across all loggers at compartment ceiling-level and outside locations within each load and compartment (e.g., data from all compartment ceiling-level loggers within a compartment of a load were averaged together to represent conditions at compartment level). Generalized linear mixed models were used to evaluate the fixed effects of compartment, space allowance (less than or greater than 0.67 m²/animal), and speed (less than 10, 10 to 50, 50 to 90, or greater than 90 km/h) on the difference between compartment ceiling-level and ambient temperature and humidity ratio. Ambient temperature and humidity ratio were covariates in the respective models. Elapsed time within the selected period was treated as a repeated measure for each compartment within each load, using a first-order autoregressive covariance structure. All interactions were tested; however, only significant interactions and main effects remained in the final model. The SE in final models were combined with the propagated systematic uncertainty using the RSS method, before calculating P-values. Square-root transformation was done on the humidity ratio difference (square root of the difference plus 10; due to negative values) to stabilize the variance in the residuals. Humidity ratio difference is presented as the transformed data.

Based on the results of the effect of transportation factors during a steady-state period, multiple regression equations were constructed to predict ceiling-level temperature and humidity from known transportation factors, using a manual backward method as described by González et al. (2012a). Due to computational limitations, only data from the first 400 min of the journeys were used to develop models, which encompassed the full journey for 54% of the loads in the current study. Transportation factors included ambient temperature or humidity, speed, compartment, and space allowance (less than or greater than 0.67 m²/animal). Linear, quadratic, and cubic effects were tested for ambient conditions followed by all interactions. The final model included only significant effects. Repeated and random effects were the same as in the analysis of the first 30 to 60 min. Square-root transformation of data was applied to ceiling-level humidity to stabilize the variance in the residuals. Pseudo-$$r^2$$ were calculated (fit of observed versus predicted) for both temperature and humidity ratio models.

To determine animal exposure to temperature–humidity index (THI) of concern for effect on thermoregulation during transportation, the mean THI across all loggers at animal-level, compartment ceiling-level, and outside locations, within the subset of 6 loads within animal-level information, by compartment was calculated and classified as either above or below the danger threshold of 78°F (Brown-Brandl et al., 2005). The danger threshold was selected as it is the lowest threshold of concern that relates to thermal status of cattle (Brown-Brandl et al., 2005), therefore, as a threshold would inherently include the higher THI classifications. Four of the 6 loads had periods where animal-level THI reached dangerous and emergency levels. To further investigate the duration of exposure, events were defined as consecutive observations with the same classification (above or below danger) within the same compartment. If events of the same classification were separated by 1 min,
they were considered to be part of the same event. Events lasting for only 1 min were not included in the final analysis. The percentage of the total journey spent in each THI classification was calculated by summing the total time within each THI classification for each compartment and dividing by the total journey duration. During events where animal-level THI was greater than the danger threshold, the amount of time within an event where ambient THI was less than the danger threshold, after adjusting for uncertainty in ambient THI, was calculated and expressed as a percentage of the total event duration.

Due to the limited sample size relative to known factors such as different feedlots, induction protocols, and year of arrival, no statistical analysis of treatment records was performed and data are presented for descriptive purposes only. Feedlot records were used to determine the number of calves receiving treatment for health disorders in the at-risk population of 1,245 calves from the subset of 14 loads with available treatment records for the first 30 DOF, representing 55.6% of the total population of calves transported within the study. Only first pulls were included in the final dataset. Treatment categories included Musculoskeletal (buller-rider syndrome, hip abscesses, foot rot, arthritis, and injuries), Metabolic (bloat and overload), Diarrhea, Respiratory, Downer (nonambulatory on truck at arrival and euthanized immediately), and Miscellaneous (all unclassified treatments). Loads were classified according to average ambient temperature during transit as above or below 5°C.

A generalized linear mixed model was used to determine effects of compartment, space allowance (greater or less than 0.67 m²/animal), journey duration, the difference between average ambient temperature during the 10 d before transport and the average animal-level temperature during transport, and interval from weaning to transport (24 or 48 h postweaning) on post-transport cortisol concentrations and hematocrits. A manual backward selection process was used to select variables for the final model for both cortisol and hematocrit by removing variables with the highest P-values only when variables with $P < 0.1$ remained in the final model (González et al., 2012a). In-transit difference from average ambient temperature during the 10 d before transport was calculated as a measure of the in-transit deviation from previous climate exposure and acclimatization of the animals before transport. Pre-transport cortisol concentration or hematocrit was used as a covariate, with individual animal treated as a random effect within compartment, using an unstructured covariance structure. Load and year were treated as random effects. Journey duration, difference between average temperature during the 10 d before transport and the average animal-level temperature during transport, and interval from weaning to transport were confounded due to a winter storm causing delays in transport (48 h between weaning and transport), longer trip durations, and larger deviation from previous temperatures for 2 of the 6 loads. Therefore, to determine which variable best explained the data, these variables were entered independently into the full model and the variable with a larger $F$-value was retained in the final model.

A generalized linear mixed model was also used to determine the effects of shrink during the interval between weaning and transport, compartment, space allowance (greater or less than 0.67 m²/animal), and average temperature at animal level during transport (above or below 5°C) on shrink during transportation. Data was from the deck and belly compartments of the 6 loads where shrink was measured on individual animals. Thirty-six calves (7% of total population with shrink records) had negative shrink values during transport and were randomly distributed across loads. The calves with negative values for shrink were removed from the dataset for analysis, as negative weight values indicate a likely measurement error since calves cannot gain weight during transport without feed and water. Animal was treated as a random effect within compartment and load, using an unstructured covariance variance structure. Year was also treated as a random effect.

**RESULTS**

Box plots of the distribution of data collected at 1-min sampling intervals from all journeys, displayed according to the level of measurement, for temperature (°C), humidity ratio (g water per kg dry air), and THI (°F) are shown (Fig. 2, 3, and 4, respectively). The distribution of THI at animal-level, compartment ceiling-level, and outside locations from the subset of 6 loads are shown (Fig. 5). None of the factors evaluated affected the difference between compartment ceiling temperature and ambient temperature during the interval between 30 and 60 min after departure. Ambient temperature was a significant covariate, with a 1°C increase in ambient temperature from the mean of 5.6°C being associated with a 0.62°C decrease in the magnitude of the difference in temperature between compartment ceiling level and ambient during the steady-state period, 30 to 60 min after departure ($P < 0.01$). Ambient humidity ratio was also associated with the transformed difference in humidity ratio, with a 1 g water/kg dry air increase in the ambient humidity ratio from the mean of 3.90 g water/kg dry air being associated with a 0.12 ± 0.003 g water/kg dry air decrease in the magnitude of the square root of the humidity ratio difference ($P < 0.01$). Additionally, for every 10 km/h increase in vehicle speed, there was a 0.001 ± 0.0003 g water/kg dry air decrease in the square root of the humidity ratio difference ($P < 0.01$).
During the first 400 min of travel, the pseudo-$r^2$ was 0.91 ($P < 0.01$) and the equation explaining ceiling-level temperature was (coefficient $[\pm$SEM$])$

$$\text{ceiling-level temperature} = 6.32 \pm 1.23 - 0.00094 [\pm 0.00012] \text{speed} + \beta_2 \text{ambient temperature} \times \text{space allowance category},$$

in which the ceiling-level temperature was in degrees Celsius, speed was in kilometers/hour, and $\beta_2$ is $0.32 \pm 0.0063^\circ\text{C ceiling}/^\circ\text{C ambient}$ when space allowance was greater than 0.67 m$^2$/animal and $0.54 \pm 0.012^\circ\text{C ceiling level}/^\circ\text{C ambient}$ when space allowance was less than $0.67$ m$^2$/animal. The pseudo-$r^2$ for the prediction of humidity ratio was 0.82 ($P < 0.01$) and the equation explaining ceiling-level humidity ratio was (coefficient $[\pm$SEM$])$

$$\text{ceiling-level humidity ratio} = 2.00 [\pm 0.082] + 0.055 [\pm 0.0021] \text{ambient humidity ratio} - 0.0002 [\pm 0.00002] \text{speed},$$
in which the ceiling-level humidity ratio was in (grams water/kilograms dry air)$^{1/2}$, ambient humidity ratio was in grams water/kilograms dry air, and speed was in kilometers/hour.

The portion of a journey spent with animal-level THI greater than the danger threshold ranged from 0.6 to 3.7% of a journey and lasted an average of $10.2 \pm 4.1$ min for the deck and belly of the 4 loads where THI events occurred. Within events at animal level where THI was classified as greater than the “danger” threshold, ambient and compartment ceiling THI was less than the danger threshold for an average of $90.1 \pm 19.0$ and $84.9 \pm 29.6$% of animal-level THI events, respectively. The average difference between animal-level THI and ambient THI during an event where animal-level THI was greater than the danger threshold was $5.0 \pm 2.1^\circ\text{F}$ and the average difference between animal and ceiling level was $4.7 \pm 2.0^\circ\text{F}$.

There was a 79% response rate for driver evaluation of calf condition from the 24 loads. From the driver records, 100% of calves were in good condition at loading, when calves were checked en route, and at unloading. One driver reported a calf being recumbent in the belly

![Figure 2. Distribution of temperature measured during fall transportation of beef calves in 24 commercial transport trailers as measured at compartment ceiling level in the 4 compartments and at a location outside the trailer. Shaded boxes cover the distribution from the first to third quartile, with internal diamond and solid line representing the mean and median temperatures, respectively. Edges of whiskers on boxes represent the distribution of 99.9% of data. Dotted points are beyond $1.5 \times$ the interquartile range. Dashed lines and solid lines represent upper and lower thresholds for thermoneutral zone and critical temperatures, respectively, for calves gaining 0.8 kg/d (Hahn, 1999).](image-url)
compartment when they stopped to check the calves in the middle of a 12 h journey; however, the calf rose easily when approached. One load had a nonambulatory calf in the belly compartment that had to be euthanized at arrival, which was recorded by research personnel but not reported in the driver’s evaluation of calf condition. Records indicated that the calf was treated with prophylactic antibiotics before transport. Pre-transport cortisol from the calf that was a nonambulatory at arrival was 0.63 and 1.23 ng/mL in duplicate samples, which resulted in a coefficient of variation of 45% that may indicate unreliable results due to errors in the sample or in processing for analysis. Pre-transport hematocrit was 0.38 L/L, which was between the 50th and 75th quartiles for the total population of calves within the current study and within the reference range for healthy cattle (Radiostits et al., 2007). The nonambulatory calf was transported in a compartment with less than 0.67 m²/animal and under conditions where in-transit ambient temperatures were less than 5°C.

Morbidity and mortality data from the 14 loads with treatment records are summarized in Table 2. The distribution of initial respiratory treatment by DOF for single- or auction-sourced calves by classification of ambient temperature during transport is shown (Fig. 6).

The range of cortisol and hematocrit in pre- and post-transport samples and expected ranges for cattle are shown (Table 3). Only pre-transport cortisol was associated with post-transport cortisol. A 1 ng/mL increase in pre-transport cortisol from the mean of 1.35 ± 0.97 ng/mL was associated with a 1.85 ± 0.74 ng/mL increase in post-transport cortisol \((P < 0.05)\). A 1.0 L/L increase in pre-transport hematocrit from the mean of 0.36 ± 0.03 was associated with a 0.66 ± 0.04 L/L increase in post-transport hematocrit \((P < 0.01)\). Space allowance less than 0.67 m²/animal was associated with greater post-transport hematocrit than space allowances that were greater than 0.67 m²/animal \((0.36 ± 0.006 \text{ vs. } 0.35 ± 0.005 \text{ L/L}; P < 0.05)\). A 1°C increase in the difference between average temperature during the 10 d before transport and the average animal-level temperature during transport from the mean of 2.4 ± 10.9°C was associated with a 0.0009 ± 0.0005 L/L increase in post-transport hematocrit \((P < 0.05)\).

Average shrink as measured on individual animals from the deck and belly compartments in the subset of 6 loads is shown (Table 4). Negative values for total

![Figure 3. Distribution of humidity ratio (g water/kg dry air) measured during fall transportation of beef calves in 24 commercial transport trailers as measured compartment ceiling level in 4 compartments and at a location outside the trailer. Shaded boxes cover the distribution from the first to third quartile, with internal diamond and solid line representing the mean and median temperatures, respectively. Edges of whiskers on boxes represent the distribution of 99.9% of data. Dotted points are beyond 1.5 \times \text{the interquartile range}.]
shrink between weaning and arrival likely reflect weight gain during the period between weaning and loading when feed and water were still available. In the subset of 6 loads, a 1% increase in shrink during the weaning to loading interval decreased transportation shrink by 0.29 ± 0.04% when average animal-level temperature was greater than 5°C and decreased transportation shrink by 0.12 ± 0.04% when average animal-level temperature was less than 5°C (P < 0.01). Transportation shrink was also greater when the average animal-level temperature during transport was less than 5°C vs. greater than 5°C (3.93 ± 0.47 vs. 2.77 ± 0.33%; P < 0.04).

**DISCUSSION**

The current study successfully used a method of monitoring microclimate conditions in moving livestock trailers that can be used in future research and commercial applications. The methodology of including uncertainty due to the measurement system is widely used in engineering applications (JCGM, 2008; NASA, 2010) but apparently not applied in previous reports of evaluation of transportation microclimate. Accuracy of measurements includes understanding the uncertainty surrounding the measurement, particularly when comparing measurements (JCGM, 2009). Accounting for systematic error due to the measurement system, in addition to random error from repeated sampling in time and space, improves the accuracy of uncertainty estimates and in turn improves understanding of the variability in measurements. The improvement in uncertainty estimates translates to improved accuracy of comparison of the effects of transportation factors on microclimate.

There was an increase in temperature and humidity at the ceiling level of compartments containing calves compared to ambient conditions, similar to other research on livestock transportation (Fiore et al., 2009; Purswell et al., 2010; Brown et al., 2011; Weschenfelder et al., 2012). Monitoring temperature at ceiling level alone, however, did not capture animal-level temperature and humidity conditions that may be of concern according to the THI. Although THI greater than the danger threshold represented a small portion of the journeys in the current study, the periods of disagreement between proxy locations (i.e., ceiling and ambient) was high. Periods where animal-level THI is clas-
The lack of difference in microclimate under different transportation management conditions may have been due to the 30 min in-transit period being too short to detect differences in microclimate due to transportation factors. The regression from the 400 min of transport, however, was also unaffected by compartment and space allowance and had small effects of speed on internal trailer conditions. We inferred that the small magnitude of the effect of transportation factors such as vehicle speed and space allowance and high pseudo-$r^2$ values indicates that it is plausible to determine a general correction factor to estimate microclimate conditions within the trailer. The correction factors could be applied across a variety of transportation conditions using ambient conditions to assess in-transit temperature and humidity relative to the internal conditions where calves are located. A broadly applicable

<table>
<thead>
<tr>
<th>Reason for treatment</th>
<th>Total no. of pulls, $n$</th>
<th>Treatment risk, $%$</th>
<th>Deaths, $n$</th>
<th>Case fatality, $%$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Respiratory</td>
<td>134</td>
<td>10.8</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>Musculoskeletal</td>
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<td>0.6</td>
<td>1</td>
<td>14.3</td>
</tr>
<tr>
<td>Metabolic</td>
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<td>0.3</td>
<td>1</td>
<td>25.0</td>
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<tr>
<td>Diarrhea</td>
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<td>0.2</td>
<td>1</td>
<td>50.0</td>
</tr>
<tr>
<td>Downer</td>
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<tr>
<td>Miscellaneous</td>
<td>8</td>
<td>0.6</td>
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<tr>
<td>Overall</td>
<td>156</td>
<td>12.5</td>
<td>5</td>
<td>3.2</td>
</tr>
</tbody>
</table>

1Feedlot 1 = 523 calves and 6 loads, Feedlot 2 = 517 calves and 6 loads, Feedlot 3 = 95 calves and 1 load, and Feedlot 4 = 110 calves and 1 load. Feedlot 1 received all single-sourced calves and feedlots 2 through 4 received auction-sourced calves.

2Treatment risk = (total number of calves pulled for treatment/1,245) × 100%.

3Case fatality = (number of mortalities/total number of pulls within treatment reason) × 100%.
correction factor should be determined based on a larger range of conditions that are representative of a variety of commercial transport conditions. Notwithstanding, the equations reported in the current study can serve as a general guide to estimating internal temperature and humidity ratios under similar conditions.

As ambient temperature or humidity decreased, the difference between internal and ambient conditions increased. Increased differences between internal and ambient conditions in colder weather has been attributed to reduced ventilation due to management practices in reports on transportation of swine and poultry (Brown et al., 2011; Burlinguette et al., 2012). The current study had no difference in trailer ventilation management during warm or cold weather. Trailers used for transporting calves are dependent on forced ventilation resulting from trailer movement and thermal gradients (Mitchell and Kettlewell, 2008). Cattle themselves will partially obstruct airflow within trailers due to their body size and the location of ventilation holes in the sidewalls of trailers (Muirhead, 1983). Therefore, trailers may have inadequate ventilation to remove excess heat and moisture produced by calves, which becomes more apparent as ambient temperatures diverge from animal-level conditions. The increase in the difference from inside to outside the trailer with declining ambient conditions may have implications for beef calves as they are raised outdoors and, depending on their previous exposure and the conditions following arrival, may or may not be able to cope with the variation in temperature and moisture during transport compared to their acclimation.

Due to limited sample size the current study was unable to statistically evaluate the relationship between average ambient temperatures in transit and risk of treatment for respiratory issues in calves. Previous research has reported that the risk of bovine respiratory disease (BRD) treatment is increased with cold monthly temperatures (Ribble et al., 1995) and, on a day-by-day basis, increases with declining temperatures in the days preceding diagnosis (Cernicchiaro et al., 2012a). Other risk factors included age class, body weight, procurement source, sex, and cohort size (Wildman et al., 2008; Cernicchiaro et al., 2012a). These risk factors interact with the risk of BRD associated with transportation factors (Cernicchiaro et al., 2012a,b,c). However, transportation factors evaluated in the previous research did not include in-transit microclimate. Additionally, the use of treatment records may be biased from misclassification due to the subjective nature of health assessments and/or differences between feedlots and across years (Cernicchiaro et al., 2012a), which were not addressed in the current study design. Therefore, comparison of the relative importance and synergy between in-transit and post-transport risk factors for respiratory disease in calves is not possible with the data from the current study. We suggest that, based on the results of previous studies and the descriptive data presented in the current study, it is possible that in-transit ambient temperature and BRD treatment could reflect a propensity to change treatment criteria relative to weather conditions (Nickell and White, 2010) or effects of worse driving conditions during colder weather. Alternatively, it is plausible
that the increased difference between ambient and internal trailer temperature during colder weather and deviations from previous exposure could contribute to calves’ susceptibility to disease after transport. In-transit temperature and distribution of initial BRD treatment, however, requires future studies extending the exploration of the effect of temperature as a risk of factor for BRD treatment in feedlots to include in-transit microclimate to investigate these hypotheses.

The indicators of calf welfare assessed in the current study supported the inference that in-transit microclimate is important to transportation management. Pre-transport status was a consistent predictor of post-transport status across all indicators of calf welfare. There were associations between in-transit temperatures, space allowance less than 0.67 m$^2$/animal, and indicators of calf welfare that did not interact with the pre-transport condition of the calves. However, comparison of measurements to the range of expected values is essential to maintaining the perspective of normal coping responses and biological relevance for species (Barnett and Hemsworth, 1990; Mendl, 1991; Rushen, 2003). Coping can indicate the success of the animal in responding to challenges versus the progression from stress to distress and subsequent development of pathologies. In the current study, the majority of biochemical indicators were within the reference ranges for healthy cattle (Chacón Pérez et al., 2004; Radiostits et al., 2007) and the 100% of calves arrived in “good” condition according to transporters’ assessments. Previous reports on transportation have focused on changes in biochemical indicators or differences in treatment groups in response to transportation (Tarrant et al., 1992; Earley et al., 2006; Schwartzkopf-Genswein et al., 2007) and did not assess the role of pre-transport status of indicators on post-transport values. The positive association between pre- and post-transport indicators of calf welfare may be due to individual variation in temperament, experience, and response to thermal challenges and nutrient restriction that could subsequently shape individual responses to transportation and handling (Wilson and Osbourn, 1960; Grandin, 1997; Coffey et al., 2001; Burdick et al., 2010). The 1 calf in the current study with clear signs of poor welfare during transportation (nonambulatory at arrival requiring euthanasia) was assessed as fit for transport by experienced animal health personnel and drivers and had hematocrit and cortisol values within the expect range for cattle. However, the calf was transported in a compartment with less than 0.67 m$^2$/animal and under conditions where in-transit ambient temperatures were less than 5°C. Investigation of the hypothesis that in-transit temperature effects the distribution of initial BRD treatment requires that future studies that extends the exploration of in-transit temperature as a risk factor for BRD treatment in feedlots was done successfully during the commercial transportation of beef calves. Comparison of internal and external conditions was more accurate due to inclusion of the uncertainty from the measuring system. Within the conditions of the current study, there were no differences in microclimate associated with transportation factors evaluated. Therefore, correction factors can be determined that are broadly applicable across compartments and space allowances. Practical use of correction factors may improve the ability of transportation management to mitigate the effect of weather on calf welfare, particularly by improving management decisions related to profitability (Cernicchiaro et al., 2012a) and in extending the exploration of the effects of in-transit temperature on risk of post-transport treatment for respiratory disease. Additionally, the welfare of calves before loading was a major determinant of their post-transport welfare for both biochemical and systematic indicators of calf welfare, with the majority of calves arriving in good condition.

**Table 3.** Ranges of pre- and post-transport cortisol and hematocrit in 6 loads of commercial beef calves, as measured on individual calves in the deck and belly compartments, and reference range for healthy cattle

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Current study</th>
<th>Reference range for healthy cattle</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stage of transport</td>
<td>No. of calves</td>
</tr>
<tr>
<td>Hematocrit, L/L</td>
<td>Pre-transport</td>
<td>277</td>
</tr>
<tr>
<td></td>
<td>Post-transport</td>
<td>276</td>
</tr>
<tr>
<td>Salivary cortisol, ng/mL</td>
<td>Pre-transport</td>
<td>232</td>
</tr>
<tr>
<td></td>
<td>Post-transport</td>
<td>231</td>
</tr>
</tbody>
</table>

In conclusion, monitoring in-transit microclimate is important to transportation management. Pre-transport status was a consistent predictor of post-transport status across all indicators of calf welfare. There were associations between in-transit temperatures, space allowance less than 0.67 m$^2$/animal, and indicators of calf welfare that did not interact with the pre-transport condition of the calves. However, comparison of measurements to the range of expected values is essential to maintaining the perspective of normal coping responses and biological relevance for species (Barnett and Hemsworth, 1990; Mendl, 1991; Rushen, 2003). Coping can indicate the success of the animal in responding to challenges versus the progression from stress to distress and subsequent development of pathologies. In the current study, the majority of biochemical indicators were within the reference ranges for healthy cattle (Chacón Pérez et al., 2004; Radiostits et al., 2007) and the 100% of calves arrived in “good” condition according to transporters’ assessments. Previous reports on transportation have focused on changes in biochemical indicators or differences in treatment groups in response to transportation (Tarrant et al., 1992; Earley et al., 2006; Schwartzkopf-Genswein et al., 2007) and did not assess the role of pre-transport status of indicators on post-transport values. The positive association between pre- and post-transport indicators of calf welfare may be due to individual variation in temperament, experience, and response to thermal challenges and nutrient restriction that could subsequently shape individual responses to transportation and handling (Wilson and Osbourn, 1960; Grandin, 1997; Coffey et al., 2001; Burdick et al., 2010). The 1 calf in the current study with clear signs of poor welfare during transportation (nonambulatory at arrival requiring euthanasia) was assessed as fit for transport by experienced animal health personnel and drivers and had hematocrit and cortisol values within the expect range for cattle. However, the calf was transported in a compartment with less than 0.67 m$^2$/animal and under conditions where in-transit ambient temperatures were less than 5°C. Investigation of the hypothesis that in-transit temperature effects the distribution of initial BRD treatment requires that future studies that extends the exploration of in-transit temperature as a risk factor for BRD treatment in feedlots was done successfully during the commercial transportation of beef calves. Comparison of internal and external conditions was more accurate due to inclusion of the uncertainty from the measuring system. Within the conditions of the current study, there were no differences in microclimate associated with transportation factors evaluated. Therefore, correction factors can be determined that are broadly applicable across compartments and space allowances. Practical use of correction factors may improve the ability of transportation management to mitigate the effect of weather on calf welfare, particularly by improving management decisions related to profitability (Cernicchiaro et al., 2012a) and in extending the exploration of the effects of in-transit temperature on risk of post-transport treatment for respiratory disease. Additionally, the welfare of calves before loading was a major determinant of their post-transport welfare for both biochemical and systematic indicators of calf welfare, with the majority of calves arriving in good condition.

**Table 4.** Shrink$^{1,2}$ by stage of transportation process in 6 loads of commercial beef calves as measured on individual calves in the deck and belly compartments

<table>
<thead>
<tr>
<th>Stage of transport</th>
<th>No. of calves</th>
<th>Mean, %</th>
<th>SD</th>
<th>Minimum, %</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weaning to loading</td>
<td>519</td>
<td>3.13</td>
<td>4.29</td>
<td>–19.23</td>
<td>23.53</td>
</tr>
<tr>
<td>Loading to unloading</td>
<td>479$^3$</td>
<td>3.02</td>
<td>2.07</td>
<td>0</td>
<td>18.28</td>
</tr>
<tr>
<td>Total</td>
<td>479$^3$</td>
<td>5.99</td>
<td>3.42</td>
<td>–14.11</td>
<td>22.18</td>
</tr>
</tbody>
</table>

$^1$Shrink is calculated as [(BW$_{initial}$ – BW$_{final}$)/BW$_{initial}$] × 100%.

$^2$Negative values indicate weight gain.

$^3$Transportation shrink from loading to unloading and total shrink was unavailable from 38 calves due to 36 with negative values for transportation shrink, 1 calf being withheld from transport due to illness, and 1 calf euthanized at arrival before weighing.
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