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Short communication

Association between human and animal thermal comfort indices and physiological heat stress indicators in dairy calves

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ABSTRACT

Warm summer episodes have a significant effect on the overall health and well-being of young cattle; however, it is not known which temperature measure should be used for estimating heat stress in dairy calves. In this study, generalized linear mixed-effects models were used to estimate the relationships between thermal comfort indices and animal-based heat stress indicators in sixteen Holstein bull calves that were housed in individual calf hutches. Data were collected under continental weather characteristics over a 5-day period: day 1 (lower-temperature day), days 2 and 3 (heat stress days), and a 2-day post-stress period. Relative humidity, ambient temperature, the heat index, the humidex and five different temperature–humidity indices (THI) were used as thermal indices. Physiological variables monitored included respiratory rate, rectal temperature, ear skin temperature and heart rate. The heat index and the humidex measuring human thermal comfort were more closely associated with physiological measures than were the ambient temperature or the THIs (in case of heat index: $R^2 = 0.87$ for respiratory rate, $R^2 = 0.63$ for rectal temperature, $R^2 = 0.70$ for ear skin temperature, and $R^2 = 0.78$ for heart rate, respectively; in case of humidex: $R^2 = 0.85$ for respiratory rate, $R^2 = 0.60$ for rectal temperature, $R^2 = 0.68$ for ear skin temperature, and $R^2 = 0.75$ for heart rate, respectively). Based on our results, parameters of human outdoor comfort seem better to estimate heat stress in dairy calves in a continental region than those of THIs or ambient temperature.

1. Introduction

Most of the world's cattle populations live in regions where the increasing frequency and severity of extreme weather events impair the well-being (Morignat et al., 2015) and increase mortality rate in cattle (Cox et al., 2015; Morignat et al., 2015). Dairy calves are commonly kept in individual polyethylene hutches with a limited outdoor space where animals are exposed to direct sunlight and are at a considerable risk of heat stress during warm of summer periods.

Besides ambient temperature, generally thermo-hygrometric indices are used for the assessment of the thermal environment in cattle. The commonest of these, the temperature-humidity index (THI) represents the combined effects of air temperature and humidity (Thom, 1959). Other two parameter-based measures, such as the humidex (Canadian Center for Occupational Health and Safety, 2017) or the heat index (Anderson et al., 2013) have been widely applied in human comfort studies proposed for outdoor comfort mapping; however, these metrics have not been used to assess the thermal environment of cattle so far.

Although the effects of THI on rectal temperature (Theurer et al., 2014) or respiratory rate (Peña et al., 2016) are often studied in dairy calves during hot periods, it is still uncertain whether THI is the most appropriate measure to characterize thermal stress in calves. For this reason, we examined the associations between a series of thermal comfort measures used in animal well-being and human comfort studies and animal-based heat stress measures in dairy calves. We hypothesized that due to calves' similar body weight/body surface area ratio to humans, human comfort indices characterizing outdoor thermal exposures might better associate with physiological heat stress indices of calves than THIs, which may in turn be more appropriate for adult cattle with their typical indoor environment and their greater body weight/body surface area ratio compared to calves.

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2. Materials and methods

2.1. Animals and experimental design

The experiment was carried out at a large-scale dairy farm in Hungary (N47°18′191″ E18°48′336″), which has a herd of 1000 lactating Holstein cows. The study was designed and timed based on the expected meteorological patterns of the regional weather forecast. The farm was visited for a 6-day period between August 15 and 20 [temperature; average/min/max (°C): 25.3/21.6/38.8, all measured in shadow] in 2016. Sixteen Holstein bull calves (means ± SD; age = 46.7 ± 2.4 d, body weight = 74.3 ± 2.6 kg) that were housed individually in 1.65 × 1.20 m plastic calf hutches with a 1.60-m^2 exercise pen in front of the hutch were used for the study. Day 0 (habituation to the study environment) was followed by day 1 (lower-temperature day, temperature; average/max (°C): 20.7/26.8), days 2 and 3 (‘heat stress days’, temperature; average/max (°C): 27.8/38.8 and 25.5/36.2) and days 4–5: (‘post-stress period’, temperature; average/max (°C): 22.4/27.3 and 20.5/26.4). Hutches were oriented north to south to maximize the exposure to solar heating. Hutches remained in the same location during the study. The diet consisted milk, calf starter and alfalfa hay that did not change throughout the experiment. Fresh water was available for calves all time.

2.2. Assessment of meteorological data

Ambient temperature and relative humidity were recorded every 30-min between day 1 00:00 and day 5 24:00 using VOLTCRAFT DL-181THP (Conrad Electronic SE, Hirschau, Germany) placed in the back of the hutch and Testo 175 H1 (Testo Inc., Sparta, USA) fitted onto the shading structure 1 m above the ground of the exercise pens. Calf location (hutch or exercise pen) was determined based on video recordings of two day/night outdoor network bullet cameras (Vivotek IP8331, VIVOTEK Inc., Taiwan) for subsequent selection of the appropriate meteorological and physiological measures during analysis (see Section 2.4). Thermal comfort indices were calculated as follows:

$THI_1 = (0.15 \times T_{db} + 0.85 \times T_{wb}) \times 1.8 + 32$

(Bianca, 1962),

$THI_2 = (0.35 \times T_{db} + 0.65 \times T_{wb}) \times 1.8 + 32$

(Bianca, 1962),

$THI_3 = (0.55 \times T_{db} + 0.2 \times T_{dp}) \times 1.8 + 49.5$

(NRC, 1971),

$THI_4 = 0.8 \times T_{db} + (RH/100) \times (T_{db}–14.4) + 46.4$

(Mader et al., 2006),

$THI_5 = (T_{db} + T_{wb}) \times 0.72 + 47$

(Thom, 1959),where T_{db} = dry bulb temperature, T_{wb} = wet bulb temperature, T_{dp} = dew point temperature and RH = relative humidity.

Air temperature and co-incident dew point temperature (calculated from temperature and relative humidity) were used to calculate the humidex, a common measure of outdoor heat exposure in human studies (Gosling et al., 2014).

$Humidex = T + 5/9 \times (e–10)$

where, T = air temperature in Celsius and $e = 6.112^{5417.7530 \times ((1/273.16)–(1/Tdp))}$

The heat index based on human physiology and clothing science also called the ‘apparent temperature’ was calculated by using the NWS algorithm (National Weather Service, 2017). This calculation agreed best with Steadman's apparent temperature (Steadman, 1979). The algorithm express heat index in Fahrenheit temperature based on a multiple regression analysis carried out by Rothfusz (1990).

2.3. Physiological heat stress parameters

Respiratory rate was recorded between day 1 00:00 and day 5 24:00 with a 4-h sampling frequency by counting the movements of the abdominal muscles in the flanks during respiration (Peña et al., 2016) while calves were in a lying posture. Immediately after respiratory rate observation, rectal temperature was measured with a 10-sec digital thermometer (Digi-Vet SC 12; Jørgen Kruuse A/S, Langeskov, Denmark) that was inserted 8 cm into the rectum. As an appropriate measure of the microenvironment around the animal (Carter et al., 2014), ear skin temperature was measured immediately after rectal temperature with the Testo 830 T2 infrared thermometer (Testo Inc., Sparta, USA).

Interbeat-intervals were recorded continuously during the experimental period using a Polar electrode belt with two integrated electrodes, a compatible Polar H7 heart rate sensor and a Polar V800 heart rate receiver (POLAR, Kempele, Finland). Equal lengths of 5-min interbeat-interval samples that were recorded with a 30-min frequency when calves were in lying posture were used to calculate heart rate (Kubios HRV standard software version 2.2, Biomedical Signal Analysis Group, Department of Applied Physics, University of Kuopio, Finland). To exclude the possible effect of human presence on heart rate, the interbeat-interval segments were used for this analysis that were recorded before respiratory rate observation. For recording the animals’ posture (lying or standing) the HOBO Pendant G data logger (Onset Computer Corporation, Bourne, MA) was used with the settings recommended to assess dairy calves’ lying behavior (Bonk et al., 2013).

2.4. Statistical analysis

Statistical analyses were performed in the R–3.0.2. statistical environment and language (R Development Core Team, 2013). Ambient temperatures and relative humidity values (recorded in the hutch or in the exercise pen) were chosen for calculation of the thermal indices according to calf location (in the hutch or in the exercise pen) at the time of sampling of animal-based parameters. Conditional R^2 values were obtained from generalized linear mixed-effects models (GLMM) with a restricted likelihood procedure (Kenward and Roger, 1997) according to Nakagawa and Schielzeth (2013), where thermal comfort indices were fixed effects and physiological measures were dependent variables. Taking into consideration the repeated measures over the 5-day period, all models included calf and time of sampling as random effects. Conditional R^2 GLMM is interpreted as variance explained by both fixed and random factors (i.e. the entire model). The statistical significance of fixed effects was tested by the Satterthwaite approximation method.

Data of individual observations between day 1 00:00 and day 5 24:00 [for heart rate with 30-min sampling frequency (n = 3840); for respiratory rate, rectal temperature and ear temperature with 4-h sampling frequency (n = 480)] were used.

3. Results and discussion

All models were significant at the level of $P < 0.001$. Results of the GLMMs indicated that the heat index showed the strongest associations with the physiological indices (Table 1). Relationships between heat index and physiological indices are shown in Fig. 1. The humidex was also better associated with physiological indices compared to the ambient temperature or the THIs. The GLMMs indicated that the strength of positive association between thermal and physiological indices tended to increase from THI1 to THI5, presumably due to the progressively increased weighting of the dry bulb temperature, more important for heat exposure than wet bulb or dew point temperature in continental regions.