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Short communication: Upper critical temperature-humidity index for dairy calves based on physiological stress variables

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ABSTRACT

In this study, upper critical values of the temperature-humidity index (THI) were determined in Holstein bull calves (n = 16) based on noninvasive physiological variables. Meteorological and animal-based data were recorded for a 4-d period following a 24-h habituation. The estimated upper critical THI values based on the assessment of respiratory rate, rectal temperature, ear temperature, heart rate, and salivary cortisol concentrations were 82.4, 88.1, 83.0, 78.3, and 88.8, respectively. We inferred that welfare of young calves may be compromised above a THI of 78 and that calves experience significant heat stress above a THI of 88. Based on the present findings, upper critical THI should be considered to minimize the duration of impaired welfare during summer heat stress episodes.
Key words: upper critical temperature-humidity index, heat stress, dairy calves

Short Communication

A common housing system used for calves in dairy farms is a polyethylene hutch with an opened exercise area. Calves housed in this type of hutch are exposed to heat stress during a warm episode in summer as evidenced by increased respiratory rate (**RR**), rectal temperature (**RT**), ear temperature, heart rate (**HR**; Kovács et al., 2018), and salivary cortisol (**SC**) concentrations (Kovács et al., 2019). Definitions for upper critical temperature-humidity index (**THI**) values are based on RT measurement in female cattle; when RT increases above 38.5°C (Dikmen and Hansen, 2009) or when RT increases significantly, the animal is suffering from heat stress and cannot dissipate the excess heat (Silva, 2015). In dairy cows, THI values between 72 and 74 (Bohmanova et al., 2007) and of 72 (Gantner et al., 2011) were considered to be critical based on milk loss, whereas da Costa et al. (2015) considered THI values from 72 to 78 to be critical based on RR and RT. Interestingly, THI values at which calves start to show signs of heat stress have not been determined. Therefore, the aim of this study was to estimate the upper critical values of THI for dairy calves under continental weather conditions based on noninvasive physiological measures of heat stress. We hypothesized that young calves would be expected to suffer less from heat stress (higher critical THI values) than lactating cows that produce an additional metabolic heat output associated with milk production.

All methods and applied procedures were performed in accordance with the relevant guidelines and regulations of the Pest County Government Office, Department of Animal Health (permit number PE/EA/1973-6/2016), which approved the study. The experiment was carried out between August 15 and August 20, 2016, on a large-scale dairy farm in Hungary with a herd of 900 cows. Preweaned Holstein bull calves (mean ± SD; n = 16, age: 46.7 ± 1.8 d; age range: 44–49 d; BW: 74.3 ± 1.6 kg; BW range: 70.3–78.6 kg) housed individually in 1.65-m × 1.20-m plastic calf hutches with a 1.60-m^2 exercise pen were used in the study.

Hutches of the experimental calves were aligned in the same row, oriented north to south. The bedding of the calves consisted of straw. Calf starter (Vitafort; Vitafort cPlc, Dabas, Hungary), alfalfa hay, and fresh water were available for the calves ad libitum.

A 24-h period (d 0) served to acclimatize the animals to the HR sensors and the presence of investigators. Between d 1 at 0000 h (first test recording) and d 4 at 2400 h (last test recording), ambient temperature and relative humidity were recorded for all calves within the hutches (Voltcraft DL-181THP; Conrad Electronic SE, Hirschau, Germany) and above the exercise pens (Testo 175 H1; Testo Inc., Sparta, NJ) with a 30-min recording frequency. The THI was calculated using the following equation by Bianca (1962) for the hutch and the exercise pen environments:

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Table 1. Temperature-humidity index (THI) values [mean ± SD, minimum (min), and maximum (max)] measured for the 5-d experimental period in the hutch and exercise pen environments

Experimental day[1]	Hutch			Exercise pen		
	THI_{mean}[2]	THI_{min}	THI_{max}	THI_{mean}[2]	THI_{min}	THI_{max}
0	70.5 ± 6.1	67.8	73.6	70.2 ± 5.8	67.6	73.3
1	82.8 ± 4.3	75.2	94.0	82.3 ± 4.0	75.0	93.7
2	82.3 ± 4.2	74.7	90.7	82.0 ± 4.0	74.3	90.5
3	80.0 ± 2.4	73.4	87.1	79.6 ± 2.3	73.2	87.0
4	73.3 ± 1.1	70.3	76.2	73.1 ± 1.0	70.1	76.1

[1]Day 0 served as a 24-h period to habituate the calves to the heart rate monitors and the presence of the investigators.

[2]Averages of THI calculated from temperature and humidity values recorded with a 30-min sampling frequency.

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

where T_{db} is the dry bulb temperature and T_{wb} is the wet bulb temperature.

The RR (breaths/min) was recorded at a 4-h sampling frequency by counting the movements of the abdominal muscles in the flanks during respiration while the calves were in a lying posture. Immediately after RR was recorded, RT was measured with a 10-s digital thermometer (VT 1831; Microlife AG, Widnau, Switzerland). Ear skin temperature was measured parallel with RT using a Testo 830 T2 infrared thermometer (Testo Inc.). Heart rate was measured with a 30-min sampling frequency and analyzed as described in Kovács et al. (2018). Saliva samples were taken with a 4-h frequency, and SC concentrations were determined using a direct RIA method as described in Kovács et al. (2019). All measurements were performed continuously during the study period.

Calf location (hutch or exercise pen) was determined based on video recordings of 2 day–night outdoor network bullet cameras (Vivotek IP8331; Vivotek Inc., Taipei City, Taiwan) for subsequent selection of the appropriate THI (calculated for the hutch or the pen area) to match the physiological measures during statistical analysis. Upper critical values of THI were determined using the piecewise linear regression, which permits the estimation of physiological thresholds by splitting explanatory variables in 2 or more linear regressions and locating where the linear trends change (Muggeo, 2008). The regression models included day, time of day, and calf location (hutch or pen) as random factors. There are 2 accepted methods to statistically test the existence of a breakpoint. One is to test the difference between the 2 slopes with the Davies test (Muggeo, 2008). The other method calculates the goodness of fit of the models measured using the Akaike information criterion. All analyses were performed in R 3.4.4 using the "segmented" R package (Muggeo, 2008). The significance level was set at $P < 0.05$.

During the previous 5 and 30 d before the experiment, THI did not exceed 74 and 75.2, respectively. During d 0, maximal temperature and THI were 26.4°C and 73.6, respectively. Days 1 and 2 were characterized by extreme heat, whereas d 3 was characterized by lower but still elevated temperatures, and d 4 was characterized by normal weather conditions (Table 1).

Results of the piecewise linear mixed models with a block diagonal covariance matrix are reported in Table 2. The smaller variance for the left slope emphasizes that most of the calves had quite similar slopes below the upper critical THI for all physiological measures. Figure 1 shows the fitted mean profiles for RR, RT, ear temperature, HR, and SC concentrations from the piecewise linear regression models with the estimated breakpoints (95% CI).

Table 2. Estimated mean (±SE) breakpoint and left and right slopes in the physiological measures that resulted from the piecewise linear regressions

Physiological measure	Breakpoint	Left slope	Right slope	*P*-value[1]	AIC L[2]	AIC PL[2]
Respiratory rate	82.4 ± 0.8	0.08 ± 0.23	0.15 ± 0.10	0.040	3,862.4	3,823.1
Rectal temperature	88.1 ± 1.0	0.02 ± 0.01	0.10 ± 0.03	0.039	395.8	388.8
Ear temperature	83.0 ± 0.5	0.87 ± 1.4	0.02 ± 0.01	0.024	538.2	533.3
Heart rate	78.3 ± 0.7	−0.97 ± 0.55	1.64 ± 0.09	<0.001	3,116.7	3,058.4
Salivary cortisol	88.8 ± 0.3	0.28 ± 0.08	6.0 ± 0.58	<0.001	3,134.4	3,034.1

[1]The *P*-value refers to Davies' test for a change in the slope.

[2]Difference in the Akaike information criterion (AIC) between the linear regression model (AIC L) and the piecewise linear regression model (AIC PL) refers to the goodness of fit of the models.

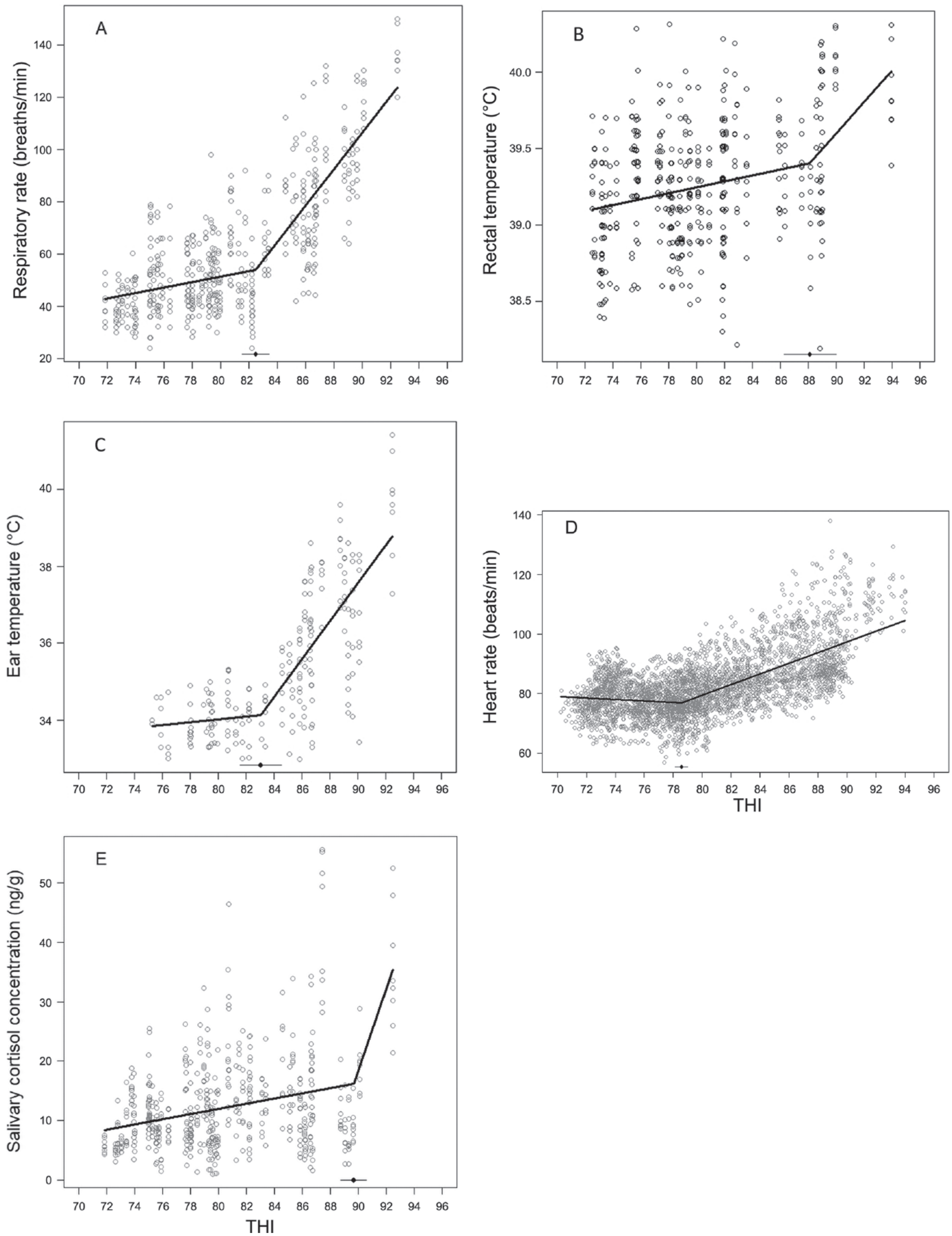

Figure 1. Fitted mean profiles for (A) respiratory rate, (B) rectal temperature, (C) ear temperature, (D) heart rate, and (E) salivary cortisol from the piecewise linear regression models for hutch-reared dairy calves (n = 16). THI = temperature-humidity index. Breakpoints and their 95% CI are marked as a line above the x-axis.

The lowest upper critical THI value was associated with HR (78.3). Although HR was analyzed only for undisturbed lying periods, it cannot be ruled out that increased overall activity caused by discomfort might have affected our results. Interestingly, the breakpoint in RR indicated that calves began experiencing heat stress when the THI reached 82.4. This result is in contrast with findings on dairy cows (Berman et al., 1985) and calves (Kovács et al., 2018) suggesting that during the early phase of heat stress forced respiration is the first response to cope with the hot environment. Upper critical THI values exceeded 88 in cases of RT and SC concentrations (Table 2). Although the breakpoint was significant, RT differed less in the slopes compared with all the other parameters (Table 2). In the present study, calves exhibited 0.88°C higher RT on the heat stress day than 39.2°C, which is suggested to be the upper threshold of the normal core body temperature of 1-mo-old dairy calves (Piccione et al., 2003) on the heat stress day when THI peaked at 94. It is possible that a more extreme increase in RT would be detected only in cases of more prolonged extremes in THI. Corresponding to our results, Neuwirth et al. (1979) reported that bull calves responded with higher HR, arterial pressure, skin temperature, plasma cortisol, and thyroxine concentrations to acute heat stress only above 32.2°C at 60% relative humidity, which corresponds to a THI of 80.6 according to the calculations we used in this experiment.

In summary, physiological measures indicated that heat stress occurs in dairy calves between THI 78 and 88; thus, calves tolerate extreme heat load better than adult cattle. Although the results supported our hypothesis, further studies involving greater populations are needed to reconfirm the present findings and to verify whether HR is an appropriate measure of the onset of heat stress, as it might be affected by overall activity that was not measured in the present study.

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