Effects of the Accumulation of Heat Load Duration on the Activity Behaviour of Lactating Dairy Cows

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Abstract

In the course of the predicted climate change, the problem of welfare and heat load (HL) of dairy cows has become increasingly important even under moderate climate conditions. The objective of the present study was to analyse the effects of the daily duration of different heat load levels (HLL) on the activity of lactating dairy cows. Additionally, the adaptation effects of the cows regarding the accumulation of heat load duration (HLD) during the three days preceding the activity measurement day was investigated. The study was conducted from June 2015 to May 2017 in a naturally ventilated dairy barn. The barn climate was measured at high temporal and spatial resolution, and the average temperature-humidity index (THI) was calculated every 10 min (m = 842,112). The THI was used to define the HL the cows were exposed to. HLL were determined by defined THI thresholds. The activity of the dairy cows (n = 177) was measured using IceTag3D^{TM} pedometers and described with several activity traits per cow and day. The analysis models included autocorrelations in time series as well as effects of individual cows. The results showed significant activity adaptations ($P < 0.01$) regarding the increasing HLD within each HLL on the measurement day. There was a decrease in lying time, number of lying bouts, average lying bout duration and number of standing bouts per day. The average standing bout duration and the number of steps per day increased with increasing HLD on the measurement day. The accumulation of HLD during the three days preceding the measurement day led to reverse activity adaptations on the measurement day ($P < 0.01$). This indicates that with persistent HL, signs of tiring occur, leading to a reversal of the initial activity adaptation of cows to HL.

Keywords: temperature-humidity index, heat load level, heat load duration, activity adaptation

1. Introduction

In recent years, heat load (HL) of dairy cows has become one of the most important challenges facing the dairy industry. Besides of physiological thermoregulatory responses to HL (Ferrazza et al., 2017; Toušová et al., 2017), the cows change their activity behaviour (Brzozowska et al., 2014; Endres and Barberg, 2007) in order to sustain their normal body temperature. Numerous studies in different climatic zones have indicated that the activity behaviour of cows is a sensitive indicator for HL. The main findings were that the total lying time (LT) decreased significantly with increasing HL, and consequently, the standing time increased (Cincović et al., 2011; Cook et al., 2007; De Palo et al., 2005). The average duration of each lying bout decreased as the HL increased (De Palo et al., 2005; Endres and Barberg, 2007).

To reduce the adverse effects of HL, it is important for farmers to know when the cows suffer from HL and to correspondingly cool cows in order to help them effectively off-loading heat. Since the use of pedometers to monitor the activity behaviour is already widely used, using activity data for the early detection of anomalies in the activity behaviour that are associated with HL would be feasible in practice and could be easily implemented on farms.

Additionally to the currently available knowledge, our study analysed the effects of increasing heat load duration (HLD) of different heat load levels (HLL) on the resting and locomotion behaviour of lactating dairy cows. In addition to the contemporaneous effects of HL on the measurement day, it is further investigated, how the accumulation of ongoing HL during the three days preceding the measurement day and the associated expected reductions in LT influences the activity adaptation on the measurement day. Cow-individual effects, such as days in milk and lactation number, have been taken into account because they influence the activity behaviour of individual cows (Bewley et al., 2010; Maselyne et al., 2017).

It is hypothesised that increasing HLD leads to a reduction in LT with shorter lying bouts and longer standing bouts as well as an increasing number of steps (NS). However, when the HLD spreads during several days preceding the measurement day, they might lie more on the measurement day even if they are still exposed to HL, because they get exhausted and compensate for the reduced LT during the preceding days.

2. Materials and Methods

Barn designs, animals

The measurements were carried out in a naturally ventilated dairy barn with a loose housing system, located in Groß Kreutz, Germany. The barn was 38.88 m long, 17.65 m wide and equipped with 51 lying cubicles (mixture of straw and lime as bedding material), an automatic milking system (Lely Astronaut A4, Maassluis, Netherlands) and three cross ventilators above the lying cubicles and the feeding area. The herd consisted of 51 Holstein-Friesian cows (first to eighth lactation), which had an average daily milk yield of 40.7 ± 6.8 kg per cow. During the experimental period there was a permanent fluctuation within the herd, whereby activity data were collected at a total of 177 different cows.

Barn climate and activity behaviour measurements

The climate and activity data were recorded from June 2015 to May 2017. The ambient temperature and relative humidity within the barn were measured automatically every 10 min using EasyLog USB 2+ sensors (Lascar Electronics Inc., USA). The sensors were positioned at eight locations inside the barn 3.4 m above the floor. The THI based on the formula of NRC (1971) was applied:

$$THI = (1.8 \times T + 32) - (0.55 - 0.0055 \times RH) \times (1.8 \times T - 26) \quad (1)$$

where T is the dry bulb temperature in °C and RH is the relative humidity in %. The THI calculations of all measurement points were averaged for each time point (every 10 min) afterwards (m = 842,112). Thus there were the considered variables: mean THI on the measurement day (THI_t), mean THI one/two/three day(s) before the measurement day (THI_{t-1}, THI_{t-2}, THI_{t-3}). In addition, the THI for each time point was classified according to THI thresholds found in the literature (Armstrong, 1994; Zimbelman and Collier, 2011). Correspondingly, the THI intensities for each time point were categorized as 68 ≤ THI < 72 (mild HL), 72 ≤ THI < 80 (moderate HL), and 80 ≤ THI (severe HL). The defined THI intensities were used within the variables of HLD (Table 1).

Table 1. Variables of heat load duration.

Mean heat load duration (HLD) on the measurement day (t)	
$HLD_t^{THI\epsilon[68.72]}$	Number of time points with 68 ≤ THI < 72 on t (gives the number of minutes the temperature-humidity index (THI) was between 68 and < 72, if multiplied by 10, because measurements were taken every 10 min)
$HLD_t^{THI\epsilon[72,80]}$	Number of time points with 72 ≤ THI < 80 on t (gives the number of minutes the THI was between 72 and < 80, if multiplied by 10, because measurements were taken every 10 min)
$HLD_t^{THI>80}$	Number of time points with THI ≥ 80 on t (gives the number of minutes the THI was 80 or higher, if multiplied by 10, because measurements were taken every 10 min)
Mean HLD during the three days preceding t	
$HLD_{t-1,t-2,t-3}^{THI\epsilon[68.72]}$	Mean HLD during the preceding three days, given that 68 ≤ THI < 72 on at least one measurement time on each of the three days (t-1, t-2, t-3) preceding t
$HLD_{t-1,t-2,t-3}^{THI\epsilon[72.80]}$	Mean HLD during the preceding three days, given that 72 ≤ THI < 80 on at least one measurement time on each of the three days (t-1, t-2, t-3) preceding t
$HLD_{t-1,t-2,t-3}^{THI\geq80}$	Mean HLD during the preceding three days, given that THI ≥ 80 on at least one measurement time on each of the three days (t-1, t-2, t-3) preceding t

The activity of the dairy cows (n = 177) was measured with pedometers. Each cow of the herd was equipped with one IceTag3D™ activity sensor (IceRobotics, Edinburgh, UK) on one hind leg. The IceTag3D™ is a noninvasive electronic sensor that measures animal activity with three-dimensional acceleration technology per second. We calculated and analysed the following activity traits per cow and day: total lying time (LT) in s, number of lying bouts (LB) in times, average lying bout duration (LBD) in s in the functional group "resting behaviour" as well as number of standing bouts (SB) in times, average standing bout duration (SBD) in s and number of steps (NS) in steps in the functional group "locomotion behaviour".

Statistical data analysis

For each of the activity traits, a (generalized) linear mixed model was used to estimate the effects of HL exposure on the measurement day and during the three days preceding the measurement day as well as how these effects depend on cow-individual factors. Cow-individual factors were the milk production levels ($Milk_t^{low}$, $Milk_t^{normal}$, $Milk_t^{high}$), the categorised days in milk (DIM_t^{1-60}, DIM_t^{61-150}, $DIM_t^{<150}$), the lactation number (L_t^1, $L_t^{2,3}$, $L_t^{\geq4}$) and the gestation status (G_t^0, G_t^{1-90}, G_t^{91-180}, $G_t^{>180}$). The models incorporate random effects of the individual cows on the activity traits as well as the within-cow correlation structure, because the observations of the same cow are temporally correlated. The temporal correlation is modelled by autoregressive-moving average (ARMA)-processes. The significance level for the (generalized) linear mixed model was 0.05.

3. Results

Activity adaptation to heat load “resting behaviour”

The significant effects to results of LT, LB and LBD are presented in table 2. Based on the model equations, it was possible to make predictions of the activity adaptation of dairy cows under different HL conditions. Assuming that there was no HL on the measurement day and the days before (mean THI was on average 46.01 on days without HL), LT was approximately 10.8 h[6] (38996.18 s) for cows in the reference group (non-pregnant, L_t^1, DIM_t^{1-60}, Milk_t^{normal}) and not in oestrus. In general, mean THI and the three HLD effects on the measurement day were negatively correlated with LT. An increase in THI_t by one unit resulted in a reduction in LT of about 3.21 min (192.75 s). Furthermore, the longer HLD on the measurement day, the shorter the cows are expected to lie down in addition to the effect of THI_t. The effect of HLD depended on HLL. Each additional 10 min of exposure to mild HL on the measurement day was expected to reduce LT by 23.83 s. LT was further reduced by 46.80 s or 94.08 s when the exposure to moderate or several HL lasted 10 min longer, respectively. Therefore, there was a reduced LT of 7.7 h[7] (27862.18 s) for cows in the reference group with HL on the measurement day (exemplary THI and HLD values were highlighted with underscores in the formulas) and without HL the days before. In contrast to the contemporaneous effects, the lagged effects were positively related to LT. The result was that cows’ LT increased again to 9 h[8] (32270.36 s) when there was HL on the measurement day and additionally during the three days preceding the measurement day (exemplary THI and HLD values are highlighted with underscores in the formulas). Independent of the climatic conditions, the cow-individual variables had significant effects on the expected LT. Low-producing cows were found to lie down more than cows with a normal or high level of milk production. Cows with $\mathrm{DIM}_t^{>150}$ lay down around 17.90 min (1074.28 s) more than cows with less than 150 DIM. This was also reflected in the increasing LT within the gestation status. LT in $\mathrm{L}_t^{\geq 4}$ increased by 47.56 min (2853.64 s) compared with LT of cows in earlier lactations. Cows in oestrus lay down significantly less than cows that were not in oestrus.

The model for LB was estimated using the log-link function. THI_t had no significant effect on LB. However, LB was negatively affected by HLD on the measurement day. Each additional 10 min of mild HL reduced LB by 0.03% and every additional 10 min of moderate HL further reduced LB by 0.05%. There were lagged effects of THI and HLD on LB. When HLD during the three days preceding the measurement day increased, LB decreased. But, all significant effects of the model influenced the LB only to a small extent. Without the influence of HL, the days in milk and the lactation number had significant effects on the expected LB. Cows with DIM_t^{61-150} and $\mathrm{DIM}_t^{>150}$ lay down around 6.63% and 7.89% more often, respectively, than cows with DIM_t^{1-60}. In $\mathrm{L}_t^{2,3}$ and $\mathrm{L}_t^{\geq 4}$, LB decreased by 29.17% and 16.11%, respectively, compared with LB of cows in L_t^1. No significant differences in LB between cows with different milk production levels or in different gestation status were found. The cows in oestrus lay down 6.17% less often than cows that were not in oestrus. Thus, the cow-individual effects led to stronger percentage changes in LB compared with HL effects.

The third model in table 2 shows the results of the linear mixed model of the logarithmized LBD. The estimated LBD of cows in the reference group without of HL on the measurement day and the days before was 47.68 min[9] (2860.82 s). In general, THI_t and THI_{t-2} were negatively correlated with LBD. However, increasing THI_{t-1} led to an increase in LBD by 0.24 % per unit. Furthermore, HLD significantly affected LBD. Longer exposure to mild, moderate and several HL on the measurement day resulted in a shorter LBD. The reference cows under HL on the measurement day and without HL the days before had an estimated LBD of 37.73 min[10] (2263.89 s). LBD under HL was therefore much shorter than LBD without HL. Concerning the HLD during the three days preceding the measurement day, LBD was significantly affected only by $\mathrm{HLD}_{t-1,t-2,t-3}^{\mathrm{THI}\in[72.80]}$. Ten more min of $\mathrm{HLD}_{t-1,t-2,t-3}^{\mathrm{THI}\in[72.80]}$ increased the expected LBD by 0.03%. In consideration of all significant effects of the model, LBD under HL on the measurement day and during the three days before increased once again slightly to approximately 38.53 min[11] (2311.59 s). Independent of HL, the cow-individual variables had significant effects on the expected LBD. LBD in DIM_t^{61-150} and $\mathrm{DIM}_t^{>150}$ was about 6.66% and 10.57% longer, respectively, than in DIM_t^{1-60}. Cows in $\mathrm{L}_t^{2,3}$ and $\mathrm{L}_t^{\geq 4}$ had longer LBD by 24.80% and 22.71%, respectively, compared with cows in L_t^1. The gestation status also affected LBD. During oestrus days, LBD was around 8.04% shorter than when the cows were not in oestrus.

[6] $38996.18 = 41723.2535-192.7514\mathrm{x}\underline{46.01}+111.3501\mathrm{x}\underline{46.01}+22.1299\mathrm{x}\underline{46.01}$

[7] $27862.18 = 41723.2535-192.7514\mathrm{x}\underline{73.49}+111.3501\mathrm{x}\underline{46.01}+22.1299\mathrm{x}\underline{46.01}-23.8339\mathrm{x}\underline{26}-46.7991\mathrm{x}\underline{56.87}-94.0757\mathrm{x}\underline{27.17}$

[8] $32270.36 = 41723.2535-192.7514\mathrm{x}\underline{73.49}+111.3501\mathrm{x}\underline{70.21}+22.1299\mathrm{x}\underline{69.89}-23.8339\mathrm{x}\underline{26}-46.7991\mathrm{x}\underline{56.87}-94.0757\mathrm{x}\underline{27.17} + 17.0419\mathrm{x}\underline{43.04}+30.1041\mathrm{x}\underline{15}$

[9] $2860.82 = \exp(8.1291-0.0041\mathrm{x}\underline{46.01}+0.0024\mathrm{x}\underline{46.01}-0.0020\mathrm{x}\underline{46.01})$

[10] $2263.89 = \exp(8.1291-0.0041\mathrm{x}\underline{73.49}+0.0024\mathrm{x}\underline{46.01}-0.0020\mathrm{x}\underline{46.01}-0.0004\mathrm{x}\underline{26}-0.0009\mathrm{x}\underline{56.87}-0.0022\mathrm{x}\underline{27.17})$

[11] $2311.59 = \exp(8.1291-0.0041\mathrm{x}\underline{73.49}+0.0024\mathrm{x}\underline{70.21}-0.0020\mathrm{x}\underline{71.08}-0.0004\mathrm{x}\underline{26}-0.0009\mathrm{x}\underline{56.87}-0.0022\mathrm{x}\underline{27.17}+0.0003\mathrm{x}\underline{43.04})$

Table 2. Mean lying time, number of lying bouts and average lying bout duration per day depending on mean temperature-humidity index (THI), daily heat load duration per heat load level (HLD), milk production level (Milk), days in milk (DIM), lactation number (L), gestation status (G) and indicator days (I) with t = measurement day and meas = measurement.

Variables	Lying time	Number of lying bouts	Average lying bout duration
THI_t	-192.7514***		-0.0041***
	(13.6192)		(0.0005)
THI_{t-1}	111.3501***		0.0024***
	(13.3279)		(0.0006)
THI_{t-2}		0.0022***	-0.0020***
		(0.0004)	(0.0005)
THI_{t-3}	22.1299**		
	(9.5413)		
$HLD_t^{THI\epsilon[68.72]}$	-23.8339***	-0.0003**	-0.0004***
	(3.7114)	(0.0001)	(0.0001)
$HLD_t^{THI\epsilon[72,80]}$	-46.7991***	-0.0005***	-0.0009***
	(3.1147)	(0.0001)	(0.0001)
$HLD_t^{THI\geq 80}$	-94.0757***		-0.0022***
	(7.1975)		(0.0003)
$HLD_{t-1,t-2,t-3}^{THI\epsilon[68.72]}$		0.0004**	
		(0.0002)	
$HLD_{t-1,t-2,t-3}^{THI\epsilon[72.80]}$	17.0419***		0.0003**
	(3.5910)		(0.0001)
$HLD_{t-1,t-2,t-3}^{THI\geq 80}$	30.1041**	0.0019***	
	(12.5319)	(0.0004)	
$Milk_t^{low}$	1154.3881**		
	(540.2129)		
$Milk_t^{high}$			
DIM_t^{61-150}		-0.0663***	0.0666***
		(0.0124)	(0.0110)
$DIM_t^{>150}$	1074.2758**	-0.0789***	0.1057***
	(432.1500)	(0.0183)	(0.0161)
$L_t^{2,3}$		-0.2917***	0.2480***
		(0.0437)	(0.0347)
$L_t^{\geq 4}$	2853.6397***	-0.1611***	0.2271***
	(1099.4544)	(0.0530)	(0.0425)
G_t^{1-90}	1424.5861***		0.0502***
	(342.6211)		(0.0130)
G_t^{91-180}	1086.6468**		0.0577***
	(553.9747)		(0.0210)
$G_t^{>180}$			
$I_{t,t-1}^{oestrus}$	-5499.1927***	-0.0617***	-0.0804***
	(282.9488)	(0.0106)	(0.0102)
I_t^{meas}	-2183.4099***	-0.0349***	-0.0205***
	(98.3097)	(0.0035)	(0.0035)
Intercept	41723.2535***	2.5624***	8.1291***
	(1009.7931)	(0.0406)	(0.0370)

***p < 0.01 and **p < 0.05

Activity adaptation to heat load "locomotion behaviour"

The significant effects to results of SB, SBD and NS are presented in table 3. The model for SB was estimated using the log-link function. THI_t had no significant effect on SB. However, SB was affected by HLD on the measurement day. The longer the cows were exposed to mild or moderate HL, the smaller was SB on the measurement day. The effect of HLD depended on HLL. The duration of severe HL on the measurement day did not led to further adaptations in SB. THI_{t-2} was associated with a significant increase in SB by approximately 0.21% per increased unit. Additionally, there was a lagged effect of HLD on SB. When HLD during the three days preceding the measurement day increased, SB increased as well. Similar to LB, all significant HL effects of the model influenced the SB only to a small extent. Independent of the climatic conditions, some cow-individual variables had significant effects on the expected SB. Cows in DIM_t^{61-150} or $DIM_t^{>150}$ were expected to stand approximately 6.92% or 8.54% less often, respectively, than cows at the beginning of lactation. The lactation number also affected SB of the cows. Compared to primiparous cows, the expected SB of cows in $L_t^{2,3}$ was 28.61%

smaller and cows in $L_t^{\geq 4}$ were expected to stand 15.52% less often than cows in L_t^1. SB reduced by about approximately 5.8%, when the cow was in oestrus.

The second model in table 3 shows the results of the linear mixed model of the logarithmized SBD. The cows in the reference group without HL on the measurement day and during the days before had an estimated SBD of 57.86 min[12] (3471.33 s). The effects of increasing THI and HLD on the measurement day led to an increase of SBD. When THI_t increased by one unit the SBD increased by 0.47 %. The effects of HLD on the measurement day were a little less pronounced and depended on HLL. As a result, SBD increased to 79.26 min[13] (4755.74 s) during days with HL (without HL the days before). This pronounced change was lower when there was additionally HL during the three days preceding the measurement day. In this case, SBD was approximately 65.49 min[14] (3929.48 s). The reason was that SBD became shorter with increasing THI_{t-1} and THI_{t-3} as well as increasing HLD during the three days preceding the measurement day. An increase in THI_{t-1} or THI_{t-3} by one unit was expected to result in a reduction in SBD of about 0.36% or 0.17%, respectively. An increase in $HLD_{t-1,t-2,t-3}^{THI\epsilon[68.72]}$, $HLD_{t-1,t-2,t-3}^{THI\epsilon[72.80]}$ or $HLD_{t-1,t-2,t-3}^{THI\geq 80}$ by 10 min led to a decrease in SBD of 0.005%, 0.007% or 0.18%, respectively. Compared to cows in the reference group, cows with DIM_t^{61-150} had approximately 4.29% longer SBD and cows within $L_t^{2,3}$ had 26.26% longer SBD, independent of the climate conditions. No differences in SBD of cows with different milk production level or pregnancy status were found. In general, cows in oestrus stood 21.1% longer per standing bout than cows which were not in oestrus.

The last model shows the results of the linear mixed model of the logarithmized NS. NS for cows in the reference group was approximately 2000 steps[15] under climate conditions without of Hl on the measurement day and the days before. In general, increasing THI and HLD on the measurement day led to an increase of NS. Keeping all other variables constant, an increase of THI_t by one unit led to an increase of NS by 0.1%. Additionally, an increase by 10 min of $HLD_t^{THI\epsilon[68.72]}$, $HLD_t^{THI\epsilon[72,80]}$ or $HLD_t^{THI\geq 80}$ led to 0.08%, 0.12% or 0.1% more steps per day. As a result of these effects, NS increased to 2309 steps[16] when the reference cows were exposed to HL on the measurement day (without HL the days before). The lagged effects of increasing THI and HLD during the three days preceding the measurement day decreased NS again. However, THI_{t-2} and THI_{t-3} did not influence NS. Consequently, the estimated NS for the reference cows was 2123 steps[17] under HL on the measurement day and additional HL during the three days preceding the measurement day. Independent of the climatic conditions, the cow-individual variables had significant effects on the expected NS. Compared to cows of the reference group, cows with DIM_t^{61-150} or $DIM_t^{>150}$ had 4.39% or 6.13% less NS, respectively. For the cows in $L_t^{2,3}$ or $L_t^{\geq 4}$, 12.07% or 39.37% less NS were predicted, respectively. Concerning the gestation status, in G_t^{1-90} and G_t^{91-180} NS was significantly lower than in $G_t^{>180}$ and non-pregnant cows.

[12] 3471.33 = exp (8.1799+0.0047x46.01-0.0036x46.01-0.0017x46.01)
[13] 4755.74 = exp (8.1799+0.0047x73.49-0.0036x46.01-0.0017x46.01+0.0008x26+0.0018x56.67+0.0023x27.17)
[14] 3929.48 = exp (8.1799+0.0047x73.49-0.0036x70.21-0.0017x69.89+0.0008x26+0.0018x56.67+0.0023x27.17-0.0005x12 - 0.0007x43.04-0.0018x15)
[15] 2000 = exp (7.6010+0.0010x46.01-0.0010x46.01)
[16] 2309 = exp (7.6010+0.0010x73.49-0.0010x46.01+0.0008x26+0.0012x56.67+0.0010x27.17)
[17] 2123 = exp (7.6010+0.0010x73.49-0.0010x70.21+0.0008x26+0.0012x56.67+0.0010x27.17-0.0009x43.04-0.0014x15)

Table 3. Number of standing bouts, average standing bout duration and number of steps per day depending on mean temperature-humidity index (THI), daily heat load duration per heat load level (HLD), milk production level (Milk), days in milk (DIM), lactation number (L), gestation status (G) and indicator days (I) with t = measurement day and meas = measurement.

Variables	Number of standing bouts	Average standing bout duration	Number of steps
THI_t		0.0047*** (0.0006)	0.0010** (0.0006)
THI_{t-1}		-0.0036*** (0.0006)	-0.0010*** (0.0005)
THI_{t-2}	0.0021*** (0.0004)		
THI_{t-3}		-0.0017*** (0.0005)	
$HLD_t^{THI\epsilon[68.72]}$	-0.0003** (0.0001)	0.0008*** (0.0002)	0.0008*** (0.0002)
$HLD_t^{THI\epsilon[72,80]}$	-0.0004*** (0.0001)	0.0018*** (0.0001)	0.0012*** (0.0001)
$HLD_t^{THI\geq 80}$		0.0023*** (0.0003)	0.0010*** (0.0003)
$HLD_{t-1,t-2,t-3}^{THI\epsilon[68.72]}$	0.0004** (0.0002)	-0.0005** (0.0002)	
$HLD_{t-1,t-2,t-3}^{THI\epsilon[72.80]}$		-0.0007*** (0.0002)	-0.0009*** (0.0001)
$HLD_{t-1,t-2,t-3}^{THI\geq 80}$	0.0021*** (0.0004)	-0.0018*** (0.0006)	-0.0014*** (0.0005)
$Milk_t^{low}$			
$Milk_t^{high}$			
DIM_t^{61-150}	-0.0692*** (0.0123)	0.0429*** (0.0152)	-0.0439*** (0.0112)
$DIM_t^{>150}$	-0.0854*** (0.0181)		-0.0613*** (0.0167)
$L_t^{2,3}$	-0.02861*** (0.0428)	0.2626*** (0.0557)	-0.1207*** (0.0365)
$L_t^{\geq 4}$	-0.1552*** (0.0519)		-0.3937*** (0.0447)
G_t^{1-90}			-0.0502** (0.0133)
G_t^{91-180}			-0.0520** (0.0218)
$G_t^{>180}$			
$I_{t,t-1}^{oestrus}$	-0.0580*** (0.0105)	0.2110*** (0.0126)	0.5203*** (0.0118)
I_t^{meas}	-0.0354*** (0.0035)		-0.0422*** (0.0040)
Intercept	2.5687*** (0.0399)	8.1799*** (0.0578)	7.6010*** (0.0381)

***$p < 0.01$ and **$p < 0.05$

4. Discussion and conclusion

The present study investigated the activity behaviour of dairy cows as influenced by the THI as it has already been shown in the literature and added novel investigations on effects of HLD and intensity. The effect of the mean THI indicated similar adaptations in the lying and locomotion behaviour of the cows as described in previous studies. It is well known that there is a negative correlation between THI and time spent lying (Herbut and Angrecka, 2018; Zähner et al., 2004). According to Brzozowska et al. (2014) and Steensels et al. (2012), who recorded the activity of cows depending on the season of the year, the time a cow spent lying down per day was significantly higher in winter compared with other seasons. A positive correlation between THI and time spent standing has been recorded by Allen et al. (2015) and Provolo and Riva (2009). Furthermore, several studies found that the length of lying bouts decreased as the THI increased (De Palo et al., 2005; Endres and Barberg, 2007). Additionally, the length of standing bouts increased with increasing THI (Allen et al., 2015). In previous studies, the frequency of lying bouts was not significantly influenced by THI (Endres and Barberg, 2007; Zähner et al., 2004). According to Brzozowska et al. (2014) and Steensels et al. (2012), LB was not associated with the season. Endres and Barberg (2007) compared the steps per hour when the THI was ≥ 72 or < 72 and found average values of 71.6 and 120.8, respectively. Therefore, there was an increase of steps per hour with increasing HL intensity. Cows' number of steps was significantly higher in summer than in winter, according to Brzozowska et al. (2014) and Steensels et al. (2012). All these findings are similar to our results regarding the mean THI during the measurement day.

The effect of the mean THI one, two or three days preceding the measurement day was not analysed in the literature until now with regard to the activity behaviour. West et al. (2003) found that during a hot period, the THI value and air temperature two and three days earlier have a greater impact on milk yield and dry matter intake than actual values. For this reason, we examined the lagged THI effects on activity and could identify significant influences on some activity traits. Reverse effects concerning the behavioural adaptation were found. This indicates that the previous climate conditions as well as contemporaneous conditions significantly affect the activity behaviour of the cows.

The scientific novelty of the present study was the analysis of HLD for different HLL and the assessment of its effects on the behavioural adaptations in the functional groups "resting behaviour" and "locomotion behaviour". The main advantage over mean THI values is that HLD provided information on how long the cows had been exposed to HL per day and the HLL included additional information on the intensity of HL. In a similar way, this innovative procedure was used previously only by Herbut and Angrecka (2018). They divided the obtained THI values into the periods neutral (maximum 3 h with THI = 68), warm (time of THI > 68 occurrence lasted less than 12 h), and hot (time of THI > 68 occurrence lasted longer than 12 h), which were characterized by different durations of THI throughout the entire day. In the present study, the intensity of HL was classified in more detail and the effect of HLD was analysed with a temporal resolution of 10 min. The activity traits influenced by different HLD and HLL during the measurement day showed the same correlations as with the effect of the mean THI during the measurement day. However, it is possible to make more precise predictions concerning the activity on a HL day when there is information to the HLD for different HLL additionally to the mean THI. On days without exposure to HL, the information of the mean THI is sufficient.

An important finding of the study was that HLD during the three days preceding the measurement day showed reversed effects to the activity adaptation compared to HLD on the measurement day. We assumed that when the cows were exposed to HL during all three days preceding the measurement day, they possibly could not further increase their adaptation beyond some limit and reacted weakened to the HL exposure on the measurement day. Consequently, it led to increased LT, LB, LBD and SB. SBD and NS during the measurement day decreased with increasing HLD during the three days preceding the measurement day. Previous studies, which analysed the reactions of cows with lying deprivation, illustrated the need for cows to lie down and the compensatory reactions (Cooper et al., 2007; Cooper et al., 2008). They recognized that the cows recovered their lost lying time by rescheduling feeding and standing time. The reduced resting times and increased standing times on the days preceding the measurement day cause exhaustion, so that the cows' strong need for rest predominates the discomfort of lying down.

Another important effect to evaluate the activity behaviour of dairy cows is the cow-individuality. The results of Bewley et al. (2010) and Maselyne et al. (2017) demonstrated the importance of including information about days in milk when interpreting data on lying and locomotion behaviour. Compared with our results, they also found that LT increased as days in milk increased. Maselyne et al. (2017) recognized additional a significant drop in LT appears during the first weeks after calving. Our results showed on the basis of further significantly cow-individual effects how important it is to estimate the activity of each individual cow.

The HLD of different HLL during the measurement day significantly influenced the activity behaviour of lactating dairy cows in the functional groups "resting behaviour" and "locomotion behaviour". The largest activity changes were found in LT, LBD, SBD and NS. In consideration of the accumulation of HLD during the three days preceding the measurement day, the activity adaptation of the cows did not further increase. On the contrary, the cows reversed to a limited extent their activity adaptations during the measurement day, which could indicate that the cows reaction weakened. The studied activity traits included many significant cow-individual effects, that might also affect the sensitivity to HL, indicating that HL activity in the future should be considered in interaction with cow-individual effects. In order to predict the activity behaviour under HL, previous climate conditions as well as cow-individual effects must be additionally taken into account.

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