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# Time budgets and adrenocortical activity of cows milked in a robot or a milking parlour: interrelationships and influence of social rank

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## Abstract

*Adrenocortical activity and time budgets in a robotic milking system in two variants of cow traffic (partially forced, free) were compared with a conventional milking system, focusing on the relationships between adrenocortical activity, time budgets, and social rank of the cows. Both groups were housed in identical conditions and consisted of 30 cows each. Within each experiment, direct observations of social behaviour and 24-hour video recordings were conducted during six two-day blocks. We calculated the dominance value and the time budget ('lying', 'feeding', 'other activity') of each cow. Faeces from each cow were collected to determine the concentration of cortisol metabolites (CCM) as an indicator of baseline adrenocortical activity and possible chronic stress. Analysis of CCM and time budgets did not indicate any adverse effects of the robotic milking system, with one exception: under partially-forced cow traffic, cows of low social rank had longer waiting times in front of the robot. Considering the fact that the number of cows milked by the robot was less than half of that recommended by the manufacturers, our results do not exclude the possibility that a higher stocking rate may lead to further adverse effects.*

**Keywords**: *animal welfare, dairy cow, faecal cortisol metabolites, robotic milking, social rank, time budget*

## Introduction

Growing public concern about animal production systems and animal welfare (Morrow *et al* 2002; Millman *et al* 2004) as well as compliance with the recommendation of the Council of Europe (Anonymous 1988) requires an assessment of new technologies for possible risks concerning health and welfare of the animals (Müller *et al* 2000). The introduction of robotic milking as a new technology into dairy farming has led to research on technical aspects of robotic milking systems and, increasingly, also on consequences of robotic milking for hygiene, animal health and animal welfare (eg Wiktorsson *et al* 2003; Rousing *et al* 2004). However, there is still a need to improve knowledge on how robotic milking affects cow welfare (Rousing *et al* 2004).

To assess animal welfare, parameters of behaviour and physiology have been used to investigate stress responses. A behavioural welfare indicator of particular relevance to robotic milking systems is the time budget of the cows, ie how much time they spend in different basic activities. For example, increased standing time may indicate stress or discomfort (Albright 1987; Winter & Hillerton 1995). In robotic milking systems, time budgets may be influenced by the cow traffic system and by social rank. Forced cow traffic reduces feeding time (Ketelaar-de Lauwere *et al* 1998; Prescott *et al* 1998; Ketelaar-de Lauwere & Ipema 2000; Calamari *et al* 2007), and cows of low social rank spend more time standing, because they have to wait in front of the robot (Ketelaar-de Lauwere *et al* 1996; Wiktorsson *et al* 2003; Hermans *et al* 2004). In contrast, Munksgaard *et al* (2002) found no difference in the cows' time budget when comparing free and forced cow traffic.

Within robotic milking, the focus has up until now largely been on acute stress experienced through the milking procedure *per se* (Hopster *et al* 2002; Wenzel *et al* 2003; Hagen *et al* 2004; Gygax *et al* 2006). These studies have yielded ambiguous results. Conclusions of the authors varied from no adverse effect of the robotic milking procedure on cows' welfare (Hopster *et al* 2002) to more stress experienced by the cows during milking in a robot (Wenzel *et al* 2003), whereas Hagen *et al* (2004) and Gygax *et al* (2006) could not find a clear tendency. Weiss *et al* (2004) exclusively analysed the stress response of cows toward the changeover period from conventional to robotic milking by measuring heart rate and concentrations of faecal cortisol metabolites. In general, the cows adapted to the new milking system within a few days, but showed great variability in coping with the new situation.

For a comprehensive evaluation of the consequences of robotic milking for animal welfare, measuring isolated events (eg the milking procedure) and acute stress responses are insufficient. Rather, the effects of the overall system (including cow traffic, handling of the cows, feeding and milking procedure) on chronic stress responses of dairy cows, should also be addressed.

Therefore, we compared baseline levels of adrenocortical activity as an indicator of chronic stress as well as time budgets in a robotic milking system, in two variants of cow traffic (partially forced and free) with a conventional milking system, focusing on the interrelationships between adrenocortical activity, time budgets, and social rank of the cows.

## Materials and methods

### Animals and housing

This study was carried out in two groups of dairy cows at the Landwirtschafliche Bundesversuchswirtschaften GmbH in Wieselburg, Austria. Each group consisted of 15 Austrian Simmental and 15 Brown Swiss; in total 30 cows per group. The robotic milking group (R-group) was milked in a single box robot (Astronaut® Series 30, Lely Industries NV, Maasland, The Netherlands). Over the course of the study, the R-group was first run (throughout 2001) with partially-forced cow traffic: cows that had been milked sufficiently had access to the feeding area through a selection gate, others were redirected and had to go through the robot. Throughout 2002, the R-group was run with free-cow traffic: free access to the feeding area independently of when cows had last been milked. The herringbone parlour group (HP-group) was milked in a 2 × 6 herringbone parlour (System Happel GmbH, Friesenried, Germany) twice a day between 0500 and 0630h and between 1530 and 1700h, throughout the study.

The study consisted of two experiments. From August to October 2001, we compared the HP-group with the R-group with partially-forced cow traffic (experiment P). From March to April 2002, we compared the HP-group with the R-group with free-cow traffic (experiment F). In the period between the two experiments, five cows in the HP-group and seven cows in the R-group had to be replaced due to ill health, for example post-parturition complications (two in HP-group; three in R-group), infertility (one and two, respectively), mastitis (one each), lameness (one each), and technical reasons (the robot was not able to attach the cups because of post-parturition oedema of the udder) (zero and two, respectively).

With the exception of during milking, the two groups were kept in similar management conditions. They were housed in the same uninsulated building in separate loose-housing pens with slatted floors. Each pen had 30 cubicles with soft, rubber mats and small amounts of straw. Each cow had its own roughage feeding place (American Calan Inc, Northwood, USA), where roughage was available for consumption *ad libitum*. Fresh roughage was offered once a day between 0730 and 0830h in the R-group and between 1630 and 1730h in the HP-group. Concentrates were delivered in the milking robot and in concentrate feeders (one in the R-group, two in the HP-group). Water was continuously available in two troughs for each group. The robot was cleaned for three minutes after every tenth milking or when the system was not used for a certain length of time (at the latest after 1.5 h). Additionally, two main cleanings around midday and midnight, for 17 min, each took place.

In both groups, a number of cows were dry during parts of the study period and excluded from data analysis. Dim, artificial lights (approximately 5 lux) were on continuously during the night, for the purposes of behavioural observations. For further details on housing and milking systems see Hagen *et al* (2004, 2005).

Twice a day, around 0800 and 1800h, cows in the R-group that had, by that time, not been milked for more than 14 h, were herded into the robot for milking.

The number of successful milkings in the robot (per cow, per day) was 2.49 (± 0.65) during partially-forced cow traffic and 2.23 (± 0.71) during free-cow traffic. The number of robot visits where cows were allowed to be milked but milking failed was 0.28 (± 1.26) during partially-forced cow traffic and 0.14 (± 0.44) during free-cow traffic.

### Time budgets and dominance values

Within each experiment, direct observations and 24-hour video recordings were carried out during six blocks of two consecutive days each (amounting to a total of 12 days per group and experiment). Social interactions (eg head play, social licking, threatening, pushing away) were observed directly by continuous behaviour sampling (Martin & Bateson 1993) for 7.5 h per day and group. We focused on periods with high levels of activity observing both groups simultaneously by two persons or separately (Table 1).

All agonistic interactions leading to displacement, ie pushing away, chasing away, chasing up and threatening (definition of the parameters according to Mülleder *et al* [2003]) were grouped for analysis. The dominance value (DV) of each cow was calculated following Sambraus (1975) by dividing the number of animals that a cow dominated by the number of all known dominance relationships of this cow within the herd. All 24-hour videotapes were scan sampled (Martin & Bateson 1993) every five minutes for 'lying', 'feeding' and 'other activity', allowing calculation of the time budget for each cow. 'Other activity' included drinking, milking and standing in different areas of the barn. For the R-group, the time budget for 'waiting in front of the robot' was also calculated.

### Adrenocortical activity (concentration of faecal cortisol metabolites)

We collected faecal samples from each cow fortnightly between 1000 and 1230h, mostly on the day after each observation block. In ruminants, faecal metabolites are excreted with a delay of 10–12 h (Palme *et al* 1999), and the concentration of cortisol metabolites in the faeces (CCM) thus reflected the cortisol production of the night before. The faecal samples were analysed for concentrations of 11,17-dioxoandrostanes as described by Palme and Möstl (1997). Samples from cows that were more than 23 weeks into



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**Table 1 Observation times for social interactions.**

| Observation time | Definition |
|---|---|
| 0630–0830h | Only the HP-group was observed after milking was completed and while the R-group was offered fresh roughage |
| 0830–1030h | Both groups were observed simultaneously after feeding of the R-group was completed |
| 1400–1530h | Both groups were observed simultaneously |
| 1530–1730h | During milking and feeding of the HP-group only the R-group was observed |
| 1800–2000h | Both groups were observed simultaneously after feeding of the HP-group was completed |

**Table 2 Comparison of R-group with partially-forced cow traffic and HP-group with regard to the proportion of time spent in different time budget parameters within 24 hours.**

| Parameter | Mean (± SD) % R-group (n = 6) | Mean (± SD) % HP-group (n = 6) | Mann Whitney *U*-test ($U_{6,6}$) | *P*-value |
|---|---|---|---|---|
| Lying | 46.5 ± 3.1 | 46.3 ± 3.3 | 19 | 0.94 |
| Other activity | 42.5 ± 2.7 | 42.9 ± 3.2 | 20 | 0.82 |
| Feeding | 11.0 ± 0.9 | 10.8 ± 0.5 | 23 | 0.49 |

gestation were excluded from the statistical analysis of CCM (experiment P: R-group 69 [38%] vs HP-group 63 [35%] of 180 possible samples; experiment F: R-group 30 [25%] vs HP-group 27 [22.5%] of 120 possible samples), because by this point the placenta produces large amounts of steroids, and the steroid metabolites may cross-react with the antibody used in the analysis (Möstl *et al* 2002).

### Statistical analysis

For the statistical analysis, we only considered data from healthy lactating cows. The data were analysed using SPSS for Windows, version 11.5 (SPSS© Inc 1989-2002). All tests were performed with alpha = 0.05 (two-tailed). Analysis was generally carried out within experiments, because changes in internal factors (changes in group composition) meant that experiments P and F could not be compared with each other.

For group comparisons of time budgets, the data of each two-day observation block were pooled, and the mean proportions of time spent 'lying', 'feeding' and 'other activity' were calculated per block (n = 6 in each experiment) for each group. For the concentration of cortisol metabolites (CCM), the median of the samples (two-to-six per animal) was used for each cow (n = 22–26, depending on experiment and milking group). For a few of the time budget parameters, Kolmogoroff-Smirnov tests revealed significant deviations from a normal distribution. However, Levene tests showed significant heteroscedacity for several parameters. Therefore, between-group differences within each experiment were tested with Mann Whitney *U*-tests.

Relationships between time budgets, DV and CCM were evaluated with Pearson correlation coefficients. To identify a possible effect of social rank on the relationship between time budget parameters and CCM, we tested Pearson correlation coefficients for categories of DV against the corresponding correlation coefficients for the whole group after *z*-transformation according to Hotelling (Sachs 1997). Following Ketelaar-de Lauwere *et al* (1996), cows with DV > 0.60 were classified as high ranking, cows with DV < 0.40 as low ranking, and intermediate values for DV as middle ranking.

## Results

### Experiment P

The R-group did not differ significantly from the HP-group in the proportion of time spent 'lying', in 'other activity' or 'feeding' (Table 2). CCM did not differ between groups (R-group: 66 nmol $kg^{-1}$ [range: 38–148] vs HP-group: 71 nmol $kg^{-1}$ [range: 35–125]; $U_{22,26}$ = 266, *P* = 0.68).

Correlations between DV and the time budget parameters within groups were negligible (Pearson correlation coefficient, $r_P$ ranging from –0.02 to 0.17). However, the time budget parameter 'waiting in front of the robot' as one component of 'other activity' was specifically analysed for the R-group and yielded a significant negative relationship with DV (n = 26, $r_P$ = –0.40, *P* = 0.045).

In the R-group (n = 22), there was a negative correlation between CCM and 'lying' ($r_P$ = –0.56, *P* = 0.007), and a positive correlation between CCM and 'other activity' ($r_P$ = 0.57, *P* = 0.005), but there was no correlation between CCM and 'feeding' ($r_P$ = 0.03, *P* = 0.90) or CCM and DV ($r_P$ = 0.08, *P* = 0.72). Correlation analysis revealed no significant relationships between CCM and time budgets or DV in the HP-group (n = 26; 'lying' and CCM: $r_P$ = –0.21, *P* = 0.31; 'other activity' and CCM: $r_P$ = 0.24, *P* = 0.23; 'feeding' and CCM: $r_P$ = –0.08, *P* = 0.70; CCM and DV: $r_P$ = 0.03, *P* = 0.87).

To test for a possible effect of social rank on the relationship between CCM and time budget variables, the correlation coefficients reported above for the whole R-group were compared with correlation coefficients within the DV-categories (Tables 3 and 4 for the R-group and the HP-group, respectively). Although the correlation measures for the subgroups seem to indicate differences in the relationship of CCM and the time budget parameters, just in the R-group, there were three significant subgroup correlation coefficients. However, all *z*-values were non-significant, indicating no major differences in the relationship between CCM and the time budget in dependence of social rank in either group.



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**Table 3 Pairwise comparison of Pearson correlation coefficients for the relationship of CCM and time budget parameters within DV categories with overall correlation (experiment P: R-group with partially-forced cow traffic).**

| DV Category | Lying | | | Other activity | | | Feeding | | |
|---|---|---|---|---|---|---|---|---|---|
| | $r_P$ | n | z | $r_P$ | n | z | $r_P$ | n | z |
| High | –0.62 | 7 | 0.044$^{ns}$ | 0.77* | 7 | 0.47$^{ns}$ | –0.03 | 7 | 0.089$^{ns}$ |
| Middle | –0.13 | 6 | 0.79$^{ns}$ | –0.18 | 6 | 1.24$^{ns}$ | 0.56 | 6 | 0.81$^{ns}$ |
| Low | –0.72* | 9 | 0.46$^{ns}$ | 0.78* | 9 | 0.66$^{ns}$ | –0.16 | 9 | 0.37$^{ns}$ |

For 'lying': overall $r_P$ = –0.56**; for 'other activity': overall $r_P$ = 0.57**; for 'feeding': overall $r_P$ = –0.03$^{ns}$.
*z* = 1.96 (two-tailed) for n < 50 *z*-transformation according to Hotelling (Sachs 1997). * *P* < 0.05; ** *P* < 0.01.

**Table 4 Pairwise comparison of Pearson correlation coefficients for the relationship of CCM and time budget parameters within DV categories with overall correlation (experiment P: HP-group).**

| DV Category | Lying | | | Other activity | | | Feeding | | |
|---|---|---|---|---|---|---|---|---|---|
| | $r_P$ | n | z | $r_P$ | n | z | $r_P$ | n | z |
| High | –0.10 | 9 | 0.25$^{ns}$ | 0.33 | 9 | 0.13$^{ns}$ | –0.56 | 9 | 1.075$^{ns}$ |
| Middle | –0.46 | 7 | 0.42$^{ns}$ | 0.40 | 7 | 0.23$^{ns}$ | 0.24 | 7 | 0.53$^{ns}$ |
| Low | –0.38 | 10 | 0.37$^{ns}$ | 0.30 | 10 | 0.079$^{ns}$ | 0.29 | 10 | 0.81$^{ns}$ |

For 'lying': overall $r_P$ = –0.21$^{ns}$; for 'other activity': overall $r_P$ = 0.24$^{ns}$; for 'feeding': overall $r_P$ = 0.08$^{ns}$.
*z* = 1.96 (two-tailed) for n < 50 *z*-transformation according to Hotelling (Sachs 1997).

**Table 5 Comparison of R-group with free-cow traffic and HP-group with regard to the proportion of time spent in different time budget parameters within 24 h.**

| Parameter | Mean (± SD) % R-group (n = 6) | Mean (± SD) % HP-group (n = 6) | Mann Whitney *U*-test $U_{6,6}$ | *P*-value |
|---|---|---|---|---|
| Lying | 53.7 ± 2.6 | 51.3 ± 1.6 | 28 | 0.13 |
| Other activity | 32.4 ± 3.1 | 36.1 ± 1.9 | 31 | 0.041 |
| Feeding | 14.0 ± 0.6 | 12.6 ± 0.6 | 35 | 0.004 |

## Experiment F

During experiment F, cows in the R-group spent significantly less time in 'other activity' and significantly more time 'feeding' compared to cows in the HP-group. Groups did not differ with regard to the proportion of time spent in 'lying' (Table 5). We observed a trend for lower CCM values in the R-group compared to the HP-group (65 nmol kg$^{-1}$ [range: 32–106] vs 79 nmol kg$^{-1}$ [range: 36–148]; Mann Whitney *U*-test: $U_{23,25}$ = 198, *P* = 0.065).

Correlations between DV and time budget parameters within groups were low and statistically non-significant ($r_P$ ranging from –0.04 to 0.25). In contrast to experiment P, in the R-group the relationship between 'waiting in front of the robot' and DV was not significant (n = 29, $r_P$ = –0.01, *P* = 0.95).

There were no significant relationships between CCM and DV (R-group: n = 23, $r_P$ = 0.06, *P* = 0.77; HP-group: n = 25, $r_P$ = 0.23, *P* = 0.28) or between CCM and time budget parameters (R-group: n = 23; 'lying': $r_P$ = –0.09, *P* = 0.68; 'other activity': $r_P$ = 0.18, *P* = 0.42; 'feeding': $r_P$ = –0.20, *P* = 0.36; HP-group: n = 25, 'lying': $r_P$ = 0.13, *P* = 0.54; 'other activity': $r_P$ = –0.14, *P* = 0.51; 'feeding': $r_P$ = 0.03, *P* = 0.89).

As in experiment P, correlation coefficients within the DV categories indicated a contrasting response of cows in different DV categories with regard to the relationship of CCM and time budget parameters. However, the test of correlation coefficients within the DV categories against the overall correlation coefficients yielded a significant difference only in the case of 'other activity' for high ranking cows in the R-group (Tables 6 and 7). Figure 1 exemplifies the different response of high ranking cows to increasing time spent on 'other activity' regarding CCM.

## Discussion

In this study, we compared a robotic milking system with a herringbone parlour with regard to (i) a physiological indicator of chronic stress, (ii) major time budget parameters and (iii) the relationships among these variables, taking social rank and cow traffic into account.

A novel approach in assessing automatic milking systems was the use of faecal cortisol metabolites to measure baseline levels of adrenocortical activity as an indicator for chronic stress (Broom & Johnson 1993; Touma & Palme 2005). In recent years, measurement of faecal glucocorticoid

**Table 6 Pairwise comparison of Pearson correlation coefficients for the relationship of CCM and time budget parameters within DV categories with overall correlation (experiment F: R-group with free-cow traffic).**

| DV Category | Lying | | | Other activity | | | Feeding | | |
|---|---|---|---|---|---|---|---|---|---|
| | $r_P$ | n | z | $r_P$ | n | z | $r_P$ | n | z |
| High | –0.74 | 8 | 1.49$^{ns}$ | 0.87* | 8 | 2.005* | –0.23 | 8 | 0.015$^{ns}$ |
| Middle | 0.01 | 7 | 0.17$^{ns}$ | –0.11 | 7 | 0.48$^{ns}$ | 0.32 | 7 | 0.88$^{ns}$ |
| Low | 0.28 | 8 | 0.67$^{ns}$ | –0.15 | 8 | 0.60$^{ns}$ | –0.51 | 8 | 0.60$^{ns}$ |

For 'lying': overall $r_P$ = 0.09$^{ns}$; for 'other activity': overall $r_P$ = 0.18$^{ns}$; for 'feeding': overall $r_P$ = 0.20$^{ns}$.
$z$ = 1.96 (two-tailed) for n < 50 $z$-transformation according to Hotelling (Sachs 1997). * $P$ < 0.05.

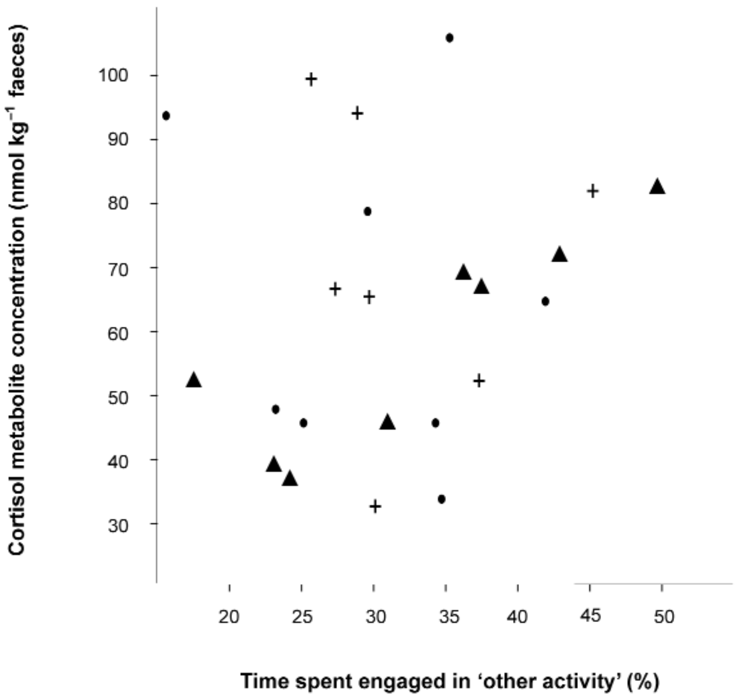
**Table 7 Pairwise comparison of Pearson correlation coefficients for the relationship of CCM and time budget parameters within DV categories with overall correlation (experiment F: HP-group).**

| DV Category | Lying | | | Other activity | | | Feeding | | |
|---|---|---|---|---|---|---|---|---|---|
| | $r_P$ | n | z | $r_P$ | n | z | $r_P$ | n | z |
| High | 0.09 | 9 | 0.102$^{ns}$ | –0.14 | 9 | 0.007$^{ns}$ | 0.21 | 9 | 0.35$^{ns}$ |
| Middle | –0.11 | 8 | 0.44$^{ns}$ | 0.26 | 8 | 0.74$^{ns}$ | –0.39 | 8 | 0.78$^{ns}$ |
| Low | 0.55 | 8 | 0.85$^{ns}$ | –0.52 | 8 | 0.74$^{ns}$ | –0.18 | 8 | 0.37$^{ns}$ |

For 'lying': overall $r_P$ = 0.13$^{ns}$; for 'other activity': overall $r_P$ = 0.14$^{ns}$; for 'feeding': overall $r_P$ = 0.03$^{ns}$.
$z$ = 1.96 (two-tailed) for n < 50 $z$-transformation according to Hotelling (Sachs 1997).

**Figure 1**

The relationship between 'other activity' and concentration of faecal cortisol metabolites for DV categories (DV > 0.6: high ▲; 0.6 > DV > 0.4: middle +; DV < 0.4: low •) in the R-group of experiment F (free-cow traffic).




metabolites has been established and validated in several species (Touma & Palme 2005). In cattle and sheep this has been achieved by Palme and Möstl (1997) and Palme *et al* (1999, 2000). Its benefit is that sampling faeces is non-invasive and does not interfere with the stress response itself (Morrow *et al* 2002; Touma & Palme 2005). To use this method effectively, certain aspects have to be considered (for guidelines, see Palme 2005). But, whatever sample material is used to evaluate adrenocortical activity, there are some limitations to interpretation. Not every type of stressor will be reflected by a change in the hypothalamic-pituitary-adrenal axis (Terlouw *et al* 1997), inter-animal variability in the concentrations can be high (Palme *et al* 1999) and, especially in the faeces, robust threshold values, indicating the



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occurrence of stress, are yet to be established. However, the latter also holds true for many other animal welfare indicators, and interpreting such data should always be done with caution. In our study, we used this method to measure the chronic stress of dairy cows as potentially caused by the overall system (including effects of the milking process itself, the cow traffic, handling of the cows).

In experiment F (free-cow traffic), cows in the HP-group tended to have higher levels of CCM compared to the R-group. One possible explanation for this is that being herded to the milking parlour twice a day and standing in restricted waiting and milking areas might be sources of stress via negative human-animal interactions (Hemsworth & Coleman 1998; Hemsworth *et al* 2000; Breuer *et al* 2003) or agonistic social interactions, resulting in a higher CCM level. Also, the HP-group spent significantly more time in 'other activity', which might be caused by the milking procedure: the milking process (including walking to the parlour, waiting, being milked and walking back) lasted 35 to 50 min each time. For some cows, this amounted to 100 min per day, or 7% of their time spent for this activity, included in 'other activity'. This corresponds to less time spent 'feeding'. According to Albright (1987) and Winter and Hillerton (1995), increased standing time can be interpreted as a sign of stress or discomfort. Although, in our case, the primary cause of increased time spent on 'other activity' was enforced directly by the management system, it might increase the cows' discomfort by forcing them to stand more and constraining the possibilities for them to choose their behaviour.

Under conditions of partially-forced cow traffic (experiment P), the R-group did not differ significantly from the HP-group in the concentration of cortisol metabolites (CCM) nor in the time budget parameters. In contrast to this, when analysing heart-rate variability, Hagen *et al* (2005) identified a higher challenge in cows in the robot group with partially-forced cow traffic, compared to cows milked in a herringbone parlour. Heart-rate variability may be a more appropriate method of identifying chronic stress than CCM. Analysing the cows' heart rate and heart-rate variability in two kinds of automatic milking systems (one with free-cow traffic, one with partially-forced cow traffic) and an auto-tandem milking parlour on four commercial farms each, Gygax *et al* (2008) identified that cows in automatic milking systems were slightly more stressed compared to cows in the auto-tandem milking parlour.

In a comparison between a herringbone parlour and a robot with partially-forced cow traffic, reported by Speroni *et al* (2004), time spent lying in cubicles did not differ between the systems. However, in their study, both groups had access to outdoor areas. They reported that when the time spent lying outdoors was included in the analysis, total time spent lying was higher, and time spent standing, including milking, was lower in the robotic milking group compared to the conventional milking group.

Group-specific median values of CCM in both experiments are comparable to findings in the concentration of faecal cortisol metabolites in beef-suckler cows in an undisturbed herd situation (Mülleder *et al* 2003). Based on their results, the authors suggested that the stress levels of the cows in their study were low. That might apply to our findings, too. However, variability in CCM within our trial groups was substantial, with maximum values exceeding those found by Mülleder *et al* (2003). This suggests a need to consider the response of individual animals, not just the average response of entire groups, to potentially stressful situations.

Several studies have previously indicated restrictions for low-ranking cows in robotic milking systems, depending on the type of cow traffic: under-forced and partially-forced cow traffic cows of low social rank usually spend more time standing, because they have to wait in front of the milking robot (Ketelaar-de Lauwere *et al* 1996; Thune *et al* 2002; Wiktorsson *et al* 2003; Hermans *et al* 2004; Melin *et al* 2006). Melin *et al* (2006) assumed that low ranking cows have to be closer to the milking unit to observe any chance of moving forward in the queue. In experiment P, we observed that in the R-group with partially-forced cow traffic, cows of low social rank (DV) spent more time 'waiting in front of the robot', thus confirming the previous findings. It should be taken into account that, although the herd size in our study was less than half of that recommended by the manufacturers, cows of low social rank were obviously subject to this constraint. Ketelaar-de Lauwere *et al* (1998) and Thune *et al* (2002) assumed that longer waiting times are not necessarily a problem, unless the cows are restricted in maintenance behaviours. However, prolonged standing may cause haemorrhages in the sole horn (Singh *et al* 1993) and could predispose lameness. In a questionnaire study by Rousing *et al* (2007), the incidence of lameness was evaluated as a highly relevant animal welfare indicator in automatic milking system herds. Additionally, longer waiting times and leaving the waiting area more often without attending the robot (Ketelaar-de Lauwere *et al* 1996) may cause frustration. Both are animal welfare issues. Similarly to Thune *et al* (2002), we did not find this negative relationship of DV and time spent 'waiting in front of the robot' in free-cow traffic (experiment F).

In experiment F there were neither statistically significant relationships between social rank and time budget variables, nor between social rank and CCM. While for the HP-group this result had been expected, for the R-group it was surprising. Social dominance becomes important when resources like food are scarce (Syme & Syme 1979). In competitive situations caused by limited feeding or resting places, dominant animals have better access to resources (Wierenga & Hopster 1990). In our study, each cow had its own feeding place, and resting places were not limited. The milking robot was expected to be a source of competition, due to concentrations of milkings during favourite times, and the situation was expected to be even worse during partially-forced cow traffic due to the forced robot visits to gain access to the feeding area. This was reflected by the negative correlation between DV and 'waiting in front of the robot' in experiment P. The fact that this relationship was neither found for the other time budget parameters in



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experiment P, nor for time budgets in experiment F, might be due to the relatively small size of the R-group compared to producer recommendations. The time budget parameter 'other activity' might also have been too broadly defined to detect a distinct pattern of rank and time budget.

There was no significant correlation of CCM with time budget parameters, except CCM with 'lying' and 'other activity' in the R-group of experiment P (partially-forced cow traffic). The latter correlations were as expected in terms of consistency of stress indicators: increasing CCM with decreasing time spent 'lying', increasing CCM with increasing time spent on 'other activity'. In the case of the R-group in experiment P, the high-ranking animals almost exclusively determined the overall group relationship between CCM and 'lying', and 'other activity', respectively.

Comparison of the correlations within DV categories for the R-groups revealed that for the subgroup of high-ranking animals, the relationship of CCM with 'lying' and 'other activity' was similar, also during free-cow traffic, where the relationship between CCM and 'other activity' for the high-ranking cows was even significantly different from the correlation coefficient for the overall group.

In the HP-group of both experiments, social rank did not differentiate the response of cows to different time budgets. It should, however, be noted that the small group size limited the power of the test for differences between correlation measures for DV subgroups and the overall group. From the findings of this study, we do not have evidence as to what might have caused the different CCM response of dominant cows in relation to time budget parameters. Analysis of CCM and time budgets did not indicate adverse effects of the robotic milking system, with one exception: under partially-forced cow traffic, cows of low social rank had longer waiting times in front of the robot. Additionally, analysis of subgroups of different social rank indicated differences in the relationship between CCM and time budget parameters. Moreover, our results advocate an increased emphasis on individual response to stress in future work.

## Conclusions and animal welfare implications

The results of the current study corroborate earlier findings, suggesting that the use of a robotic milking system with partially-forced cow traffic negatively impacts on the welfare of cows, especially low ranking ones. Considering the fact that the number of cows milked by the robot was less than half of that recommended by the manufacturers, our results suggest that a higher stocking rate may lead to further adverse effects. In conclusion, from an animal welfare perspective, free-cow traffic should be preferred in robotic milking systems. However, this management system also needs further evaluation with higher numbers of cows per robot.

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