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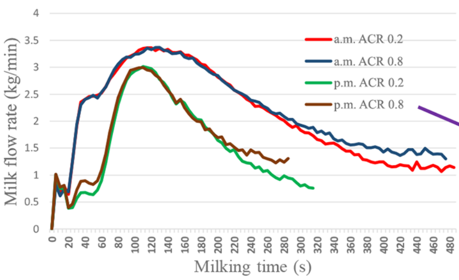
Short Communication
Health, Welfare, and Behavior

# Measurement of cow comfort during milking on different cluster removal settings through the use of leg-mounted accelerometers

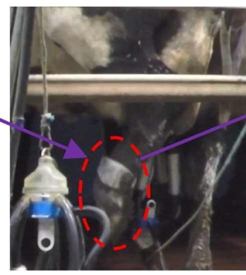
Martin Browne,[1,2]* Pablo Silva Boloña,[1] and John Upton[1]

## Graphical Abstract

Can increasing cluster removal switch-point improve cow comfort?




Milk flow curves combining values of milkings from cows on trial disaggregated by milking interval and ACR switch point (minimum of 30 milkings per time point)



Tested impact of ACR milk flow switch-point on stepping

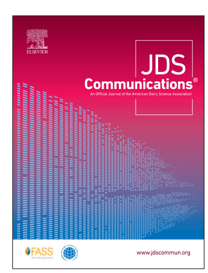
Accelerometer step count

| | ACR0.2 | ACR0.8 | Chi square P Value |
|---|---|---|---|
| Steps during milking per day | 11.7 | 10.1 | 0.02 |
| Steps per a.m. milking | 5.74 | 5.41 | 0.35 |
| Steps per p.m. milking | 5.75 | 4.96 | 0.01 |

Detaching clusters at a higher milk flow-rate reduced stepping and improved cow comfort during milking

## Summary

This crossover experiment assessed differences in stepping/kicking during milking, measured by rear leg-mounted 3-dimensional accelerometers, between 2 automatic cluster remover (ACR) milk flow-rate switch-point settings (0.2 and 0.8 kg/minute) using 37 cows over a 4-week period. Significantly more rear leg stepping occurred during daily milking (combined step count of 11.7 for a.m. and p.m. milkings) where the ACR activated at 0.2 kg/minute compared with 0.8 kg/minute (10.1 steps). Significantly greater rear leg movement was recorded during p.m. milkings when removing clusters at 0.2 kg/minute. No significant difference was found between ACR switch-points for rear leg movement during a.m. milking, corresponding to similar postmilking teat condition scores. There was a much shorter interval before p.m. milking, resulting in lower udder fill and reduced milk flow-rates at p.m. milking. Removing the cluster earlier (0.8 kg/minute) can improve cow comfort by reducing kicking and stepping activity during milking while reducing milking time and without affecting milk yield.



## Highlights

- Increased cluster removal flow-rate threshold improved cow comfort.
- Detaching clusters at a higher flow-rate eliminated most of the over-milking period.
- Effects were more apparent at p.m. milking due to low udder fill.

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The list of standard abbreviations for JDSC is available at adsa.org/jdsc-abbreviations-24. Nonstandard abbreviations are available in the Notes.

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# Measurement of cow comfort during milking on different cluster removal settings through the use of leg-mounted accelerometers

Martin Browne,[1,2]* Pablo Silva Boloña,[1] and John Upton[1]

**Abstract:** Increasing levels of data are routinely collected on modern dairy farms. These include multiple variables measured by milking machine sensors and software and cow-attached sensor data, used predominantly for fertility and health monitoring. Following milking efficiency principles, including milking gently, quickly, and completely, there is utility in investigating how various milking machine settings affect gentleness of milking through a proxy measurement of cow comfort during milking. The use of leg-mounted accelerometers was investigated as a noninvasive labor-efficient means of estimating cow comfort on different automatic cluster remover (ACR) milk flow-rate switch-point settings. Accelerometer step count measurements during milking were collected from 37 cows divided into 2 groups allocated to either an ACR milk flow-rate switch-point setting of 0.2 kg/min or 0.8 kg/min for a 2-wk period and then crossed over to the other setting. Significantly more rear leg stepping occurred during daily milking (combined step count during a.m. and p.m. milkings) where the ACR activated at 0.2 kg/min (11.7 steps) compared with 0.8 kg/min (10.1 steps). Shorter milking interval between a.m. and p.m. milkings resulted in lower udder fill and reduced milk flow-rate. Under these lower udder fill conditions, rear leg movement, as an indicator of cow comfort, reduced when milk flow-rate switch-point for cluster removal increased from 0.2 kg/min (5.75 steps) to 0.8 kg/min (4.96 steps). There was no significant difference between stepping rates on both cluster removal settings during a.m. milkings. Similarly, no significant differences were noted in assessed postmilking teat condition, which was conducted after a.m. milking. The 0.2 kg/min setting extended total daily milking time by 70 s, resulting in lower mean flow-rates while producing similar milk yield. Higher vacuum levels at the teat-end were also recorded on this milking setting. This provides further incentive to consider cluster removal settings above 0.2 kg/min.

Three pillars of successful milking are recognized as the ability to milk gently, quickly, and completely. Optimized milking machine settings, including the use of automatic cluster removers (**ACR**), can affect all 3. Automatic cluster removers, through automating the end of milking process, also attenuate increased labor demands of expanding herd size (Hogan et al., 2022). Optimized ACR settings (milk flow-rate switch-point at which ACR detach clusters from a cows' udder) have been found to reduce milking time without adversely affecting milk yield or quality (Jago et al., 2010; Edwards et al., 2013). By preventing vacuum build-up on the teat-end (experienced during low milk flow conditions such as at the end of milking), higher ACR milk flow-rate switch-points may also benefit cow health and comfort (Upton et al., 2023). The International Dairy Federation recommends that specific setting of switch-points and delay settings are evaluated within each farm (Poulet et al., 2018).

Suboptimal cow comfort during milking can lead to several issues. Eicker et al. (2000) highlighted how, when cows experience discomfort at low or no milk flow levels, it could lead to reluctance to subsequently enter the milking parlor, extending row filling and overall milking time. Bruckmaier (2005) found nervous cows tended to have reduced oxytocin levels, which inhibited milk let-down, resulting in low milk flow and increased vacuum levels acting on the teat. This in turn could precipitate cluster kick-off, further interrupting the milking process.

Holst et al. (2021) described mechanical impacts on teat tissue from milking equipment that increased risk of cluster kick-offs with reduced milk flow. The seal between the teat-barrel and milking cluster liner likely weakened as milk flow decreased. This in turn increased mouthpiece chamber (**MPC**) vacuum, which can increase teat-barrel congestion as well as ringing at the teat base, both of which could negatively affect cow comfort. Penry et al. (2017) found high MPC vacuum, which induced teat-barrel congestion capable of also constricting blood flow from the teat-end.

Visual or physical assessment can be conducted on teats to assess the impact that any forces exerted on the tissue during the milking process can have on short-, medium-, and long-term changes to teat condition. Mein et al. (2001) reviewed classification methodologies of bovine teat condition used to assess impact of milking management and equipment on teat tissue.

Various strategies have been employed to develop a proxy metric likely to indicate the level of cow comfort during milking. Blood concentration of oxytocin, which induces calmness (as well as being critical in milk let down) or the stress hormone cortisol, indicative of an antagonistic effect, have been measured on various occasions (Bruckmaier et al., 1993; Watters et al.,

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2015; Wredle et al., 2022). Blood sampling during milking is a restrictive methodology with respect to the objective pursued in these instances. The procedure itself is invasive in nature with cows usually catheterized to enable repeated sampling. Collection of samples during milking is likely to affect the secretion of hormones of interest and is resource intensive in terms of sample collection and analysis.

Another labor intensive method of assessing cow comfort during milking is by visual assessment of animal movement while milking. This can be conducted directly at milking time by an observer (Meyer et al., 2021) or by analyzing video footage of milkings (Wenzel et al., 2003). No example of an automated method based on computer vision techniques has been found to identify stepping or kicking events. Pastell et al. (2006) used video recordings together with load sensors under the milking box platform of an automatic milking system where cows stood during milking to measure foot displacement. They also used laser measurement of lateral movement for estimating respiration rate. Foot displacement measurement by load cells in the parlor stall was similarly used by Reinemann et al. (2002) to elicit differences in cow activity during milking based on electrical current paired with 2 other common milking machine defects.

Raoult et al. (2021) attached accelerometers to milking clusters to assess leg movement during milking. This relied on hind leg movement being transmitted to rocking movement of the milking claw with sufficient accuracy. Periods of leg activity rather than number of leg movements were calculated as varying numbers of rocking motion movements result from different steps or kicks. Cows could also step repeatedly during the same period of rocking motion of the cluster. Movement detection by a cluster-mounted accelerometer could also be affected by movement induced solely as part of the milking process such as milk flow, pulsation, and vacuum fluctuations.

Meyer et al. (2021) found type rather than prevalence of leg movement corresponded to milking conditions likely to cause discomfort with kicking events associated with increased vacuum forces on the teat-end. They also raised the possibility that the presence of personnel other than the regular milking staff could affect leg movement during milking.

Leg-mounted accelerometers were previously employed to assess cow rear leg movement during milking (Upton et al., 2023). Although designed as a full crossover trial, a failure with recording of valid accelerometer data over half of the trial period resulted in an inability to control for the effect of cow, necessitating the need for further investigation. That work also included validation of the accelerometers used by conducting an agreement study with visual assessment data and found the accelerometer step count logged 76% of the quantity of leg movements observed.

Scope exists to relate noninvasive measures of cow comfort during milking to increased data collection capacity of modern milking infrastructure, particularly milk flow profile data now routinely recorded by more automated parlors. The present study filled this gap in knowledge by synchronizing leg-mounted accelerometer data recorded over the milking period with various milking machine data disaggregated based on ACR milk flow-rate switch-point. Such output can augment pre-existing data in determining optimal ACR settings.

This study was conducted with approval of the Teagasc Animal Ethics Committee (TAEC; TAEC2022–336) and in accordance with the Animal Health and Welfare Act 2013 (updated to September 1, 2023; Law Reform Commission, 2023) and European Council Directive 86/609/EEC (European Council, 1986).

This experiment was carried out at the Teagasc Dairy Research Centre in Moorepark, Ireland. Forty-four cows (35 Holstein Friesian and 9 Jersey × Holstein Friesian) included in the trial recorded a milk SCC of less than 150,000 cells/mL at 2 weekly recordings before the start of the experiment when they were on average 98 DIM (range 61–131 DIM) and 2.5 parity (range 1–7). Cows were blocked by breed and parity (1 and >1) and assigned to one of 2 ACR treatment groups balanced for milk yield, milking time, and SCC.

IceTag accelerometers (Ice Robotics) were attached to a rear leg of each cow to record kicking or stepping during milking. The accelerometers were removed from the cows at the end of the experiment when the data were downloaded. Accelerometer data were combined with milking time data (based on cluster attachment time and duration of milking) downloaded from the milking management software (Dairymaster Milk Manager) to calculate the number of steps measured over the duration of milking.

A mid-line 30 unit herringbone, swing-over milking system (Dairymaster) was used to milk the cows on the trial twice per day. The cows received a full premilking routine consisting of fore-stripping, prespraying, and wiping with a dry paper towel before cluster attachment. The milking system used 4 × 0 (simultaneous) pulsation milking at a rate of 60 cycles per minute and ratio of 65:35 (a, b, c, and d phases of pulsation were 103, 547, 92, and 258 ms, respectively). System vacuum was set at 47 kPa. Automatic cluster removers and weigh-all milk meters were fitted (Dairymaster). The milking management software recorded the milk flow-rate from each cow at every milking at 5-s intervals (referred to as milk flow-rate profiles) and removed clusters at 1 of 2 milk flow-rate switch-points based on the following pre-programmed cow treatments: (1) **MFR0.2**: cluster removed at milk flow-rate of 0.2 kg/min, and (2) **MFR0.8**: cluster removed at 0.8 kg/min. A cross-over design was implemented whereby all cows received each treatment. The experiment began on May 25, 2022. Each group of 22 cows spent 2 wk on each treatment. The experimental unit was cow. Accelerometer data from a previous experiment were used to determine group size.

Milking data—a.m. and p.m. milk yields (kg), milking duration (s), average milk flow-rate (**AMF**, kg/min), and peak milk flow-rate (**PMF**, kg/min)—were downloaded from the milking management software. Nonstandard milking variables were computed from the milk flow-rate profiles. These variables were a.m. and p.m. dead time (time from cluster attachment to reach a milk flow-rate of 0.2 kg/min; s), a.m. and p.m. time to peak (time from cluster attachment to reach PMF; s), and a.m. and p.m. low-flow time (time that milk flow-rate remained below 0.2 kg/min before cluster removal; s).

A composite sample of milk was taken from each cow once per week for composition and SCC analysis via a Fossomatic machine (Foss). The SCC data were log-transformed ($\log_{10}$) for subsequent analysis due to nonnormal distribution. All data were combined in SAS 9.4 (SAS Institute Inc.). Milking durations of less than 183 s were removed from the dataset. This was the minimum time set on the milking machine above which the cluster removers could be activated. Milkings with a yield of less than 1 kg were removed. This filtering removed less than 1% of data points from the dataset.

The first 2 d of each period were also removed from the dataset to minimize carryover effects.

The teats of each cow were assessed after a.m. milking once per week by the same trained observer. Teats were scored for teat-end congestion and ringing at the base of the teat-barrel according to the method described by Mein et al. (2001). In addition to each quarter level teat-end score (**TE**), each cow received an overall cow level teat-end score (**TEC**) of normal or firm. A TEC score of firm was recorded if one or more of the individual teat-ends were firm on the day of recording. Similar methodology was used for teat-barrel scoring (**TB** and **TBC**) using normal or ringed classification.

A milking time test was carried out using a VaDia device (BioControl) on 4 occasions during the study to record short milk-tube vacuum, mouthpiece chamber vacuum, and pulsation-chamber vacuum. This dataset included 36 milkings from 33 cows split across both treatments.

Statistical analyses were performed in SAS 9.4 (SAS Institute Inc.). A generalized linear mixed model was used to analyze the effect of the treatment on various leg movement variables using the GENMOD negative binomial regression procedure as follows:

$$y = \text{Treatment} + \text{Period} + \text{Breed} + \text{Parity Class}, \quad [1]$$

where y = steps during milking per day, steps during milking per day excluding minute of attachment, steps per milking a.m., steps per milking excluding minute of attachment a.m., steps per milking p.m., steps per milking excluding minute of attachment p.m. Treatment = MFR0.2 and MFR0.8. Period = period of data recording (2 × 2 wk intervals). Breed = Holstein Friesian or other. Parity Class = parity 1 or >1. Treatment, cow, period, parity class, and breed were declared as class variables. Cow was defined as a repeated measure.

A linear logistic regression model was used to analyze the effect of treatment on the TE, TB, TEC, and TBC score of the cows using the LOGISTIC procedure as follows:

$$y = \text{Treatment} + \text{Period} + \text{Breed} + \text{Parity Class}, \quad [2]$$

where y = TE, TB, TEC, or TBC. Treatment = MFR0.2 or MFR0.8. Treatment, breed, cow, period, and parity class were declared as class variables.

A generalized linear mixed model was used to analyze the effect of the treatment on various dependent variables using the MIXED procedure as follows:

$$y = \text{Treatment} + \text{Period} + \text{Breed} + \text{Parity Class}, \quad [3]$$

where y = milking duration, milk yield, AMF, PMF, $\log_{10}$ SCC, dead time, time to peak, and low-flow time. Treatment, breed, cow, period, and parity class were declared as class variables. Cow was defined as a random variable and a repeated measure. An autoregressive covariance structure was used, SAS 9.4 command AR(1). This structure has homogeneous variances and correlations that decline exponentially with distance.

Optimizing cow comfort during milking is integral to implementation of the 3 pillars of successful milking. Critical to this is selecting the appropriate milk flow-rate switch-point for cluster removal to avoid pain and discomfort caused by prolonged increased vacuum load on teat tissue. Any such discomfort could precipitate increased movement during milking. Establishing an easily measurable and reliable metric for rear leg movement could serve as a good indicator of discomfort experienced across various milking regimens.

Thirty-seven IceTags with complete data were downloaded at the end of the experiment. The others had data or battery failures or were lost from the cows' legs. During daily milking (a.m. and p.m. milkings combined) the step count of 11.7 on MFR0.2 was significantly higher than 10.1 on MFR0.8 ($P = 0.02$; Table 1). This was also the case when analyzing only p.m. milkings ($P = 0.01$). Leg movement data were also interrogated while excluding the minute of cluster attachment. This was done to mitigate against other sources of agitation the cow might experience during the cluster attachment process separate from any discomfort experienced due to increased vacuum acting on the teat-ends resulting from declining milk flow toward the end of milking. For p.m. milkings, excluding minute of cluster attachment reduced step count by 35% on MFR0.2 and 37% on MFR0.8 when compared with the total for the entire p.m. milkings, yet the same significant difference remained between treatments. Differences in leg movement between ACR treatments during a.m. milkings, with or without minute of cluster attachment, were not significant.

This is in contrast to previous work where differences in leg movement for a.m. milkings were significant but p.m. milkings were not (Upton et al., 2023). Due to recording equipment failure in the earlier work a full crossover trial could not be completed. The full crossover nature of the present study was able to control for the effect of cow. In contrast to the previous work this study was focused more toward the peak lactation period where the risk of bimodal milk flow, which would likely increase teat-end vacuum, was less.

**Table 1.** Least squares means for rear leg movement parameter results by treatment[1]

| Parameter | ACR setting | | Chi square |
|---|---|---|---|
| | MFR0.2[1] | MFR0.8 | *P*-value |
| Steps during milking per day[2] | 11.7 | 10.1 | 0.02 |
| Steps per milking a.m. | 5.74 | 5.41 | 0.35 |
| Steps per milking p.m. | 5.75 | 4.96 | 0.01 |
| Steps during milking per day excluding minutes of cluster attachment | 8.18 | 6.63 | 0.01 |
| Steps per a.m. milking excluding minute of cluster attachment | 4.16 | 3.68 | 0.05 |
| Steps per p.m. milking excluding minute of cluster attachment | 3.72 | 3.11 | 0.01 |

[1]MFR0.2 where the cluster was removed at 0.2 kg/min; MFR0.8 where the cluster was removed at 0.8 kg/min.

[2]Milking duration = time from cups on to cups off, minus 1 min when excluding minute of attachment.

**Table 2.** Teat scoring results for teat-end and teat-barrel congestion by treatment

| Parameter | ACR setting | | P-value |
|---|---|---|---|
| | MFR0.2[1] | MFR0.8 | |
| TEC[2] | 22 | 21 | 0.80 |
| TE[3] | 7.7 | 7.1 | 0.72 |
| TBC[4] | 34 | 37 | 0.70 |
| TB[5] | 14 | 14 | 0.93 |

[1]MFR0.2 where the cluster was removed at 0.2 kg/min; MFR0.8 where the cluster was removed at 0.8 kg/min.

[2]TEC = percentage of cows with at least one teat-end scored as firm.

[3]TE = percentage of teat-ends scored as firm.

[4]TBC = percentage of cows with at least one teat-barrel scored as ringed.

[5]TB = percentage of teat-barrels scored as ringed.

The IceTag accelerometers used had tri-axial capability to measure movement in x, y, and z planes. However, the step count metric, designed to detect stepping movement with or without forward movement, was preferred in the analysis of the present study which, similar to the work conducted by Raoult et al. (2021) with cluster mounted accelerometers, relied on movement detection in only one plane. Visual observation work of rear leg movement during milking conducted by Meyer et al. (2021) found that type (kicking vs. stepping) rather than frequency of leg movement related to elevated mouthpiece chamber vacuum levels.

Assessment for postmilking short-term changes in teat tissue condition as detailed by Mein et al. (2001) showed no significant differences between both cluster removal settings (Table 2). Such assessment, even when conducted by a trained observer, is a more subjective measure in contrast to the objective measure of leg movement logged by the accelerometer. Unfortunately, all teat scoring assessments were conducted after a.m. milkings so it was not possible to determine any treatment impact on tissue condition from p.m. milkings where significant differences in leg movement were recorded. The p.m. milkings were generally of shorter duration with lower average flow-rates. Values for teat-end congestion were generally within recommended ranges given by DairyNZ (2012). These state that incidence of both teat-barrel ringing and teat-end firmness should be below 20% of cows in the herd and 8% of overall teats within a herd to promote good udder health. Incidence of teat-barrel ringing in the present study was somewhat above this recommendation (TBC 34% for MFR0.2, 37% for MFR0.8). The research farm where the study was conducted practiced more extensive pre-milking udder preparation than would be typical of Irish pasture-based farms. This, allied to the study being conducted close to the time of peak lactation, should mitigate against bimodal milk flow. However, daily milk yields of under 20 kg on this grass-based system would still be relatively low compared with more intensive indoor systems with udder fill further reduced at p.m. milkings due to the uneven 16:8 milking interval.

Consistent with previous work (Upton et al., 2023), there was a significant ($P < 0.001$) effect of treatment (milk flow-rate switch-point) on AMF, low-flow time, and milking duration (Table 3). Daily milking duration for MFR0.8 was 70 s (12%) shorter than MFR0.2. The AMF for MFR0.8 was 0.24 kg/min (14%) greater than MFR0.2. Conversely, low-flow time for MFR0.8 was 21 s (379%) less than MFR0.2. Treatment differences in the limited

**Table 3.** Least squares means estimated from the mixed model analysis for the main milking parameter results by treatment

| Parameter | ACR treatment | | P-value |
|---|---|---|---|
| | MFR0.2[1] | MFR0.8 | |
| Milk yield (kg) | 18.8 | 18.6 | 0.24 |
| a.m. milk yield (kg) | 12.5 | 12.4 | 0.65 |
| p.m. milk yield (kg) | 6.2 | 6.1 | 0.07 |
| Total solids (kg/d) | 1.65 | 1.61 | 0.17 |
| Milk duration (s) | 643 | 573 | <0.001 |
| a.m. milk duration (s) | 379 | 345 | <0.001 |
| p.m. milk duration (s) | 263 | 228 | <0.001 |
| Peak flow-rate (kg/min) | 3.72 | 3.72 | 0.89 |
| a.m. peak flow-rate (kg/min) | 3.90 | 3.89 | 0.79 |
| p.m. peak flow-rate (kg/min) | 3.54 | 3.54 | 0.90 |
| Average flow-rate (kg/min) | 1.75 | 1.99 | <0.001 |
| a.m. average flow-rate (kg/min) | 2.01 | 2.23 | <0.001 |
| p.m. average flow-rate (kg/min) | 1.39 | 1.62 | <0.001 |
| Dead time (s) | 11.5 | 11.9 | 0.24 |
| a.m. dead time (s) | 5.9 | 6.2 | 0.28 |
| p.m. dead time (s) | 5.5 | 5.7 | 0.59 |
| Time to peak (s) | 261 | 265 | 0.48 |
| a.m. time to peak (s) | 149 | 150 | 0.72 |
| p.m. time to peak (s) | 112 | 115 | 0.37 |
| Low-flow time (s) | 27 | 5.71 | <0.001 |
| a.m. low-flow time (s) | 11.8 | 4.1 | 0.001 |
| p.m. low-flow time (s) | 15.6 | 1.8 | <0.001 |
| $Log_{10}$ SCC[2] | 1.48 | 1.47 | 0.90 |
| SCC ('000 cells/mL) | 50 | 50 | 0.98 |

[1]MFR0.2 where the cluster was removed at 0.2 kg/min; MFR0.8 where the cluster was removed at 0.8 kg/min.

[2]Log-transformed somatic cell count.

number of records of overmilking measured by VaDia devices at a.m. milkings were even more pronounced with overmilking time for MFR0.8 being 42 s less than MFR0.2. No effect on yield, peak flow-rate, or SCC was found and no case of clinical mastitis was recorded.

While there was a significant reduction in low-flow time as measured by milk flow profiles between MFR0.2 and MFR0.8 for both a.m. and p.m. milkings ($P = 0.001$ and $P < 0.001$, respectively; Table 3), there was much greater proportional reduction in low-flow time when employing the higher milk flow-rate switch-point for p.m. milkings compared with a.m. milkings. This may explain why the difference in step count when comparing both settings was significant for p.m. milkings but not for a.m. milkings. It is also possible that such effects may partially result from differences in flow-rate at the beginning of milking. This could eventuate if the marginal volume of cisternal milk left in the udder under a higher milk flow-rate switch-point at a.m. milking enabled greater milk volume readily available for removal at the lower yielding p.m. milking. Although dead time and time to peak data from Table 3 do not support the latter hypothesis, the flow-rate curves depicted in the graphical abstract do hint at a slightly less pronounced bimodal pattern for MFR0.8 than MFR0.2 during p.m. milkings.

The MFR0.2 resulted in lower mean milk flow-rates ($P < 0.001$). Lower milk flow-rates tend to increase vacuum under the teat (Bruckmaier, 2005), potentially affecting cow comfort. From the limited number of VaDia records, this measurement was somewhat higher on the MFR0.2 treatment producing average short milk-tube vacuum levels of 34.7 kPa for the main milking period and 43 kPa for the overmilking period compared with 33.6 kPa for the main milking period and 41.1 kPa for the overmilking period on the MFR0.8 setting.

Significantly more rear leg stepping ($P = 0.02$) occurred during daily milking (11.7) where the ACR activated at 0.2 kg/min compared with 0.8 kg/min (10.1). A significant difference between treatments was also found for rear leg movement during p.m. milkings ($P = 0.01$). No significant difference was found between thresholds for rear leg movement during a.m. milking. Shorter milking intervals between a.m. and p.m. milkings resulted in lower udder fill and reduced milk flow-rate (32% lower on MFR0.2) with less leg movement when detaching clusters at a higher milk flow-rate switch-point.

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## Notes


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The authors have not stated any conflicts of interest.

**Nonstandard abbreviations used:** ACR = automatic cluster remover; AMF = average milk flow-rate; MFR0.2 = cluster removed at milk flow-rate of 0.2 kg/min; MFR0.8 = cluster removed at milk flow-rate of 0.8 kg/min; MPC = mouthpiece chamber; PMF = peak milk flow-rate; SFI = Science Foundation Ireland; TB = percentage of teat-barrels scored as ringed; TBC = percentage of cows with at least one teat-barrel scored as ringed; TE = percentage of teat-ends scored as firm; TEC = percentage of cows with at least one teat-end scored as firm.