Improving ergonomics in milking parlors: Empirical findings for optimal working heights in five milking parlor types

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ABSTRACT

Milking postures have shifted from seated milking in tethered stalls to milking in a standing position in parlors. However, the musculoskeletal workload of dairy farmers remains high. Previous studies have shown that different working heights affect ergonomics, but they could not objectively evaluate and quantify the workload. The aim of the present study was to assess the effect of working height in different milking parlor types on the milker's workload during the task of attaching milking clusters. Computer-assisted recording and long-term analysis of movements were used to record positions of joints and body regions while performing certain tasks in terms of angular degrees of joints (ADJ) according to the neutral zero method. The 5th, 50th, and 95th percentiles described the distribution of angular degree values measured for each joint. The ADJ were evaluated according to international standards and other scientific literature on the issue to assess the muscular load. The workload was compared between 5 parlor types (auto tandem, herringbone 30°, herringbone 50°, parallel, and rotary) on 15 farms with 2 subjects per parlor and 1 milking period per subject. The working height was defined as a coefficient based on the milker's body height, the floor level, and the cow's udder height. The data recorded during the attachment task were analyzed using generalized linear mixed-effects models taking into account the hierarchical experimental design. The results indicated that the interaction of the cow's udder height, the milker's body height, and the parlor type had a larger effect on ergonomics than each parameter had independently. The interaction was significant in at least 1 of the 3 percentiles in 28 out of 31 ADJ. The postural differences between parlor types, however, were minor. A milking health formula was created to calculate the ideal depth of pit by considering the parlor type, the milker's

height, and the mean herd udder height. This formula can be used to develop individual recommendations for future parlor construction.

Key words: guideline, milking health formula, posture, workload, herringbone

INTRODUCTION

Dairy farmers display high levels of musculoskeletal disorders; thus, the present study aimed at analyzing and improving posture during milking. The milking process represents a large part of the daily work routine on dairy farms, and despite position being improved compared with milking in stanchion systems, it has been associated with awkward postures (Jakob et al., 2009). Although milking may not be perceived as strenuous because it has been considered light work for the cardiovascular system (Perkiö-Mäkelä and Hentilä, 2005), several questionnaire-based studies showed that a large percentage of dairy farmers suffer from musculoskeletal problems, particularly disorders associated with the wrists and hands (Stål et al., 1996; Kauke et al., 2010; Kolstrup et al., 2010). Pinzke (2003) reported 83% of men and 90% of women to be affected by such problems, which is in line with Douphrate et al. (2009), who stated that 80% of dairy farmers suffer from musculoskeletal disorders. In addition, Karttunen and Rautiainen (2011) reported a decline in working ability, which was caused by these problems, in 39% of dairy farmers.

Health and efficiency considerations have influenced dairy husbandry in the past. As a consequence of dairy farm automation and industrialization, herd sizes have increased and milking is commonly performed in parlors. Previous research assessed the muscular load of the upper extremities during milking in parlors compared with that during milking in a tethered system and showed that the peak loads in milking parlors were decreased (Stål et al., 2000). Despite the expectation that milking in parlors reduced the physical load, problems in the neck, shoulder, and upper extremities of milkers remained (Arborelius, 1986; Jakob et al., 2012).

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Tuure and Alasuutari (2009) reported that 1 out of 3 milkers who worked in a loose-housing barn were affected by problems in the upper limb, such as the neck and shoulder regions. Previous ergonomic research has focused on assessing the workload of the elbow, shoulder, and hip regions, but results also demonstrated a significant effect on the torsion and side bending of the trunk when milkers had to operate heavy milking clusters (Jakob et al., 2009). Liebers and Caffier (2006) also identified severe strains on the milkers' knees, upper limbs, and lower backs. Specific research investigated the ergonomic benefit of support arms, because milking clusters were lifted in a static posture and could weigh up to 3 kg, yet surprisingly little effect was seen (Stål et al., 2003). Conversely, the distance between the udder and the milker has been reported to cause a leverage action of up to 9 N·m, indicating a high muscular load during the attachment task (Jakob et al., 2007). Pinzke et al. (2001) described the attachment task as the most strenuous task, because it involved the lifting and attaching of the milking cluster. Furthermore, Kauke et al. (2010) reported that 14% of survey participants perceived cluster attachment to be most strenuous. These results were in line with other international studies that indicated that the attachment task negatively affected ergonomics (Stål et al., 1996, 2003; Jakob et al., 2012). Whereas all tasks during milking were carried out in the udder region, and thus the working height was relatively similar, the attachment task was particularly interesting, as the milker spent 0.2 min/cow and milking procedure on attaching the milking cluster (Schick, 2000). During this period of time, the milker had to lift the cluster, which weighed between 2.6 and 3.1 kg, to the udder base; thus the task is physically more demanding than other tasks carried out during milking, such as premilking, stimulation, swiveling the milking cluster, or dipping or spraying the teats.

Ergonomics during milking were determined by multiple factors, such as parlor type, cow dimension, udder base height, parlor height, and milker height, and were linked strongly to the horizontal distance between the cow and the milker (Jakob et al., 2009). Of the few studies that have assessed the ergonomic differences in milking parlor systems, Stål et al. (2003) reported improved wrist positions in rotary systems compared with herringbone and tethered systems, indicating ergonomic differences between parlor types. Results from early studies suggested that ergonomics could be improved when floors were adjusted to a height at which the milker's elbows were considered to be at an ideal level during the working procedure (Billon et al., 1985; Stål and Pinzke, 1991). Jakob et al. (2012) further stated that muscle activity was lowest when light milking clusters were used and the teat ends were

at shoulder level. Hence, some parlors were equipped with adjustable floors to enable ideal ergonomic posture for milkers of different heights. However, studies have shown that udder base height varies between 22 and 69 cm (Jakob et al., 2009), with a mean of 56 cm depending on the age and breed of the cows (Jakob, 2011). Jakob et al. (2009) reported that such factors could cause a variation of the ideal floor height for good posture of up to 50 cm. Furthermore, Billon (2009) found that the ideal depth of pit could vary between parlor types and advised that pits in parallel parlors should be higher than other pits. Tuure and Alasuutari (2009) further indicated differences between parlor types, as they reported horizontal reaching distance in herringbone 30° (**HB 30°**), autotandem (**ATD**), and parallel (**PAR**) parlors to vary between 36 and 58 cm. As body heights vary between milkers, a practical guide is needed for adjusting floors to the ideal working height at which the milker can work in an optimized ergonomic posture. Research, therefore, needs to identify methods to improve ergonomics in milking parlors to reduce the negative effect of milking postures on the musculoskeletal system of milkers. The present study aimed to analyze ergonomics in different milking parlor types and develop individual recommendations on working heights to improve posture in a variety of milking parlors.

MATERIALS AND METHODS

Body Posture Recording with the CUELA System

Computer-assisted recording and long-term analysis (**CUELA**) was used to record musculoskeletal motions. The CUELA system has been used to assess ergonomics in different professions, such as nursing (Freitag et al., 2007) and flight attendance (Glitsch et al., 2007), and in several work environments, such as visual display unit workplaces (Ellegast et al., 2012b), places that require the pulling and pushing of waste containers (Backhaus et al., 2012), offices (Ellegast et al., 2012a), and animal facility washrooms (Kiermayer et al., 2011). Additionally, the CUELA system was validated in a milking parlor environment during a feasibility study (Kauke et al., 2009).

The CUELA system uses movement sensors (ADXL 3D accelerometers 103/203, Analog Devices, Norwood, MA; and muRata ENC-03R gyroscopes, Murata, Tokyo, Japan) to record the inclination and torsion of joints. Positions of joints are recorded in terms of angular degrees of joints (**ADJ**) according to the neutral zero method (Ryf and Weymann, 1995). The system further records how long each posture is maintained (Ellegast, 1998).

Experimental Design and Subjects

The study was performed in a commercial setting on a total of 15 farms. The following parlor types were assessed on 3 farms each: HB 30°, herringbone 50° (**HB 50°**), ATD, PAR, and rotary (**ROT**). Each farm was sampled by monitoring 2 different subjects (milkers) for the duration of 1 full shift of milking (6 subjects per milking parlor type). Ultimately, each cow on every farm was milked by 2 milkers. All 30 subjects (4 female, 26 male) were experienced professional milkers and accustomed to milking in the investigated environment. The subjects were familiar with both the cows and the parlor. All subjects were introduced to the CUELA system and participated voluntarily. The CUELA system was attached during 1 milking period per subject and recorded the movement of monitored joints and body parts with a continuous sampling rate of 50 Hz. Subject, parlor, and udder details are displayed in Table 1.

Data Processing

The ADJ data were processed with the CUELA-specific statistical software WIDAAN (Winkel Daten Analyze, IFA, Sankt Augustin, Germany). The subjects were filmed simultaneously to the data recording. The WIDAAN software links the video to the CUELA data and visualizes the movements in a motion figure. This facilitated the precise separation of events and, therefore, allowed us to define specific tasks or phases during milking, such as cluster attachment, stimulation, premilking, dipping or spraying, and swiveling the milking cluster. The data were subsequently assigned to the specific tasks. Only the task “attachment” was evaluated in the data analysis. A standard rating was available for 25 joint movements; each movement could result in various joint positions that were expressed

as ADJ and were rated as acceptable, conditionally acceptable, or not acceptable in regard to ergonomics (Drury, 1987; McAtamney and Corlett, 1993; ISO, 2000; European Commission, 2005; Hoehne-Hückstädt et al., 2007; Deutsche Gesetzliche Unfallversicherung, 2013). Only the 25 rated joint movements monitored during the attachment task were considered in the analysis (see Table 2).

Height Coefficient

A height coefficient was created to present the ratio between working height and milker’s height by using the formula: (individual udder base height + floor level)/milker’s individual height. This height coefficient was used to account for the effects of the milker’s body height and the cow’s udder height in the statistical analysis. The 5th, 50th, and 95th percentiles (WIDAAN output) of the ADJ express the measuring incidence of a specific posture. These were statistically evaluated to find differences in both the median (50th percentile), the 5 lowest (5th percentile), and the 5 highest (95th percentile) percent of measured postures.

Statistical Analysis

The generalized linear mixed-effects model (Pinheiro and Bates, 2000) was used to evaluate the target variables. Statistical differences were evaluated separately for the 5th, 50th, and 95th percentiles of each ADJ. The statistical analysis was performed in R 1.9.1 (R Development Core Team, 2006), and parlor type (factor with 5 levels: ATD, HB 30°, HB 50°, PAR, and ROT), height coefficient (continuous), and all possible 2-way interactions between parlor type and height coefficient were fixed effects. Milkers nested in cows and in

Table 1. Subject and milking parlor specifications (mean ± SD) and height coefficients (minimum and maximum values) by parlor type

Item	Subject (milker)					Milking parlor			Height coefficient	
	Age (yr)	Height (cm)	Shoulder height (cm)	Weight (kg)	Dominant hand (right/left/both)	Depth of pit (cm)	Scaffold height (cm)	Milking cluster (kg)	Minimum	Maximum
Parlor type										
Auto tandem	34 ± 14	172 ± 7	142 ± 8	81 ± 21	3/2/1	90.4 ± 1.7	164.9 ± 7.6	2.9 ± 0.6	0.72	1.09
Herringbone 30°	36 ± 12	177 ± 4	146 ± 4	81 ± 12	6/0/0	92.4 ± 4.0	155.2 ± 8.6	2.6 ± 0.4	0.70	0.96
Herringbone 50°	46 ± 5	176 ± 4	146 ± 4	77 ± 7	4/2/0	92.0 ± 3.1	165.6 ± 3.7	3.1 ± 0.2	0.71	0.94
Parallel	36 ± 10	176 ± 5	146 ± 5	75 ± 16	5/1/0	99.1 ± 7.3	169.4 ± 3.9	2.7 ± 0.0	0.71	0.98
Rotary	33 ± 11	176 ± 4	146 ± 5	83 ± 11	5/1/0	91.6 ± 3.8	168.4 ± 8.0	2.6 ± 0.6	0.67	0.93

Table 2. Percentage of not acceptable angular degrees of joints (ADJ) in the 5th, 50th, and 95th percentiles for joints and body regions or movements, expressed as means across all milking parlor types

Joint/body region	Sensor number	Movement	5th	50th	95th
Head	15	Inclination forward	73	45	17
	16	Inclination sideward	68	51	68
Cervical spine	5	Lateral flexion	53	33	57
	6	Flexion/extension	92	68	40
Trunk movements	22	Flexion/extension	39	20	7
	23	Lateral flexion	2	1	4
	21	Torsion	0	0	0
Back bending	19	Lateral inclination	2	0	1
	20	Inclination	46	30	19
Knee joint	13 (left)	Flexion/extension	42	48	71
	14 (right)		51	58	78
Shoulder joint	28 (left)	Ad-/abduction	9	31	53
	29 (right)	Flexion/extension	33	62	82
	30 (left)	Inward/outward	11	39	71
	31 (right)	rotation	17	45	75
	32 (left)		25	12	13
Cubital joint	33 (right)		17	6	25
	3 (left)	Flexion/extension	94	70	19
	4 (right)		100	77	23
Lower arm	34 (left)	Pronation/supination	23	4	27
	35 (right)		14	9	30
Wrist	9 (left)	Radial/ulnar duction	50	28	24
	10 (right)		13	3	16
	7 (left)	Flexion/extension	3	0	2
	8 (right)		0	0	5

farms were included as random effects. The residuals and random effects were checked graphically to ensure that they met the model assumptions.

Proportion of Not Acceptable Postures

The raw data were further analyzed by calculating the percentage of acceptable, conditionally acceptable, and not acceptable ADJ in all percentiles of the 25 rated joint movements. The proportion of not acceptable postures across all parlors was calculated to establish which joints were largely affected by poor working posture.

Model Development

The statistical output from recordings and analysis of the rated joints and body parts were used in a mathematical model to calculate the ADJ at specific constant factors between 0.7 and 1.0 (in intervals of 0.05). The generalized linear mixed effects model not only calculates the significance of the model components, but also the significance of their interaction. In this case the interaction was significant, and the estimates that were calculated by R could be used in a function:

Estimate of the angular degree at a specific constant factor = estimate intercept + estimate milking parlor type + estimate height coefficient $\times$ specific constant factor which will be calculated + estimate height coefficient $\times$ estimate interaction.

The statistical data were used to assess the most acceptable posture by summarizing the numbers of ADJ that were rated as acceptable (Deutsche Gesetzliche Unfallversicherung, 2013) at a specific constant factor. The numbers of acceptable ADJ across all ADJ in the 5th, 50th, and 95th percentiles were counted and summarized for each milking parlor type and height coefficient. If 100% of all modeled ADJ were acceptable, this would result in a total of 25 positive occurrences in each of the 3 percentiles and a maximal score of 75. The estimates of the height coefficients resulting in the most acceptable postures were used as a constant factor in the milking health formula.

RESULTS

Empirical Data

A significant ($P < 0.05$) interaction of parlor type and height coefficient was observed in 22 out of 31 (50th percentile) or 25 out of 31 (5th and 95th percentiles)

Table 3. Number of acceptable angular degrees of joints (ADJ) across all joint movements in regard to the 5th, 50th, and 95th percentiles at a specific constant factor (modeled data; maximum value per constant factor when all ADJ are acceptable is 75)¹

Parlor type	Constant factors							Σ
	0.7	0.75	0.8	0.85	0.9	0.95	1	
Auto tandem	44	45	45	46	45	45	39	307
Herringbone 30°	42	41	40	42	42	40	42	289
Herringbone 50°	48	49	46	42	37	39	36	297
Parallel	42	40	38	38	33	34	32	257
Rotary	39	41	40	36	34	35	34	259

¹The values in bold show the largest number of acceptable ADJ for the individual parlor type.

ADJ (the levels of significance are stated in Figure A1). In contrast, few ADJ were influenced significantly by only 1 of the main effects (parlor type or height coefficient). The height coefficient was significant ($P < 0.05$) in 3 out of 31 ADJ (in the 5th, 50th, and 95th percentiles: knee flexion left; shoulder adduction right; in the 5th and 50th percentiles: lower arm pronation left). The parlor type was significant ($P < 0.05$) in 2 out of 31 ADJ (thoracic spine inclination forward in the 50th and 95th percentiles; shoulder adduction left in the 5th percentile).

Proportion of Not Acceptable Postures

Table 2 shows the percentage of not acceptable ADJ of the rated joint movements across all parlor types in the 5th, 50th, and 95th percentiles. It was apparent that the cubital joint flexion toward the left and right, the cervical forward bending, the flexion of the right knee, the forward head inclination, and the adduction of the right shoulder were not acceptable in the 50th percentile over 50% of the time and that the flexion of the left knee and the right shoulder were not acceptable over 40% of the time (Table 2).

Model Calculation

The numbers of acceptable ADJ across the rated joint movements at a specific constant factor are listed in Table 3. These numbers were created by using model data. It was apparent that the ROT parlor had the lowest number of acceptable ADJ (41 acceptable out of 75 total ADJ) when the most acceptable ROT-specific constant factor was considered. The PAR parlor had 1 more acceptable ADJ (42 out of 75) at its most acceptable constant factor than the ROT parlor. The HB 50° parlor had the largest number of acceptable ADJ (49 out of 75). However, the ATD parlor had the most acceptable ADJ across different constant factors, followed by HB 50°. The total number of acceptable ADJ across all constant factors was lowest in PAR (257 acceptable ADJ). According to the definition of the constant fac-

tor, the ideal working height in each parlor type was dependent on the coefficient of the milker’s body height and the udder base height and varied across parlor types. Therefore, it was apparent that body height had a lesser effect in the ATD parlor than in the ROT parlor as the number of acceptable ADJ varied less with differing constant factors (for further details see Table 3 and Figure A1). Despite using modeled data, it was not possible to create a situation in which all ADJ were acceptable in any parlor type.

Development of the Milking Health Formula

A formula that facilitated the individual calculation of the ideal depth of pit was developed:

$$\begin{aligned} &\text{Individual milker height (cm)} \times \text{parlor-specific} \\ &\text{constant factor} - \text{mean herd udder height (cm)} = \\ &\text{ideal depth of pit (cm)}. \end{aligned}$$

The optimal parlor-specific constant factors for each parlor type are indicated in Table 3.

DISCUSSION

The data indicated a strong interaction between the milking parlor type and the height coefficient (i.e., the proportion of the udder base height and the floor level to the milker’s body height) regarding ergonomics during the attachment task. Results from the present study revealed that the ideal working height varied between milkers and parlors, as the ideal constant factor of udder base, floor level, and milker’s body height differed between parlor types. The HB 50° enabled milkers to maintain the highest number of acceptable body postures (49) at the ideal constant factor (constant factors: 0.75), whereas ROT allowed for the lowest number of acceptable body postures (41) at the most acceptable constant factor (constant factor: 0.75; Table 3). The ATD was shown to be the most beneficial parlor when multiple milkers of varying heights work in the same

parlor. This was reflected by the highest number of acceptable ADJ (45/46) among different constant factors (0.75, 0.8, 0.85, and 0.9). However, if a parlor is operated by 1 milker alone or by milkers of similar heights, the ideal depth of pit can be calculated by using the new milking health formula and the constant factors that were established as a result of our study. The ideal constant factors in Table 3 can be used to identify the best possible working position and thus improve ergonomics for each parlor type.

The milking health formula [milker's height (cm) $\times$ parlor-specific constant factor – mean udder height (cm) = ideal depth of pit (cm)] can therefore be used as a guideline for future milking parlors, as well as to set the correct working height in parlors with adjustable floors. This formula accounts for variable heights in milking personnel as well as variable mean udder heights. Furthermore, it takes into account the effect of horizontal reaching distance in the different parlor types, which has been reported to differ between HB 30°, PAR, and ATD parlors (Tuure and Alasuutari, 2009).

Ideal working height for the attachment task has been discussed in previous research, and authors suggested working height in HB 30° parlors to be best when the milker's shoulder is level to the teat end (Jakob et al., 2012). The current study found HB 30° and ATD parlors to be relatively tolerant across different working heights, thus suggesting that neither working at shoulder or at elbow level would cause bad posture. Nevertheless, a higher coefficient, and thus a deeper milking pit (higher depth of pit), resulted in more acceptable ADJ particularly in ATD but also in HB 30° parlors, thus indicating a benefit of working with the udder at shoulder level in these parlor types. The milking health formula, however, recommended the depth of pit in HB 50°, PAR, and ROT parlors to be smaller; this is in line with the findings of Stål and Pinzke (1991), who recommended the elbow to be 30 cm above the floor level of the cow. The differences in ideal working height could be explained by the reaching distance, which is larger in PAR than in the other parlor types. Billon (2009) stated that different working heights are recommended for the different parlor types and points out that pits of PAR parlors should be higher. The current study also suggested higher pits for PAR parlors and recommended differing ideal working heights for the milking parlor types, which is in line with the recommendations made by Billon (2009).

Douphrate et al. (2013) reported that PAR parlors required milkers to attach the milking cluster from behind the cow, which required an increased reaching distance compared with parlors, such as ATD or HB 30°, in which the milker attached the cluster from the

side. The shoulder-udder distance in the ATD parlor is smaller than in HB 30° parlors, as the angular position of the cow makes it necessary for the milker to reach over the platform (Douphrate et al., 2013). The ROT parlors in the current study were inside milkers. The cows were stood at a 30° angle and milked from the side. Due to the round platform in ROT parlors, the udder-shoulder distance was increased compared with a normal HB 30° parlor. In outside-milking ROT parlors cows are milked from behind, thus we would expect the shoulder-udder distance to be similar to that in a PAR parlor.

Although not directly addressed, the shoulder-udder distance is indirectly reflected by the individual recommendations of the milking health formula. It appeared that with increased shoulder-udder distance, such as in the PAR parlors, the ideal working height is higher and thus the depth of pit is smaller than when the shoulder-udder distance is decreased. For each parlor type, we identified a parlor-specific constant factor that is multiplied by the milker's height in the developed formula. The ideal constant factors can result in a variation of the ideal depth of pit between different parlor types of up to 16 cm for a person at 160 cm of height and up to 19 cm for a person at 190 cm of height. Although the formula developed in the current study is useful to optimize the parlor-specific working height, it does not necessarily imply that the resulting ergonomics are satisfactory and eliminate the occurrence of musculoskeletal problems in dairy workers. Due to opposite ideal constant factors of different joints, certain joints will operate at a not acceptable level when the movements and positions of other joints are acceptable. The interactions of the left shoulder, the elbows, and the cervical spine illustrate this issue. Whereas the elbows operate in an acceptable posture when the constant factor is 1.0 and in a not acceptable posture when the constant factor is 0.7, the shoulder joint operates in a conditionally acceptable posture when the constant factor is 0.7 but in a not acceptable posture when the constant factor is 1.0. Further, the bending of the cervical spine is acceptable when the constant factor is 0.7 and not acceptable when the constant factor is 1.0 in most parlor types. These findings are in line with previous research that reported opposite interactions between joints (Jakob et al., 2009). Hence, despite the consideration of the ideal constant factor, certain joints will operate in nonideal working postures during parts of the milking procedure. It is not possible for all joints to simultaneously be at an acceptable ergonomic posture during milking.

The ideal constant factors were calculated by counting the numbers of ADJ in an acceptable ergonomic range (according to norms and ergonomic literature) in the 5th, 50th, and 95th percentiles. Although this

approach gives a useful estimate of the quality of the working posture, the interpretation has proven difficult. The 50th percentile, for instance, represents the median level of postures at a specific ADJ; however, certain joints might cause severe problems if they remain at strain for a short period of time. For example, overbending a joint may result in similar or more severe pain than holding a joint in an uncomfortable position for an ongoing period of time, thus it is important to also consider the 5th and 95th percentiles. To give practical recommendations, it was justifiable to simplify the data by considering the range of postures (5th, 50th, and 95th percentiles). However, considering the 25th and 75th percentiles and the direction of movements would allow for a more detailed assessment and thus analysis of certain milking parlor elements, such as cradle bars. Future research should aim at considering such elements to improve existing parlors by making small adjustments.

Across all 5 examined parlor types, only 43 to 49 out of 75 ADJ represented an acceptable posture at the recommended ideal constant factors. Therefore, it can be concluded that even when workers were milking at an ideal working height, only 57.3 to 65.3% of all ADJ were in an acceptable ergonomic range throughout the 5th, 50th, and 95th percentiles. Hence, the working conditions can be improved, but it is impossible to develop a milking parlor that is acceptable for all joints. This may be due to the distance between the udder and the milker, which requires the milker to reach out and lift the milking cluster to attach it to the udder and so load weight on shoulders, elbows, and wrists. Tuure and Alasuutari (2009) assessed this criterion and emphasized the importance of appropriate parlor dimensions for improved ergonomics. When planning and constructing milking parlors, farmers should therefore specify details on musculoskeletal problems so that special attention can be paid to joints of concern for the particular farmer (see Figure A1). Due to technical challenges, the horizontal reaching distance could not be measured directly in our study; however, the milking health formula considered heights of milker and udder and took the parlor type into account. Hence, the distance was included indirectly in the formula.

The 50th percentile indicated high levels of not acceptable postures in the knees [48% of the left knee (sensor 13) and 58% of the right knee (sensor 14); Table 2] and supported earlier findings that reported a high physical strain on the knees during milking (Liebers and Caffier, 2006). Previous research stated that high levels of upper limb and lower back disorders were the result of milking postures (Liebers and Caffier, 2006). The percentage of not acceptable postures in the trunk (flexion: 20%, lateral flexion: 1%, torsion: 0%) and back

bending (lateral inclination: 0%, inclination: 30%) do not confirm these findings. In contrast, the present study found high percentages of not acceptable postures in the shoulder and arm regions (see Table 2).

The ideal depth of pit recommended in the present study appears to be lower than that identified in previous research (e.g., Jakob et al., 2009) and provides advanced information on ideal working height in different milking parlor types. Furthermore, the milking health formula can be used to calculate the ideal depth of pit. Future research should focus on the validation of the milking health formula in an experimental setting.

CONCLUSIONS

The present results are of benefit for farms with adjustable floors, as they facilitate an easy calculation of the ideal working height and can be used to improve posture during milking. The depth of pit in milking parlors should therefore be constructed according to the ideal working height, which predominantly depends on a combination of the parlor type and the height coefficient between the udder base height, the floor level, and the milker's body height. Ergonomics of the parlor types ROT and PAR were disadvantageous compared with those of HB 30° or ATD, and ergonomics of HB 50° were the most advantageous when the individually recommended working heights were applied. However, the differences between parlor types were minor, whereas the differences in the interaction of parlor type and height coefficient were significant. Some joints or body regions were in an opposing relationship to each other, which indicated that ergonomics cannot be improved for all joints that are involved in any given posture. However, the results of our study can be used to give individual recommendations and improve ergonomics in parlors with the help of the milking health formula that was established in the current study.

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APPENDIX

Joint flexion angle	Percentile	Parlor type and constant factor															Interaction parlor type x height coefficient
		ATD			HB 30°			HB 50°			PAR			ROT			
		0.7	0.8	1.0	0.7	0.8	1.0	0.7	0.8	1.0	0.7	0.8	1.0	0.7	0.8	1.0	
Cubital joint flexion left	5	29	34	42	29	31	36	26	30	36	12	31	68	22	31	48	***
	50	46	51	62	55	54	62	43	51	67	28	44	75	47	52	62	***
	95	62	67	76	77	75	89	60	71	93	44	59	89	68	76	93	***
Cubital joint flexion right	5	23	24	26	39	35	26	18	28	40	11	18	30	16	25	45	***
	50	51	48	43	56	58	64	44	51	63	40	47	60	34	40	53	***
	95	76	70	58	71	77	90	73	74	76	76	79	83	54	58	59	***
Cervical bending right	5	-20	-14	-3	-8	-10	-16	-13	-12	-9	-14	-11	-4	-12	-11	-10	**
	50	-12	-6	7	2	1	-1	-6	-1	8	-7	-3	6	-4	1	9	*
	95	-6	3	19	12	12	13	4	9	20	3	7	14	8	11	16	**
Cervical bending forward	5	-3	-11	-26	-18	-19	-20	-9	-18	-36	-7	-10	-16	-11	-16	-25	*
	50	6	-1	-16	-6	-6	-6	4	-6	-27	8	2	-9	-1	-5	-12	**
	95	19	10	-7	7	7	8	17	6	-14	22	14	-1	15	10	1	*
Wrist flexion left	5	-21	-25	-31	-31	-26	-16	-19	-24	-32	-9	-15	-26	-20	-28	-45	**
	50	-15	-12	-6	-21	-10	10	-9	-9	-10	-1	-4	-9	-9	-15	-26	***
	95	7	8	10	13	14	17	13	14	16	7	8	10	10	11	13	n.s.
Wrist flexion right	5	-31	-26	-16	-35	-27	-10	-11	-19	-33	-17	-19	-22	-26	-27	-29	***
	50	-15	-11	-4	-20	-11	5	-1	-4	-11	4	0	-6	-15	-18	-23	***
	95	12	16	25	3	12	30	24	19	10	24	26	31	5	-3	-17	***
Wrist radialuction left	5	-28	-24	-17	-33	-25	-7	-19	-24	-33	-17	-28	-51	-22	-23	-24	***
	50	-20	-15	-4	-23	-15	1	-12	-14	-20	-9	-18	-37	-6	-4	-1	***
	95	-10	-2	14	-8	-2	5	-1	0	1	3	-7	-26	6	10	18	***
Wrist radialuction right	5	-22	-17	6	-21	-16	-7	-7	-12	-20	-13	-18	-26	-2	-3	-6	***
	50	-14	-9	2	-15	-9	4	1	-5	-16	1	-4	-15	4	2	-1	***
	95	0	4	12	-7	0	14	9	4	-5	19	12	-3	13	10	4	***
Knee flexion left	5	9	7	3	10	8	5	7	5	1	13	11	8	5	3	0	n.s.
	50	13	10	4	16	13	7	11	8	2	20	17	11	12	8	2	n.s.
	95	16	14	8	22	20	15	16	14	8	28	26	21	20	17	12	n.s.
Knee flexion right	5	7	7	6	0	8	22	-1	3	12	17	13	3	6	5	2	***
	50	13	11	7	7	12	23	1	6	16	25	19	7	12	9	4	***
	95	18	16	13	15	21	32	11	13	19	34	29	18	24	18	7	***
Head inclination forward	5	14	6	-10	-3	-2	-4	11	-1	-24	8	0	-17	10	0	-18	**
	50	21	12	-6	3	3	4	17	4	-21	14	5	-14	16	7	-11	***
	95	33	24	5	15	17	20	30	17	-8	31	18	-6	38	25	-2	***
Head inclination sideward	5	-27	-19	-1	-12	-15	-22	-13	-13	-12	-30	-23	-11	-7	-7	-7	**
	50	-17	-8	11	3	0	-5	-8	0	15	-17	-11	1	3	9	20	**
	95	-7	-4	24	17	16	15	4	14	34	-5	1	13	21	24	30	**
Dorsal bending right	5	-8	-5	0	-3	-3	-2	-5	-4	-1	-7	-9	-12	2	1	-2	*
	50	0	1	1	2	2	3	2	3	3	-6	-6	-5	6	7	7	n.s.
	95	6	6	7	6	7	7	7	7	8	-1	-1	0	11	12	12	n.s.
Dorsal bending forward	5	8	4	-5	0	1	2	8	4	-5	5	2	-4	4	-1	-10	**
	50	11	7	-2	2	3	5	12	8	-1	8	5	-1	8	3	-8	***
	95	15	10	0	5	6	7	15	11	2	11	8	2	12	7	-3	***
Dorsal torsion right	5	-1	-1	-3	-2	-3	-5	-5	-3	1	-6	-4	1	-1	-2	-3	***
	50	3	2	0	0	1	2	-1	0	3	-3	-1	5	3	2	0	***
	95	7	6	3	3	4	6	4	4	5	0	3	8	6	6	5	***
Trunk inclination forward	5	5	6	8	5	5	5	7	5	1	-2	-8	12	6	-5	-5	***
	50	11	11	12	8	9	9	11	10	5	6	2	-6	16	11	3	***
	95	15	15	15	12	12	13	15	14	11	11	7	-2	22	16	5	***
Lateral trunk inclination right	5	-7	-6	-6	-8	-7	-7	-5	-5	-4	-11	-11	-10	0	0	1	n.s.
	50	-2	-1	0	-2	-1	0	1	1	2	-6	-6	-5	6	6	7	n.s.
	95	2	4	7	6	5	2	3	6	11	0	0	0	12	12	13	*
Shoulder adduction left	5	-14	-16	-18	-25	-27	-29	-36	-37	-40	-13	-14	-16	-32	-34	-36	n.s.
	50	-7	-5	-1	-18	-17	-13	-19	-17	-14	-7	-5	-2	-12	-10	-7	n.s.
	95	-5	4	22	-7	-7	-5	-17	-6	16	13	8	-3	-1	6	20	***
Shoulder adduction right	5	-27	-20	-6	-15	-8	6	-13	-11	3	-38	-31	-17	-7	0	14	n.s.
	50	-13	-5	12	1	10	27	0	9	26	-9	0	17	2	11	28	n.s.
	95	2	10	27	20	28	46	19	27	45	15	23	41	133	22	39	n.s.
Shoulder flexion left	5	14	29	60	29	37	53	44	41	35	28	35	49	33	38	47	***
	50	26	42	73	52	55	60	53	60	75	38	45	57	56	64	60	**
	95	35	53	88	68	68	67	63	76	103	47	55	69	73	80	94	***
Shoulder flexion right	5	24	31	47	45	47	51	28	30	34	45	38	24	41	52	73	***
	50	44	51	66	56	64	82	59	52	38	67	64	56	54	61	76	***
	95	56	64	81	66	78	103	70	65	57	74	78	84	65	69	77	***
Shoulder rotation left	5	-12	-13	-17	-23	-24	-28	-7	-8	-12	-12	-14	-17	-27	-29	-32	n.s.
	50	1	-1	-4	-8	-10	-13	12	10	6	-2	-3	-7	-14	-16	-19	n.s.
	95	20	21	24	7	8	11	25	26	29	5	6	9	24	25	28	n.s.
Shoulder rotation right	5	-4	2	14	12	-14	-66	-12	-9	-2	-18	-16	-12	1	7	18	***
	50	15	18	24	23	1	-43	9	8	7	3	7	16	16	19	25	***
	95	47	44	38	30	27	20	37	34	28	58	55	49	36	33	27	n.s.
Lower arm pronation left	5	-30	-28	-23	-44	-41	-34	-27	-27	-29	-20	-33	-60	-35	-43	-59	***
	50	-3	-7	-15	-12	-16	-24	-4	-8	-16	-22	-26	-34	-6	-10	-18	n.s.
	95	15	17	20	34	24	3	-6	15	57	10	5	-7	46	42	35	***
Lower arm pronation right	5	-28	-32	-42	-17	-17	-16	-23	-31	-49	-26	-37	-59	-30	-26	-17	***
	50	8	-1	-19	-8	6	33	3	-10	-35	-6	-11	-20	-7	-8	-9	***
	95	37	28	8	12	30	67	30	20	2	34	32	28	19	12	-3	***

Figure A1. Model calculation presenting parlor-specific angular degrees of joints (ADJ) at each constant factor (with *P*-values for the interaction of parlor type × height coefficient; **P* < 0.05, ***P* < 0.01, ****P* < 0.001; n.s. = not significant). The ADJ values were color coded according to the BGI/GUV-I 7011 (Anhang 3) and scientific literature [gray (green) = acceptable, white (yellow) = conditionally acceptable, black (red) = not acceptable; Drury, 1987; McAtamney and Corlett, 1993; ISO, 2000; European Commission, 2005; Hoehne-Hückstädt et al., 2007; Deutsche Gesetzliche Unfallversicherung, 2013). ATD = autotandem parlor; HB 30° = herringbone 30° parlor; HB 50° = herringbone 50° parlor; PAR = parallel parlor; ROT = rotary parlor. Color version available online.