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HIGHLY REPETITIVE WORK OPERATIONS IN A MODERN MILKING SYSTEM. A CASE STUDY OF WRIST POSITIONS AND MOVEMENTS IN A ROTARY SYSTEM

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Abstract: With the use of electrogoniometers wrist positions and movements were measured in 13 milkers while working in a modern rotary milking system. The rotary system put considerable demands on the wrists and hands regarding both velocities and repetitiveness. Values were found close to those described in other repetitive industrial work with high risk of wrist and hand disorders. For the right hand the repetitiveness was 0.57 Hz and 0.46 Hz for the left hand. In addition, the median value (50th percentile) of the angular velocity distribution was also high, being 36°/s for the right hand and 26°/s for the left, and with respect to the peak value (90th percentile) the corresponding values were 155°/s and 135°/s, respectively. Furthermore, when milking in the rotary system, there was less possibility to hold the hands still than in the other milking systems. The right hand rested only 1.4% of the milking time and the left only 1.0%. The hands were therefore moving throughout almost the entire milking procedure. High velocity, repetitiveness and fewer opportunities for rest are risk factors that might lead to disorders in the wrists and hands. Regarding wrist positions, the left wrist was held in a more dorsiflexed position than the right, 37° and 29°, respectively. Compared with tethering and loose-housing parlour milking, the wrist positions were, however, improved in the rotary system. When introducing new milking systems these negative effects on wrist and hand movements must be borne in mind in order to minimize the prevalence of wrist and hand disorders.

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INTRODUCTION

Machine milking appears to be associated with a considerable risk of injuring the wrists and hands [24]. Previous studies of female milkers have shown that repetitive wrist and hand movements with high velocity and awkward positions during milking are risk factors for injuring the wrists and hands [25].

Stål *et al.* [24] reported that according to the milkers' own experience, the most strenuous task during milking was premilking (drawing the first milk out of the udder, performed with the hand and fingers placed round the teats). Furthermore, the task of attaching the four teat cups to the udder with one hand while holding the unit with the other hand was also experienced as strenuous. Pinzke *et al.* [17] showed by direct technical measurement that premilking, attaching and drying (cleaning the udder with a towel) were the most physically demanding milking tasks for the wrists and hands.

Studies of injuries in the wrists and hands such as the carpal tunnel syndrome (CTS) have identified certain wrist positions and movements as important risk factors [2].

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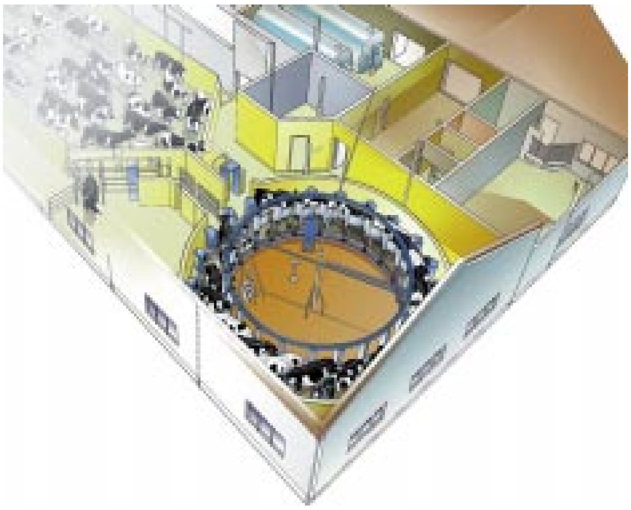

Figure 1. A overview of the rotary milking system. Copyright DeLaval Sales AB.

Figure 2. Milker's work position in the carousel. The platform (which can be raised and lowered to suit the height of the milker) is not shown. Copyright DeLaval Sales AB.

Furthermore, repetitive loaded movements are also associated with wrist symptoms [5, 6, 15, 16, 23, 25]. Repeated loaded work is very common with work in dairy barns [11].

Swedish agriculture is at present being subjected to great changes, aimed at increasing productivity. Specialization and growing numbers of animals on the farms are creating occupational risk factors. Today, the loose-housing system, where milking is performed in a parlour is seen more and more often in dairy barns, but the traditional tethering milking system, where the cows are tied up, is still the most common [22]. In the parlour the milking equipment is stationary whereas with the tethering system, the milker has to carry all the equipment to the cows which increase the workload on the milker.

In large scale milk production quite a new milking system has been introduced in Sweden, the *rotary system* (Fig. 1, 2). Here the cows walk on to a rotating platform or carousel, and normally one milker does the milking while the carousel is rotating. The milker stands in the same place at a level of about 0.8–0.9 m below the rotating platform inside or in certain systems outside the carousel. Observations of the work revealed the awkward positions, the rapid movements of the wrists and the almost complete lack of pauses. Furthermore, during the attaching task one hand is loaded with the weight of the cluster (1.8 kg) held with the arm almost fully extended. The tasks for the milker working in the rotary system are reduced to just drying, premilking and attaching whereas other systems involve supplementary tasks such as detaching the cluster, grouping the cows, etc.

To obtain generic and quantitative information, direct technical measurements of wrist positions and movements have been conducted previously for two types of milking systems, traditional tethering, and a more modern, loose-housing parlour system [25]. However, searches in data bases have not revealed any corresponding study of a rotary milking system.

In the present study, the aim was to quantify the wrist positions and movements while working in a rotary milking system and to compare the results with measurements from working in the previous generations of milking systems.

MATERIALS AND METHODS

The measurements were carried out in 2 similar newly built dairy barns with a rotary system each containing a carousel with 24 cow places (Fig. 1, 2). About 270 cows in each system were milked 3 times a day, morning, afternoon and evening, and the time for each milking shift was about 2 h 40 min. Each cluster placed at each cow position had a weight of 1.8 kg. The diameter of the base of the cluster was about 11–15 cm, which does not fit the size of a woman's hands. The milking movements were performed in a similar way throughout the entire milking procedure and were carried out almost without a break. Recordings, which were continuous, of each milker were on average 30 minutes long.

SUBJECTS

Thirteen milkers (8 males and 5 females) participated in the study; 6 milkers were employed in 1 farm and 7 in the other. The mean age was 29 years (range 19–45). The mean height and weight of the subjects was 176 cm (range 165–190) and 74 kg (range 53–100), respectively. Ten subjects were right-handed, two left-handed and one ambidextrous. All were free from symptoms in the wrists and hands, except for one who had a sports injury in the left wrist which reduced mobility regarding both flexion and deviation to less than 50% of the average value of the other 12 subjects. The injury did not bother the milker during the milking, but since his reduced mobility biased the results, his data for the left wrist were excluded. All the milkers were used to working in the rotary system.

Table 1. Wrist positions, percentile values (°), and movements (velocities, percentile values (°/s) and fraction of time with a velocity below 1°/s, in % time as well as repetitiveness, for both flexion and deviation, and for both the right and left hands during milking in a rotary system. Mean values (m) and standard deviations (Sd) within brackets are shown for 13 individuals. The corresponding data for tethering (n = 11) and loose-housing parlour milking systems (n = 11) are shown for comparison [25].

	Flexion				Deviation			
	Right		[a]Left		Right		[a]Left	
	m	Sd	m	Sd	m	Sd	m	Sd
Positions[b)]								
Distribution, Percentile (°)								
10^{th}								
Rotary	-29 ^{x,y,*}	9	-37 *	9	-13	6	-15	6
Tethering	-41 ^{x,z,*}	8	-35 *	8	-15	6	-22	9
Loose-housing	-46 ^{y,z,*}	10	-37 *	7	-12 *	7	-22 *	6
50^{th}								
Rotary	-3 ^{x,y}	8	-8	9	-1	7	-1	5
Tethering	-11 ^{x,*}	6	-8 *	6	0	5	-4	6
Loose-housing	-15 ^{y,*}	9	-8 *	5	2	8	-4	6
90^{th}								
Rotary	21 ^{x,y}	12	16	8	14	7	11	11
Tethering	14 ^{x}	9	13	7	16	7	13	6
Loose-housing	10 ^{y}	12	12	8	17	8	12	6
Movements								
Velocities below 1°/s (% time)								
Rotary	1.4 ^{x,y,*}	1	1.0 ^{x,y,*}	1	2.2 ^{x,y}	0.5	2.3 ^{x,y}	0.6
Tethering	6.4 ^{x}	4.4	7.4 ^{x}	2.8	9.4 ^{x}	5.6	8.7 ^{x}	2.4
Loose-housing	4.9 ^{y}	3.0	5.6 ^{y}	3.1	7.6 ^{y}	4.0	7.8 ^{y}	3.8
Distribution (Percentile °/s)								
50^{th}								
Rotary	36 ^{x,*}	5	26 ^{x,*}	9	17	2	14	5
Tethering	24 ^{x,*}	8	16 ^{x,*}	3	15 *	3	12 *	2
Loose-housing	28 *	8	20 *	6	16	3	14	4
90^{th}								
Rotary	155	19	135	33	74	11	74	18
Tethering	136 *	20	98 ^{z,*}	22	72 *	12	63 ^{z,*}	10
Loose-housing	147 *	19	114 ^{z,*}	26	76	11	71 ^{z}	14
Repetitiveness MPF Hz								
Rotary	0.57 ^{x}	0.11	0.46 ^{x}	0.12	0.50 ^{x}	0.08	0.53 ^{x,y}	0.11
Tethering	0.45 ^{x,z,*}	0.05	0.37 ^{x,*}	0.09	0.43 ^{x,*}	0.07	0.33 ^{x,z,*}	0.03
Loose-housing	0.50 ^{z,*}	0.08	0.42 *	0.08	0.47 *	0.00	0.39 ^{y,z,*}	0.05

[a)] Due to technical problems during recording n=12 in left dorsal/palmar flexion and n=10 in left ulnar/radial deviation.
[b)] Positive values denote flexion in the palmar direction and deviation in the ulnar direction.
[x)] Statistically significant difference between the rotary and tethering milking systems [y)] Statistically significant difference between the rotary and loose-housing parlour milking systems.
[z)] Statistically significant difference between the loose-housing parlour and tethering system.
[*)] Statistically significant difference between the right and the left side.

Almost all the milkers used their right hand to hold the cluster during the attaching procedure.

The flexion mobility was for the right side 137º (74º in the palmar and 63º in the dorsal direction, n = 13) and for the left side 129º (67º in the palmar and 62º in the dorsal direction, n = 12). The deviation mobility was for the right side 50º (29º in the ulnar direction and 21º in the radial direction, n = 13) and for the left side 48º (34º in the ulnar- and 15º in the radial direction, n = 12).

Wrist positions and movements. Biaxial electrogoniometers, (XM65 and M110) Biometrics Ltd., Cwmfelinfach, Gwent, UK) were used for recording the flexion and deviation angles of both the right and left wrists. A 12-bit data logger with a sampling frequency of 20 Hz was used [9]. After recording, the data were transferred to a personal computer and analysed [7]. The reference position (0º of flexion and deviation) was defined as the wrist angles obtained when the subject was standing up with the arms and hands hanging relaxed alongside the body [25]. A wrist mobility test was also performed [7]. The wrist positions during work were characterized, for both dorsal-palmar flexion and radial-ulnar deviation, by the median position (50^{th} percentile of angular distribution) and the two extreme positions (10^{th} and 90^{th} percentiles).

In order to describe the movements, the angular velocity was calculated, and the 50^{th} and 90^{th} percentiles of the velocity distribution as well as the mean velocity were used for characterization. Moreover, the mean power frequencies (MPF) of the power spectra were calculated and used as a measure of repetitiveness, and the fraction of time with a velocity below 1º/s for continuous periods of at least 0.5 s was selected to characterize when the hand was still.

Statistics. The Wilcoxon matched-pairs signed-ranks test was used to analyse the differences between the right and left wrist. The Mann-Whitney U-test was used for comparisons between the rotary milking, to the other milking systems. A statistical significance level of $p < 0.05$ was chosen.

RESULTS

There were no obvious differences with respect to positions and movements during milking in the rotary systems between males and females. Therefore the data were not split by gender.

Positions

Flexion. The left hand was held in a more dorsi-flexed position than the right hand (Tab. 1). For the 10^{th} percentile the difference was statistically significant (37º for the left hand and 29º for the right) and the corresponding numbers for the 50^{th} percentile were 8º and 3º, respectively. For the palmar flexion (90^{th} percentile), the right hand was held in a more flexed position than the left hand (21º and 16º, respectively). The differences with respect to the 50th and 90th percentiles were not statistically significant.

Deviation. For 10% of the time the left hand was held in a 15º radial position and in a ulnar position exceeding 11°. For the right hand the corresponding values were 12° and 14°, respectively. There was no significant difference regarding sides or radial and ulnar deviations.

Movements

The rotary system put very high demands on the wrists and hands regarding both velocities and repetitiveness. In addition the work was performed almost continually without any pauses.

Flexion. The velocity was significantly higher for the right than for the left hand with respect to the 50th percentile (median velocity).

The right hand was held still for only 1.4% of the total milking time and for the left hand the corresponding value was even lower, 1.0% of the total milking time. The difference was statistically significant.

Deviation. The velocity was more pronounced in flexion than in deviation both with respect to the 50th and the 90th percentiles. In addition, the right and left hands were held still for a somewhat longer time in deviation than in flexion, 2.2% and 2.3%, respectively, of the total milking time.

The velocity distribution were skewed, the mean velocities for flexion were for the right and left side 62º/s and 52º/s, respectively and for deviation 29°/s and 28°/s respectively (not in table). All mean velocity values were higher than the median ones.

Repetitiveness. Both the right and left hands were exposed to a high degree of repetitive work 0.57 Hz *vs.* 0.46 Hz in flexion and 0.50 Hz *vs.* 0.53 Hz in deviation, respectively. There was no significant difference between the right and left side.

DISCUSSION

Positions. Several studies have shown that there is a correlation between the hand positions and perceived symptoms in the wrists and hands [1, 2, 23, 25]. The result of this study showed that the hand positions were improved with milking in the rotary system compared to the tethering and loose-housing parlour systems. In the rotary system the right hand was in 29º in a dorsiflexed position for 10% of the recording time compared to 41º and 46º in the tethering and the loose-housing systems, respectively [25]. The differences were statistically significant. Regarding the left side the positions were almost the same in all three systems. In the rotary system the right hand was held in a more palmar flexed position in comparison with both the tethering and the loose-housing systems. In the rotary system the milking equipment was hung up on the right side of the platform and consequently was grasped with the right hand. In the tethering and loose-housing parlour systems the equipment was most frequently lifted with the left hand. This might cause the differences for the right and the left hand in palmar direction between the systems. However, with regard to the deviation angles there were no significant differences between the three systems.

The 3 milking tasks that are included in the rotary system, cleaning and drying the udder, premilking, and attaching the cluster to the udder have been analysed in a loose-housing system in an earlier study [17]. They found extreme flexion values (42º) during premilking and attaching. Dorsal and palmar flexion exceeding 45º has been described as an unsuitable position for the hand during work [23]. In the rotary system the left hand was held in 15º of radial deviation for 10% of the recording time. These positions were exactly on the mobility value 15º in radial deviation. It has been claimed that when the angle of deviation exceeds 50% of the maximum value, there is an increased risk of developing median nerve entrapment at the level of the wrist - the carpal tunnel syndrome (CTS) [19, 23]. Results from other studies have shown that the carpal tunnel pressure (CTP) increased with increasing wrist deviation and wrist extension [18]. Radial deviation recorded during milking in the rotary system indicate that there could be an increased carpal tunnel pressure for 10% of the milking time when the angle of radial deviation is >15º. This angle value also exceeds the limits for unacceptable radial deviation suggested by Bergamasco *et al.* [4]. They set the limits for the ulnar deviation at 24°, and at 15º for the radial deviation. Our milkers held their hands at a radial deviation of >15º for more that 10% of the recording.

Movements. Compared to the tethering and loose-housing systems, considerable dynamic demands were found in the rotary system for both hands i.e. the velocity and the repetitiveness were high. Furthermore there were scarcely any pauses. In flexion the hands were held still for only 1.4% and 1.0% of the total time for the right and the left hand, respectively. The cow carousel was rotating throughout the milking procedure so the milker had a very poor share of pauses and little opportunity for resting the hands. In the other two milking systems the cow stood still during the milking process and for some cows it took longer time to empty the udder giving more room for pauses and the amount of cow places decide the amount of pauses. In the tethering system the right and left hands were held still in 6.4% and 7.4% of the time and in the loose-housing system the corresponding values were 4.9% and 5.6% [25]. The differences were statistically significant. In the ulnar/radial deviation the hands were held still somewhat longer in all the three systems.

Mean values of velocities exceeding 42°/s have been described in a group at high risk of injuring the wrist [13]. In this present study the corresponding value was 62°/s in the right wrist. Malchair *et al.*, [12] showed that high angular velocity of the wrist predicted musculoskeletal wrist injuries (OR = 1.46) and it was shown that the risk increased when the flexion velocity was more than 50°/s. The mean velocity distribution was in flexion significantly higher in the rotary system than in the tethering systems on both sides. The rotary milking system showed a tendency to higher velocities than the loose-housing parlour system 62º/s vs. 57º/s (p = 0.06). It has been established in studies that highly repetitive wrist movements are risk factors for developing symptoms in the wrist and hand such as CTS [20, 5]. Moreover Silverstein *et al*. [20] found that the median nerve in the carpal tunnel was affected to a greater extent by repetitive movements (OR 5.5) than by handling with a high demand on force (OR 2.9). The repetitiveness found in the present study was at the same (0.57 Hz) Hz level as in the fish processing industry (0.54 Hz) Ohlsson *et al.* [16] loose-housing parlour milking (0.50 Hz) Stål *et al*. [25] poultry-processing (0.58 Hz), Juul-Kristensen *et al.* [10]), mink-fur sorting (0.62 Hz), Hansson and Mikkelsen [8], (0.54 Hz) Arvidsson *et al.* (in press)[3]. In addition, a high prevalence of wrist and hand disorders is presented in all these studies.

There is a strong correlation between disorders and the impossibility to rest the hands during intensive manual work where high velocity and high repetitiveness of movements are frequent [21]. When milking in the rotary system the possibility to rest the wrists and hands was limited. Insufficient recovery time may be a contributory factor for developing injuries.

Pinzke *et al.* [17] concluded that the 3 milking tasks, cleaning, premilking and attaching, contained high velocities and extreme wrist positions which were greater than those described from the repetitive work with a high risk of hand disorders in the fish-processing industry [16] and giroform data entry work [14]. Furthermore, the registered times for these main milking tasks were together about 23 s/cow which means that for about half the time in the parlour the milkers were exposed to extreme wrist positions and high wrist velocities. In the rotary system, the three tasks were carried out almost in the same way as shown in the study by Pinzke *et al*. [17] performed in the loose-housing parlour milking system. However, compared to the loose-housing parlour milking, the rotary milking is carried on continuously with almost no time for rest. In the tethering and loose-housing systems the milker had better control over the time to take for the different milking tasks. In a rotary milking system it is mainly the speed of the carousel that determines the time for each task. Normally, the carousel moves continuously without stopping.

Measurements considerations. The main source of error in measurements of the wrists is caused by the cross-talk of the goniometers between flexion and deviation which appears when a pronounced flexion/extension and/or deviation occurs together with a simultaneous supination/ pronation of the forearm [7]. However, only a fraction of the forearm rotation is transferred to the goniometer, and the errors in did not invalidate the results. In addition, due to a smaller range of motion in deviation as compared to flexion, the relative error angles and movements are smaller for flexion than for deviation.

Consequences of increased productivity. In order to gain better productivity, new labour-intensive milking systems are being introduced in Sweden. One of the large scales milking systems is *rotary milking.* This system is intended to increase the number of cows milked per unit of time. Furthermore there was less muscular recovery in the rotary system than in the other systems possibly partly caused by a higher productivity and increased numbers of milking units (6, 18, and 24 milking units in the tethering, in the loose housing parlour system and in the rotary system, respectively). About 40 and 80 cows per hour were milked in the tethering and the loose-housing parlour milking system, respectively [26]. In the rotary system the corresponding number was about 120 cows per hour. Thus, the rotary system has both the highest productivity and the highest dynamic demands.

From an ergonomic point of view technical aids have to be introduced to facilitate the work tasks [27]. Moreover, it is advisable to reduce the time for exposure to the high loads and also to make changes in the organization of the work. The milkers should be offered the possibility to vary their work tasks by introducing some form of job rotation. The duration of exposure to the high demands reflected by the velocities and repetitiveness must be reduced and time for short breaks must be made available. The insufficient recovery time during milking in the rotary system warrants further.

CONCLUSIONS

Milking in a modern rotary system showed high values of velocities and repetitiveness for both the right and left hands, and these might be contributory factors to the development of symptoms in the wrists and hands. Furthermore, the present study showed that there was almost no time for rest. According to our findings the load on the wrists and hands increased in the rotary system with respect to the dynamic demands compared to milking in the tethering or the loose-housing parlour systems.

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