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REVIEWS

Ergonomics in Modern Dairy Practice: A Review of Current Issues and Research Needs

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ABSTRACT. Dairy farming is an ancient occupation. Traditionally, cows have been manually milked while tethered in stalls or stanchions. In the latter half of the 20th century as machine milking emerged, the parlor milking system has become more popular, especially among larger dairy farms. The transition from manual milking to automatic milking systems as well as the transition from stanchion to parlor milking systems involved a dramatic change in milking tasks. These transitions have resulted in changing patterns of occupational exposure to risk factors for work-related musculoskeletal disorders among dairy workers. However, aspects of the milking task such as sanitization of teats, stripping milk from teats, and attachment and detachment of milking equipment have remained relatively the same. Work-related musculoskeletal symptoms have been reported in the low back, shoulders, hands/wrists, and knees. Research that has measured exposures to risk factors for work-related musculoskeletal disorders among dairy farm workers has been limited, especially when using ergonomic tools to directly measure exposure, such as electrogoniometry or electromyography. Self-reported exposure measures have been most commonly used. The interventions that have been tested to reduce exposure to risk factors for work-related musculoskeletal disorders include assisted lift-hold devices, use of lighter-weight equipment, adjustable flooring, and use of rubber mats. However, research evaluating potential solutions

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to reduce dairy farm worker exposure to risk factors for musculoskeletal disorders is scarce. Future research efforts should further characterize hazards while simultaneously testing viable solutions that fit within the business model of the dairy farm industry.

KEYWORDS. Agriculture, dairy, ergonomics, musculoskeletal disorders

INTRODUCTION

Dairy farming has been part of agriculture for thousands of years.[1] Initially, milk and dairy products were made primarily for home or local use. As nations developed and populations expanded, it became necessary to mass produce and improve the quality of milk for public consumption.[2] Until the late 1800s, cows were milked by hand. With the invention of vacuum bucket milking and the availability of electrical power, the efficiency of milk production was drastically increased.[2] Technological improvements also led to the development of milking pipelines, which eliminated the physical workloads associated with the manual transport of heavy buckets of milk.[3] Introduction of the automatic milking system during the 20th century reduced manual milking and associated physical risk factors, and involved a dramatic change of work tasks for milkers. Additional technological advances such as the introduction of the milking parlor reduced occupational exposure to awkward trunk and lower extremity postures associated with milking in stanchion style barns. However, parlor milking has introduced new exposures to ergonomic risk factors primarily associated with upper extremity, neck, and trunk work-related musculoskeletal disorders (WMSDs). The purpose of this review is to describe the working environments of modern parlor milking as well as present a scientific review of research addressing WMSDs on dairy farms, and specifically focus on the work environment inside milking parlors. Additionally, a review of exposure assessment strategies is presented with significant findings. Interventional studies aimed at reducing ergonomic risk factors will be presented followed by a discussion of research needs to reduce or eliminate the risk for WMSDs on modern dairy farms.

WORKING ENVIRONMENTS

Milking Systems and Designs

Two milking systems predominate modern milking: stanchion and the parlor.[4] Stanchion milking systems involve a milking unit being brought to a tethered cow for milking. Cows are tethered and workers will kneel or squat to perform milking tasks and attach the milking unit (Figure 1). Stanchion systems are more common among smaller milking operations ($<$100 head).[5] Parlor milking systems involve cows moving into milking stalls where they are milked simultaneously by workers located in a pit adjacent to and at a lower level than the milking platform. Milking parlor capacity is dependent on the number of milking stalls in the parlor. Parlor systems can accommodate larger quantities of cows and are used almost exclusively in large-herd operations.[6] Parlor systems are configured in several ways, including herringbone, parallel, rotary (Figures 2, 3, and 4), and side-open (tandem) (Figure 5). These

FIGURE 1. Milking in stanchion system (color figure available online).

FIGURE 2. Herringbone parlor.

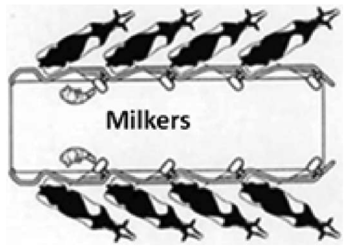


FIGURE 3. Parallel parlor.

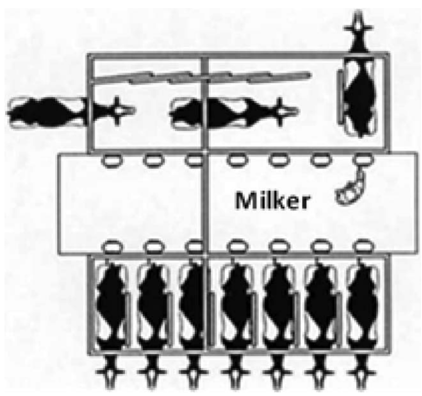


FIGURE 4. Rotary parlor.

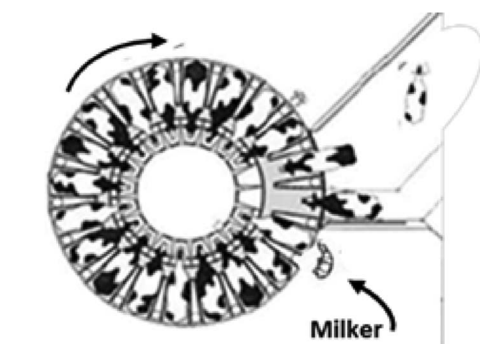


FIGURE 5. Tandem parlor.

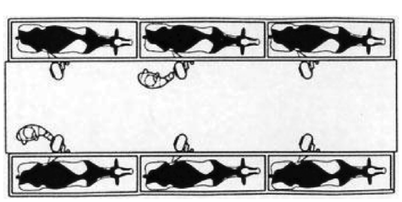


FIGURE 6. Milking in herringbone parlor (color figure available online).

FIGURE 7. Milking in tandem parlor (color figure available online).

configurations present different workstation designs and may create varying worker exposures to physical demands. In tandem parlors, cows stand in a line, one in front of another in individual stalls in parallel to the long side of the milking pit. In herringbone parlors, cows enter and stand next to each other, facing away from the milking pit at an angle. In both herringbone (Figure 6) and tandem (Figure 7) parlors, workers access the udder from the side of the cow. In parallel parlors, cows stand perpendicular to the pit and workers usually access the udder between the hind legs (Figure 8). The advantage of the parallel design is that cows stand closer together so the walking distance for milkers is shorter, and more cows can be milked per area

FIGURE 8. Milking in parallel parlor (color figure available online).

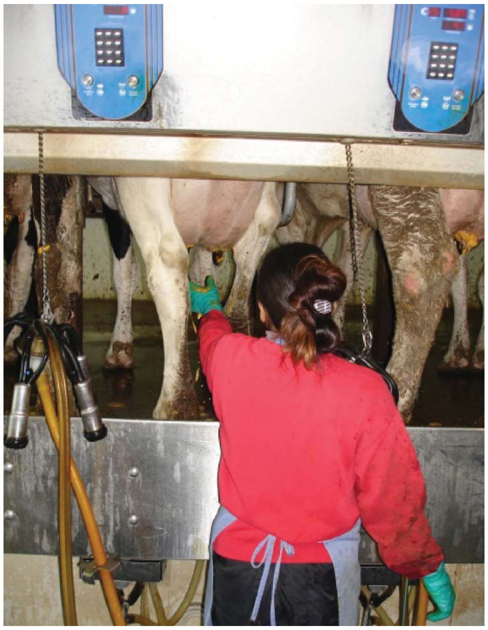
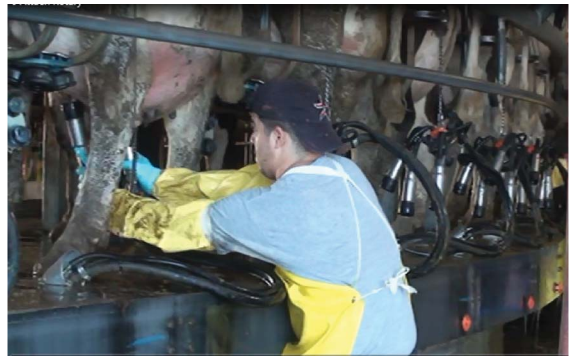


FIGURE 9. Milking in rotary parlor (color figure available online).



in the parlor as compared with herringbone and tandem parlor designs. The disadvantage is that cows must be milked from behind, requiring a longer reach distance for the worker. In tandem parlors, cows are let in and are released individually; therefore, a slow-milking cow does not delay the release of other cows in the parlor once milking is complete. In herringbone and parallel parlors, cows enter and are released in batch. A unique technological feature found in some parlors is a retractable arm located behind the cow to support the milking unit. The support arm is used to suspend and properly position the milking unit below the cow's udder and off the parlor floor. The device is predominantly utilized in herringbone parlors as the udder is accessed by the worker from the side of the cow. A support arm may reduce worker exposure to upper extremity loading, as milking units can weigh up to 3.5 kg.[7] Rotary (i.e., carousel) parlors are gaining in popularity among large-herd operations. The milker stands in the center of the carousel or outside or around its perimeter to perform milking tasks. Cows walk onto a slowly moving platform that rotates in a turntable-like fashion (Figure 9). Since cow movement is largely automated, one operator can run the entire milking operation from the same position while cows enter and exit at a constant rate with little or no pause in milking tasks. From a milking efficiency perspective, the rotary milking parlor design is preferred, as more cows can be milked per unit time compared with other parlor designs. However, rotary parlors cost more to install compared with parallel, tandem, and herringbone designs (D. Reinemann, PhD, December 16, 2009; and R. Sorenson, BS, December 18, 2005; oral communications).

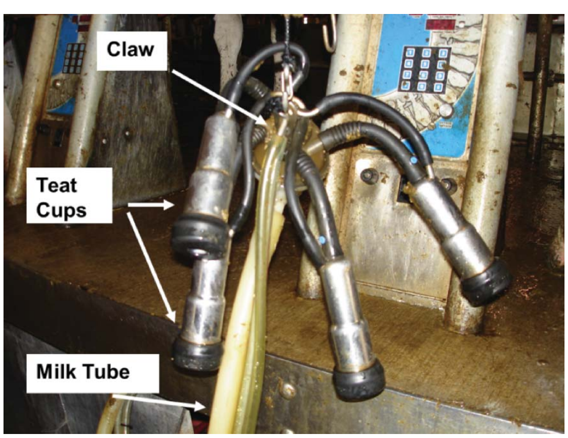
The automatic milking system (AMS or voluntary milking system [VMS]) is a relatively new milking system gaining in popularity especially among European dairy operations.[8] In this system, cows are housed in loose housing systems and move voluntarily to a milking robot, where the cows are milked two to three times a day with minimal to no worker involvement. The capacity of the AMS/VMS is about 60–70 cows per day depending on milk yield. This system is revolutionary, especially for small family farms with 60–120 cow herds.[9]

Milking Tasks

Milking has been reported as being the most physically demanding[10] and time-consuming[11,12] activity on dairy farms. The milking procedure involves several tasks that include the following: (1) pre-dipping of teats with a cup or spray for sanitization; (2) wiping of teats; (3) stripping of each teat to stimulate milk flow and inspect pre-milk for signs of infection; (4) cluster attachment; (5) cluster detachment; and (6) post-dipping of teats for sanitization.[13] All milking tasks must be performed in sequence in an efficient and timely manner to maximize milk output from each cow. O'Brien et al.[14] described the interdependency between milking efficiency and parlor performance, and reported that optimum milking efficiency was achieved when the number of milking units was appropriate for the operator work routine and the cow milk production level such that both over-milking and worker idle time are minimized. This finding suggests an efficient milking system in terms of labor demand allows little opportunity for worker rest. The milking routine is similar to assembly-line work, characterized by repetitive specialized tasks.[15–17] Cluster attachment has been identified as one of the more physically strenuous milking tasks (Figure 9).[10] A milking unit consists of a number of parts: claw, teat cups, and milking tubes. Together, the claw and the teat cups together constitute a milking cluster (Figure 10). Job rotation is often not employed in large-herd operations, and the entire herd is milked two to three times per day. Additionally, when parlor turnover times are kept to a minimum, rest breaks may be inadequate to prevent worker fatigue and reduce the risk for injury in the upper extremities.[17,18]

Recent technological advancements have led to the mechanization and automation of the entire milking process via the utilization of automatic milking systems. However, at present, investment costs limit widespread and rapid acceptance of AMS/VMS in the global industry. Dairy science research has led to significant advances in dairy practice, resulting in an optimization of cow milk production and parlor efficiency as it relates to cow throughput. However, little research has addressed worker health and safety or worker productivity and efficiency. As the global dairy industry continues to move towards larger herd sizes[19,20] with the goal of increased milk production at lower costs, focused research should investigate milking practices and parlor designs as they relate to worker safety and health.[4]

FIGURE 10. Milking unit (color figure available online).



Additional trends to consider include modern milking technologies, practices, and parlor designs are being adopted in developing countries. If the impacts of these on worker health and safety are not carefully analyzed and evaluated, poor designs or hazardous practices could be adopted in developing countries where worker health and safety is given much less consideration than in developed countries.

MUSCULOSKELETAL SYMPTOMS, INJURIES, AND ILLNESSES

Several studies have shown that farming is a physically demanding occupation with work tasks that can cause musculoskeletal disorders (MSDs). Research has demonstrated that MSDs are common among dairy farmers especially in the lower back, shoulders, hands/wrists, and knees.[21–30] Due to a lack of reliable and accepted measurement of MSDs, researchers have been forced to rely on self-reported musculoskeletal symptoms (MSS) as an indicator of MSDs. Studies involving the prevalence of MSS and MSDs among Irish, Australian, and Swedish dairy farmers and hired workers have been reported. Researchers estimated over 80% of Swedish dairy farmers and hired workers complain of MSS in a 12-month period.[21,23,25,26,31] Prevalence of MSS in any body part was approximately 81–90% among Swedish dairy farmers and 76–86% among hired workers. Musculoskeletal symptoms were mainly located in the lower back (43–57%), shoulders (32–54%), and knees (22–41%), with lower prevalences in the neck (23–36%), hand/wrists (20–41%), and hips (18–35%) among farmers and workers. In general, females usually report significantly higher frequencies of MSS in all body parts (84–93%) and especially in the hands/wrists (39–61%) than males. Further, studies have also found females report significantly more discomfort from repetitive and monotonous work than their male colleagues.[23,31] Among Irish dairy farmers, 36% reported having low back pain, 22% neck/shoulder pain, and 8% hip pain.[29] Lower et al.[27] reported 57% of Australian dairy farmers experienced back trouble directly related to dairy farming activities. See Table 1 for a study comparison of MSS prevalence in different body regions.

Previous studies have indicated that larger dairy operations are associated with an increased risk for injury.[32–34] Larger herd sizes, different parlor environments and milking methods, and cultural differences that influence self-reporting of symptoms make comparisons between dairy studies difficult. These factors may have a more significant influence on MSS among parlor workers on farms with growing herd sizes. Between 2005 and 2009, US dairy farms with fewer than 500 cows declined, whereas farms with 500–999 cows remained relatively constant. In contrast, US farms with 1000 or more cows increased 20%, driven by significantly lower costs of production. In 1998, nearly 70% of milk produced in the United States came from small-herd operations (<500 head). By 2011, over 63% of milk produced in the United States came from large-herd operations (>500 head), and 34.6% came from operations of 2000 head or more.[20]

Information regarding the prevalence of MSS among US agriculture workers is scarce. Pratt et al.[33] did concentrate on US dairy farmers when they evaluated “injury” in several anatomical sites. However, this study did not focus specifically on musculoskeletal problems, and the researchers categorized upper extremity injuries only as “arm” or “hand.” Dairy farming has the second highest prevalence of injuries among all US agriculture groups.[32,35,36] The majority of these injuries originate from interactions with dairy cattle during milking activities.[33,35,37] Nonnenmann et al.[40] assessed MSS prevalence among Iowa dairy farmers. One of the primary objectives of the study was to examine the association between type of milking facility (stanchion versus parlor) and prevalence of MSS of the upper extremity. No association was found between type of milking facility and upper extremity MSS. Nonnenmann

TABLE 1. Prevalences (%) of Work-Related Musculoskeletal Symptoms Among Dairy Farmers and Hired Workers

Location	Gustafsson et al., 1994[33] Sweden *N* = 2085 (*N* = 920)	Stal and Pinzke, 1991[32] Sweden *N* = 197 (*N* = 61)	Lower et al., 1996[29] Australia *N* = 138	Pinzke, 2003[27] Sweden N = 476 (*N* = 185)	Kolstrup et al., 2006[25] Sweden *N* = 42 (*N* = 14)	Osborne et al., 2010[31] Ireland *N* = 103 95% male	Lunner Kolstrup, 2012[23] Sweden *N* = 66 (*N* = 25)	Nonnenmann et al., 2008[40] USA *N* = 341
Neck	25 (35)	17 (23)		31 (39)	33 (50)	22	33 (48)	43
Shoulder	37 (49)	31 (46)	14	44 (59)	48 (71)		47 (60)	54
Elbows	18 (22)	15 (18)		20 (28)	10 (21)		23 (28)	24
Wrist/hand	18 (35)	24 (33)	3	24 (46)	26 (57)		23 (44)	40
Upper back	12 (18)	8 (13)	43	12 (15)	26 (43)		15 (20)	
Lower back	55 (50)	46 (43)		54 (47)	41 (50)	36	50 (60)	
Hips	23 (27)	20 (21)		28 (34)	14 (21)	8	12 (8)	
Knees	41 (37)	27 (28)	36	38 (33)	24 (29)		21 (24)	
Feet	13 (16)	8 (16)		14 (20)	14 (14)		21 (32)	
Any body part	82 (86)	73 (74)		83 (90)	86 (93)		85 (88)	75

Note. Female-only sample size and prevalence are given in parentheses.

et al.[38] were the first to estimate MSS of the upper extremity among US dairy farmers and found that shoulder MSS was the most prevalent at 54%. Additionally, hours milking per year was associated with an increased risk for elbow MSS. Since milking involves repetitive motions and muscle forces at the wrist, Patil et al.[39] examined the prevalence of carpal tunnel syndrome (CTS) among US large-herd parlor workers. The prevalence of CTS among parlor workers was 16.6% and 3.6% among non-parlor workers, a statistically significant difference. Results suggested that repetitive motion injuries (RMIs) such as CTS may be a significant health challenge for large-herd parlor workers. Additionally, Stål et al.[40] identified that pronator syndrome may also be a significant health challenge for dairy parlor workers. Karttunen and Rautiainen[41] conducted a retrospective cohort study to evaluate the incidence of and risk factors for compensated occupational injuries and diseases in Finnish agriculture. Findings suggest that dairy farmers have a 2.2 relative risk of injury compared with cereal crop farmers.

EXPOSURE STUDIES

A limited number of prior studies have addressed physical exposures related to the development of musculoskeletal disorders. Worker self-report is one method previously employed[12,23,25,27,38] as well as observation-based exposure assessment.[42–44] Direct measurement exposure assessment techniques have also been used, including heart rate monitoring and oxygen consumption estimation,[43,45] electrogoniometry,[10,17,46,47] surface electromyography (sEMG),[10,48–50] and laboratory-based three-dimensional (3D) optoelectronic motion analysis.[49]

Self-Report

Among factors identified as causing back trouble, 32% of Australian dairy farmers reported milking as being a contributor to back trouble, ranking second behind tractor work (37.3%).[27] Innes and Walsh[12] also investigated dairy work in Australia and reported lifting down cows and calving cows as having the highest mean ratings of perceived exertion (RPE). Boyle et al.[35] reported milking as having the greatest increase in risk for injury among dairy farmers in the Midwest region of the United States. Among small-herd (<500) US dairy farms, hours milking was found to be associated with elbow symptoms.[38] Consistent with this finding, Pinzke[25] reported an association between elbow MSS among female milkers and number of cows milked. Additionally, the number of cows milked in the parlor was associated with elbow MSS among female milkers. Using questionnaires, Kolstrup et al.[23] studied six dairy tasks: machine milking, handling of feed, manure removal, feeding, litter strewing, and parlor cleaning. They found machine milking to be the most harmful operations.

Observational Exposure Assessment

Ovako Working posture Analysing System (OWAS)[51] is a widely used method of observation to identify and evaluate harmful work postures at different work sites, including dairy farms. Using OWAS, Lundqvist[52] found that milking in stanchion barns with tied cows involved unacceptable working postures during 38% of total time, compared with 9% of the time when working in loose housing systems with parlor milking. Using OWAS to analyze video-based observational (VBO) data, Perkiö-Mäkelä and Hentilä[43] reported the most common work posture used during parlor milking on small-herd Finnish farms was standing with the back straight and upper arms below shoulder level. These findings support results of another study involving Finnish dairy farmers on small-herd operations.[44] Hwang et al.[42] also utilized the OWAS and VBO to analyze working postures in a stanchion system, and compare milking processes between stanchion and loose-housing systems. Researchers concluded dairy-farm work relied heavily on the usage of upper-body segments, with the worker frequently standing. Researchers acknowledged the limited practicality of using VBO in these work settings due to inherent researcher time and effort.

Muscle Forces

Surface EMG (sEMG) is an effective ergonomic research method to assess the physiological response to the demands placed on muscles during the performance of work activities. Ergonomic research of milking in Sweden began in the late 1970s. Laboratory studies of simulated milking evaluated shoulder load as well as the load on the knees and leg musculature. Results revealed the importance of minimizing the weight of milking machines and also determined optimal vertical and horizontal distances from the milker's body to the cow's udder.[50,53] Stål et al.[48] demonstrated using sEMG that Swedish small-herd parlor milking systems required high static muscle loads and low rest times. Peak loads for forearm flexor and extensor muscles were close to their maximum capacity, which, in combination with positions and movements of the hand and forearm, might contribute to the development of nerve injuries in addition to other tissue lesions such as tendonitis. Also investigating muscle loads in small-herd Swedish milking parlors, Pinzke et al.[10] reported that the milking tasks of stripping, drying, and attachment involved high muscle loads, with almost no time for rest. The highest load values for the biceps and forearm flexor muscles were found during attachment and drying. The authors concluded high muscle loads in combination with extreme positions and movements of the hand and forearm might contribute to the development of injuries. Using a biomechanical model and sEMG, Ekholm et al.,[54] Svensson et al.,[55] Arborelius et al.,[50] and Németh et al.[56] investigated joint loads and muscle activities associated with shoulder, ankle, knee, low back, and hips during milking tasks in parlor and stanchion systems. These studies involving small-herd operations found a parlor system lowered the lower limb muscle activity compared with a stanchion system.

Limb Posture and Motion

Nonnenmann et al.[46] quantified exposures to awkward knee postures among small-herd (<500 head) US dairy workers who performed milking and feeding tasks. Using electrogoniometry and short sample duration (30 min), the authors found that the percentage of time in $\geq 110°$ knee flexion was significantly greater in stanchion milking facilities as compared with parlor facilities. The authors concluded that working in stanchion milking facilities results in greater exposures to awkward knee postures compared with working in parlor milking facilities. Pinzke et al.[10] and Stål[17,47] utilized electrogoniometry to record motion and posture at the wrist among parlor workers on small-herd Swedish farms. Each of these studies used a task-based, short-sampling duration (<30 min). Extreme wrist positions of dorsiflexion were found during the milking tasks of stripping and attachment, and extreme deviation (ulnar and radial) postures were recorded during drying and attachment. High movement velocities were reported for drying and attachment tasks. Using acceleromety to estimate movement and postures at the shoulder, Douphrate et al.[13] conducted the first study to document full-shift (mean sampling duration of 7 h 25 min) biomechanical exposures among US large-herd (>500 head) parlor workers. Results from this feasibility study suggested that large-herd parlor workers may be exposed to exposure levels (posture, movement velocity, repetition, and inadequate rest) that are recognized as being associated with the development of shoulder pathology. Compared with other high-risk occupations involving shoulder-intensive work, these findings suggested that parlor workers may have higher exposure levels involving the shoulder.

Physiological Workload

A Finnish study on small-herd farms estimated oxygen consumption (VO_2) and heart rate (HR) during the milking process. Average sampling duration of VO_2 was 18 min and HR 115 min. Findings suggested that milking involved mostly light work with low VO_2 (0.6 1/min) and mean heart rate (95 beats/min).[44] Ahonen et al.[45] also estimated the physical stress and strain in dairy farming using ambulatory heart rate and oxygen consumption measurements. The handling of feed and manure was the heaviest work task in dairy farming on small-herd (mean 12 head) Finnish farms. Perkiö-Mäkelä and Hentilä[43] studied the physical workload and strain of dairy farming and reported that milking was light work and feeding was moderately heavy work for the cardiovascular system on small-herd (mean 45 head) Finnish farms.

GOOD PRACTICES AND INTERVENTIONAL EFFORTS

Several practices and interventions to prevent MSDs when milking cows were observed by ergonomists during farm visits and meeting with farmers across Belgium, Poland, Sweden, and UK.[57] These good practices included the installation of a milking rail in tie stall barns to ease transportation of milking equipment, and the installation of a floor adjustable to the height of the worker in parlor systems. Installation of perforated rubber matting on existing floors in parlors aimed to decrease the physical load on the lower extremities and reduce fatigue. Other good solutions were found for specific tasks in parlor milking. For udder cleaning, a centralized placement of a bucket for wipe towels or cloths on a cart would reduce both walking distance and exposure to awkward trunk posture among milkers. Installation of a support arm was also considered to reduce the workload when attaching clusters, as well as the use of lightweight clusters and tubes. Instead of using a dip cup for teat dipping, the worker can spray the teats with disinfectant. This spray application reduces the reach distance of the worker.

Despite these solutions found on existing farms, research is scarce addressing specific ergonomic interventions in milking parlors. Jakob et al.[58] investigated the effects of working height and milking unit weight during milking in a laboratory setting. Using 3D optoelectronic motion analysis, sEMG, HR, and perceived exertion, the authors demonstrated that the optimal working height for cluster attachment is having cow teats at the shoulder level of the parlor worker. Additionally, workload reduction was achieved via the reduction in weight of the milking cluster and tubes, which was demonstrated in a study by Pinzke et al.[59] A second laboratory study by Jakob et al.[53] investigated the effects of a new quarter-individual milking unit with a single tube in absence of a claw on the reduction of muscle load and extreme postures. Results suggested that this new milking unit has potential to reduce extreme postures and muscle loads for parlor workers. Stål et al.[7] investigated the impact of the workload on the milker's forearm, wrist, and hands resulting from using a prototype support arm designed to facilitate the cluster attachment task. Using electrogoniometry and sEMG, the authors demonstrated a minimal decrease in muscular load while using the support arm and little change in wrist posture.

CONCLUSIONS

Limited research has demonstrated that dairy operators and parlor workers are exposed to physical risk factors associated with the development of MSDs. Awkward postures, high muscle forces, high movement velocities and repetitions, and minimal opportunity for rest have been documented in the literature to be characteristic of parlor working environments. As the world's population grows, global dairy producers will be forced to produce more dairy products to meet the increasing global demand. Dairy producers will seek more cost-effective means to produce their products. Farms will continue to increase in size reflecting economies of scale associated with larger herd sizes, as well as seek novel and more efficient milking strategies such as AMS. Workers on farms with larger herd sizes are exposed to ergonomic risk factors associated with the development of WMSDs. Continued ergonomic research is needed on dairy farms of all sizes. Due to different parlor configurations, milking practices, herd sizes, cow breed, and varying worker anthropometrics, future research should reflect these unique farm characteristics.

Ergonomic exposure assessment research has been limited by direct measurement technologies. Additionally, limitations in memory capacity have prevented the continuous recording of physiological activity for long sampling durations. Prior research has documented the need for continuous, long duration, direct measurement methodologies.[60,61] Advancements in modern direct measurement technologies such as sEMG, motion capture, and physiological monitoring have enabled more precise and valid estimations of physical exposures. Additionally, advancements in memory capacity have enabled long duration and full-shift measurement. Future ergonomic exposure field researchers should consider using these new technologies that may enable more precise and representative exposure estimation, as well as improved demonstration of intervention effectiveness. Additionally, standardized exposure metrics should be utilized to enable the comparison across studies.

In addition to the need for continued exposure estimation, future research needs to demonstrate intervention effectiveness in reducing physical exposures. Interventions should not only address the health and safety of the worker, but also worker productivity and efficiency, which would result in improved parlor performance and profitability. Furthermore, examining relationships between the organization of milking routines and how exposure times may be reduced by the modification of work tasks or schedules are important issues to consider in future studies. Future research efforts should also utilize the methods and metrics as described to evaluate the effectiveness of different interventions to reduce ergonomic exposures in large-herd milking parlors. The aforementioned feasibility studies demonstrate the successful utilization of modern, direct measurement technologies, as well as objective exposure metrics to characterize full-shift ergonomic exposures in challenging work environments. The methods and metrics used in these studies will be used in future research to investigate exposure-outcome relationships as well as the determination of intervention effectiveness in milking parlors and other occupational settings and industries.

The dairy industry faces a challenge by the introduction of new, technologically advanced milking systems such as the automatic milking system that replaces manual milking. As automated milking replaces traditional milking methods in some regions such as northern Europe, the milking process may be less hazardous, since automated milking eliminates many of the ergonomic stressors and safety hazards associated with traditional parlor milking. However, work-related mental stress or fatigue may result among dairy farmers due to the necessity for continuous monitoring and the potential for mechanical breakdown. Therefore, the impact of these new technologies on worker health should be explored.

Dairy production continues to trend toward large-herd operations in some regions of the world. Large-herd milking parlors may involve ergonomic risk factors associated with the development of WMSDs. Dairy producing regions where herd size enlargement is restricted may adopt new milking technologies such as AMS. Future research should continue to identify best practices and cost-effective technologies and strategies that minimize or eliminate worker exposures in these changing working environments. Future research efforts should involve international, multicenter collaborative studies using standardized study designs and methods. Additionally, industry involvement in future research is paramount to ensure stakeholder input, thereby increasing the likelihood of adoption of identified best practices and injury-reducing strategies.

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