Applied Ergonomics 43 (2012) 604–613

Contents lists available at SciVerse ScienceDirect

Applied Ergonomics

journal homepage: www.elsevier.com/locate/apergo

Full shift arm inclinometry among dairy parlor workers: A feasibility study in a challenging work environment

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ARTICLE INFO

Article history:
Received 23 March 2011
Accepted 12 September 2011

Keywords:
Work-related musculoskeletal disorders
Exposure assessment
Agriculture

ABSTRACT

Over the last 20 years, the US dairy industry has experienced a significant transformation from small farm operations to an industrialization of the milking process. This transformation has resulted in improvements in process efficiency and product quality. Milking tasks in large-herd parlors are highly-repetitive involving awkward postures and high muscle loads of the upper extremity. Field-based direct measures of physical exposures have been limited in challenging work settings such as dairies. This study evaluated full-shift exposures of posture and motion of the upper extremity among large-herd parlor milkers using wireless inclinometry. Results suggest large-herd parlor workers may be exposed to high exposure levels (posture, movement velocity, repetition, and inadequate rest) associated with the development of shoulder pathology. Compared to other high-risk occupations involving shoulder-intensive work, parlor workers may have higher exposure levels. These findings warrant the need for continued field-based research with larger sample sizes to facilitate the development of cost-effective intervention strategies.

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1. Introduction

1.1. Industry profile and trends

Over the past two decades, the US dairy industry has transformed into an efficient and quality driven work process in response to higher consumer demands. From 1989 through 2009, the number of US milking operations decreased by 68%, while during the same period milk production increased by 32%. Increased milk production despite a decreased number of dairy farms has been accomplished through increased milking herd sizes. The number of small herd operations (<500 head) continues to diminish whereas the number of large herd (≥500 head) operations continue to rise (Douphrate et al., 2009). In 1998, nearly 70% of milk produced in the US came from small herd operations. By 2009, over 60% of milk produced in the US came from large herd operations, and 31% came from operations of 2000 head or more (NASS, 2010). Limited research has addressed worker health and safety in these mass-production milking environments, and additional injury research is needed given the trend to large herd dairy farms (Douphrate et al., 2009).

1.2. Parlor operations

Two types of milking systems are used on US dairy farms: The stanchion (tethered) system and the parlor (loose-housing) system. In stanchion systems, milking units are brought to the tethered dairy cow. In contrast, parlor systems involve cows freely moving into stationary milking stalls where they are milked simultaneously. After milking, cows exit and a new group enters the parlor to begin the milking process. Milking parlors can accommodate large numbers of cows and, consequently, the parlor system is used almost exclusively in large herd operations. In 2006, 78% of US dairy cows were milked in a parlor compared to 54.9% in 1996. In 2006, 100% of large herd dairy operations used a milking parlor (USDA, 2007).

Milking parlor configurations are defined by the orientation of the cow in relation to each other and in relation to the worker. The cow's orientation affects udder accessibility and may have

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doi:10.1016/j.apergo.2011.09.007

an influence on worker physical demands. Three primary types of parlor configurations are used: herringbone, parallel and rotary. In herringbone parlors, workers operate in a pit below the level of the dairy cows. Cows are turned 40–45° away from the milking pit (Fig. 1). The orientation of the cow allows workers to access the udder from the side of the animal. Like the herringbone configuration, workers in a parallel parlor work in a milking pit. In contrast, cows are aligned parallel to one another and perpendicular to the worker (Fig. 2). Therefore, the udder must be accessed from between the hind legs of the animal. The parallel configuration allows for larger numbers of cows to be milked per linear foot of the milking pit compared to the herringbone alignment. In a rotary parlor, cows walk onto a slowly moving carousel (Fig. 3). Workers operate outside of the carousel at a level below the animal. Like a parallel parlor, the udder is accessed from between the hind legs of the animal. In comparison to herringbone and parallel configurations, the rotary style requires greater capital investment. In 2006, 47% of US large herd parlors were herringbone, 32% parallel, and 5% rotary (USDA, 2007). Dairy researchers and parlor equipment experts share the opinion that the parallel configuration is becoming more common due to lower costs as compared to herringbone and rotary parlors (Reinemann, personal communication; Sorenson, personal communication).

Herringbone, parallel and rotary parlors present different workstation designs as they relate to the milker–cow interface. Cow orientation in a herringbone parlor presents a shorter upper extremity reach for the milker. Parlor dimension measurements among seven herringbone parlors revealed a mean distance of 56.6 cm (SD 1.9) cm from platform edge to mid-udder. In addition, milkers access the under by reaching around a hind leg (Fig. 4). Measurements taken from 17 parallel parlors revealed a longer mean distance of 59.6 cm (SD 2.1) from platform edge to mid-udder. Additionally, the milker must access the udder by reaching between the cow's hind legs (Fig. 5). A rotary parlor workstation is setup similarly to a parallel configuration. A cow's udder is accessed between the cow's hind legs but with an additional dynamic of the cow moving slowly on a carousel (Fig. 6). Measurements taken among seven rotary parlors revealed a mean distance of 59.5 cm (SD 3.5) from platform edge to mid-udder. All milking parlor dimensions vary due to construction differences as well as cow differences such as breed, age and udder morphology. Milkers must also work in a small milking "window" often reaching around protective railings (Figs. 4, 5 and 6). In addition to repetitive reaching, awkward upper extremity and trunk postures, and muscular loads, milkers are at risk of being kicked due to the close proximity to the hind legs of the cow.

A milking unit consists of a number of parts: claw, teat cups, milking tubes and in some dairy parlors a positioning/support arm.

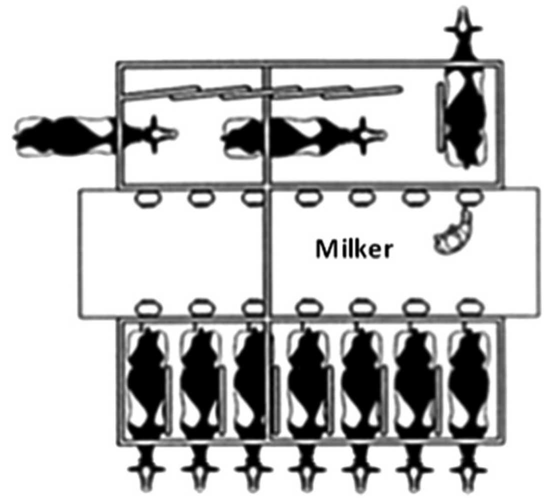

Fig. 2. Parallel parlor.

Together, the claw and the teat cups constitute a cluster. Milking clusters can weigh up to 3.5 kg (Stål et al., 2000). A retractable support arm is often used to suspend and properly position the cluster below the udder and off the parlor floor in herringbone parlors.

In addition to different parlor designs and dimensions, the milking procedure involves several tasks. These tasks include 1) stripping of cow teats to stimulate milk flow; 2) pre-dipping of the teats with a cup or spray for sanitization; 3) wiping teats; 4) attachment of milking cluster; 5) detachment of the milking cluster; and 6) post-dipping of teats for sanitization. All tasks involve unique worker demands. Cluster attachment to the udder has been identified as one of the more physically strenuous dairy tasks (Pinzke et al., 2001b). Cluster attachment involves holding the claw with one hand and attaching teat cups with the other hand. The attachment process takes place while the worker is reaching behind or to the side of the cow to access the udder.

A variety of milking routines are employed in herringbone and parallel parlors: territorial, sequential and group milking. Sequential milking occurs when one milker, in sequence, follows another milker down one side of the milking pit to complete the milking task. A territorial milking routine differs in that one milker performs all tasks on all cows within one area of the milking pit. Group milking is a territorial routine when one or more milkers perform all procedures within two or more territories in larger parlors (Smith et al., 1998). In rotary parlors, task specialization is

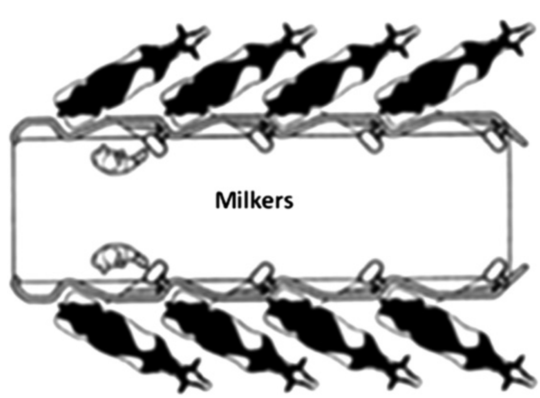

Fig. 1. Herringbone parlor.

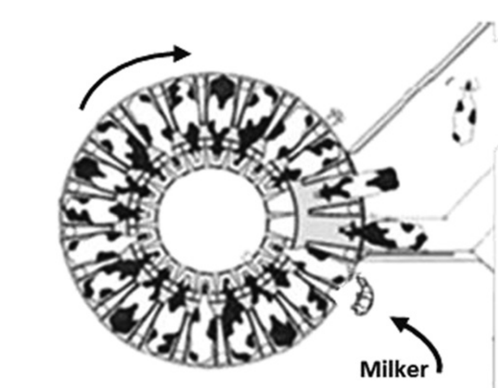

Fig. 3. Rotary parlor.

Fig. 4. Herringbone milker.

Fig. 6. Rotary milker.

evident as milkers typically stand in one location and perform 1–2 tasks as each cow moves past on the carousel. Cows are typically milked 2–3 times a day, 7 days a week, and 24 h a day without interruption. Typical work shifts are 8–12 h in duration, with 2–3 work shifts comprising the work day.

Large herd sizes, varying parlor configurations and dimensions, irregularly shaped and often heavy milking units, specialized tasks, different milking routines, close proximity to the hind of a cow, and long work shifts all characterize modern milking parlors. These attributes may affect physical exposures which may increase the risk for development of MSD among parlor workers.

Fig. 5. Parallel milker.

1.3. Worker population

A large proportion of US dairy workers are Hispanic males (Douphrate et al., 2011; Roman-Muniz et al., 2006). On average, large herd parlor workers report working 9.0 h per day (SD 1.7), 6.0 days per week (SD 3.3), 49.6 weeks per year (SD 8.2) (Douphrate et al., 2011).

1.4. Musculoskeletal symptoms

Upper extremity injuries account for about 22% of all lost time injuries that occurred on farms in 1995 (Meyers et al., 2000). Upper extremity injuries have plagued dairy farms with 27% of all injuries being attributed to this region of the body, and almost 20% in the neck and head region (Pratt et al., 1992). The majority of peer-reviewed literature about musculoskeletal symptoms (MSS) among dairy workers and exposure to physical risk factors during dairy work involves Swedish operations. The observed prevalence of shoulder and hand/wrist MSS among Swedish dairy workers exceeds 50% (Pinzke, 2003; Stål et al., 2000). Moreover, increased automation of the milking process requires forceful arm and hand motions (Stål et al., 2000), and milking and feeding tasks have been reported as being the most physically demanding (Pinzke et al., 2001b).

Results from these studies cannot be applied uniformly to US dairy operations. In contrast to the Swedish dairy industry, most milk production in the US comes from large herd dairy operations (NASS, 2002). Previous studies have indicated that working on large dairy operations is associated with an increased risk for injury (Crawford et al., 1998; Pratt et al., 1992; Stallones et al., 1986). In addition, parlor systems and processes are different in the US as compared to European milking methods. Larger herd sizes and different milking methods in the US make comparisons to European dairy investigations difficult. Among Iowa dairy farmers, neck and upper extremity MSS were found to be common and associated with common dairy farming practices (Nonnenmann et al., 2008) Parlor systems appear to reduce exposure to awkward knee postures compared to stanchion systems (Nonnenmann et al., 2010), however, the effect of parlor system configuration on upper extremity postures or MSS is understudied. Preliminary observations by the authors of over 50 large herd milking parlors in the US revealed the upper extremity was involved in highly-repetitive reaching and lifting activities in non-neutral postures when accessing udders to place and remove milking units. Workers are also exposed to forceful muscle exertions of the shoulder, wrist and hand. A current study involving US large herd (>500 herd size) milkers is investigating work-related musculoskeletal symptoms. Preliminary data suggest 41% of milkers report symptoms in the upper back, 39% report symptoms in the shoulder, 32% report symptoms in the wrist, and 24% report symptoms in the neck (Douphrate et al., 2011).

1.5. Posture and shoulder disorders

Working with arms elevated at the shoulder joint has been associated with neck/shoulder symptoms and disorders, including rotator cuff tendonitis (Jonsson, 1988; Leclerc et al., 2004; Miranda et al., 2001; Ohlsson et al., 1994; Punnett et al., 2000; Silverstein et al., 2008, 2006; Svendsen et al., 2004a; Svendsen et al., 2004b; Viikari-Juntura et al., 2001). A causal relationship has been suggested by several critical systematic reviews (Ariëns et al., 2000; Bernard, 1997; Hagberg and Wegman, 1987; van der Windt et al., 2000). Sustained activity of the neck and shoulder muscles, compromised circulation, and mechanical pressure on the shoulder muscles and/or tendons are possible pathophysiological mechanisms explaining this relationship (Bernard, 1997; Järvholm et al., 1989; Sjogaard et al., 2000; Svendsen et al., 2004b).

1.6. Exposure assessment among dairy parlor workers

Prior studies have assessed physical exposures among dairy parlor workers using self-report (Innes and Walsh, 2010; Lower et al., 1996; Nonnenmann et al., 2008; Pinzke, 2003), observation (Hwang et al., 2010; Perkio-Makela and Haentila, 2005), ambulatory heart rate monitoring and oxygen consumption estimation (Ahonen et al., 1990; Perkio-Makela and Haentila, 2005), electrogoniometry (Nonnenmann et al., 2010; Pinzke et al., 2001a; Stål et al., 1999, 2003), electromyography (EMG) (Arborelius et al., 1986; Jakobs et al., 2009; Pinzke et al., 2001a; Stål et al., 2000), and laboratory-based 3D optielectronic motion analysis (Jakobs et al., 2009). No studies have attempted to collect and quantify full-shift posture and motion data among large herd dairy parlor workers in challenging work environments of milking parlors.

1.7. Motion capture

Direct measurements provide objective and quantitative measures appropriate for estimating exposure to physical risk factors and evaluating possible interventions (Hansson et al., 2009). Direct measurements provide the most precise estimates of exposure to forceful exertions, postures and repetitions as compared to self-report or observational techniques (Amasay et al., 2009; Burdorf and van der Beek, 1999; van der Beek and Frings-Dresen, 1998; Winkel and Mathiassen, 1994). Several motion capture technologies have been used to evaluate human motion and postures. They can be briefly categorized as: optical, image-based, mechanical, magnetic, inertial, acoustic, and hybrid systems (Dong et al., 2008). Among them, inertial measurement units (IMUs) built with micromachined accelerometers appear to be the most promising of the available motion capture technologies for data collection in field settings when considering size, accuracy, portability, and cost (Dong et al., 2008; Zhu and Zhou, 2004). Zhou et al. (2006) demonstrated that IMUs consisting of accelerometers, gyroscopes and magnetometers used to measure upper limb motion can accurately estimate arm position.

Postures and movements of the upper arm are rarely sufficiently quantified among workers suspected to be at risk. Few all day posture assessments have been reported to date (Balogh et al., 2004; Freitag et al., 2007; Hansson et al., 2001b) likely due to difficulties of establishing an accurate, long-term field-based measurement system (Straker et al., 2010). In addition, extracted posture or movement variables rarely include all three principal exposure dimensions: magnitude, frequency, and duration (Hagberg et al., 1995; Wahlström et al., 2010; Winkel and Mathiassen, 1994). Accurate full-shift acquisition of posture and movement data is critical for the investigation of these physical exposures as risk factors for MSDs (Straker et al., 2010).

In light of the US trend towards large herd milking operations, parlor workers may be exposed to physical risk factors associated with the development of upper extremity MSDs. The purpose of this field-based feasibility study was to collect and compare full-shift exposure data assessing posture and motion of the upper extremity among large herd parlor workers using a wireless data-logging inclinometer. Results from this study would guide future research efforts as well as the development of cost-effective injury prevention strategies.

2. Methods

2.1. Subjects

Nine parlor workers (milkers) were recruited for this feasibility study. This sample size was adequate to evaluate methods involving full-shift data collection, as well as to collect pilot exposure data leading to future research. Each milker worked full-time in the dairy parlor and was free from pain or pathology in each upper extremity. After meeting criteria, the study was explained and participants were asked to sign an informed consent. The informed consent was made available in both English and Spanish, and a bilingual investigator was present for translation purposes. The study was approved by the Colorado State University Institutional Review Board. Each milker was paid $20 for participation.

Of the nine participants, six were male. Mean age was 29.0 (range: 21–39) and 30.0 (range: 29–31) years for males and females respectively. Mean height and weight was 169.8 cm (range: 160.0–182.9) and 68.8 kg (range: 56.7–81.7) respectively for males, and 161.7 cm (range: 152.4–167.6) and 61.1 kg (range: 58.1–66.7) respectively for females. All participants were right-hand dominant. Mean workshift sample duration was 7 h and 25 min, or 449 min (373–533) (Table 1).

Table 1
Parlor worker characteristics, means (SD).

	Male n=6	Female n=3
Age (years)	31.1 (9.1)	32.7 (6.6)
Height (cm)	168.0 (24.3)	157.9 (10.2)
Weight (kg)	74.3 (15.6)	64.8 (12.3)
Experience in parlor (years)	3.1 (1.6)	2.9 (.85)

2.2. Study setting

Data were collected in milking parlors of five large-herd dairy operations during the summer months of 2010. These dairies were located in Colorado, New Mexico and Texas. Among these five dairies were two parallel parlors, two herringbone parlors, and one rotary parlor. Two males and two females represented the two parallel parlors. Two males and one female represented the two herringbone parlors. Two male subjects represented the one rotary parlor. Full-shift posture data were successfully collected from each participant representing each parlor configuration.

2.3. Study equipment

Shoulder elevation and trunk inclination angles were derived using a triaxial accelerometer (inclinometer) called the Virtual Corset (VC) (Microstrain, Williston, VT, USA). The VC is a wireless, battery-powered, pager-sized portable logger with 2 MB of on-board memory, weighing 72 g and measuring 6.8 × 4.8 × 1.8 cm. Each unit measures and stores accelerations from two orthogonally positioned, low-pass filtered triaxial accelerometers. Each VC was sampled at a rate of 7.5 Hz. While recording postural angles the inclinometers have a reported error of 1.8° (±1.0°) when used according to manufacturer specifications (Johnson et al., 2002). Triaxial accelerometers have been previously validated for use in posture analysis (Hansson et al., 2001a) and for use at the shoulder (Amasay et al., 2009).

One VC was mounted to the posterior trunk at midline and approximately at T4 level (Trask et al., 2006) using a 15 × 20 cm Tegaderm Transparent Film Dressing (3 M Health Care, St. Paul, MN, USA). One VC was mounted to each posterior upper arm half the distance between the lateral epicondyle of the humerus and the acromioclavicular joint. Each arm VC was secured to the subject's skin using pre-wrap taping foam reinforced with elastic athletic tape. Trunk inclination (flexion/extension) and shoulder elevation (flexion/extension) relative to gravity were measured throughout the full workshift. Each VC recorded shoulder and trunk flexion as a positive inclination, and extension as a negative inclination.

2.4. Procedure

Approximately 30–45 min prior to starting work, each milker was equipped with a VC on each arm and trunk. Each subject was asked to stand in an upright position with arms hanging to each side. An offset reference posture of the upper arm (0°) was recorded when the arm was hanging in the gravity line holding a 2 pound (.9 kg) weight. Each VC was zeroed, launched, and milkers began their work in usual fashion. The research protocol was designed to minimize parlor milking disruption and evaluate full-shift exposures of all tasks combined, not individual job tasks. Mean sample duration for all participants was 7 h and 52 min (SD 9 min).

Due to gravity dependency of accelerometer-based inclinometer, shoulder posture was measured relative to gravity, not relative to trunk inclination. Attempts were made prior to data collection to synchronize each VC with the intent of estimating shoulder elevation relative to trunk inclination. This approach would insure a more anatomically-correct shoulder posture. Following the launch of each VC a distinctive maneuver was performed with the subject assuming a forward trunk inclination of 10° and bilateral shoulder inclination of 90° (relative to gravity). This maneuver induced a distinctive signature in the recorded VC data to allow for temporal synchronization and a spatial calibration/reference between the arm and trunk sensors during post processing. Upon completion of full-shift data collection, each VC was removed and data transferred from each unit to a personal computer for analysis using custom software (Fethke et al., 2004) written in LabVIEW® (National Instruments Inc., Austin, TX). Descriptive statistical analyses were performed using SAS (SAS Institute, Cary, NC).

2.5. Exposure metrics

Consistent with exposure metrics from previous limb posture and movement studies (Kazmierczak et al., 2005; Wahlström et al., 2010), we extracted selected percentiles (10th, 50th, and 90th) from the cumulative distribution of postures and movements, variables describing 'extreme' postures such as percent time with the arms elevated >45° and variables assumed to describe the occurrence of 'rest' and recovery. The definition of 'rest' was an upper arm posture less than 20° of elevation and angular velocity less than 5° s^{-1}; frequency of micro-recovery periods was defined as the number per minute of substantial periods (greater than 3 s) in a neutral posture (less than 20° elevation). Also, the proportions of time working with high (greater than 90° s^{-1}) and low (less than 5° s^{-1}) for at least three consecutive seconds) angular velocities were retrieved. The difference between the 90th and 10th percentiles was used to describe exposure variation (Mathiassen, 2006). As an index of repetitiveness, mean power frequency (MPF) percentiles of the power spectra (Hansson et al., 1996; Radwin and Lin, 1993) were also calculated.

3. Results

3.1. Posture

Median shoulder elevation among all workers during parlor milking was 22.7° and 10.2° for the right and left arms respectively. Mean 90th percentile shoulder elevation was 71.9° and 61.3° for the right and left respectively. On average, parlor workers worked with the arms elevated in extreme postures (greater than 45° elevation) for 28.1% (128 min) and 20.6% (94 min) of the total work day with the right and left arm respectively (Table 2). Rotary parlor workers had the highest percent times spent in a neutral posture and similar times spent in extreme postures bilaterally as compared to herringbone and parallel parlor workers (Table 3). Female parlor workers had higher 90th percentile postures, lower percent times spent in neutral postures, and higher percent times spent in extreme postures bilaterally as compared to their male counterparts (Table 4).

3.2. Movement velocities

Median angular velocity among all workers was 28.7° s^{-1} and 26.9° s^{-1} for the right and left arms respectively. Mean 90th percentile angular velocity was 148.0° s^{-1} and 134.9° s^{-1} for the right and left respectively (Table 2). Female parlor workers were exposed to higher angular velocities than their male counterparts (Table 4), and rotary parlor workers were exposed to lower velocities than herringbone and parallel workers (Table 3).

3.3. Repetition

The average MPF for the right and left upper extremity was .73 Hz and .60 Hz respectively. Mean 90th percentile MPF was 1.28 Hz and 1.10 Hz for the right and left respectively (Table 2). Female and male workers had comparable levels of repetitiveness (Table 4). Rotary workers had lower levels of repetitiveness than herringbone and parallel workers (Table 3).

Table 2
Full-shift posture and movement exposure metrics of the upper extremity (shoulder) (n = 9) (3 herringbone, 4 parallel, 2 rotary).

Exposure	Left	Right
Postures (negative values denote postures in extension, positive values in flexion)		
10th percentile (°)	−14.2 (2.1)	−3.5 (2.1)
50th percentile (°)	10.2 (3.0)	22.7 (3.3)
90th percentile (°)	61.3 (5.7)	71.9 (4.0)
Percentile range (10th–90th) (°)	75.6 (5.6)	75.3 (3.4)
Time in neutral posture (<20°) (%)	61.6 (4.0)	44.9 (4.7)
Time in extreme posture (>45°) (%)	20.6 (3.1)	28.1 (3.4)
Time in extreme posture (>60°) (%)	12.6 (2.3)	16.8 (3.3)
Movement velocities (°s^{-1})		
10th percentile	6.3 (.18)	6.5 (.17)
50th percentile	26.9 (2.0)	28.7 (1.6)
90th percentile	134.9 (7.3)	148.0 (6.2)
Percentile range (10th–90th)	128.6 (7.2)	141.5 (6.3)
Time at low velocities (<5°s^{-1}) (%)	24.0 (1.7)	22.6 (1.3)
Time at high velocities (>90°s^{-1}) (%)	12.2 (1.7)	14.3 (1.2)
Rest/Recovery		
# per min. of substantial periods (>3s) in neutral posture	2.6 (.21)	1.7 (.3)
# per min. of substantial periods (>3s) at low velocities	.46 (.08)	0.4 (.07)
Time in neutral posture for substantial periods (>3s) (%)	42.0 (6.2)	22.2 (4.3)
Time at low velocities for substantial periods (>3s) (%)	5.8 (.84)	5.9 (.7)
Time in neutral posture and low velocity (%)	16.7 (1.8)	12.2 (1.5)
Time in neutral posture and low velocity for substantial periods (>3s) (%)	4.8 (.76)	3.8 (.50)
Repetition		
Mean Power Frequency (Hz)	0.6 (.04)	.73 (.06)
10th percentile	.21 (.01)	.22 (.01)
50th percentile	.54 (.04)	.63 (.06)
90th percentile	1.1 (.06)	1.28 (.10)
Percentile range (10th–90th)	0.9 (.06)	1.06 (.09)

3.4. Rest

Parlor workers had minimal opportunity for rest, having only 12.2% (right) and 16.7% (left) of their workshift in neutral posture *and* low velocity. When evaluating rest for substantial periods, workers had considerably less opportunity, having only 3.8% (right) and 4.8% (left) of their workshift spent in neutral posture and low velocity for a minimum of 3 consecutive minutes (Table 2). Female workers had less opportunity for rest than their male counterparts (Table 4), and rotary workers had higher opportunities for rest than herringbone and parallel workers (Table 3).

4. Discussion

Several occupational exposures have been associated with shoulder complaints and disorders; these include work with elevated arms, monotonous repetitive work, forceful exertions and inadequate rest. However, most epidemiological investigations of the work-relatedness of shoulder disorders suffer from methodological limitations, including imprecise exposure assessment and self-report of health outcome. The current lack of knowledge hampers the development of interventions to prevent work-related shoulder disorders. Work with elevated arms has been hypothesized to cause degenerative changes in the rotator cuff tendons and thus predispose to tears. It is unclear how high and for what duration the arms must be elevated for these harmful effects occur. Existing evidence suggests angles above 60° are problematic, but the majority of studies cannot separate effects of postural load and monotonous repetitive work. Few studies have focused on elevation angles above 90°, and the literature is scarce on the effects of varied patterns of arm elevation (Svendsen et al., 2004b). A recent study found a significant association between shoulder flexion ≥45° for ≥15% of time combined with forceful exertions ≥9% time or forceful pinch >0% time and the development of rotator cuff syndrome (Silverstein et al., 2008).

Table 3
Full-shift posture and movement exposure metrics of the upper extremity (shoulder) based on parlor configuration (n=9) (3 herringbone, 4 parallel, 2 rotary).

Exposure	Herringbone		Parallel		Rotary	
	Left	Right	Left	Right	Left	Right
Postures (negative values denote postures in extension, positive values in flexion)						
10th percentile (°)	−11.0 (16.0)	−1.2 (6.8)	−18.2 (2.90)	−5.7 (0.6)	−11.2 (2.9)	−2.4 (0.5)
50th percentile (°)	13.4 (5.9)	24.6 (10.6)	7.9 (5.1)	21.7 (2.5)	10.0 (5.1)	21.7 (4.0)
90th percentile (°)	61.2 (10.1)	69.7 (9.5)	62.5 (12.0)	72.9 (6.2)	59.0 (1.8)	73.1 (8.5)
Percentile range (10th–90th) (°)	72.2 (6.7)	70.9 (4.2)	80.8 (12.2)	78.6 (6.0)	70.2 (1.20	75.6 (8.5)
Time in neutral posture (<20°) (%)	58.1 (8.8)	42.6 (15.1)	64.4 (6.9)	45.7 (3.4)	61.0 (5.5)	46.6 (5.0)
Time in extreme posture (>45°) (%)	22.0 (6.4)	30.3 (9.7)	19.9 (5.8)	26.6 (3.5)	19.8 (1.9)	28.0 (6.2)
Time in extreme posture (>60°) (%)	13.5 (3.9)	19.5 (6.4)	12.8 (4.9)	19.2 (4.9)	10.7 (.93)	7.9 (5.7)
Movement velocities						
10th percentile (°s^{-1})	6.4 (.17)	6.6 (.17)	6.4 (.16)	6.4 (.27)	5.8 (.77)	6.5 (.01)
50th percentile (°s^{-1})	29.9 (3.1)	28.3 (2.6)	27.4 (3.2)	31.0 (2.6)	21.3 (.13)	24.8 (2.2)
90th percentile (°s^{-1})	138.2 (12.7)	141.4 (4.1)	139.5 (13.6)	163.3 (7.7)	120.4 (9.2)	127.2 (4.0)
Percentile range (10th–90th) (°s^{-1})	131.2 (12.7)	134.9 (4.2)	133.1 (13.4)	156.9 (7.8)	114.7 (8.4)	120.7 (4.0)
Time at low velocities (<5°s^{-1})	21.9 (2.7)	21.8 (2.7)	23.1 (2.7)	21.4 (1.8)	28.8 (1.1)	26.2 (1.4)
Time at high velocities (>90°s^{-1}) (%)	14.0 (3.1)	13.9 (1.3)	12.7 (2.8)	16.8 (1.5)	8.4 (.01)	9.7 (1.5)
Rest/Recovery						
Number per minute of substantial periods (>3 s) in neutral posture	2.6 (.60)	1.6 (0.8)	2.6 (.27)	1.6 (0.2)	2.7 (.14)	2.1 (0.2)
Number per minute of substantial periods (>3 s) at low velocities	0.41 (.14)	0.39 (.14)	0.44 (.15)	0.42 (.12)	0.57 (.08)	.53 (.04)
Time in neutral posture for substantial periods (>3s) (%)	35.5 (11.9)	23.2 (13.7)	44.3 (11.3)	19.4 (2.8)	46.9 (8.3)	26.2 (4.3)
Time at low velocities for substantial periods (>3s) (%)	5.5 (1.60	5.4 (2.1)	5.2 (1.40	5.5 (.77)	28.8 (1.1)	7.1 (.33)
Time in neutral posture and low velocity (%)	14.2 (2.5)	11.6 (4.1)	16.6 (3.3)	11.0 (1.4)	20.3 (2.1)	15.4 (2.9)
Time in neutral posture and low velocity for substantial periods (>3s) (%)	4.1 (.84)	3.8 (1.3)	4.5 (1.5)	3.1 (.36)	6.5 (1.3)	5.1 (.69)
Repetition						
Mean Power Frequency (Hz)	0.59 (.03)	0.70 (.06)	0.63 (.07)	0.86 (.08)	0.54 (.05)	0.53 (.06)
10th percentile	0.23 (.00)	0.24 (.01)	0.21 (.01)	0.16 (.02)	0.17 (.01)	0.16 (.02)
50th percentile	0.57 (.03)	0.65 (.05)	0.60 (.06)	0.75 (.08)	0.37 (.01)	0.36 (.01)
90th percentile	1.09 (.12)	1.25 (.12)	1.13 (.10)	1.47 (.14)	1.00 (.02)	0.94 (.09)
Percentile range (10th–90th)	0.85 (.12)	1.01 (.12)	1.02 (.09)	1.24 (.14)	0.83 (.02)	0.78 (.08)

Table 4
Full-shift posture and movement exposure metrics of the upper extremity (shoulder) based on gender (6 male, 3 female).

Exposure	Male		Female	
	Left	Right	Left	Right
Postures (negative values denote postures in extension, positive values in flexion)				
10th percentile (°)	−12.8 (1.7)	−3.3 (3.2)	−17.0 (5.6)	−3.8 (1.5)
50th percentile (°)	10.2 (3.5)	21.1 (4.9)	10.1 (6.6)	25.8 (2.0)
90th percentile (°)	56.6 (5.3)	69.1 (5.2)	70.8 (13.6)	77.5 (6.1)
Percentile range (10th-90th) (°)	69.4 (3.8)	72.4 (3.9)	87.9 (13.9)	81.3 (5.8)
Time in neutral posture (<20°) (%)	62.3 (5.1)	47.5 (6.9)	60.1 (7.7)	39.6 (1.8)
Time in extreme posture (>45°) (%)	18.8 (3.5)	27.1 (4.9)	24.1 (6.4)	30.3 (3.7)
Time in extreme posture (>60°) (%)	10.8 (2.1)	13.7 (3.9)	16.2 (5.8)	22.9 (5.5)
Movement velocities				
10th percentile ($^\circ s^{-1}$)	6.2 (.26)	6.3 (.17)	6.4 (.18)	6.7 (.02)
50th percentile ($^\circ s^{-1}$)	25.2 (2.1)	27.9 (1.9)	30.1 (3.9)	30.3 (3.3)
90th percentile ($^\circ s^{-1}$)	127.8 (8.5)	142.5 (6.4)	148.9 (11.8)	158.9 (12.9)
Percentile range (10th–90th) ($^\circ s^{-1}$)	121.6 (8.4)	136.1 (6.6)	142.5 (11.7)	152.3 (12.9)
Time at low velocities ($<5^\circ s^{-1}$)	25.3 (1.6)	23.6 (1.3)	21.4 (3.9)	20.6 (2.9)
Time at high velocities ($>90^\circ s^{-1}$) (%)	10.8 (1.9)	13.3 (1.5)	14.9 (2.8)	16.1 (2.0)
Rest/Recovery				
Number per minute of substantial periods (>3s) in neutral posture	2.7 (.30)	1.9 (0.4)	2.4 (.23)	1.2 (0.1)
Number per minute of substantial periods (>3s) at low velocities	0.50 (.05)	0.48 (.04)	0.37 (.23)	0.35 (.19)
Time in neutral posture for substantial periods (>3s) (%)	43.2 (7.6)	26.3 (5.8)	39.6 (12.7)	14.1 (1.1)
Time at low velocities for substantial periods (>3s) (%)	6.5 (.79)	6.6 (.55)	4.6 (2.0)	4.3 (1.7)
Time in neutral posture and low velocity (%)	17.5 (1.7)	13.7 (2.0)	15.0 (4.6)	9.1 (1.4)
Time in neutral posture and low velocity for substantial periods (>3s) (%)	5.1 (.66)	4.5 (.56)	4.3 (2.1)	2.5 (.30)
Repetition				
Mean Power Frequency (Hz)	0.58 (.02)	0.70 (.06)	0.62 (.11)	0.80 (0.15)
10th percentile	0.21 (.01)	0.21 (.02)	0.21 (.02)	0.24 (0.00)
50th percentile	0.53 (.05)	0.61 (.09)	0.56 (.08)	0.67 (0.11)
90th percentile	1.14 (.05)	1.6 (.12)	1.1 (.18)	1.3 (0.23)
Percentile range (10th–90th)	0.94 (.04)	1.06 (.10)	0.90 (.18)	1.1 (0.23)

Due to the exploratory nature of this study and small sample size a true experimental study design was not employed which precluded any testing of statistical effects attributable to parlor configuration or gender. However, the results of this study suggest parlor workers may be exposed to extreme shoulder postures, high movement velocities and repetitions. In addition, the shoulder may be exposed to limited opportunities for rest or recovery. Interestingly, the two rotary parlor workers were exposed to comparable postures but lower movement velocities, lower repetitions and higher opportunities for rest/recovery. One possible explanation to this finding could be that the rotary parlor sampled utilized a job task rotation strategy allowing milkers to rotate every hour to a different task, resulting in exposure variation. Parallel and herringbone parlors often employ a territorial or group milking routine where milkers perform all milking tasks without variation or opportunity for job rotation. This finding is of interest in light of the industry trend toward parallel parlors, and a lower prevalence of rotary parlors among large-herd milking operations. A simple administrative control such as job rotation in parallel or herringbone parlors may be an effective means to reduce exposures. A cow pusher is a worker that goes from the parlor to cow pins and herds cows to the parlor for milking. This position requires a dependable worker that does not mix cows in different pins and is usually a more senior worker. One strategy may be to cross-train parlor workers to serve the role of cow-pusher. This would allow herringbone and parallel parlor workers to rotate between tasks thus providing a potential opportunity for reduced exposure to the upper extremity.

Results suggest the three female milkers (2 parallel and 1 herringbone) in this small sample were exposed to higher extreme postures, higher angular velocities, higher levels of repetition, and reduced rest as compared to their 6 male counterparts (2 parallel, 2 herringbone, and 2 rotary). This finding was possibly due to gender differences in body anthropometrics. Smaller body frames with a shorter arm reach may predispose the female milker to potentially higher upper extremity exposures and reduced opportunity for rest. As previously stated the exploratory nature of this study precluded any statistical testing attributable to gender. Additionally, conclusions cannot be drawn as to the degree of confounding by parlor design on gender effects. Further studies with larger sample sizes are necessary to study the effects of gender and parlor configuration on physical exposures.

In the present study, exposure variation analysis allowed for the reporting of extreme shoulder postures using both >45° and >60° threshold criteria which enabled comparison to previous studies of other occupations. Compared to other occupations, results suggest parlor workers may experience higher proportions of time spent in extreme shoulder postures than car disassembly workers (Kazmierczak et al., 2005) house painters, car mechanics, machinists (Svendsen et al., 2005), hairdressers (Wahlström et al., 2010) hospital cleaners (Unge et al., 2007), dentists (Jonker et al., 2009), material pickers (Christmansson et al., 2002), air traffic controllers (Arvidsson et al., 2006) and poultry processing workers (Juul-Kristensen et al., 2001).

The 90th percentile for time exposed to high velocities was 14.3% and 12.2% for the right and left shoulder respectively. Compared to other studies, parlor workers also have higher extreme angular velocities than car disassembly workers (Kazmierczak et al., 2005) house painters, car mechanics, machinists (Svendsen et al., 2005), hairdressers (Wahlström et al., 2010) hospital cleaners (Unge et al., 2007), dentists (Jonker et al., 2009), air traffic controllers (Arvidsson et al., 2006) and poultry processing workers (Juul-Kristensen et al., 2001). Material pickers showed higher extreme velocities (Christmansson et al., 2002) than parlor workers in the current study.

In some studies, percentile range has been proposed as an estimate of posture variation, reported as the difference between the 90th and 10th posture percentiles (Kazmierczak et al., 2005; Wahlström et al., 2010) or between the 95th and 5th percentiles (Arvidsson et al., 2006). In the present study, mean shoulder elevation percentile ranges (between 90th and 10th percentiles) were 75° and 76° for the right and left arms respectively. These estimates of posture variation were higher than those reported among air traffic controllers (Arvidsson et al., 2006), hairdressers (Wahlström et al., 2010) and car disassembly workers (Kazmierczak et al., 2005). Large postural variation expressed as percentile range does not necessarily imply an increased risk for MSDs. A more dynamic pattern of movement is believed to be associated with a lower incidence of MSD development (Kilbom, 1994; Kilbom and Persson, 1987). Work tasks involving more variable motor strategy (i.e., greater posture variation) may protect workers from work-related MSDs (Madeleine et al., 2008).

4.1. Limitations

Data collection for long periods using technical instrumentation may create sampling rate drift. The sampling rate of each VC drifted slightly from the 7.5 Hz sampling rate which may have resulted in some temporal dyssyncrony between the units. These shifts in sampling frequency were visually inspected in the LABVIEW graphical interface and corrected during data processing which introduced the potential for human error. Another limitation with using accelerometers for measuring arm motion is their sensitivity to linear acceleration resulting from non-zero angular velocities and accelerations. Previous studies suggest that these errors are small and predictable. Lastly, a small sample size in this feasibility study limits generalizability of findings.

4.2. Future research

Recently developed tracking sensors combine triaxial accelerometers, gyroscopes and magnetometers to obtain six-degrees-of-freedom kinematic information for field-based research (Dong et al., 2008; Zhu and Zhou, 2004). The integration of these sensors into a microelectromechanical (MEMS) system-based unit with Kalman processing filters has been observed to overcome the limitations of each sensor when used individually for motion capture research purposes (Dong et al., 2008; Rotenberg et al., 2005; Sabatini, 2006; Zhu and Zhou, 2004). Motion tracking systems using MEMS technology enable the reporting of postures using standardized conventions such as the Global Coordinate System recommended by the International Society of Biomechanics (Wu et al., 2005). While these more sophisticated sensors hold promise, they have been limited by size, memory, expense and commercial availability. Future studies evaluating this technology for field-based ergonomics research is warranted.

Due to a small sample size a true experimental study design was not employed. Future research will employ larger sample sizes to examine the effects of parlor configuration and gender on exposures to the upper arm such as posture and movements. Rotary parlors involve a higher degree of task specialization, but administrative controls such as job rotation may provide protective features that reduce biomechanical exposures. Future studies will investigate the effects job rotation in herringbone and parallel parlors. Additionally, future research will evaluate the effectiveness of ergonomically-designed milking equipment to reduce exposures associated with the development of MSDs.

Previous studies have noted a lack of standardized metrics for describing both variation and diversity in biomechanical exposure (Mathiassen, 2006; Wells et al., 2007). This feasibility study successfully utilized similar biomechanical exposure metrics presented in previous studies. Using standardized metrics in future studies will enable the evaluation of intervention effectiveness and a comparison to other studies and occupations.

5. Conclusion

This feasibility study demonstrates the ability to capture full-shift posture and movement exposures in a challenging work environment. In addition, exposure metrics employed in this study enabled the reporting of objective posture, movement and rest exposures as developed and reported in previous studies. Using standardized exposure metrics in ergonomic research will enable the comparison of independent studies, progress exposure-outcome research, and provide a means to evaluate intervention effectiveness. This is the first study to document full-shift biomechanical exposures to the shoulder among US large-herd dairy parlor workers. Results suggest these workers may be exposed to exposure levels (posture, movement velocity, repetition, and inadequate rest) associated with the development of shoulder pathology. Compared to other high-risk occupations involving shoulder-intensive work, parlor workers may have higher exposure levels. These findings warrant the need for continued field-based research with larger sample sizes to facilitate the development of cost-effective intervention strategies.

Acknowledgments

This pilot project was supported by the High Plains Intermountain Center for Agricultural Health and Safety (Centers for Disease Control and Prevention grant no. U50/OH008085). This project represents a collaborative effort of researchers from three NIOSH-funded Agricultural Centers: High Plains and Intermountain Center for Agricultural Health and Safety (HICAHS), Southwest Center for Agricultural Health, Injury Prevention, and Education (SWAG), and Great Plains Center for Agricultural Health. Its contents are solely the responsibility of the authors and do not necessarily represent the official views of the Center for Disease Control and Prevention or the National Institute for Occupational Safety and Health. The authors would like to express their appreciation to the dairy owners and workers for allowing us to collect this data on their dairies.

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