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Effects of milking unit design on upper extremity muscle activity during attachment among U.S. large-herd parlor workers

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Abstract

Background—Large-herd dairy parlor workers experience a high prevalence of musculoskeletal symptoms in the upper extremity. The purpose of this study was to evaluate the effect of milking unit design on upper extremity muscle activity during milking unit attachment.

Methods—Upper extremity muscle activity was recorded among U.S. large-herd parlor workers (n=11) using surface electromyography. Participants performed several milking unit attachment cycles with each of six milking unit designs. Muscle activity levels were then compared between unit designs.

Results—Mean muscle activity levels (in %MVE) across milking units ranged from 6.8 to 8.2 for the upper trapezius, 8.2 to 10.3 for the anterior deltoid, 13.8 to 17.2 for the forearm flexors, and 9.9 to 12.4 for the forearm extensors. Pairwise comparisons between milking units did not reveal statistically significant differences in muscle activity levels across milking unit designs. However, a general pattern of higher muscle activity was observed with specific milking units. Milking unit weight, milk tube spread, and teat cup shape may explain differences in muscle activity levels.

Conclusions—Milking unit design may influence muscle activity levels among parlor workers. Small reductions in muscle activity associated with milking unit design have the potential to delay the onset of fatigue or development of musculoskeletal health outcomes among parlor workers.

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Author contributions statement

All authors attest that they have made substantial contributions to this manuscript including 1) the conception of the design of the study, 2) data acquisition, analysis and interpretation of work, 3) drafting the manuscript including revision for intellectual content, and 4), approving the submitted version of the manuscript. Authors agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Conflict of interest statement

All authors declare no conflicts exist in this study or manuscript.

Keywords

Dairy; Electromyography; Milking unit; Equipment

1. Introduction

1.1. U.S. dairy profile

Dairy production in the U.S. has rapidly progressed toward a large-herd model due to associated economies of scale (Reinemann, 2001). In 2012, there were 46,000 dairy operations in the U.S. (USDA, 2012), down from 72,500 in 2002 (37% decrease). Concurrently, milk production and herd sizes have increased. In 2012, 63% of milk produced in the US came from large-herd operations (>500 head) (USDA NASS, 2013), compared with only 37% in 2002 (USDA NASS, 2004). Operations with 2000 head or more accounted for 35% of milk production in 2012 (USDA NASS, 2013), up from just 15% in 2002 (USDA NASS, 2004). The relatively recent shift towards large-herd dairy production may lead to an increased risk of work-related musculoskeletal disorders (MSD) among parlor workers due to task specialization and greater work demands. As herd sizes increase, the need for effective health and safety intervention research in the U.S. dairy industry will also increase (Douphrate et al., 2009a).

About 79% of U.S. milk production is on farms employing immigrant workers (Adcock et al., 2015). Previous studies have reported that Hispanic labor on U.S. dairies is common [e.g., 50% in New York (Maloney, 2002), 85–89% in Colorado (Reynolds et al., 2009, Roman-Muniz et al., 2006), 92% in Vermont (Baker and Chappelle, 2012), and 94% in California (Eastman et al., 2012)]. Prior research by the authors suggests that 97% of U.S. large-herd parlor workers are Hispanic, with the majority (89%) being male (Douphrate et al., 2014). Hispanic immigrant men, particularly those with limited English skills, who work on farms that have been found to have significantly high rates of fatal and non-fatal injuries (Dávila et al., 2011).

Dairy workers have the second highest prevalence of injuries among U.S. farm workers (Boyle et al., 1997, Crawford et al., 1998, NIOSH, 1993) Pinzke (2003) reported over 83% of dairy workers experience musculoskeletal symptoms (MSS). Additionally, Karttunen and Rautiainen (2011) reported a decline in working ability in 39% of dairy farmers caused by musculoskeletal disorders. Despite increased mechanization with parlor milking, musculoskeletal health outcomes are prevalent among parlor workers. Tuure and Alasuutari (2009) reported one out of three parlor workers were affected by problems in the upper extremity. Kolstrup et al. (2006) reported 86% of Swedish dairy workers reported some kind of MSD which was most prevalent in the upper extremity (52%). Other Swedish dairy farm studies reported prevalences of shoulder and hand/wrist MSS exceeding 50% (Pinzke, 2003, Stål et al., 2000). A recent study involving Hispanic, large-herd parlor workers in the U.S. revealed 76% experienced work-related MSS in at least one body part, and the highest prevalence was in the upper extremity (55%) (Douphrate et al., 2014). Dairy workers file 8.6 workers' compensation claims per 200,000 work hours (Douphrate et al., 2006), higher than the national injury rate (6.2 per 200,000 h) (BLS, 2004). The largest percentage (35%) of injury claims involves the upper extremity, and nearly 50% of injuries occur in the milking parlor (Douphrate et al., 2009b).

1.2. Milking routine

The milking routine includes five primary tasks: 1) teat dip with a cup for sanitization; 2) teat strip to stimulate milk flow; 3) teat wipe; 4) milking unit attachment (Fig. 1); 5) automatic detachment of milking unit after milking; and 6) post-dip of teats for sanitization. Milking unit attachment to the udder has been identified as among the most physically strenuous tasks of the milking routine (Douphrate et al., 2014).

A milking unit consists of a number of parts: claw, teat cups, liners, and tubing. Together the claw, teat cups and liners constitute a milking unit (Fig. 2). Milking unit designs differ based on shape of milking claw and component materials. Studies have reported milking units can weigh more than 3.0 kg (Schick, 2000, Stål et al., 2003). Techniques for attaching the milking unit include either holding the claw with one hand and attaching teat cups with the other hand (Fig. 3a), or using each hand to attach two teat cups simultaneously (Fig. 3b). The attachment process involves a forward reach into a confined area between the hind legs of the cow.

Repetitive work and non-neutral postures have been reported as risk factors associated with having MSD among parlor workers (Kolstrup et al., 2006). Increased automation of the milking process requires forceful arm and hand motions (Stål et al., 2000), and attachment of the milking unit has been reported as the most strenuous task because of repeated lifting and attaching of milking units (Pinzke et al., 2001b). Shoulder to udder reach distance has been reported to contribute to a lever action up to 9.0 N m contributing to high muscle load during unit attachment (Jakob et al., 2007). Douphrate et al. (2014) reported 32% of large-herd parlor workers perceived milking unit attachment to be the most strenuous. These findings were in line with other studies that identified milking unit attachment to be among the most demanding milking task (Jakob et al., 2012, Stål et al., 1996, Stål et al., 2003).

1.3. Study objective

Milking parlor productivity and efficiency involves a triad of interactions between the cow, milking equipment and environment, and worker. Worker performance has the potential to have a profound influence on milk production, cow health and parlor productivity. Within each milking parlor, worker milking routine consistency is paramount. Inconsistent or improper milking routine can prolong or reduce cow milk let-down, increase milking time, adversely affect teat health, and decrease optimization of milk harvest volume. Human error, lack of training, fatigue, or discomfort can contribute to milking process drift and a reduction in milking consistency. To date, research emphasis has been placed on the cow or milking equipment and their effects on milk production. Little attention has been placed on the worker, and his/her interaction with the cow, equipment or his/her working environment.

An ongoing five-year investigation has involved the estimation of physical exposures (i.e. muscle forces, posture, motion) among U.S. large-herd parlor workers using direct-measurement technologies, as well as the evaluation of effectiveness of targeted interventions to reduce these exposures. One task-specific intervention strategy could be focused on the reduction of muscular burden associated with milking unit attachment task. Lighter milking units or alternative unit shapes have the potential to reduce upper extremity muscular burden. The purpose of this study was to evaluate the effects of milking unit design on upper extremity muscle activity during milking unit attachment among large-herd parlor workers. Our evaluation included two prototype milking unit designs which were lighter in weight and non-traditional in shape as compared to other commercially available milking units. We hypothesized that these prototype designs would be preferred by experienced milkers, and their use would result in lower upper extremity muscle activity during milking unit attachment task as compared to other commercially available milking units. To our knowledge, no prior studies have attempted to quantify the effect of a task-specific milking intervention on upper extremity muscle activity among the U.S. large-herd dairy working population.

2. Materials and methods

2.1. Study sample

Eleven experienced large-herd parlor workers were recruited from a Central Texas dairy farm with a milking herd size of over 4000. All parlor workers aged 18 years or older were invited to participate. Each participant worked full-time in the parlor and was free from pain or pathology in each upper extremity. After meeting criteria, the study was explained and participants were asked to provide written informed consent. The informed consent document was made available in both English and Spanish and a bilingual investigator was present for translation purposes. Each participant received $20 in appreciation for their time. The University of Texas Health Science Center at Houston, Committee for the Protection of Human Subjects approved all study procedures.

Age, height, weight, upper extremity anthropometrics and years milking are summarized in Table 1. All participants were male and right hand dominant, with a mean age of 27.3 years (range: 19–40 years). Mean height was 1.7 m (range: 1.7–2.1 m) and mean body mass was 71.6 kg (range: 59.0–86.2 kg). Mean shoulder to floor distance was 137.4 cm (range: 132.1–142.2 cm) and mean arm reach was 60.1 cm (55.9–63.5 cm).

2.2. Work environment and task performance

Data collection took place at the Southwest Regional Dairy Center at Tarleton State University, located in Stephenville, Texas. The facility operates a 24-stall rotary milking parlor. To simulate the milking unit attachment task and control for variable cow udder heights, 24 artificial udders of identical height (46.4 cm from teat end to platform) were positioned on the milking carousel. Each artificial udder was positioned in the middle of each milking stall, equidistant from the carousel edge (Fig. 3c). As the carousel rotated, each participant stood in the same position and attached the milking unit to the artificial udder as it passed, simulating actual milking unit attachment. Participants attached the milking units with both hands, with teat cups held between the fingers (Fig. 3b).

2.3. Milking unit designs

A milking equipment manufacturer provided six milking unit designs for evaluation, which varied by shape, weight, and materials. Of the six units evaluated, one was currently in use at the study facility (Unit C) which participants were accustomed to using, three additional units were also commercially available (Units D, E and F), and two units were prototype designs from a single manufacturer (Units A and B). These two prototype designs were lighter than other commercially available units, and were flat and round (discus-shaped) in shape which was a departure from traditional milking claw designs. The other milking claws (Units C, D, E, and F) were a more traditional barrel-shape. A discus-shape design of the milking claw (Units A and B) resulted in a larger claw width and milk tube spread as compared to the other milking designs. The two prototype milking claws (Units A and B) were also made primarily of a plastic composite material to minimize unit weight, and the other claws included metal components (Units C, D, E, and F). Four milking unit designs included a full stainless steel covering of each of four teat cups (Units B, C, E, and F) while two units had only partial stainless steel coverings to reduce unit weight (Units A and D). Unit shapes, dimensions, and materials are summarized in Table 2. The selection of these milking units provided a diversity of shapes, weights and composite materials which were commercially available as well as in development. Researchers were not granted permission to include milking unit images because two units were prototypes and not commercially available.

2.4. Measurement overview

Muscular effort during the milking routine was estimated using surface electromyography (EMG) from four upper extremity muscles (bilateral). Surface EMG was collected continuously during the data collection period, and beginning and end of each milking unit attachment task was recorded using a push-button digital marker connected to a portable EMG data logger (Datalog MWX8, Biometrics Ltd., UK) attached to a belt worn about the participant's waist. Four examples of each of the six milking unit designs were randomly assigned to the milking stalls (6 milking unit designs x 4 examples per design = 24 total milking units). The carousel completed nine revolutions during data collection; therefore, each participant would perform 36 attachment cycles per milking unit design (9 revolutions x 4 units per design = 36 attachment cycles per design). Eight muscle-specific cycle observations from one subject were discarded due to digital marking error.

2.4.1. Surface EMG methods—Surface EMG data were recorded from the upper trapezius, anterior deltoid (shoulder flexor), flexor digitorum superficialis (forearm flexor), and extensor digitorum communis (forearm extensor). These muscles were selected because of substantial upper extremity involvement during the milking routine (Douphrate et al., 2012). The EMG electrodes (Model SX230, Biometrics Ltd., UK) were positioned on the skin over each muscle using published guidelines (Criswell, 2010) and a reference electrode was placed over the non-dominant clavicle. The dry EMG electrodes (37 × 20 × 6 mm) had dual 10 mm diameter, silver-silver chloride surfaces with an inter-electrode distance of 20 mm, on-site differential amplification (gain = 1000), a bandwidth of 20–460 Hz, and an input impedance of $>10^{12}\Omega$.

Before electrodes were placed, skin was shaved using an electric trimmer (as needed) and cleaned with alcohol using a gauze pad. Each electrode was affixed to the skin using double-sided electrode tape. Skin-Prep◊ (Smith and Nephew) was then applied to the area around each electrode and Hypafix® tape (Smith and Nephew) was used to secure the electrode. Lastly, each participant wore a long-sleeved compression shirt (Under Armour Heat Gear®) to provide additional sensor-placement security. Each electrode was connected to the data logger, which digitized the raw EMG signals (14-bit analog-to-digital converter) at a sampling rate of 1000 Hz. The raw EMG data were stored on a compact flash memory card and transferred to a computer for signal processing and analysis.

2.4.2. EMG signal processing—Custom LabVIEW programs (version 2013, National Instruments, Inc., Austin, TX) were used to process all EMG recordings. The nature of the work environment did not allow for real-time monitoring of EMG signal quality. Therefore, signal quality was assessed during post-processing of EMG recordings. For each EMG recording and muscle group, signal quality checks included (i) examination of the mean value of 100 m epochs of the raw EMG signal across the full recording duration for evidence of signal drift, (ii) examination of periods of very low muscle activity to identify the presence of electrocardiogram interference, and (iii) analysis in the frequency domain to identify the presence of electromagnetic interference (e.g., 60 Hz). When present, electrocardiogram interference was attenuated using a high pass filter (Drake and Callaghan, 2006, Redfern et al., 1993) and electromagnetic interference was attenuated using a notch filter. Finally, DC offset was removed and the signals converted to instantaneous root-mean-square (RMS) amplitude using a 100-sample moving window with a 50-sample overlap (Fethke et al., 2012).

2.4.3. EMG normalization procedures—For each muscle, RMS EMG voltage values during attachment of each milking unit were expressed as a percentage of the RMS EMG voltage observed during maximal, isometric reference exertions (%MVE, i.e. normalization in the bioelectric domain). Standing with the arm forward flexed to 120° and the elbow in full extension, participants performed a maximal, isometric contraction against a manual resistance applied at the wrist. This procedure produced maximum reference exertions for the anterior deltoid and upper trapezius (Boettcher et al., 2008). This normalization reference was chosen for the upper trapezius due to its primary role as a shoulder stabilizer during the performance of milking tasks. For the forearm flexor and extensor, participants held a 0.4 kg hand grip dynamometer (Hydraulic Hand Dynonometer, Chattanooga Group, Hixon, TN, USA) and performed a maximal, isometric power grip with their elbow flexed to 90° and the forearm and wrist in neutral postures (Anton et al., 2005). This normalization reference was chosen for the forearm extensor due to its primary role as a wrist stabilizer during the performance of milking tasks involving hand gripping actions.

Three repetitions of each reference contraction were performed, with a 2-min rest between repetitions. Each reference contraction was maintained for 5 s, and, for each muscle separately, the maximum RMS EMG amplitude within the middle 3 s of the contraction was identified. The maximum RMS EMG amplitude (EMG_{Max}) was then defined as the maximum RMS EMG amplitude observed across the three repetitions (Mathiassen et al., 1995). We also recorded the RMS EMG amplitude for 60 s while the participant sat in a relaxed position with the arm supported and wrist in a neutral posture. For each muscle separately, the lowest RMS EMG amplitude during this 60-sec resting recording was compared to the lowest mean RMS EMG amplitude observed during the entire data collection recording. The lowest RMS EMG amplitude between these two recordings was defined as the baseline noise (EMG_{Noise}). Baseline noise was subtracted from all RMS EMG amplitudes in a power sense (Thorn et al., 2007) using Equation (1), where EMG_i is the RMS EMG amplitude at sample *i* recorded during data collection and $EMG_{\%MVEi}$ is the resulting normalized RMS EMG amplitude at sample *i*.(1)

2.4.4. EMG summary measures—For each muscle, summary measures of the normalized RMS EMG data (in %MVE) included the mean amplitude and the 10th, 50th and 90th percentiles of the amplitude probability distribution function (APDF) (Jonsson, 1988). These summary measures were computed for each milking unit attachment cycle. The duration of each milking unit attachment cycle was also calculated.

2.4.5. Participant milking unit preference assessment—After EMG data collection for all milking units, participants completed questionnaires to assess their preference of milking unit designs. Participants rated each milking unit design on the basis of hand fit, functionality, ease of use, quality, feeling, grip force required, and weight. Attributes were rated using a Likert-style scale with responses ranging from 1 (strongly disagree) to 5 (strongly agree). Participants also provided a ranked order of overall milking unit design preference from 1 (milking unit most preferred) to 6 (milking unit least preferred) based on unit shape, weight, and ease of use.

2.4.6. Statistical analysis—The EMG summary measure distributions were described (i.e., using means and standard deviations) for each milking unit across all participants, body sides, and unit attachment cycles. EMG summary metric distributions were examined using standard tests for normality (i.e., Shapiro-Wilk test) and an appropriate transformation (e.g., natural log) was made prior to hypothesis testing. To test the effect of milking unit on each muscle activity summary measure we used multilevel linear mixed-effects models to account for nesting effects. We assumed residuals by milking unit were independent but allowed for heteroscedasticity (variable variance) of the measures of muscle activity since these could change over time; therefore, we estimated distinct error variances for each milking unit. We performed a preliminary overall comparison of all milking units using a more liberal alpha level of 0.10 to identify possible differences between milking units. We then used the Scheffé method to perform specific pairwise comparisons of muscle activity summary measure distributions between all combinations of milking units (Sahai and Ageel, 2000). A statistically significant difference was declared using a more conservative alpha level of 0.05. The mixed models included *milking unit* as a fixed effect, adjusted for body side (fixed effect) and *subject* as a random effect (observations were nested within subject). The random component of each model was constructed to estimate variance components, each quantifying the mean deviation at each level of the data structure hierarchy: between-subject and observation-within-subject (i.e. the residual component in the models). The small sample size precluded meaningful statistical testing of participant preference data but results were interpreted descriptively. All statistical procedures were performed using Stata © (v. 14.1, StataCorp LP, College Station, TX).

3. Results

EMG summary measure statistics for all muscles are provided in Table 3. During the milking unit attachment task, the upper trapezius stabilizes the upper extremity as the milking unit is lifted and attached to the udder. The mean normalized RMS amplitude for the upper trapezius was greatest (8.2 ± 2.0%MVE) for Unit F (highest unit weight) and lowest (6.8 ± 1.6%MVE) for Unit E (second lowest weight). In general, Unit E had lower summary measures than other milking units, and Unit F had higher summary measures than other milking units. No statistically significant ($p < 0.05$) differences were observed between milking units.

The anterior deltoid serves as a primary shoulder flexor during milking unit attachment as a forward reach of the arm is required to position the unit and attach the teat cups to the udders. Similar to the upper trapezius results, mean normalized RMS amplitude for the anterior deltoid was greatest (10.3 ± 2.7%MVE) for Unit F and lowest (8.2 ± 1.7%MVE) for Unit E. In general, Unit E had lower summary measures than other milking units, and Unit F had higher summary measures than other milking units. No statistically significant ($p < 0.05$) differences were observed between milking units.

The forearm flexors are responsible for flexion of the wrist and fingers, and are primarily used to grip teat cups during unit attachment. Forearm extensors are used to extend the wrist and fingers, and stabilize the wrist during unit attachment. Mean normalized RMS amplitude for the forearm flexors was greatest (17.2 ± 6.0%MVE) for Unit A (largest milk tube spread) and lowest (13.8 ± 3.9%MVE) for Unit C, but no statistically significant ($p < 0.05$) differences were observed between milking units. Mean normalized RMS amplitude for forearm extensors was greatest (12.4 ± 3.4%MVE) for Unit F (second largest milk tube spread), and lowest (9.9 ± 2.7%MVE) for Unit E (smallest milk tube spread). No statistically significant ($p < 0.05$) differences were observed between milking units.

Examination of variance components (data not shown) revealed small between-subject variances was across all muscle activity summary measures for all muscles. In general, muscle activity levels in the dominant upper extremity were greater than those in the non-dominant upper extremity. Regarding task performance duration, participants performed unit attachment in the shortest time using Units E (9.6 ± 2.6 s) and Unit C (10.0 ± 2.3 s). Unit attachment took the longest time using Unit F (11.3 ± 3.2 s).

Participants rated Unit E more favorably than all other units with respect to fit, functionality, ease of use, quality, feeling, required grip force and weight (Table 4). Participants rated Unit A least favorably on all attributes except for ease of use. Unit E was also ranked as the most preferred (overall) among all milking unit designs evaluated in this study (the majority of participants assigned Unit E a rank of 1 for shape, weight and ease of use).

4. Discussion

To our knowledge, no prior study has evaluated the effect of milking unit design on muscle activity levels during the milking unit attachment task among a Hispanic working population which characterizes the U.S. dairy workforce. The use of Unit E generally resulted in the lowest muscle activity levels across muscles and summary measures, although differences between designs were small in magnitude. Importantly, measures of task performance (i.e. unit attachment duration) and user preference also favored Unit E.

Three design features of Unit E may partially explain the observed results. First, Unit E had the second lowest weight (1.6 kg) among all units. A lower unit weight may reduce muscular demand when lifting and attaching the unit. Second, Unit E had the shortest spread between milk tubes (2.5 cm). Third, the teat cups of Unit E were tapered at the bottom. A shorter milk tube spread and narrower teat cup base (compared to the other designs) may be mechanically advantageous for a smaller hand breadth which is characteristic of a Hispanic working population (Gnaneswaran and Bishu, 2011). Conversely, Unit A (prototype), which had the lowest unit weight (1.4 kg), teat cup weight (0.2 kg) and greatest milk tube spread (3.8 cm) was least preferred based on shape, weight and ease of use.

Examination of the between-subject component of muscle activity variance provides an important insight into potential intervention strategies. The relatively small between-subject variance suggests that engineering (e.g., milking unit design) or administrative (e.g., task rotation) controls to reduce upper extremity muscular loading may be efficiently applied at the group level (Burdorf, 2005). As expected, we observed a general pattern of slightly higher muscle activity in the dominant extremity (data not shown) which suggests asymmetric loading of the upper extremity muscles. The higher muscle activity levels on the dominant side (i.e., the right arm for all participants) were likely a function of the spatial arrangement between the milking unit and the participants. As participants faced the simulated udders, the milking units were hanging at approximately waist level in front and slightly to the right (in a manner consistent with actual production practices). To attach a milking unit, participants would first grasp the claw and lift the unit with the right hand, then bring the left hand to grasp the milk tubes on the left side of the unit, and finally move the right hand from the claw to grasp the milk tubes on the right side of the unit as it approached the udders.

A few previous studies have assessed muscle activity levels among workers in smaller-herd European milking parlor operations. However, direct comparison to our results is problematic. For example, Stål et al. (2000) reported ‘high’ peak loads of the forearm flexors and extensors during parlor milking but did not report muscle activity levels during milking unit attachment, specifically. Similarly, Pinzke et al. (2001a) reported ‘high’ muscle load values for the biceps and forearm flexors during milking unit attachment but did not indicate the method participants used to hold the milking unit. Stål et al. (2003) reported upper extremity muscle activity during milking unit attachment, but participants in this study held the cluster in the left hand while attaching teat cups with right hand (Fig. 3a). In our study, participants attached the unit with teat cups held between fingers of each hand (Fig. 3b). This method of attachment is more common among male workers in U.S. parlors. In comparison to Pinzke et al. (2001a) and Stål et al. (2003), we observed similar lower 10th and 50th percentiles of the APDF and a similar 90th percentile of the APDF for the forearm flexors across all unit designs. No other muscle-specific comparisons can be made with other studies.

To put into perspective the potential effect of small reductions in muscle activity associated with milking unit design, one might consider a worker in a double-40 parallel parlor (80 total milking stalls) staffed with three workers (i.e. milkers). Depending on parlor routine and milker assignments, each worker will perform the milking routine on a minimum of ten cows five times an hour, or every 12 min. This equates to 50 milking unit attachment cycles every hour, or 550 cycles in a 12-h shift (assuming an hour of break time and cleanup), or 3300 cycles in a 6 day work week, or 165,000 cycles in a year (assuming 50 work weeks). Therefore, small reductions in muscle activity associated with each cycle of a highly repetitive task may substantially reduce cumulative muscle loading over time, which in turn may delay the onset of fatigue or (ultimately) the development of musculoskeletal health outcomes. In this context, if one milking unit design leads to reduced muscle loading while maintaining production requirements (e.g., quality and consistency), then its use should be considered even in the absence of empirical evidence about its effect on health (e.g., through a randomized controlled trial). Our findings support the notion that effective tool (i.e. milking unit) design can address multiple criteria across performance domains including worker productivity, preference, and exposure to physical risk factors.

4.1. Limitations

There were several limitations to this study. Although we observed differences in EMG summary measures between several pairs of milking unit designs, other variables may influence the relationship between milking unit design and muscle activity. Most importantly, muscle activity during attachment may depend partly on anthropometric characteristics of the parlor workers. For example, workers with shorter arm lengths might experience higher levels of upper trapezius activity while reaching forward during unit attachment than workers with longer arms; or workers with larger hand breadths may experience lower levels of forearm flexor or extensor activity than workers with smaller hand breadths. However, the repeated-measures nature of our experimental design allowed for control of such effects analytically. Additionally, the non-random selection of participants limits our ability to generalize the observed results to the broader population of parlor workers.

The use of EMG to estimate muscular loading (i.e. the physical risk factor “force”) has a long history in ergonomics research. However, numerous EMG summary measures have been used to describe different aspects of EMG signal intensity and temporal patterns, and there is no consensus as to which summary measure(s) is (are) “best”. While EMG amplitude percentiles were used in this study, other EMG measures may be more sensitive to risk in work (e.g., parlor milking) involving relatively low muscle activity levels (Hansson et al., 2000, Westgard, 1988). For example, a decrease in the frequency and cumulative duration of periods of EMG silence or “gaps” has been associated with neck/shoulder pain (Veiersted, 1994, Veiersted et al., 1990). Other physical risk factors have also been found to be associated with work-related fatigue, discomfort, or musculoskeletal disorders, including biomechanically disadvantageous postures (which can both increase internal loads and reduce the capacity to exert them), highly repetitive movements, and inadequate rest (Da Costa and Vieira, 2010). The strongest associations have been reported for combinations of these risk factors (Frost et al., 1998, Frost et al., 2002, Garg et al., 2006, Gerr et al., 2013, Silverstein et al., 1987).

Many of the milking units evaluated in this study were unfamiliar to participants, which may have influenced muscle activity levels, attachment cycle times, and participants' ratings of design characteristics and overall preference. However, participants practiced with each milking unit prior to data collection. General observations made by the research team and feedback solicited from participants revealed no difficulty in adapting to the new designs. Since Unit E (an unfamiliar design) was rated most favorably, we have no basis upon which to conclude that unfamiliarity was a particularly strong driver of the design characteristic and overall preference ratings.

Because some units had yet to be used in actual milking parlors, rubber tubes connecting teat cups to claws were stiffer than tubes on units that had been in use prior to the study. Rubber tube stiffness may have contributed to difficulty when handling milking units during attachment, resulting in higher muscle activity levels. While our study focused on the effect of milking unit design on muscle activity during unit attachment, further studies are needed to evaluate operational performance of unit designs such as milking efficiency, milk flow dynamics, vacuum pressures, and cup to teat attachment integrity.

4.2. Conclusions

Our findings suggest small muscle activity differences exist between milking unit designs. Unit weight, milk tube spread, and teat cup shape are three design features which may contribute to the reduction in muscle activity levels during attachment as well as increased worker satisfaction. Milking unit designs which result in a reduction of muscle activity have the potential to reduce fatigue or discomfort, thus influencing worker performance or the development of musculoskeletal injury. Future research should examine other task-specific or job organization controls to prevent musculoskeletal symptoms and improve performance among large-herd dairy parlor workers.

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Highlights

- One milking unit design resulted in lower muscle activity levels in many upper extremity muscle groups.
- Unit weight, milk tube spread, and teat cup shape are design features which may reduce muscle activity levels.
- Milking unit designs which reduce muscle activity may reduce cumulative muscle loading over time.

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Fig. 1.
Milking unit attachment.

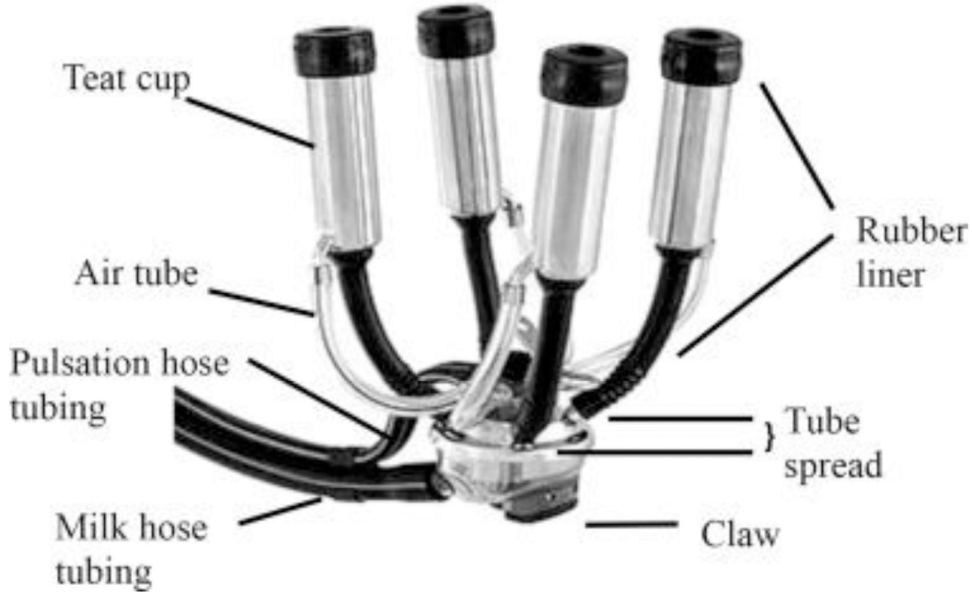

Fig. 2.
Milking unit components.

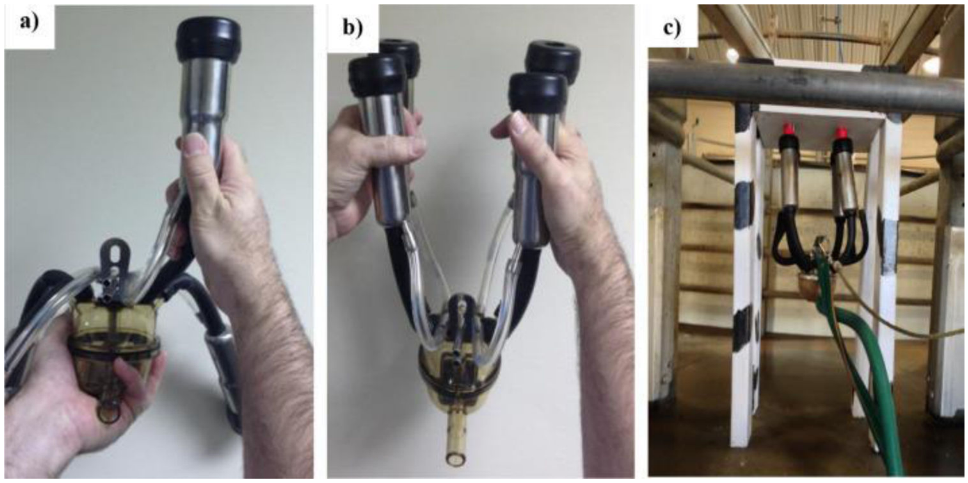

Fig. 3.
a) milking unit hold using left hand to hold cluster, b) milking unit hold using bilateral hands to raise and attach unit, and c) artificial udder on milking platform.

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Table 1.

Summary of demographic variables (n = 11).

	Mean (SD)	Min	Max
Age (years)	27.3 (6.3)	19.0	40.0
Milking (years)	8.3 (5.3)	0.6	20.0
Weight (kg)	71.6 (7.8)	59.0	86.9
Height (m)	1.7 (0.1)	1.7	2.1
Shoulder to floor (cm)	137.4 (2.6)	132.1	142.2
Arm reach (cm)	60.1 (2.0)	55.9	63.5
Hand span (cm)	20.8 (1.2)	18.4	22.2

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Table 2.

Milking unit characteristics and dimensions.

	Milking unit					
	A	**B**	**C**	**D**	**E**	**F**
Overall unit weight (kg)	1.43	2.00	1.90	1.63	1.60	2.10
Cluster only weight (kg)	0.53	0.53	0.41	0.51	0.40	0.51
Overall unit height (cm)	37.52	37.52	39.01	38.10	38.12	38.10
Cluster width (cm)	13.52	13.52	11.02	12.01	9.51	12.01
Teat cup length (cm)	31.10	31.10	29.01	31.81	30.50	31.81
Teat cup weight (kg)	0.22	0.37	0.31	0.28	0.30	0.39
Milk tube spread (cm)	3.81	3.81	3.01	3.62	2.50	3.62
Cluster shape	discus	discus	barrel	barrel	barrel	barrel
Cluster material[a]	C	C	SS/C	SS/C	SS/C	SS/C
Teat cup shape	straight	straight	straight	straight	tapered	straight
Teat cup material	partial	full	full	partial	full	full

[a]Denotes cluster composite material: C = composite material, SS/C = stainless steel plus composite material.

Table 3.

Distributions of [mean (SD)] of EMG summary measures and cycle duration of attachment task across milking unit designs.

Summary measure	Milking unit					
	A	**B**	**C**	**D**	**E**	**F**
Mean RMS (%MVE)						
Upper trapezius	7.4 (1.7)	7.5 (1.7)	7.2 (1.6)	8.1 (1.8)	6.8 (1.6)	8.2 (2.0)
Anterior deltoid	10.2 (2.5)	8.9 (2.2)	8.3 (1.8)	9.8 (2.7)	8.2 (1.7)	10.3 (2.7)
Forearm flexors	17.2 (6.0)	15.9 (5.3)	13.8 (3.9)	14.8 (4.7)	14.1 (4.2)	15.4 (4.5)
Forearm extensors	10.8 (2.9)	11.4 (2.9)	11.3 (2.5)	11.9 (3.2)	9.9 (2.7)	12.4 (3.4)
10th APDF (%MVE)						
Upper trapezius	1.3 (0.9)	1.4 (1.0)	1.3 (0.9)	1.6 (1.1)	1.4 (1.0)	1.5 (1.1)
Anterior deltoid	0.7 (0.5)	0.6 (0.3)	0.6 (0.2)	0.7 (0.5)	0.6 (0.4)	0.7 (0.4)
Forearm flexors	2.6 (1.6)	2.3 (1.3)	2.1 (1.1)	2.3 (1.3)	2.1 (1.1)	2.3 (1.2)
Forearm extensors	1.9 (1.0)	1.7 (0.9)	1.7 (1.1)	1.8 (0.9)	1.5 (0.8)	1.8 (1.1)
50th APDF (%MVE)						
Upper trapezius	5.8 (1.7)	6.0 (1.8)	5.6 (1.6)	6.6 (1.9)	5.4 (1.7)	6.8 (2.0)
Anterior deltoid	5.6 (3.1)	3.8 (2.3)	3.6 (2.3)	4.7 (3.2)	3.7 (2.0)	5.0 (3.4)
Forearm flexors	13.2 (5.5)	11.7 (4.6)	10.1 (3.2)	10.9 (3.9)	10.2 (3.6)	11.4 (4.1)
Forearm extensors	8.0 (2.7)	8.2 (2.8)	7.8 (2.4)	8.6 (2.8)	6.9 (2.6)	9.1 (3.2)
90th APDF (%MVE)						
Upper trapezius	16.6 (3.9)	16.6 (3.8)	16.4 (3.8)	17.1 (4.1)	15.0 (3.4)	17.6 (4.3)
Anterior deltoid	32.1 (7.7)	32.2 (8.2)	30.4 (7.2)	32.3 (8.0)	30.1 (7.2)	35.1 (8.7)
Forearm flexors	38.0 (15.7)	36.8 (15.3)	32.3 (11.8)	34.0 (13.6)	32.5 (11.4)	35.4 (13.0)
Forearm extensors	22.6 (6.7)	26.0 (7.5)	26.4 (7.3)	26.6 (8.6)	23.3 (8.1)	28.0 (8.3)
90th–10th APDF (%MVE)						
Upper trapezius	15.3 (4.0)	15.2 (3.9)	15.1 (3.9)	15.5 (4.1)	13.6 (3.4)	16.0 (4.3)
Anterior deltoid	31.5 (7.9)	31.7 (8.2)	29.9 (7.1)	31.7 (7.9)	29.5 (7.2)	34.5 (8.6)
Forearm flexors	35.4 (15.5)	34.4 (15.1)	30.2 (11.)	31.7 (13.4)	30.4 (11.2)	33.0 (13.0)
Forearm extensors	20.7 (6.8)	24.3 (7.4)	24.8 (7.3)	24.8 (8.6)	21.8 (8.1)	26.2 (8.3)
Cycle Duration (sec)	10.9 (2.0)	10.6 (1.8)	10.0 (1.7)	10.9 (2.2)	9.6 (1.6)	11.3 (2.7)

Table 4.

Participant (n = 12) perceptions of milking unit designs.

	Milking unit design					
	A	**B**	**C**	**D**	**E**	**F**
Mean (SD) participant ratings [a]						
Fit in hand	2.7 (1.7)	3.1 (0.9)	4.2 (0.7)	3.4 (1.1)	4.6 (0.7)	4.1 (0.9)
Functionality	3.2 (1.7)	3.2 (1.1)	3.9 (0.6)	3.1 (0.8)	4.5 (0.4)	3.8 (1.0)
Ease of use	3.1 (1.9)	2.9 (1.2)	4.0 (0.7)	3.2 (1.0)	4.7 (0.5)	3.9 (0.9)
Quality	3.0 (1.9)	3.4 (1.2)	3.4 (1.2)	3.6 (1.2)	4.7 (0.5)	3.8 (1.0)
Feeling	3.1 (1.6)	3.2 (1.0)	3.8 (0.8)	3.4 (1.1)	4.9 (0.4)	4.2 (0.7)
Required grip force	2.6 (1.6)	3.3 (1.2)	3.4 (1.2)	2.8 (1.0)	4.3 (1.3)	3.9 (1.1)
Weight	3.1 (1.5)	3.4 (1.2)	3.4 (1.2)	3.1 (1.1)	4.9 (0.4)	4.0 (0.7)
Participant rankings						
Shape						
1 (most preferred)	0%	0%	18%	9%	73%	0%
2	0%	0%	27%	0%	18%	45%
3	0%	36%	27%	27%	0%	36%
4	9%	45%	18%	9%	9%	0%
5	18%	18%	9%	36%	0%	9%
6 (least preferred)	73%	0%	0%	18%	0%	9%
Median	6	4	3	5	1	3
Max.	6	5	5	6	4	6
Min.	3	3	1	1	1	2
Overall Rank	6	4	3	5	1	2
Weight						
1 (most preferred)	0%	0%	9%	9%	82%	0%
2	9%	9%	27%	0%	18%	36%
3	0%	9%	36%	27%	0%	27%
4	27%	55%	9%	9%	0%	0%
5	18%	9%	9%	36%	0%	27%
6 (least preferred)	45%	18%	9%	18%	0%	9%
Median	6	4	3	5	1	3
Max.	6	6	6	6	2	6
Min.	2	2	1	1	1	2
Overall Rank	6	4	3	5	1	2
Ease of use						
1 (most preferred)	0%	0%	9%	9%	82%	0%
2	0%	9%	36%	9%	9%	36%
3	0%	9%	36%	9%	9%	36%
4	9%	64%	0%	9%	0%	18%
5	18%	18%	18%	45%	0%	0%
6 (least preferred)	73%	0%	0%	18%	0%	9%

	Milking unit design					
	A	**B**	**C**	**D**	**E**	**F**
Median	6	4	3	5	1	3
Max.	6	5	5	6	3	6
Min.	4	2	1	1	1	2
Overall Rank[b]	6	4	3	5	1	2

[a]Ratings based on Likert-scale: 1 = strongly disagree; 5 = strongly agree.

[b]Equal number of votes for Rank 2 and 3.