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Full-shift and task-specific upper extremity muscle activity among U.S. large-herd dairy parlor workers.

David I Douphrate, PhD, MPT, MBA, CPE, CSP[1], **Nathan B Fethke, PhD, CPE**[2], **Matthew W Nonnenmann, PhD, CIH**[3], **Anabel Rodriguez, BS**[4], **Robert Hagevoort, PhD**[5], **David Gimeno Ruiz de Porras, PhD**[6]

[1]University of Texas Health Science Center at Houston, School of Public Health, Texas, USA San Antonio Regional Campus, 7411 John Smith Drive, Suite 1100, San Antonio, TX 78229

[2]University of Iowa, College of Public Health, Iowa City, Iowa, USA 145 N. Riverside Drive, S347 CPHB, Iowa City, IA 52242

[3]University of Iowa, College of Public Health, Iowa City, Iowa, USA 145 N. Riverside Drive, S335 CPHB, Iowa City, IA 52242

[4]University of Texas Health Science Center at Houston, School of Public Health, Texas, USA San Antonio Regional Campus, 7411 John Smith Drive, Suite 1100, San Antonio, TX 78229

[5]New Mexico State University, Dairy Extension, Clovis, New Mexico, USA 2346 SR 288 Clovis, New Mexico 88101

[6]University of Texas Health Science Center at Houston, School of Public Health, Texas, USA San Antonio Regional Campus, 7411 John Smith Drive, Suite 1100, San Antonio, TX 78229

Abstract

US large-herd dairy parlour workers experience a high prevalence of musculoskeletal symptoms in the upper extremity. The purpose of this study was to estimate and compare full-shift and task-specific muscle activity of the upper extremity among parlour workers. Surface electromyography data were recorded continuously throughout a full work shift for each participant ($n = 60$). For a subset of participants ($n = 33$), muscular effort was estimated for milking task cycles. Lower muscle activity levels and higher per cent muscular rest was observed among rotary parlour participants as compared to herringbone and parallel parlour participants for anterior deltoid, forearm flexor and forearm extensor muscles. These findings suggest rotary parlours may offer workstation designs or work organisational dynamics which may be more beneficial to the health and performance of the worker, as compared to parallel or herringbone parlours.

Practitioner Summary:

phone: 1-210-276-9005 david.i.douphrate@uth.tmc.edu.

Author contributions

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.

Disclosure statement

No potential conflict of interest was reported by the authors.

Study findings suggest milking parlour configurations present different biomechanical demands on workers which may influence worker health and performance. Our findings will enable more informed decisions regarding both engineering (e.g. parlour configuration or milking equipment) and administrative (e.g. work organisation) control strategies for large-herd milking parlours.

Keywords

Agriculture ergonomics; intervention effectiveness; biomechanics; equipment design; task analysis

1. Introduction

Work-related musculoskeletal symptoms (MSSs) and disorders (MSDs) are prevalent among workers employed in several agricultural sectors (Fathallah 2012; Fethke et al. 2015; Osborne et al. 2012; Xiao et al. 2013) including dairy production. In Europe, estimates of the 12-month prevalence of MSSs in any body region among dairy workers have exceeded 80% (Kolstrup et al. 2006; Pinzke 2003), with the upper extremity as the most common MSS location (Kolstrup et al. 2006; Tuure and Alasuutari 2009). A relatively mature literature of investigations among European dairy workers includes the estimation of associations between occupational exposure to biomechanical factors and MSSs of the upper extremity (Kolstrup et al. 2006), characterisations of physical exposure using direct measurement techniques (e.g. surface electromyography [EMG] to estimate muscular loading), and identification of milking tasks perceived as the most physically demanding (Lunner Kolstrup 2012; Pinzke, Stal, and Hansson 2001; Stål, Hansson, and Moritz 2000).

There are substantial differences in both technology used and scale of dairy production between the US and European industries which limit the extent to which results of studies among European dairy workers may be generalised to dairy in the US (or elsewhere). For example, the US dairy industry has changed rapidly over the past two decades from a small-herd to a large-herd (>500 head) production model due to economies of scale (Reinemann 2001). According to the US Department of Agriculture, large-herd operations experience lower production costs per cow, leading to increased profitability in comparison to small-herd operations. As a result, investments have been concentrated in larger herd operations, leading to higher profit growth rates and further consolidation of US milk production (USDA 2007). Not surprisingly, in 2012, more than 60% of milk produced in the US came from large-herd dairy operations (USDA 2013), an increase from less than 40% in 2002 (USDA 2004).

Prior studies have indicated working on large-herd dairy operations is associated with an increased risk for injury (Crawford et al. 1998; Pratt et al. 1992; Stallones, Pratt, and May 1986). Dairy workers in the US file 8.6 workers' compensation claims per 200,000 work hours (Douphrate, Rosecrance, and Wahl 2006), higher than the national injury rate (6.2 per 200,000 h) (BLS 2014). The largest percentage (35%) of injury claims involves the upper extremity, and nearly 50% of injury events occur inside the milking parlour (Douphrate et al. 2009). The experience and anatomic distribution of MSSs among US large-herd dairy workers appears consistent with studies of European dairy workers (Douphrate et al. 2014), as do estimates of association between biomechanical factors (e.g. repetitive motion and non-neutral posture) and MSSs (Douphrate, Nonnenmann, et al. 2016). However, most previous estimates of exposure to biomechanical factors among US large-herd dairy workers are based on self-report, which fails to capture exposure information with sufficient detail to enable quantitative comparisons of milking parlour designs and/or specific milking tasks.

1.1. Milking parlour operations

Milking parlours on large-herd operations are designed to accommodate large numbers of cows simultaneously to maximise production efficiency (NAHMS 2003). Working in large-herd milking parlours involves task specialisation and intense work demands due to higher cow volume and throughput rates which may increase the risk of work-related MSDs among workers (Douphrate, Nonnenmann, and Rosecrance 2009).

Milking parlour systems involve cows moving into stalls on a platform which is elevated relative to the floor where the worker stands (i.e. workers are located in a 'pit') while performing milking tasks. This arrangement positions the cow's udder at approximately the same level as a worker's shoulder. Common parlour configurations include herringbone, parallel, and rotary, each characterised by the orientation of the cows in relation to each other and in relation to the worker. Large-herd milking parlours generally operate 24 h a day to maximise productivity and efficiency. The herd is generally milked three times per day (Douphrate et al. 2013), and parlour workers often work 8–12 h shifts, six days a week (Douphrate et al. 2014).

One Health is the multidisciplinary effort to achieve optimal health for people, animals and the environment (American Veterinary Medicine Association 2016). The One Health concept recognises that human health is connected to the health of both animals and the environment (Centers for Disease Control and Prevention 2016). Within the One Health framework, parlour milking involves multiple interactions between the worker, cow and working environment (Figure 3). Many of these interactions could influence the health or performance of the worker (Douphrate et al. 2017). The majority of dairy research conducted inside the milking parlour has emphasised cow health or milk production, while limited research has addressed the health of the parlour worker resulting from his/her interactions with the cow, equipment or working environment.

1.2. Study objective

Given the US industry trend towards large-herd milking operations, workers in these milking parlours may be exposed to biomechanical risk factors associated with the development of upper extremity MSDs. Among these risk factors include high muscle forces and insufficient muscular rest. The purpose of this study was to estimate and compare full-shift as well as task-specific muscle activity of the upper extremity among US large-herd parlour workers. We hypothesised that rotary parlour workers would experience lower full-shift and task-specific muscle activation levels as well as higher muscular rest (% time) in comparison to herringbone and parallel parlour workers.

2. Methods

2.1. Participants

Access to large-herd dairy farms (1,000+ head) was enabled through a partnership with state-based dairy extension personnel. A total of 60 parlour workers were recruited from 17 large-herd dairies in four Western US states. Male workers aged 18 years or older, who worked full-time in the milking parlour, with no history of pain or pathology in the upper extremities were eligible for inclusion. Only male parlour workers were recruited to reflect large-herd parlour workforce characteristics as previous research has demonstrated nearly 90% of large-herd parlour workers are male (Douphrate, et al. 2014). After meeting inclusion 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 and years milking are summarised in Table 1. All participants were right hand dominant, with a mean age of 29.9 years (range: 18–61 years). Mean height was 170.0 cm (range: 140.0–180.0 cm) and mean body mass was 75.8 kg (range: 54.4–99.8 kg). On average, participants had 5.6 years of milking experience.

2.2. Parlour configurations and task performance

In herringbone parlours, cows are oriented 45–60 degrees away from the pit (Figure 2(a)) which typically requires the worker to reach around a hind leg of a cow to access the udder (Figure 2(b)). In parallel parlours, cows are oriented perpendicular to the worker (Figure 2(c)) who gains access to the udder between the cow's hind legs (Figure 2(d)). The size of a herringbone or parallel parlour is specified as the number of cows accommodated on each side of the pit; for example, a 'Double-24' parlour can simultaneously accommodate 24 cows on each side of the pit (or 48 cows total at one time). In rotary parlours, cows stand on a slowly revolving carousel (Figure 2(e)). Milking tasks are performed on each cow as she passes workers positioned on the carousel periphery (Figure 1(f)). Workers access the udder the same as in a parallel configuration but with an additional dynamic of the cow slowly moving as the carousel turns. The size of a rotary parlour is specified as the number of cow stalls on the carousel. While herringbone configurations are common among older and smaller dairy operations, parallel parlours are most common among more modern, US large-herd dairy parlours. Rotary parlours are becoming more prevalent in the US as the machine-paced carousel allows greater control of aspects of the milking routine critical to production and food safety, such as the amount of time the disinfectant is in contact with the udder prior to stimulation of milk flow (Figure 2).

A typical milking routine, as described in a previous publication (Douphrate, Fethke, et al. 2016), includes six sequential tasks: (1) pre-dipping of teats with a cup or spray for sanitisation (Figure 3(a)); (2) teat strip to stimulate milk flow (Figure 3(b)); (3) teat wipe (Figure 3(c)); (4) milking unit attachment (Figure 3(d)); (5) detachment of milking unit post milking; and (6) post-dip of teats for sanitisation. Of the six tasks, only the detachment is automated and occurs when the milking system senses a decrease in milk flow. Workers in herringbone and parallel parlours are typically assigned up to 10 milking stalls on one side of the parlour and will perform all milking tasks for each stall for the duration of the shift. In contrast, workers in rotary parlours are assigned to a station corresponding to one milking task and will rotate to a different station corresponding to a different milking task every one to two hours. Consequently, although the milking tasks do not functionally change with parlour configuration, the machine-paced carousel and common use of job rotation in rotary parlours could impact workers' exposure to physical demands.

Study participants represented herringbone ($n = 17$), parallel ($n = 32$) and rotary ($n = 11$) parlour configurations. Herringbone parlours included two Double-20 and two Double-24 configurations. Parallel parlours included one Double-25, one Double-35, five Double-40, one Double-48 and one Double-50 configurations. Rotary parlours included one 40 stall, two 60 stall and one 72 stall configurations. Herringbone and parallel parlours used a territorial milking routine where each worker was assigned a set of milking stalls on both sides of the milking pit. A group of cows would enter the parlour and align themselves in each milking stall. In sequential fashion down the line of assigned cows, each worker would perform a milking routine which included teat dip, followed by strip, wipe then milking unit attachment. Workers performed the same milking routine on both sides of the milking pit. Rotary parlours used a task rotation strategy where workers performed a specific milking task in an assigned position on the periphery of the rotating carousel. Throughout the shift, workers rotated to other task positions every one to two hours.

2.3. Surface EMG methods

Muscular effort was estimated using surface EMG recordings from five muscles of the dominant upper extremity. Surface EMG data were recorded continuously throughout a full work shift for each participant. For a subset of participants ($n = 33$), milking task cycles (dip, strip, wipe and attach) were identified using a push-button digital marker connected to a portable EMG data logger. Task cycles were marked in 'blocks' of ten cows, with blocks distributed throughout the work day (i.e. tasks were not marked continuously), typically during the morning, mid-day and afternoon portions of the shift.

Full technical details of the surface EMG processing and normalisation methods used in this study are available in Douphrate et al. (2017). To summarise, raw surface EMG signals were recorded from the upper trapezius, anterior deltoid, biceps, flexor digitorum superficialis (forearm flexor) and extensor digitorum communis (forearm extensor). Electrodes were connected to a belt-worn data logger (Datalog MWX8, Biometrics Ltd., UK), which digitised the raw EMG signals at a sampling rate of 1,000 Hz. Custom LabVIEW programs (version 2013, National Instruments, Inc., Austin, TX) were used to process the recorded data. During post-processing, the raw EMG signals were examined in the time domain for evidence of signal drift (e.g. as may occur if the skin-to-electrode interface were compromised) and electrocardiogram interference, and in the frequency domain for electromagnetic interference. (Douphrate et al. 2017). All raw EMG signals were then (i) adjusted for DC offset, and (ii) converted to instantaneous root-mean-square (RMS) amplitude using a 100-sample RMS window with a 50-sample overlap (Fethke et al. 2012).

For each muscle separately, the processed RMS EMG amplitudes were normalised to the RMS EMG amplitudes observed during maximal, voluntary isometric reference contractions (%MVE, i.e. normalisation in the bioelectric domain). Baseline noise was subtracted from all RMS EMG amplitudes in a power sense (Thorn et al. 2007).

2.4. Exposure summary measures

Mean amplitude (in %MVE) across the entire full-shift and task-specific recordings was calculated as an index of overall muscular load. Gaps in muscular activity during full-shift recordings were defined as any periods in which muscle activity fell below 0.5% MVE for a minimum of 0.25 s (Veiersted, Westgaard, and Andersen 1990). Gap frequency was defined as the number of gaps/min and muscular rest was defined as the summed duration of all gaps expressed as a percentage of total full-shift recording time. Full-shift static (10th percentile), median (50th percentile) and peak (90th percentile) amplitudes of muscle activity were calculated using a 'Traditional' amplitude probability distribution function (APDF) (Jonsson 1982) and using a recent modification referred to as the 'Active' APDF (Marker et al. 2016). The Active APDF removed all EMG amplitude values below the 0.5% MVE muscular rest threshold prior to calculating percentiles, and reflects the amplitude of muscle activity only during periods of *active* muscle contraction. Only Traditional APDF was computed for short duration, task-specific recordings. The mean duty duration (in seconds) of each milking task cycle was calculated, as well as a composite (all milking tasks combined) inter-cycle time or Between Cow Time (BCT).

2.5. Statistical analysis

The EMG summary measures were first described across all participants (i.e. using means and standard errors) for the full-shift recordings and separately for each milking task. Upon examination of standard plots of quantiles (*Q*–*Q* plots), standardised normal probability plots (*P*–*P* plots) and results of Chen–Shapiro tests (Chen and Shapiro 1995), it was determined the distributions of the EMG summary measures for each muscle violated assumptions of normality. No transformation adequately normalised the distributions. Also, examination of residuals in preliminary ordinary least square regression models of the relationship between the full-shift EMG measures and parlour configuration showed signs of heteroscedasticity and the presence of outliers. Similar normality violations were observed in preliminary examination of task-specific EMG summary measures. To perform adequate statistical testing, and given the different data structure for the full-shift and the milking task-specific samples, different statistical analysis approaches were used.

The effect of parlour configuration on each EMG full-shift summary measure, stratified by muscle, was estimated using robust regression models. Robust regression assigns less weight to observations with large residuals using MM-estimators, which are known to be resistant to different types of outliers. To further increase robustness of the estimates, 95% asymptotic efficiency for normal errors was computed. Because parlour configuration types were entered in the model as dummy variables, the initial estimator for the corresponding EMG estimates was the MS-estimator instead of the S-estimator, which may have computational problems for dummy variables. Further, initial *F*-tests were performed to detect overall differences in the full-shift measures by parlour configuration type. A *p*-value of <0.10 was then used to decide when to perform Bonferroni-corrected *post hoc* comparisons between parlour configuration types. Statistically significant differences between configuration types were declared at a more conservative *p*-value of 0.05. The ‘mmregress’ command as implemented in Stata© (v. 14.1, StataCorp LP, College Station, TX) was used for the above analyses.

To estimate the effect of parlour configuration on each milking task-specific EMG summary measure, stratified by muscle, multilevel linear mixed-effects models were used to account for the inherent nested data structure (i.e. observations within individuals). Restricted maximum likelihood estimation was used since this method is preferred with somewhat small sample sizes such as ours (Kenward and Roger 1997). Models assumed residuals to be independent by parlour configuration type but allowed for heteroscedasticity of the EMG summary measures. Given both the small sample size and the violation of the assumption of normality of EMG measures, bootstrapping was used to obtain more accurate estimates (Kelley 2005; Sufahani and Ahmad 2012). Starting with 500 replications with increments of 500, the final models were performed with 4,000 replications at which point the estimates did not change meaningfully. While we reported that Bonferroni-corrected *post hoc* comparisons for full-shift models were corrected for multiple comparisons, multilevel modeling (for task-specific comparisons) yielded more reliable estimates since correction of estimates from multilevel models for multiple comparisons would likely result in overcorrection (i.e. production of wider confidence intervals than necessary) (Gelman, Hill, and Yajima 2012). Statistically significant differences were declared at a *p*-value of 0.05.

3. Results

3.1. Full-shift muscle activity levels

We analysed full-shift EMG recordings representing a total 60 dairy parlour workers which included 17 herringbone, 32 parallel and 11 rotary workers. Our sample included 299 muscle-specific full-shift recordings. A single muscle-specific (forearm extensor) full-shift recording from one participant was excluded due to compromised integrity of the skin-to-electrode interface. Mean full-shift sampling duration across all participants was 8 h and 18 min. Mean RMS, muscular rest, gap frequency, and Traditional and Active APDF values for all muscles are presented in Table 2.

Comparisons of summary measures between parlour configurations suggested a general pattern of lower muscle activity levels (both Traditional and Active APDF) and higher per cent muscular rest among rotary parlour participants as compared to herringbone and parallel parlour participants for anterior deltoid, forearm flexor and forearm extensor muscles. Additionally, parallel parlour participants generally had the highest muscle activity levels and lowest per cent muscular rest for the same muscles with the exception of the forearm flexor (highest among herringbone parlour participants). No trends were observed in upper trapezius muscle activity or rest levels between parlour configurations. As expected, Active APDF values were higher than Traditional APDF values due to removal of all values below the 0.5%MVE muscular rest threshold prior to calculating the APDF percentiles.

Post hoc comparisons of full-shift summary measures between parlour configurations revealed several differences that were statistically significant. For the anterior deltoid, parallel mean RMS (7.5 ± 0.5%MVE) was significantly higher ($p < 0.05$) than herringbone mean RMS (5.9 ± 0.4%MVE). Whereas significantly higher Traditional APDF median (50th percentile) and peak (90th percentile) RMS levels were observed for parallel as compared to herringbone, only Active APDF peak levels were different.

For the biceps, parallel mean RMS (5.2 ± 0.3%MVE) was significantly lower than herringbone mean RMS (7.1 ± 0.6%MVE). Whereas only the herringbone Traditional APDF peak value (13.1 ± 0.8%MVE) was lower than parallel peak value (18.3 ± 1.5%MVE), all Active APDF values were significantly lower than parallel values. Additionally, biceps parallel muscular rest (12.4 ± 1.3% time) was significantly lower than both herringbone (17.7 ± 1.1% time) and rotary (19.0 ± 1.5% time).

For the forearm flexors, herringbone mean RMS (11.0 ± 0.9%MVE) was significantly higher than rotary mean RMS (8.3 ± 0.5%MVE). Both herringbone Traditional and Active APDF peak values were significantly higher than parallel values. Active APDF peak (37.9 ± 2.3%MVE) was also significantly higher than rotary peak value (29.8 ± 2.0%MVE).

For the forearm extensors, parallel mean muscle activity level (8.7 ± 0.9%MVE) was significantly higher than rotary (5.7 ± 0.7%MVE). Whereas only parallel Traditional APDF peak (22.0 ± 2.0%MVE) was higher than herringbone (14.7 ± 1.3%MVE), only parallel Active APDF median (11.5 ± 0.6%MVE) was higher than herringbone median (9.6 ± 0.4%MVE). Both rotary Traditional APDF static and peak values were lower than parallel values, but only rotary Active APDF median (9.4 ± 0.6%MVE) was lower than parallel median (11.5 ± 0.6%MVE). Lastly, rotary muscular rest for the forearm extensor (14.9 ± 1.6% time) was significantly higher than parallel muscular rest (8.8 ± 0.8% time).

3.2. Task-specific muscle activity levels

We analysed 19,077 task cycles across the sub-sample of participants with task-specific data ($n = 33$) with an average of 29 cycles of each milking task per participant. To assess if the task-specific sub-sample of participants was representative of the full-shift sample of participants ($n = 60$), we compared the full-shift summary measures of the sub-sample to the entire full-shift sample of participants. No significant differences in results were observed between the two groups.

Task-specific EMG summary metrics by parlour configuration are presented in Table 3. Comparisons of milking tasks between parlour configurations revealed lower upper trapezius, anterior deltoid and biceps muscle activity levels during the wipe and milking unit attachment tasks among rotary participants as compared to herringbone and parallel participants. In general, no significant differences were observed between configurations for dip and strip tasks for upper trapezius, anterior deltoid and biceps muscle groups. Forearm flexor and extensor muscle activity levels were lower among rotary participants during dip and attachment tasks as comparted to herringbone and parallel. Peak forearm flexor (41.9 ± 3.0%MVE) and extensor (19.2 ± 3.9%MVE) muscle activity levels were significantly lower among rotary participants as compared to parallel participants during wipe task.

Task times by parlour configuration are also presented in Table 3. Milking unit attachment had longer mean duration (4.1 ± 1.9s) across all parlour configurations as compared to dip (2.0 ± 1.1s), strip (3.0 ± 1.5s) and wipe (2.9 ± 1.5s) tasks. Comparison of parlour configurations revealed significantly longer rotary task durations (all milking tasks) as compared to herringbone and parallel milking tasks. Additionally, composite (all tasks combined) inter-task time or BCT was significantly longer in duration among rotary participants (3.0 ± 2.5s) as compared to both herringbone (1.4 ± 2.5s) and parallel (1.5 ± 2.3s) (not presented in table).

4. Discussion

To our knowledge, this study is the first of US large-herd dairy workers to (i) characterise full-shift patterns of muscle activity and (ii) explore the effect of parlour configuration on both full-shift muscle activity and muscle activity during specific elements of the milking routine. Summary measures included a set of well-established variables commonly used to describe overall muscle effort (i.e. mean muscle activity [Richter et al. 2009]), the distribution of EMG signal amplitudes (i.e. Traditional APDF [Jonsson 1982]) and the quantity and temporal aspects of muscle rest (i.e. the proportion of work time with muscle rest and EMG gap frequency [Veiersted, Westgaard, and Andersen 1990]). In addition, for the full-shift analyses, the distribution of EMG signal amplitudes independent of muscle rest was also considered (i.e. Active APDF [Marker et al. 2016]).

4.1. Full-shift muscle activity levels

Full-shift mean muscle activity levels, which include periods of muscle rest, were greatest among those in parallel parlours for the anterior deltoid, biceps, and forearm flexors, and greatest among those in herringbone parlours for the forearm flexors. These observations, along with the general pattern reduced Traditional APDF levels, reduced Active APDF levels and greater amounts of muscle rest, suggest that those working in rotary parlours experience lower muscular load than those in parallel and herringbone parlours. Specifically, (i) 11 of the 15 Traditional APDF summary metrics (5 muscles × 3 metrics) were lowest among rotary participants, (ii) 10 of the 15 Active APDF summary metrics were lowest among rotary participants and (iii) the proportion of work time with muscle rest was highest among rotary participants for all muscles. Further inspection of the results (Table 2) suggests that reductions in muscle activity levels among rotary participants were most consistently observed for the forearm flexors and forearm extensors.

Despite the general similarity of work across large-herd milking parlours, each dairy operation is unique with variation in workstation designs, milking routines, staffing levels and work–rest schedules both within and between parlour configurations. Such variation could partially explain the observed differences in common EMG summary measures between parlour configurations, such as mean muscle activity, Traditional APDF levels, and the proportion of work time with muscle rest. Most importantly, rotary parlours use a machine-paced production strategy in which cows are brought to the worker on a revolving carousel, whereas herringbone and parallel workers must move to each stationary cow to perform milking tasks. While the machine-pacing in rotary parlours controls the speed of milking task performance, workers in herringbone and parallel parlours rapidly perform a milking task down a line of successive cows. Our task-specific analyses revealed longer duration composite inter-cycle times (i.e. BCT) among rotary parlour participants than among both herringbone and parallel participants. An example representation of BCT differences between parlour configurations is presented in Figure 4. Longer duration inter-cycle task times in rotary parlours may provide increased opportunity for muscle rest as compared to herringbone and parallel parlours. Machine-paced production in rotary parlours may also improve quality control since workers are restricted from performing milking tasks at speeds which may compromise task effectiveness, cow health and overall parlour productivity (e.g. machine pacing ensures the pre-dip disinfectant remains on the udder for a sufficient duration).

The observed differences in Active APDF levels between parlour configurations (i.e. lower among those in rotary parlours), however, suggests that increased muscle rest time as a consequence of machine pacing does not fully account for differences in the more common EMG summary measures. The faster work pace in herringbone and parallel parlours implies greater movement velocity, which has been associated with increased EMG amplitudes (Freund and Büdingen 1978; Mustard and Lee 1987). Alternatively, localised muscle fatigue, which results in increased EMG amplitude accompanied by a shift in spectral content of the EMG signal to lower frequencies (Kallenberg et al. 2007), may have been more prevalent among those in herringbone and parallel parlours. An increase in muscle activity in response to psychosocial stressors has also been observed in many occupational settings (Eijckelhof et al. 2013; Lundberg et al. 1994; Rissén et al. 2000; Van Galen et al. 2002; Visser et al. 2004). Occupational psychosocial stress, commonly quantified using the psychological job demands/decision latitude model (Karasek et al. 1998) has been linked to upper extremity musculoskeletal outcomes in several epidemiological studies among non-agricultural workers (Bongers, Kremer, and Laak 2002; Gerr et al. 2014; Hauke et al. 2011) and was consistently retained in adjusted models of associations between agricultural activities and upper extremity pain in a recent study of agricultural workers (Fethke et al. 2015).

Rotary parlours also use a task rotation strategy in which workers perform a specific milking task for one to two hours then rotate to another task assignment. In contrast, herringbone and parallel workers perform milking tasks in sequential fashion down a line of assigned cows. Task rotation is used in many work settings to produce task variety and to reduce worker fatigue and injuries (Tharmmaphornphilas and Norman 2004), although evidence of rotation to minimise physical exposures and the occurrence of musculoskeletal health outcomes is mixed (Bao et al. 2016; Leider et al. 2015).

With volatile milk prices and low-profit margins, there is a need to develop practical, low-cost interventions to prevent adverse musculoskeletal health outcomes or fatigue among parlour workers. Higher muscular rest and lower muscle activity levels among rotary participants provides supporting evidence of the potential effectiveness of task rotation in reducing physical exposures associated with large-herd parlour milking. Implementing a task rotation strategy in herringbone and parallel milking is one plausible strategy to introduce opportunity for muscular rest and task variability. An ancillary milking parlour position is a 'cow pusher' who is responsible for directing cows from pens to the parlour for milking. In a task rotation strategy, herringbone or parallel parlour milkers could rotate into a cow pusher role periodically during the shift which would introduce increased task variability and reduced physical exposures.

4.2. Task-specific muscle activity levels

In addition to lower full-shift muscle activity levels, our findings also suggest lower task-specific muscle activity levels among those in rotary parlours. Fifty-three of the 80 task-specific EMG summary metrics compared between parlour configurations (5 muscles × 4 metrics × 4 tasks) were lowest among rotary participants (Table 3). Similar to the full-shift results, the reductions associated with the rotary configuration were most consistent for the forearm flexors, forearm extensors and biceps muscle groups. Notably, activity levels across all metrics and muscles were lowest among rotary participants during the milking unit attachment task.

Observed muscle activity levels between were greater during the pre-milking tasks (i.e. dip, strip and wipe) than during the milking unit attachment task. The results suggest that interventions directed at reducing muscle loads should consider these pre-milking tasks. Douphrate, Fethke, et al. (2016) compared upper extremity muscle activity levels during the manual pre-milking tasks (as performed in the current study) to the levels observed during use of an alternative teat preparation system designed to replace the manual pre-milking tasks. Results were mixed, with greatly reduced anterior deltoid muscle activity but modestly increased biceps, forearm flexor and forearm extensor activity. Importantly, however, the alternative system resulted in a substantial decrease in repetitiveness associated with manual pre-milking tasks. In the context of full-shift exposure to forceful manual exertions, the reduced repetition during use of the alternative teat preparation system may offset the modest increases in activity levels (on a per-cycle basis) for some muscles. We are aware of no other study that has examined the effect of alternative approaches to performing the pre-milking tasks on muscle activity levels.

The vast majority of previous ergonomics intervention research in dairy has targeted the milking unit. For example, Jakob, Liebers, and Behrendt (2009) reported a significant effect of milking unit weight on upper extremity muscle activity levels, and Jakob and Liebers (2011) observed a reduction of muscle activity during use of a novel quarter individual milking unit design. Stål, Pinzke, and Hansson (2003) observed a small reduction in upper extremity muscle activity when a prototype support arm was used to balance the weight of the milking unit during the attachment task. Most recently, Douphrate et al. (2017) observed small differences in upper extremity muscle activity levels during use of both existing and prototype milking units from multiple manufacturers. Reductions in muscular load and user satisfaction appeared to be related to reduced milking unit weight, smaller 'spread' between the milk tubes, and milk tubes that were tapered (i.e. narrower) at the hand grasp location.

4.3. Study strengths and limitations

An important strength of this study is the use of a full-shift sampling strategy, which remains rare in field-based ergonomics research (Mathiassen et al. 2003). Exposure assessments based on short-duration or task-specific sampling strategies have been used to represent full-shift (Norman et al. 1998) or lifetime exposures (Kumar 1990). Common arguments for short-duration or task-specific sampling include (i) cost due to the time requirements or data storage and (ii) computational difficulties associated with large data files (van der Beek and Frings-Dresen 1998; David 2005; Trask et al. 2008). Dramatic advances in data logging technology and the ability of relatively inexpensive computing hardware to process large data files common to direct measurement approaches have eased many the past impediments to prolonged measurement in field environments. Even so, a single full-shift measurement (as in this study) does not necessarily capture the full extent of the temporal variation in physical demands that must be understood to establish unbiased estimates of exposure at the level of the individual worker (Fethke et al. 2012; Mathiassen, Moller, and Forsman 2003; Trask et al. 2008). However, due to the cyclic nature of milking parlour work and the day-to-day consistency in the parlour operation, large between-day differences (within-worker) in muscle activity summary measures are not expected.

Although a sample size of 60 workers was sufficient to detect statistically significant differences in EMG summary measures between parlour configurations, other factors may affect muscle activity levels. Most importantly, muscle activity may depend partly on individual anthropometric characteristics. For example, workers with shorter arm lengths or lower stature might experience higher levels of upper trapezius activity while reaching forward during unit attachment than workers with longer arms or higher stature. Another limitation is that we were unable to control for differing milking unit designs between the parlours from which participants were recruited. Milking units vary by shape and weight, and workers use different methods to attach the units to the cows (Douphrate et al. 2017). Such differences may influence muscle activity during the milking unit attachment task. Lastly, the non-random selection of participants limits our ability to generalise the observed results to the broader population of parlour workers.

4.4. Industry implications

Maximisation of dairy operation economies of scale is dependent on herd size as well as parlour capacity, efficiency and throughput. Number of workers and pre-milking routine are two factors often considered when determining an ideal parlour design and capacity. However, worker performance should also be considered. Our findings suggest that parlour work organisational factors may have a significant influence on worker muscle activity and potentially the development of worker fatigue. In turn, worker fatigue could result in compromised parlour productivity or cow health. In addition to parlour configuration and pre-milking routine, dairy producers should consider work organisation factors and their influence on worker performance. Further research is needed to investigate the role of worker health and fatigue on performance, cow health and parlour productivity.

4.5. Conclusions

Our study, which employed continuous measurement of upper extremity muscle activity over entire work shifts, revealed more desirable lower muscle activity levels and higher muscular rest among rotary parlour workers as compared to herringbone and parallel parlour workers. These findings suggest rotary parlours may offer workstation designs or work organisational dynamics which may be more beneficial to the health and performance of the worker, as compared to parallel or herringbone parlours. Our findings can enable more informed decisions regarding both engineering (e.g. parlour configuration or milking equipment) and administrative (e.g. work organisation) control strategies.

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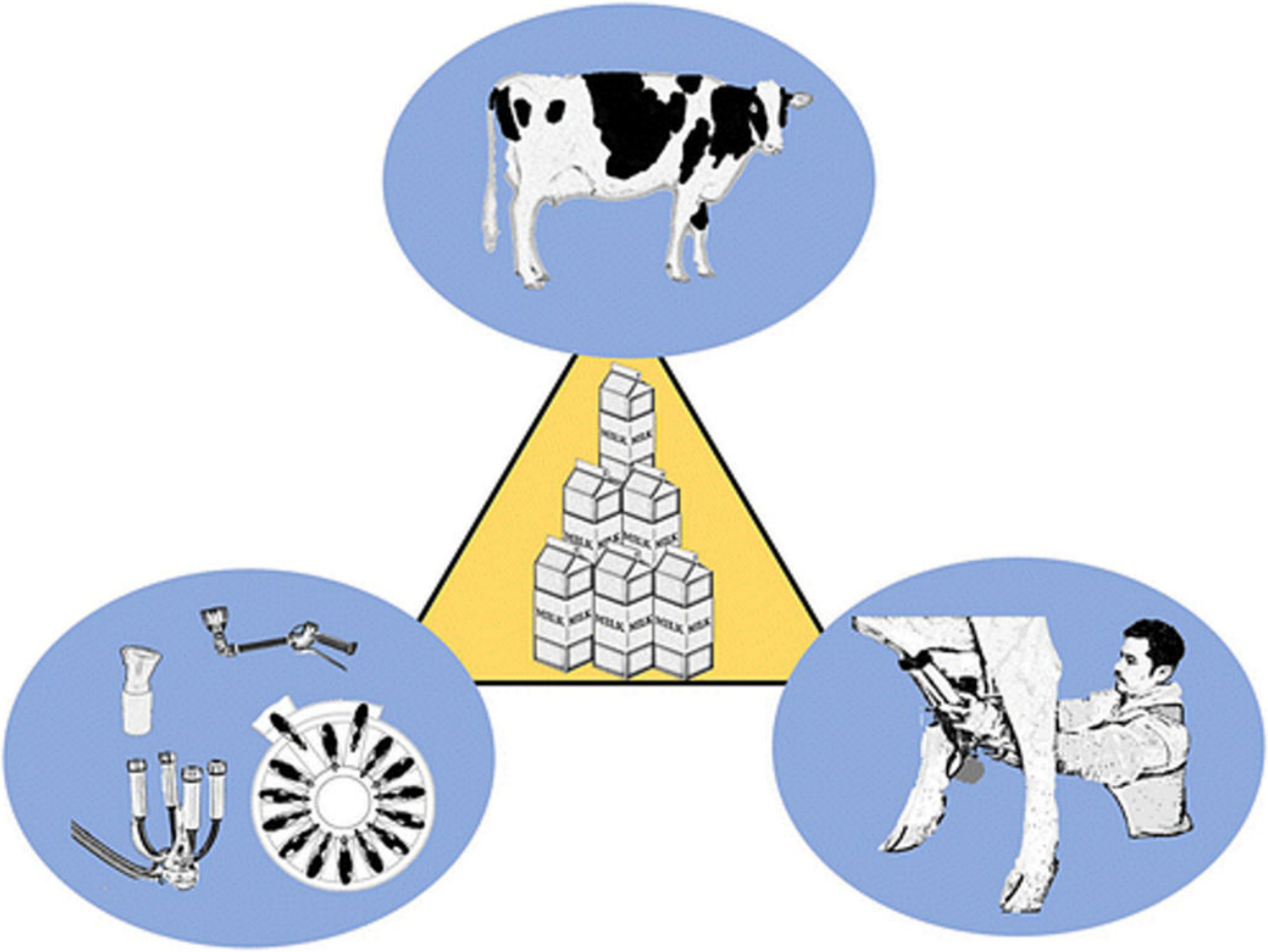

Figure 1.
Triad of interactions between cow, equipment/environment and worker.

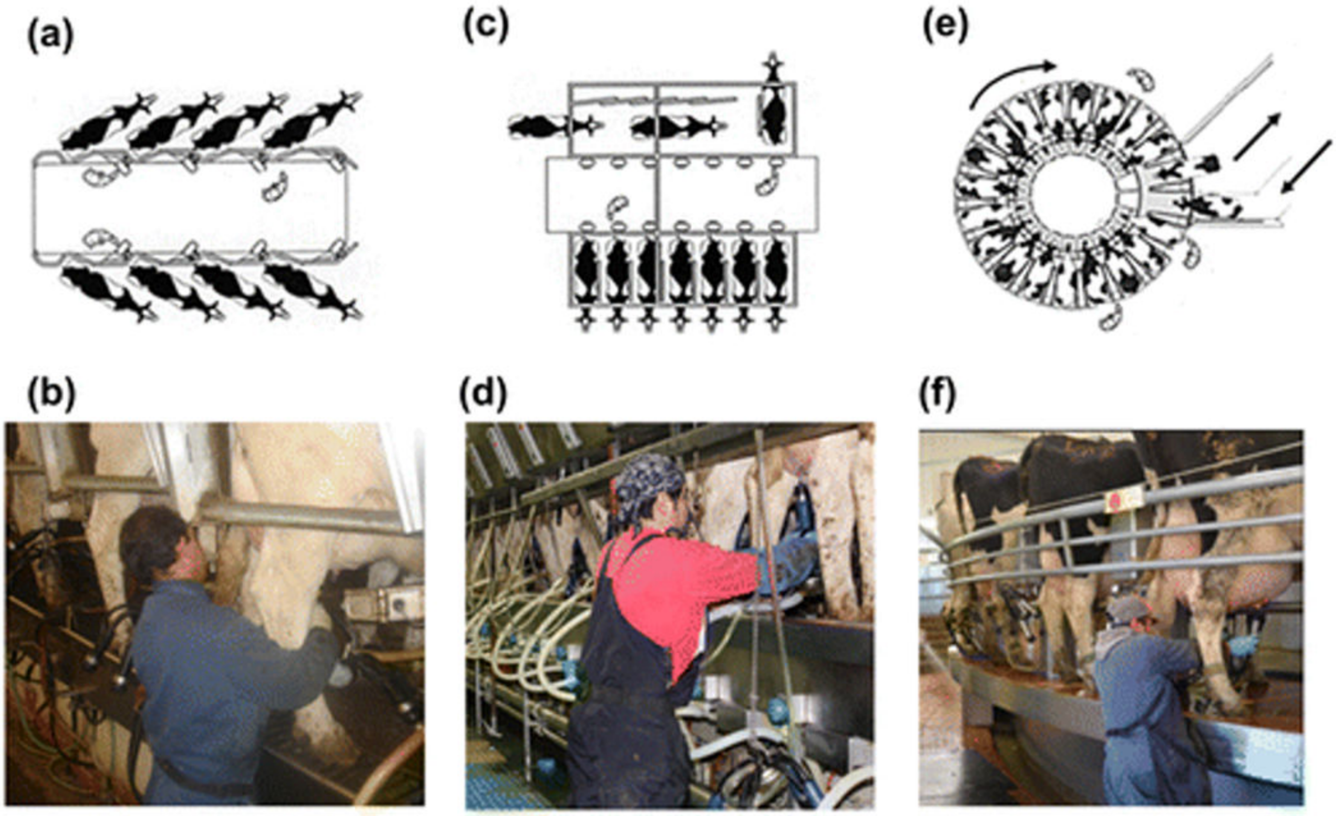

Figure 2.
Parlour configurations and worker postures during performance of milking tasks: ((a) and (b)) herringbone; ((c) and (d)) parallel; ((e) and (f)) rotary. (Douphrate et al. 2014).

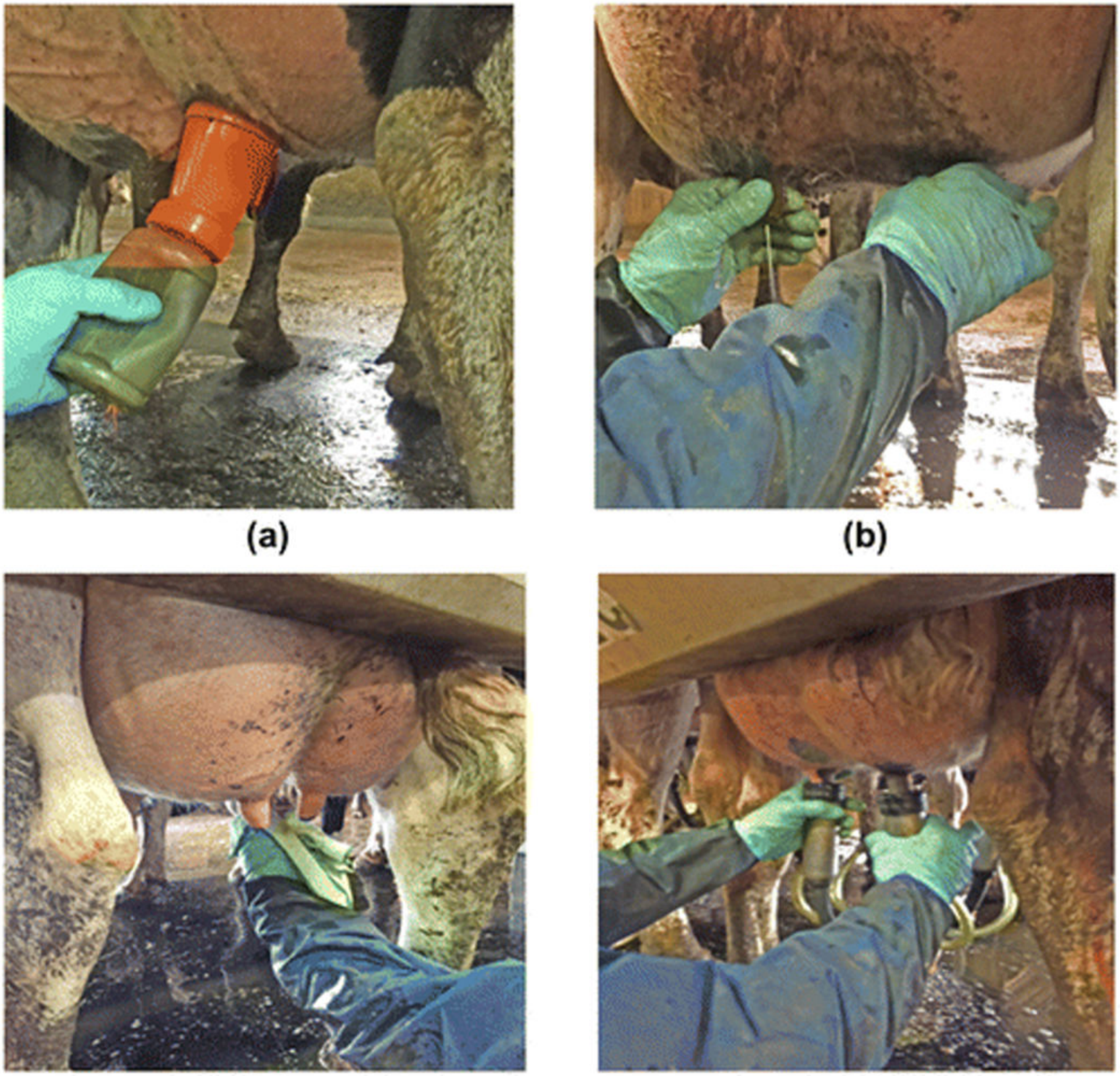
(a) (b) (c) (d)

Figure 3.
Milking tasks: (a) dip, (b) strip, (c) wipe and (d) milking unit attachment. (Douphrate, Fethke, et al. 2016).

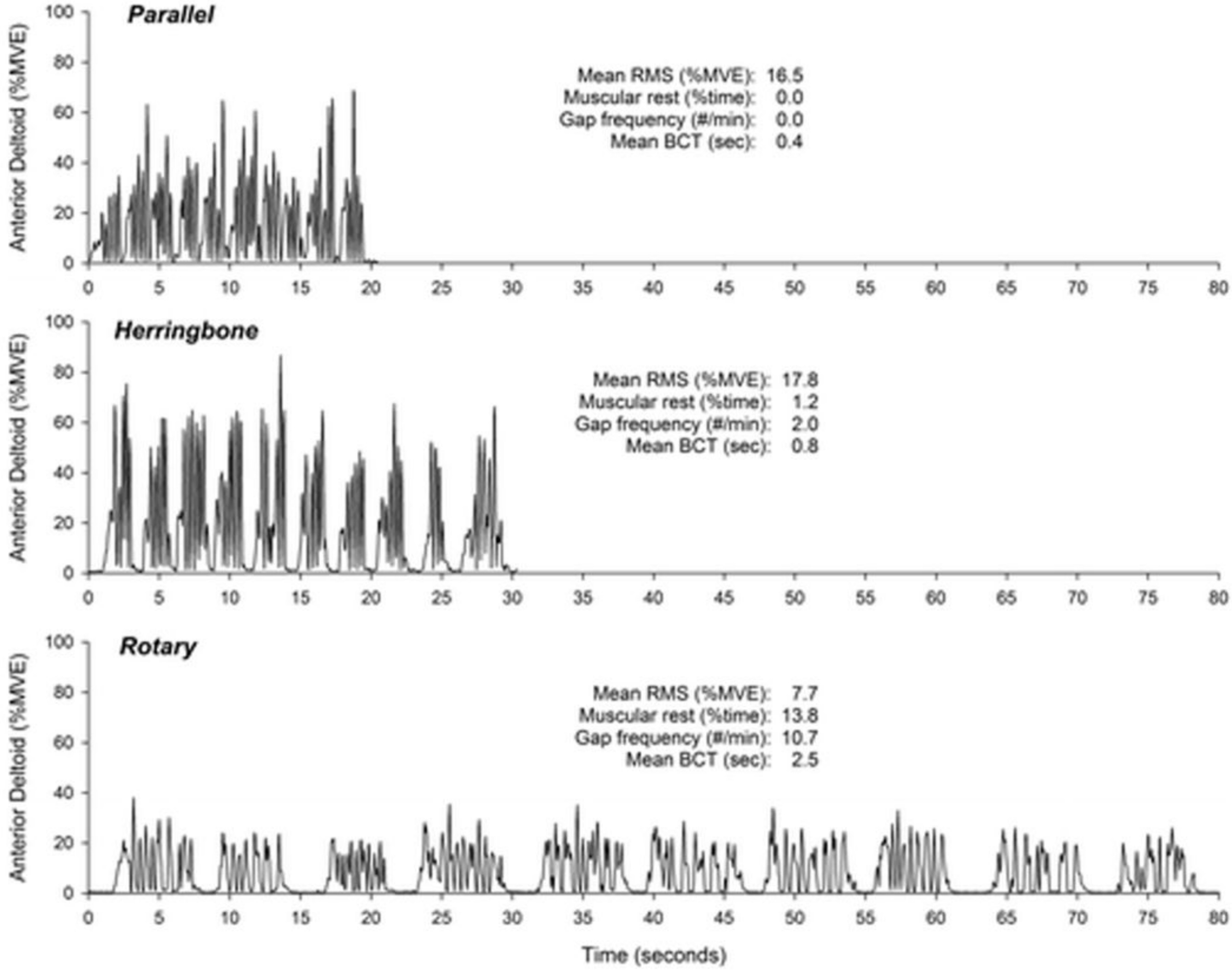

Figure 4.

Samples of anterior deltoid muscle activity from three parlour workers (herringbone, parallel and rotary) performing dip task on 10 cows.

Table 1.

Summary of demographic variables (*n* = 60).

	Mean (SD)	Min	Max
Age (years)	29.9 (9.2)	18.0	61.0
Milking (years)	5.6 (4.7)	0.25	20.0
Weight (kg)	75.8 (12.2)	54.4	99.8
Height (m)	1.7 (0.15)	1.4	1.8
BMI (kg/m^2)	29.3 (16.0)	20.8	35.5

Table 2.

Comparison of full-shift EMG summary measures (mean [SE]) across parlour configurations.

Summary Measure*	Herringbone (n=17)†	Parallel (n=32)	Rotary (n=11)	Total (n=60)
Upper trapezius				
Mean RMS (%MVE)	9.6 (0.7)	8.6 (0.7)	9.8 (1.9)	9.6 (4.4)
Gap frequency (#/min)	1.2 (0.4)	1.5 (0.2)	1.9 (0.8)	2.6 (3.0)
Muscular rest (% time)	1.1 (0.4)	1.7 (0.2)	2.8 (1.0)	6.0 (15.5)
Traditional APDF (%MVE)				
Static	1.3 (0.2)	1.2 (0.1)	1.0 (0.2)	1.4 (1.0)
Median	7.2 (0.6)	5.8 (0.5)	7.1 (1.5)	6.9 (3.6)
Peak	20.8 (1.5)	19.9 (1.8)	21.7 (3.7)	21.2 (9.5)
Active APDF (%MVE)				
Static	6.0 (0.1)	5.9 (0.1)	5.9 (0.3)	6.1 (0.6)
Median	11.2 (0.5)	10.9 (0.5)	11.2 (1.2)	11.4 (3.1)
Peak	25.1 (1.4)	26.0 (1.8)	25.8 (3.5)	26.5 (9.1)
Anterior deltoid				
Mean RMS (%MVE)[A]	5.9 (0.4)	7.5 (0.5)	6.5 (1.9)	7.6 (3.5)
Gap frequency (#/min)[A,B]	15.8 (1.0)	11.6 (1.1)	12.0 (1.1)	12.8 (5.1)
Muscular rest (% time	21.4 (1.9)	19.1 (2.3)	29.4 (3.9)	21.7 (11.3)
Traditional APDF (%MVE)				
Static	0.3 (0.0)	0.3 (0.0)	0.2 (0.0)	0.3 (0.2)
Median[A,C]	1.6 (0.2)	2.4 (0.3)	1.1 (0.2)	2.2 (1.5)
Peak[A]	18.1 (1.2)	22.6 (1.4)	18.6 (4.5)	23.2 (10.6)
Active APDF (%MVE)				
Static	6.2 (0.1)	6.3 (0.1)	6.2 (0.2)	6.4 (0.6)
Median	12.9 (0.5)	14.2 (0.4)	13.1 (1.4)	14.6 (3.9)
Peak[A]	28.7 (1.5)	35.4 (1.4)	27.9 (4.5)	36.6 (18.1)
Biceps				
Mean RMS (%MVE)[A]	5.2 (0.3)	7.1 (0.6)	5.4 (0.5)	7.7 (5.5)
Gap frequency (#/min)[A,B]	9.6 (0.5)	7.1 (0.6)	6.4 (0.4)	7.7 (2.8)
Muscular rest (% time)[A,C]	17.7 (1.1)	12.4 (1.3)	19.0 (1.5)	15.2 (6.5)
Traditional APDF (%MVE)				
Static[C]	0.2 (0.0)	0.3 (0.0)	0.2 (0.0)	0.3 (0.3)
Median	3.1 (0.2)	4.0 (0.5)	3.0 (0.4)	4.3 (3.1)
Peak[A]	13.1 (0.8)	18.3 (1.5)	14.3 (1.3)	19.6 (14.1)
Active APDF (%MVE)				
Static[A]	5.7 (0.0)	5.9 (0.1)	5.7 (0.1)	5.9 (0.6)
Median[A]	9.3 (0.2)	11.2 (0.5)	10.0 (0.4)	11.5 (4.4)
Peak[A]	19.5 (0.8)	25.1 (1.6)	21.6 (1.5)	26.9 (16.1)
Forearm flexors				

Summary Measure*	Herringbone (n=17)†	Parallel (n=32)	Rotary (n=11)	Total (n=60)
Mean RMS (%MVE)[B]	11.0 (0.9)	10.0 (0.9)	8.3 (0.5)	11.1 (5.6)
Gap frequency (#/min)	5.4 (0.5)	6.5 (0.5)	5.1 (0.6)	5.8 (2.4)
Muscular rest (% time)	9.0 (1.5)	10.6 (1.1)	10.9 (1.4)	10.3 (5.7)
Traditional APDF (%MVE)				
Static	0.5 (0.1)	0.4 (0.0)	0.4 (0.1)	0.5 (0.4)
Median	5.3 (0.6)	4.5 (0.4)	4.4 (0.2)	5.5 (3.0)
Peak[B]	27.7 (2.1)	26.1 (2.2)	21.1 (1.5)	28.6 (15.0)
Active APDF (%MVE)				
Static	6.1 (0.1)	6.1 (0.1)	5.9 (0.1)	6.2 (0.5)
Median	13.2 (0.6)	13.3 (0.6)	11.9 (0.5)	13.7 (3.6)
Peak[B,C]	40.1 (2.8)	37.9 (2.3)	29.8 (2.0)	39.9 (17.1)
Forearm extensors				
Mean RMS (%MVE[C]	6.3 (0.6)	8.7 (0.9)	5.7 (0.7)	8.3 (4.2)
Gap frequency (#/min)	6.1 (0.5)	5.3 (0.4)	5.6 (0.4)	5.6 (2.1)
Muscular rest (% time)[C]	11.8 (1.4)	8.8 (0.8)	14.9 (1.6)	10.9 (5.3)
Traditional APDF (%MVE)				
Static[C]	0.4 (0.1)	0.5 (0.1)	0.3 (0.0)	0.5 (0.3)
Median	4.2 (0.4)	4.7 (0.4)	3.7 (0.4)	5.1 (2.8)
Peak[A,C]	14.7 (1.3)	22.0 (2.0)	13.2 (1.6)	20.0 (10.4)
Active APDF (%MVE)				
Static	5.7 (0.1)	5.8 (0.1)	5.7 (0.1)	5.9 (0.5)
Median[A,C]	9.6 (0.4)	11.5 (0.6)	9.4 (0.6)	11.3 (3.4)
Peak	21.0 (1.3)	29.6 (2.1)	19.1 (1.7)	28.0 (13.3)

*Post hoc comparisons ($p<0.05$) of summary metrics between parlor configuration: A = herringbone vs parallel; B = herringbone vs rotary; C = parallel vs rotary

†16 observations for the forearm extensor muscle group

Table 3.

EMG summary measures (mean [SE]) by task and parlour configuration.

Summary Measure (%MVE)*	Dip			Strip			Wipe			Attach		
	Herring.	Parallel	Rotary	Herring.†	Parallel	Rotary	Herring.†	Parallel	Rotary	Herring.	Parallel	Rotary
Upper trapezius												
Mean RMS$^{A2\ A3}$	19.5 (2.0)	15.2 (1.5)	17.3 (3.4)	15.2 (na)	15.8 (1.2)	15.0 (3.3)	11.2 (na)	18.1 (1.6)	16.5 (2.5)	12.2 (1.3)	12.2 (1.1)	7.9 (1.7)
10th APDF$^{A2\ A3\ W3}$	4.1 (0.7)	4.5 (0.4)	3.8 (0.7)	3.9 (na)	4.6 (0.6)	2.5 (0.6)	3.0 (na)	4.5 (0.5)	3.0 (0.5)	3.0 (0.4)	3.6 (0.4)	1.8 (0.3)
50th APDF^{A3}	18.1 (1.8)	14.1 (1.4)	16.8 (3.5)	14.1 (na)	14.3 (1.1)	11.7 (2.5)	10.2 (na)	16.6 (1.5)	15.0 (2.4)	10.5 (1.2)	11.4 (1.0)	6.8 (1.5)
90th APDF^{A2}	37.8 (4.3)	28.1 (2.8)	30.6 (5.7)	27.6 (na)	30.2 (2.1)	35.3 (7.8)	20.2 (na)	34.0 (3.0)	32.5 (4.7)	25.4 (2.9)	22.3 (1.8)	15.4 (3.5)
Anterior deltoid												
Mean RMS$^{A1\ A3}$	20.7 (2.7)	18.5 (1.3)	23.0 (4.5)	15.0 (na)	23.3 (1.5)	24.2 (5.4)	18.8 (na)	24.8 (1.4)	28.4 (5.5)	15.6 (1.9)	20.3 (0.9)	11.0 (2.1)
10th APDF$^{D1\ S3\ W3\ A2\ A3}$	2.4 (0.4)	3.6 (0.3)	2.7 (0.6)	1.4 (na)	4.9 (0.5)	2.3 (0.8)	1.8 (na)	3.7 (0.5)	1.6 (0.3)	2.5 (0.4)	3.1 (0.3)	0.9 (0.1)
50th APDF$^{A1\ A3}$	18.7 (2.7)	17.0 (1.3)	21.3 (4.2)	13.3 (na)	21.4 (1.4)	24.8 (5.8)	15.6 (na)	22.9 (1.3)	27.3 (5.1)	14.1 (1.8)	19.1 (0.9)	9.4 (2.3)
90th APDF^{A1}	45.0 (5.5)	36.6 (2.5)	48.1 (9.0)	33.7 (na)	46.0 (2.5)	50.2 (10.4)	45.2 (na)	51.3 (2.6)	63.6 (12.3)	31.3 (3.7)	40.6 (1.9)	28.6 (6.3)
Biceps												
Mean RMS$^{W3\ A2\ A3}$	15.1 (2.2)	15.3 (0.9)	12.7 (1.7)	10.3 (na)	11.6 (0.6)	12.1 (1.6)	18.8 (na)	16.5 (0.9)	13.0 (1.0)	11.7 (1.4)	13.3 (0.7)	7.5 (0.8)
10th APDF$^{D2\ D3\ S3\ W3\ A2\ A3}$	4.7 (1.1)	5.6 (0.4)	2.3 (0.4)	2.0 (na)	2.9 (0.2)	1.1 (0.2)	5.7 (na)	5.2 (0.4)	2.5 (0.4)	3.4 (0.7)	3.4 (0.2)	2.0 (0.2)
50th APDF$^{W3\ A2\ A3}$	13.9 (2.1)	14.3 (0.9)	11.5 (1.7)	8.9 (na)	10.3 (0.5)	9.3 (1.1)	16.0 (na)	15.1 (0.9)	11.2 (0.9)	10.2 (1.5)	10.6 (0.6)	6.4 (0.7)
90th APDF$^{A1\ A2\ A3}$	27.0 (3.3)	26.6 (1.8)	25.8 (3.4)	21.4 (na)	22.6 (1.4)	29.6 (4.0)	36.6 (na)	30.2 (1.7)	25.9 (1.9)	21.5 (2.3)	27.7 (1.6)	14.6 (2.2)
Forearm flexors												
Mean RMS$^{A2\ A3\ D2\ D3}$	21.7 (3.2)	22.4 (3.7)	12.3 (1.1)	32.7 (na)	22.4 (2.3)	17.8 (1.4)	25.4 (na)	32.6 (4.5)	23.8 (1.9)	28.8 (4.9)	22.0 (2.6)	11.3 (0.4)
10th APDF$^{D2\ D3\ A2\ A3}$	6.4 (0.6)	8.2 (1.5)	4.0 (0.4)	7.5 (na)	5.3 (0.8)	4.8 (0.3)	6.7 (na)	7.3 (0.8)	8.0 (0.7)	5.7 (0.9)	4.5 (0.4)	2.2 (0.3)
50th APDF$^{D2\ D3\ A2\ A3}$	18.1 (2.6)	20.1 (3.5)	10.7 (1.0)	26.3 (na)	17.8 (2.0)	16.6 (1.1)	20.0 (na)	25.6 (3.0)	21.0 (1.8)	21.8 (3.7)	16.8 (1.8)	8.4 (0.4)
90th APDF$^{A2\ A3\ D2\ D3\ S3\ W3}$	42.7 (7.2)	41.6 (6.3)	22.3 (2.0)	66.4 (na)	49.1 (4.8)	31.0 (3.4)	52.3 (na)	69.8 (10.8)	41.9 (3.0)	63.7 (11.1)	49.9 (6.7)	24.6 (0.7)
Forearm extensors												
Mean RMS$^{D2\ D3\ A1\ A3}$	18.4 (2.9)	18.4 (1.5)	10.8 (1.8)	12.2 (na)	11.0 (1.0)	10.6 (2.3)	18.4 (na)	15.6 (1.0)	11.8 (2.4)	11.3 (1.3)	17.1 (1.1)	9.5 (1.4)
10th APDF$^{D3\ A1\ A3}$	6.8 (1.0)	7.8 (0.7)	4.5 (0.8)	4.7 (na)	3.5 (0.3)	4.8 (1.1)	5.0 (na)	5.4 (0.3)	5.5 (1.1)	3.3 (0.5)	5.1 (0.4)	2.4 (0.2)
50th APDF$^{D2\ D3\ A1\ A3}$	16.1 (2.4)	17.0 (1.5)	9.8 (1.8)	10.0 (na)	8.6 (0.8)	9.5 (2.2)	14.4 (na)	12.9 (0.8)	10.6 (2.3)	9.0 (1.1)	14.5 (1.0)	8.0 (1.3)
90th APDF$^{D2\ D3\ W3\ A1\ A3}$	33.4 (5.3)	31.6 (2.7)	18.6 (2.8)	22.6 (na)	22.8 (2.1)	16.9 (3.7)	37.8 (na)	30.7 (2.2)	19.2 (3.9)	22.2 (2.5)	32.7 (2.0)	18.4 (3.0)

Summary Measure (%MVE)*	Dip			Strip			Wipe			Attach		
	Herring.	Parallel	Rotary	Herring.†	Parallel	Rotary	Herring.†	Parallel	Rotary	Herring.	Parallel	Rotary
Cycle times (mean SD)												
Duty duration (s)	2.5 (0.7)	1.6 (0.6)	4.1 (2.3)	4.4 (1.1)	2.6 (1.0)	7.1 (1.4)	3.4 (0.5)	2.5 (1.0)	6.2 (1.5)	5.3 (1.9)	3.4 (1.4)	6.3 (2.2)

*Statistically significant differences at p<.05 w*here A=Attach, D=Dip, S=Strip, W=Wipe; and 1= Herringbone vs. Parallel, 2=Herringbone vs. Rotary, 3=Parallel vs. Rotary*

†Herringbone strip included only two participants, and wipe included only one participant precluding SE estimation and statistical comparisons