

DISSERTATION

DIRECT ASSESSMENT OF UPPER LIMB MUSCLE ACTIVITY ASSOCIATED WITH
DAIRY MILKING TASKS THROUGH USE OF SURFACE ELECTROMYOGRAPHY:
AN OCCUPATIONAL RESEARCH PROJECT

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ABSTRACT

DIRECT ASSESSMENT OF UPPER LIMB MUSCLE ACTIVITY ASSOCIATED WITH DAIRY MILKING TASKS THROUGH USE OF SURFACE ELECTROMYOGRAPHY: AN OCCUPATIONAL RESEARCH PROJECT

Work-related musculoskeletal disorders (WRMSDs) are an economic burden on employers across all industries. Within agriculture, a high prevalence of WRMSDs have been found among dairy workers (specifically those involved in milking tasks) in small and large-herd operations. However, the effects of milking activities in large-herd dairy operations have not been investigated with the direct physical exposure measures, such as surface electromyography (sEMG), necessary to best quantify occupational risk. The goal of the research reported in this dissertation was to fill that gap, using sEMG to better quantify upper-limb muscle activity among large-herd dairy workers and to compare the muscle activity across large and small-herd operations. Three studies were conducted to reach this goal. In the first, sEMG was used to detail activity of upper-limb muscles across all milking tasks in large-herd dairies. This study revealed that the biceps brachii have the most activity in overall milking work. In the second study, sEMG was used to examine the muscle activity associated with each of the five primary milking tasks: pre-dipping, stripping, wiping, milk cluster attachment, and post-dipping. This study revealed that wiping and milk cluster attachment tasks required the most muscle activity. Identification of these two tasks as the most strenuous provides the groundwork for future researchers to explore different ergonomic intervention methods for milking tasks in addition to milk cluster attachment. The third study compared the sEMG associated with milking activities at large-herd operations with those in small-herd dairies. The results revealed that although work pace and total tasks completed per milking shift differed from one size of dairy to the other, milking work was strenuous in both cases. The

comparison of muscle activity associated with small-herd and large-herd milking activities establishes that interventions to alleviate exposure to ergonomic risk factors may potentially be used interchangeably. Future research should continue to analyze differences between small and large-herd dairy operations by examining the specific milking tasks in both settings.

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LIST OF ACRONYMS

- Amplitude probability distribution function (APDF)
- Functional maximum voluntary contraction (fMVC)
- Maximum voluntary contraction (MVC)
- Measurement of percent muscular rest (%MR)
- Musculoskeletal disorders (MSDs)
- Musculoskeletal symptoms (MSS)
- Root Mean Square (RMS)
- Occupational Health and Safety Administration (OSHA)
- Surface electromyography (sEMG)
- Work-related musculoskeletal disorders (WRMSDs)

1. CHAPTER 1- DISSERTATION OVERVIEW

1.1 INTRODUCTION

Work-related musculoskeletal disorders (WRMSDs) are estimated to cost \$20 billion annually in direct costs across all industries and up to \$100 billion for indirect costs (OSHA 2014). In the dairy industry, where milking has evolved from hand milking for local or home use to mechanized milking for commercial use, industrialization has increased the prevalence of WRMSDs (Kolstrup 2012, Douphrate, Gimeno et al. 2013, Douphrate, Stallones et al. 2013) and musculoskeletal symptoms (MSS), which are considered precursors to WRMSDs. Douphrate, Gimeno et al. (2013) ascertained that 75% of U.S. workers in large-herd dairies (>1000 cows) reported onset of MSS. A review article (Douphrate, Kolstrup et al. 2013) reported that in Sweden, within a one-year period, over 80% of dairy farmers and workers report MSS. The high prevalence of both MSS and WRMSDs among dairy workers in combination with the estimated costs of WRMSDs indicates a need for ergonomic intervention.

To date, the dairy industry has been evaluated for ergonomic risk factors with multiple exposure assessment tools including the Nordic questionnaire, Strain Index, electrogoniometry, inclinometry, and surface electromyography (sEMG). These tools have different specific applications but some have been used in conjunction, such as analyzing body posture and muscular load (Pinzke, Stål et al. 2001, Rosecrance and Douphrate 2012). Of the exposure assessment tools that have been used by previous literature, the Strain Index and sEMG were the most appropriate for this dissertation. However, the Strain Index is at a disadvantage when compared to sEMG for two reasons; it does not capture muscular load, but rather an estimate of the force needed to complete a work task, and the Strain Index only addresses the forearm, wrist, and hands (Moore and Garg 1995).

The majority of investigations examining dairy work have been conducted in small-herd dairy operations (<500 cows). These operations are found primarily in European countries. Within the United States, large-herd dairy operations are responsible for the majority of the milk production, but are under researched especially using direct exposure assessment measures. No studies of large-herd dairies have used sEMG to investigate milking work. Use of sEMG will provide a direct measure of muscle activity associated with various milking tasks in a large-herd environment. Quantifying muscle activity will provide a measure of muscular load that can be used to estimate difficulty of milking work. Additionally, muscular load can estimate exposure to risk factors associated with development of WRMSDs such as tendonitis, bursitis, and Carpal Tunnel Syndrome. The research presented in this dissertation will provide novel evidence of the muscle activity associated with milking work in large-herd environments and will compare results directly with small-herd environments. The novel comparison will provide evidence for how intervention strategies can be developed for parlor environments. The investigation will be accomplished through three unique studies. First, upper-limb muscle activity associated with overall milking work will be quantified investigated. Second, upper-limb muscle activity associated with the individual milking tasks will be researched. Finally, upper-limb muscle activity associated with large-herd dairy milking work will be directly compared with that of small-herd dairy milking work. The results from the three studies will provide novel evidence for future researchers on how to target intervention strategies to reduce muscular load in large-herd dairy parlor environments to minimize exposure to occupational risk factors.

The dissertation begins with a brief literature review, followed by a summary of the research and then the details of the three original studies which comprise the research.

1.2 DISSERTATION AIMS & HYPOTHESES

- To complete a novel documentation and characterization of upper-limb muscle activity from the upper trapezius, anterior deltoid, biceps brachii, wrist flexor, wrist extensors associated with milking work and tasks in a large-herd dairy environment through use of surface electromyography
 - I hypothesize that the anterior deltoid and wrist flexors will be the most active muscles, while the biceps brachii muscle will be the least active muscle.
 - I hypothesize that milk cluster attachment, stripping, and wiping will be the more difficult milking tasks, with milk cluster attachment the most difficult.
- To conduct a novel comparison of upper-limb muscle activity associated with small-herd dairy milking to upper-limb muscle activity associated with large-herd dairy milking using identical methodologies
 - I hypothesize that the large-herd environment will demonstrate greater muscle activity and less muscular rest than the small-herd environment.

1.3 WORK-RELATED MUSCULOSKELETAL DISORDERS

1.3.1 *CAUSES OF MUSCULOSKELETAL DISORDERS*

Work-related musculoskeletal disorders (WRMSDs) are often called repetitive stress injuries or overuse injuries. They are a subset of MSDs that arise through exposure to occupational risk factors. It can be difficult to determine the exact cause of WRMSDs because of several different occupational contributors, but epidemiological research has determined that there are occupational risk factors that have strong associations with WRMSDs. Punnett and Wegman (2004) summarized the findings from the

2001 report commissioned by National Research Council and Institute of Medicine. The authors determined that repetitive upper extremity movements, forceful exertions, non-neutral postures, and vibration are physical risk factors associated with MSDs when adjusting for confounding variables such as but not limited to age, gender, BMI, and smoking. Since the publication of Punnett and Wegman (2004) findings, WRMSDs have been analyzed in several fields including but not limited to forestry, the textile industry, the medical field, transportation, manual materials handling, and manufacturing assembly (da Costa and Vieira 2010). Gallagher and Heberger (2012) reviewed epidemiological studies published between January 1st, 1980 and May 3rd, 2011 that evaluated an interaction between force demands and repetitive movements. From 501 citations that met the search criteria, 12 studies were reviewed based on evaluation of force and repetitions. According to the reviewers, ten studies established evidence of an interaction between force and repetition, which was associated with increased risk for WRMSDs. Primarily, the ten research groups used a four-condition combination of repetition and force similar to that described in Barbe, Gallagher et al. (2013): high force, high repetition; high force, low repetition; low force, high repetition; and low force, low repetition. Low force and high repetition resulted in a moderate increase in risk for MSDs. High force and high repetition resulted in a substantial increase in risk for WRMSDs. Finally the reviewers recommended that ergonomic guidelines should incorporate an interactive effect between force and repetition similar to what is demonstrated when using the Strain Index (Moore and Garg 1995).

As determined by Punnett and Wegman (2004) non-neutral or awkward postures are also a risk factor associated with WRMSDs. The relationship between posture and WRMSDs has been established in several industries and is linked primarily to overhead work, epicondylitis, and computer usage. [See da Costa and Vieira (2010) for further review]. Several ergonomic assessment tools use posture as a focal point in determining the risk score for a job (McAtamney and Corlett 1993, Moore and Garg 1995, Occhipinti 1998, Hignett and McAtamney 2000). A 2012 study (Farooq and Khan) examined the effects

of posture on a repetitive gripping task. The authors placed participants in different elbow and shoulder joint postures and had them perform a grip task. The participants then rated the amount of discomfort they felt on a scale from one to five. The authors determined that shoulder and upper arm rotation as well as elbow flexion all had a significant effect on discomfort. These results were similar to other studies that also examined upper-arm posture and pain (Coury, Kumar et al. 1998, Mukhopadhyay, O'Sullivan et al. 2007, Mukhopadhyay, O'Sullivan et al. 2009). These findings are not inconceivable as awkward postures place the joints in unstable and mechanically disadvantaged positions. Soft tissues are placed in positions not designed to properly support the muscle tension needed to complete work, which can lead to overloading the joint and muscle fatigue and then discomfort (Coury, Kumar et al. 1998). Posture, force demand, and task repetition are all strong risk factors for development of WRMSDs. Unfortunately, there are limitations with epidemiologic research regarding WRMSDs. Specifically within the dairy industry, epidemiologic studies have been used to determine prevalence and association rather than examine causation so it is appropriate to visit experimental research.

Animal models have been used to examine risk factors associated with WRMSDs: repetitive movements and forceful exertions. Barr, Barbe et al. (2004) reviewed the results of 11 rat model studies with regards to musculoskeletal disorders. The reviewers determined that high repetition with a controlled load and high load with low repetition created pathological conditions for MSDs in humans. Cutlip, Baker et al. (2009) presented evidence that increasing frequency of stretch-shortening cycles also creates necessary pathology for development of MSDs. A 2013 study (Barbe, Gallagher et al.) examined the interactive effect between force and repetition using a rat model. The authors examined four different tasks over a period of twelve weeks to distinguish physiological changes. The tasks were high force with high repetition, high force with low repetition, low force with high repetition, and low force with low repetition. Rats performed their respective tasks for two hours per day, three days per week over the course of the experiment. The researchers determined that there was a statistically significant

interaction between repetitions and force ($p < 0.05$). The high repetition with low force and high force with low repetition tasks yielded physiological changes associated with WRMSDs. The results from these studies provide empirical evidence that risk factors such as task repetition and force requirements do lead to conditions contributing to WRMSDs. However, understanding simply the physical causes of WRMSDs is not enough. It is necessary to understand the pathological changes that occur for WRMSDs to fully manifest.

1.3.2 PATHOLOGY OF WORK-RELATED MUSCULOSKELETAL DISORDERS

Common WRMSDs such as Carpal Tunnel Syndrome, De Quervain's Syndrome, or Epicondylitis are characterized by localized inflammation of tendons or tendon sheaths. However, the specific pathological mechanisms that lead to the inflammation may be quite different from each other. Barbe and Barr (2006) examined literature studying inflammation and the relationship with WRMSDs. The authors determined that micro traumas occurring from occupational exposures result in mechanical tissue injury which then leads to systemic inflammation. Additionally, continued use of damaged tissue can lead to tissue reorganization from pathological adaptations, i.e. tendonitis. Furthermore, nervous system restructuring has been demonstrated to occur under continued use of damaged tissue through hypersensitivity of nociceptors increasing excitability of secondary neurons (Barr, Barbe et al. 2004). The systemic inflammation combined with tissue reorganization nervous system restructuring (Barr, Barbe et al. 2004) can lead to development of WRMSDs. Other researchers (Baker, Mercer et al. 2007, Cutlip, Baker et al. 2009, Gallagher and Heberger 2012) determined similar results with the inflammatory response occurring after an acute or overuse muscular injury. Continuing to use the damaged tissue rather letting the injury heal can lead to chronic damage which can then develop into a WRMSD (Visser and van Dieën 2006, Baker, Mercer et al. 2007, Cutlip, Baker et al. 2009, Gallagher and Heberger 2012).

The inflammatory response is linked to development of WRMSDs, but it is not the only prominent macro-level pathophysiological mechanism responsible.

Continued use of damaged connective tissue can also lead to development of WRMSDs (Barr, Barbe et al. 2004, Barbe and Barr 2006, Barbe, Gallagher et al. 2013). Connective tissues can also be damaged as a result of overuse or overexertion. Ligaments can become inflamed when their limits are exceeded, for example through a sprain (Solomonow 2009). Continued use can lead to detrimental outcomes as pointed out by Solomonow (2009). Use of damaged ligaments can lead to joint instability, further sprains, and in extreme cases osteoarthritis. In the shoulder complex, ligament damage can lead to bursitis and impingement syndrome. Continued use of damaged ligaments will lead to MSDs (Solomonow 2009). Cytokines associated with inflammation were revealed by examination of tenosynovial biopsies (Biffl 1996, Freeland 2002, Hirata, Tsujii et al. 2005). Tendon damage due to overuse has also been simulated using animal models. Barr, Barbe et al. (2004) summarize several studies that analyze the effects of continued repetitive loading on tendons. In rabbit models it was determined that in a higher demand kicking task (150 kick/min) tendon inflammation and damage was evident. However, in a less demanding kicking task (75 kick/min) tendon inflammation was evident, but there was no presence of tendon damage. From rat models it was determined that repetitive tendon overuse is associated with inflammation, and failure to heal properly caused structural damage to the tendon tissue. Continued use of damaged connective tissue will lead to development of WRMSDs (Barr, Barbe et al. 2004, Barbe and Barr 2006, Barbe, Gallagher et al. 2013).

Forde, Punnett et al. (2002) constructed a review of relevant pathomechanisms related to WRMSDs. The authors determined that posturally induced muscle imbalance, neural modifications, and how motor units are recruited were all macro-level mechanisms that could be partly responsible for the pathology of WRMSDs. Muscle imbalances occur from constant static posture in which one set of

muscles is constantly overused and others become heavily underused. Repetitive work further reinforces the cycle, creating muscular imbalances which lead to abnormal postures outside of the work environment. Neural alterations, these researchers found, were demonstrated to have occurred by completion of repetitive tasks. The somatosensory cortices of owl monkeys were indicated to degrade differently based on the task definition. Repetitive hand squeezing resulted in deterioration and dedifferentiation of the cortex, while a repetitive arm pulling task resulted in mild degradation of the cortex. Additionally, evidence of peripheral nerve injury as it pertains to the study of WRMSDs was obtained through animal models. An extensive review (Barr, Barbe et al. 2004) revealed that nerve injury occurs primarily through compression and over-stretch. Compression of the tissue can lead to disruption of axons and the myelin sheaths, discontinuation of axonal transport, reduction of conduction velocity and nerve perfusion, demyelination of the axons, and (in worse case scenarios) neural fibrosis. Barbe and Barr (2006) observed a decrease in nerve conduction velocity as a result of compression in their rat model. A 2013 study by the same research group (Barbe, Gallagher et al. 2013) noted axonal degeneration and damage to myelin sheaths when rats were subjected to forceful and repetitive tasks.

Although muscular imbalance and neural alterations have been demonstrated to lead to WRMSDs, a specific pattern of motor recruitment described by Hägg (1991) may be a more likely macro-mechanism responsible for the pathology of WRMSDs observed in work with low force exertion. Hägg (1991) created the “Cinderella hypothesis” which describes how sustained, low- force contractions create a recruitment pattern in which same low-threshold motor units are constantly active because of the size principle (Henneman, Somjen et al. 1965). An extensive review of the pathophysiology of the upper extremity WRMSDs (Visser and van Dieën 2006) presented evidence supporting the Cinderella hypothesis. The reviewers determined that continuous muscle activity in the upper trapezius and forearm extensors had been reported across a range of different work tasks. Although the evidence for the Cinderella hypothesis has been presented in literature reviews (Forde, Punnett et al. 2002, Visser

and van Dieën 2006), the Cinderella hypothesis is a macro-level mechanism similar to neural alterations, muscular imbalances, and musculoskeletal tissue damage.

In addition to macro-level changes occurring within the musculoskeletal tissues, there is evidence of micro-level changes. Forde, Punnett et al. (2002) theorized that reperfusion injury and impaired heat shock are possible micro-level mechanisms contributing to WRMSDs. Reperfusion injuries develop when a complex biochemical process takes place once oxygen rich blood is restored to ischemic tissue (Carden and Granger 2000). These injuries may be responsible for WRMSD development through the inflammatory response seen in the tissue. Additionally, reperfusion injuries may cause cellular damage to the sarcoplasmic reticulum (Visser and van Dieën 2006). Impaired heat shock response occurs when a cell is exposed to stress and can no longer regulate the total quantity of heat shock proteins, resulting in cellular harm (Robbins and Cotran 1979). Continual stress brought on by repetitive movements and sustained force exertions could disrupt this cellular mechanism (Forde, Punnett et al. 2002). Sjøgaard, Zebis et al. (2012) examined how work-induced stress affects cellular proteins in people with myalgic muscles. The authors tested this by having 28 subjects with trapezius myalgia and 16 control subjects, all women, complete a seven-hour work day. The day began with two hours of sitting, followed by forty minutes of repetitive low-force work, another two hours recovering, then ten minutes of high stress work, and finally a one-hour recovery period. Biopsies of the trapezius were conducted on each subject before the start and end of the work day. In short, the authors determined that work-induced stress from repetitive work increased the levels of metabolic proteins, including heat shock proteins, in women with trapezius myalgia. These results support the theory presented by Forde, Punnett et al. (2002). In addition to the heat shock response and reperfusion injuries, calcium accumulation can be a mechanism describing the pathology of WRMSDs. Visser and van Dieën (2006) report that in rat skeletal muscles, constant low frequency stimulation, similar to constant low-force high repetition tasks, caused calcium accumulation. This accumulation can lead to mitochondrial calcium

resorption causing structural damage (Gissel 2000). Additionally, calcium accumulation can lead to cellular membrane damage, with subsequent pain in the damaged muscle (Visser and van Dieën 2006). Furthermore, damage to the cellular membrane further increases influx of calcium, creating a constant cycle of cellular membrane damage, further pain, and increased calcium resorption (Visser and van Dieën 2006).

1.4 DAIRY INDUSTRY

1.4.1 *PREVALENCE OF WRMSDS*

Work-related musculoskeletal disorders (WRMSDs) are at present a major problem for the workforce. In 2010, the Bureau of Labor Statistics reported that WRMSDs accounted for 30% of all nonfatal occupational injuries reported across all industries (BLS 2010). The Occupational Health and Safety administration reports that WRMSDs can account for nearly \$20 billion annually in direct medical costs (OSHA 2014). Dunning, Davis et al. (2010) examined workers compensation claims associated with MSDs and determined the average cost for WRMSDs claims for multiple industries. Manufacturing and construction industries were the highest in total costs at \$1.1 billion. Tak and Calvert (2011) estimated the burden of physical ergonomic hazards among workers in the U.S. using the Occupational Information Network (O*NET) and the Occupational Employment Statistics. They examined several different industries and multiple risk factors including repetitive motion and awkward postures. The authors estimated that 27% of the U.S. workforce is exposed to repetitive motion and nearly 45% of the U.S. workforce is exposed to awkward postures. This evidence suggests that WRMSDs should be expected in almost all industries, especially construction and manufacturing. In comparison, WRMSDs costs totaled roughly \$15 million between 1999 and 2004 for agriculture (Dunning, Davis et al. 2010). It should be noted, however, that underreporting (Davis and Kotowski 2007), may be deflating this

number: farms with less than 11 full time employees do not fall under the Occupational Safety and Health Act.

Although the reported and claimed costs of agricultural WRMSDs may be low in relation to costs across all industries, there is a high prevalence for WRMSDs in agriculture. A review (Osborne, Blake et al. 2012) examined all literature related to WRMSDs and farmers to determine the prevalence of WRMSDs in farmers. From initially 304 studies found that related to MSDs or farmers, 24 studies were reviewed. The reviewers determined the lifetime prevalence of experiencing an MSD at 90.6%. One year prevalence ranged from 60% to 92% with a pooled result at 76.5%. This is astoundingly high compared to the monetary impact of WRMSDs. The reviewers further determined that farmers had higher prevalence rates than all non-farmer controls groups regardless of case-control or cohort study, suggesting farmers were at risk of developing WRMSDs compared to other occupations (Osborne, Blake et al. 2012). When examining specifically the dairy industry, the prevalence of MSS and MSDs is staggering both in the U.S. and worldwide. Self-reported MSS are used by researchers as indicators of MSDs (Doupbrate, Kolstrup et al. 2013). Doupbrate, Gimeno et al. (2013) examined the prevalence of MSS in large-herd dairy workers in the Western United States. The authors revealed a prevalence of 76.4% of work related MSS among the 492 workers that participated in the study. The upper extremity had the highest prevalence for MSS at 55.2% compared to the neck and upper back (46.5%), low back (30.1%), and lower extremities (51.8%). These values are very comparable to those presented by Osborne, Blake et al. (2012) in their review of MSDs in farmers. Doupbrate, Kolstrup et al. (2013) reviewed prevalence of MSS in dairy workers internationally comparing rates across several countries. The reviewers determined that in Sweden dairy workers 76% to 86% report any MSS in a 12 month period. Specifically for body regions the low back and shoulder area reported the highest at 43% to 57% and 32% to 54%, respectively. Dairy farmers in Ireland report MSS in the low back and shoulder at 36%

and 22%, respectively. The reviewers reported a prevalence of 57% for low back MSS among Australian dairy farmers. The dairy industry has a relatively high prevalence of MSS.

1.4.2 MODERN DAIRY FARMING

Dairy farming is a fairly old agriculture practice in human history (Kalumuddin 2011) which has changed substantially over the centuries. Now that milk is a globally exported commodity, dairy farm herd sizes are orders of magnitude larger than they were in the 1800s when milk products were primarily for local and home use. Today's large-herd (1000-1500) and mega herd (1500+) farms in the United States (USDA 2007) run 24 hours a day, seven days a week milking the entire herd two to three times per day. Today, although farms of over 1000 cows make up only about 5% of all U.S. dairy operations, (NASS 2013) they produce roughly 63% of the country's milk. In 2001, large-herd operations produced about 35% of U.S. milk, and by 2009 that number had grown to 56%. This large increase in over the span of eight years suggests that large and mega-herd operations will continue.

Not only have herd sizes grown, milk yields have increased substantially as well thanks to technological improvements (Doupbrate, Kolstrup et al. 2013) which enable the dairy industry to meet modern milk demands. Hand milking of old and the stanchion systems of smaller dairies have given way to three types of loose-housing "parlor" configurations (USDA 2007) in large and mega-herd dairies to streamline the milking process.

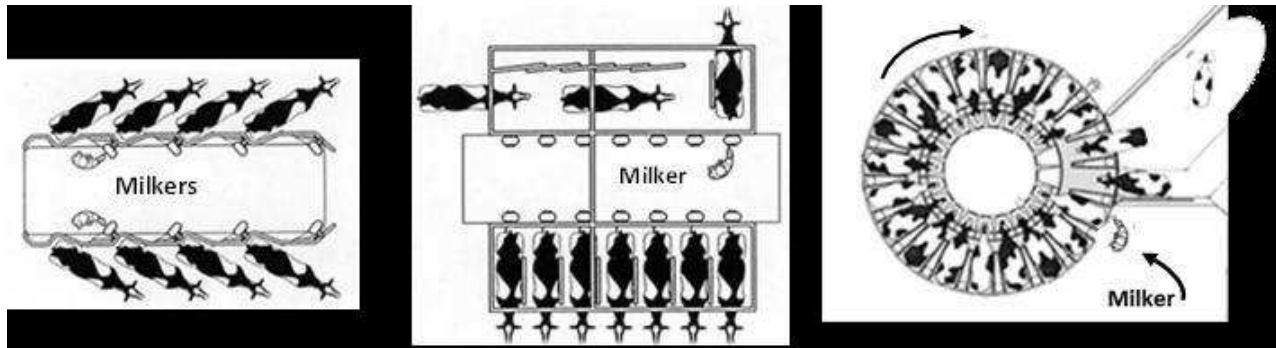


Figure 1.4-1 Dairy parlor configurations (Left) Herringbone configuration, (Center) Parallel configuration, (Right) Rotary configuration (Doupbrate, Kolstrup et al. (2013))

The three common configurations for modern U.S. milking parlors are herringbone, parallel and rotary (Figure 1.4-1). In the herringbone system, cows enter stalls and stand next to each other rotated between 45 to 70 degrees from the pit in which the workers milk them. In the parallel system, cows enter stalls and stand next to each other facing perpendicular to the workers' pit. In rotary systems, cows enter stalls on a rotating platform facing towards the center, perpendicular to the workers. In herringbone parlors, the workers approach the cows from the side. In parallel and rotary parlors, the workers approach the cows from directly behind, where they are closer to the udders, and therefore have less distance to reach than in the herringbone system.

Although the loose-housing parlor configurations are generally different, the milking process is the same in all of them. To successfully milk a cow, there are six tasks that must be completed in order; (1) Pre-dipping of the teats with a sanitization solution, (2) stripping of each teat to stimulate milk letdown and inspect for milk abnormalities, (3) wiping of the teats to clean them, (4) attachment of the milking cluster (composed of 4 teat cups connected to a central claw), (5) detachment of the milk cluster, and (6) post dipping of each teat with a sanitization solution. Detachment of the milk cluster is automated in most dairy operations. Each of the milking operations require the workers to undergo similar gross motor movements, such as shoulder flexion, elbow flexion, and finger flexion. The differences between the tasks arise in the fine hand and finger movements. To complete any of the

milking tasks, the worker has to access the cow's teats individually, which requires shoulder flexion and elbow flexion as the cows' udders often located near shoulder height. Stripping and wiping additionally require finger movements and flexion as they milkers have to interact with the teats directly.

Douphrate, Kolstrup et al. (2013) summarize that to reach optimal milking performance (preventing over-milking and minimizing idle time) the worker must balance various stages of this process for multiple cows simultaneously. However, this balance creates an assembly like environment where workers have little rest. For this reason, milking is considered the most demanding job on a dairy farm (Douphrate, Kolstrup et al. 2013). The strenuous nature of milking has been linked with MSS (Douphrate, Kolstrup et al. 2013), but has also been linked to specific MSDs including carpal tunnel syndrome (Patil, Gilkey et al. 2010, Patil, Rosecrance et al. 2012), pronator syndrome (Stål, Hansson et al. 2000), and low back pain (Park, Lim et al. 2010). Patil, Rosecrance et al. (2012) assessed over 100 dairy milkers and revealed that carpal tunnel syndrome is five times more prevalent amongst dairy milkers than non-milkers. Stål, Hansson et al. (2000) examined muscle activity associated with milking and revealed that the peak loads from the flexors in combination with supination during cluster attachment could lead to mechanical pressure on the nerve along the elbow, pronator syndrome. Park, Lim et al. (2010) examined Korean milkers and uncovered an association between low back pain and milking for greater than 4 hours, and large-herd dairies have shifts running up to 12 hours. Because of the necessity to maintain an efficient milking system while minimize the risk of developing MSS and MSDs, it is necessary to analyze the milking tasks.

1.4.3 EXPOSURE ASSESSMENT TOOLS TO EVALUATE RISK OF WRMSDS IN DAIRIES

Work-related musculoskeletal disorders (WRMSDs) arise as the result of exposure to occupational risk factors and the physiological changes they induce. Because WRMSDs have multiple causes, it is difficult for any single exposure assessment tool to assess WRMSDs. Instead there are a

multitude of exposure assessment tools used to evaluate the prevalence of WRMSDs and associated MSS, as well as the severity of exposure to risk factors, and their physiological effects. David (2005) conducted a thorough review of exposure assessment techniques used in ergonomic evaluations: self-reporting tools, observational methods, and quantitative direct measurements.

Self-report data from workers can be used to assess physical ailment, occupational exposures, and demographic variables. This is accomplished through questionnaires, surveys, or interviews. For example, the Nordic questionnaire (Kuorinka, Jonsson et al. 1987) was developed to standardize reporting of MSS in work environments. Forestry, manufacturing, health care, office environments and agriculture have been studied with self-report data (David 2005). Self-reporting MSS through the Nordic questionnaire has been used extensively in dairy research (Stål, Moritz et al. 1996, Pinzke 2003, Stål, Pinzke et al. 2003, Nonnenmann, Anton et al. 2008, Kolstrup 2012, Douphrate, Gimeno et al. 2013). The principal problem with self-reporting is the subjectivity, as the qualitative nature of the data relies on bias of both the subjects and the researchers. Observational methods like Strain index (Moore and Garg 1995), OCRA method (Occhipinti 1998), or the Rapid Upper Limb Analysis (RULA) method (McAtamney and Corlett 1993) remove the subject bias, but maintain the researcher bias (David 2005).

Semi-quantitative observational methods are used to identify exposure to occupational risk factors. David (2005) presents 16 different simple observational methods including but not limited to the Strain Index, Occupational Repetitive Actions (OCRA) method, National Institute for Occupational Safety and Health (NIOSH) lifting equation, Quick Exposure Check, and Rapid Upper Limb Analysis (RULA). Strain Index and OCRA have been used to assess manufacturing work and exposure risk with high degree of repeatability (Paulsen, Gallu et al. 2015). Both tools classify number of forceful exertions, body postures, repetitive movements, and overall cycle time to quantify risk of development of MSS (Moore and Garg 1995, Occhipinti 1998). The primary drawback of these semi-quantitative measures is

the knowledge and experience of the rater. Advanced observational techniques using video analysis were developed to assess postural variability in dynamic work (David 2005). Analysis techniques such as multimedia video tasks analysis (Burt, Crombie et al. 2011, Burt, Deddens et al. 2013) allow researchers to investigate in real time kinematic variables, like acceleration, based on worker postures. While observational analysis tools do provide quantitative data, simple observational tools are semi-quantitative and still have subjective researcher bias, and dependent on the experience of the researcher conducting the analysis.

The final exposure assessment techniques being used to investigate occupational exposures are quantitative direct measurements (David, 2005). David acknowledges that these data collection techniques, including electric goniometry, inclinometry, inertial measurement units, force measurement, and surface electromyography (sEMG), are complex and with difficult analysis. He goes on to argue that the methods provide highly accurate data on a range of exposure variables. Within the dairy research, inclinometry and sEMG are used to evaluate occupational exposures (Stal 2000, Pinzke, Stål et al. 2001, Stål, Pinzke et al. 2003, Jakob and Liebers 2009, Jakob and Liebers 2011, Douphrate, Fethke et al. 2012, Jakob, Liebers et al. 2012). The former is useful in collecting and quantifying kinematic variables (Douphrate, Fethke et al. 2012), while the latter (sEMG) is used to collect and quantify muscle activity data (Basmajian 1985). Although inclinometry has been successfully used to evaluate dairy work, sEMG is of greater interest for this dissertation because analysis of sEMG data will return the muscle activity directly associated with dairy work. When analyzed with common processing techniques such as root mean square (RMS) or Fourier analysis, sEMG data provide temporal and spectral information about how the muscle is being activated. Having this data is advantageous when seeking to evaluate how work affects muscle groups. However, there are disadvantages with use of sEMG primarily through processing of the data. Because sEMG is a complex signal summarizing the activity of many muscle fibers under a sensor, difficulties can arise in using sEMG as a standalone

exposure assessment tool (Wimalaratna, Tooley et al. 2001). This is especially true if force output is being estimated as sEMG does not directly correlate with force output as both shortening velocity and contractile filament length of the muscle fibers have different relationships with muscle force (Peterson and Bronzino 2007, Winter 2009). However, sEMG has been successfully demonstrated as a diagnostic tool for low back pain (Ambroz, Scott et al. 2000, Sung, Zurcher et al. 2005, Kaufman, Zurcher et al. 2007) and neuromuscular disease (Fuglsang-Frederiksen 1990, Zwarts, Drost et al. 2000, Sakakibara, Uchiyama et al. 2009, Koçer 2010). However, with relation to WRMSD, sEMG has not been used as a diagnostic tool, but rather to measure exposure risk through ergonomic processing techniques.

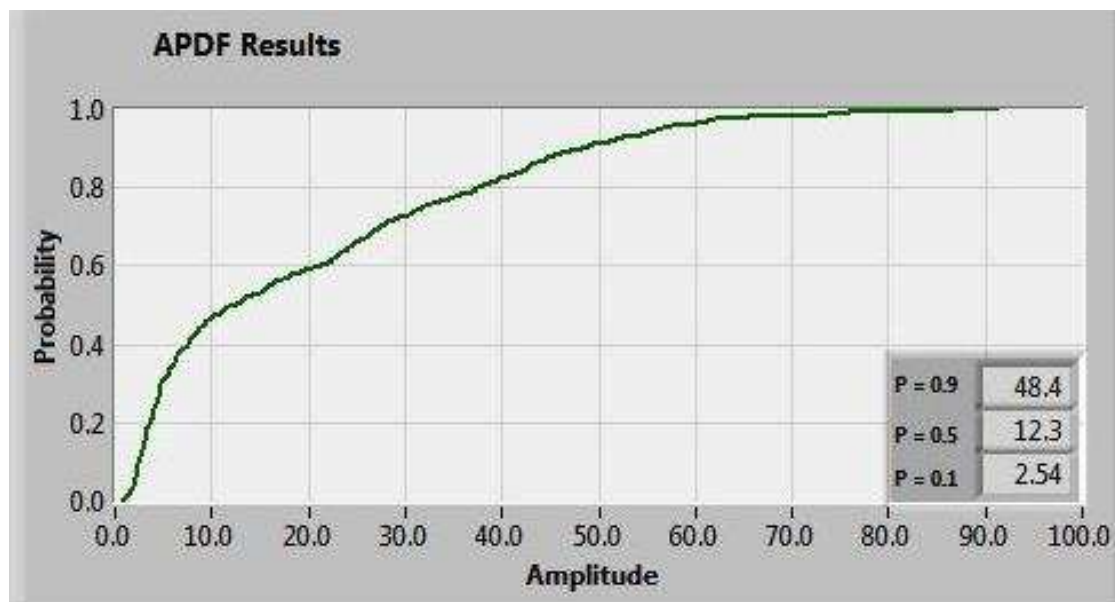


Figure 1.4-2: Example of APDF plot. Amplitude is a percentage of the subject's maximum activity.

Amplitude probability distribution function (APDF) has been used to evaluate sEMG in work environments (Mathiassen and Winkel 1991, Marek, Noworol et al. 1992, Nordander, Hansson et al. 2000, Stal 2000, Pinzke, Stal et al. 2001, Moffet, Hagberg et al. 2002, Fethke, Gerr et al. 2007, Jakob and Liebers 2009, Ostensvik, Veiersted et al. 2009). It was developed to analyze muscular strain or load during work (Jonsson 1982). The APDF is determined by creating a cumulative amplitude distribution histogram from post-processed sEMG, then converting the histogram into an amplitude probability

distribution curve, and, finally, combining this curve with normalization values (Figure 1.4-2). In the resulting ADPF curve, the intersection of the amplitude and probability represents the probability that the sEMG activity will be less than or equal to that activity level for that percentage of the total recording time (Hagberg 1979). For example, in Figure 1.4-2, the probability (P) at the 50th percentile is equal to 12.3% of the subject's maximum voluntary contraction (MVC) level. This can be interpreted to mean that for 50% of the total recording time, the activity level will be less than or equal to 12.3% MVC. Similarly, at the 90th percentile (P=0.9), the 90% of the total recording time the sEMG activity level will be less than or equal to 48.3% MVC. Jonsson (1982) presented recommended activity levels for the static (10th percentile, P=0.1), mean (50th percentile, P=0.5), and maximum (90th percentile, P=0.9) levels based on studies of muscular endurance during work (Jonsson 1976, Jonsson 1977, Hagberg 1979) the static load should be below 2% MVC and never above 5% MVC (Jonsson 1977, Jonsson 1988); the mean load should be below 10% MVC (Hagberg 1981) and must never exceed 14% (Rohmert 1973, Rohmert 1973); and the maximum load should be below 50% MVC and must never exceed 70% MVC. Investigating sEMG data collected from work environments with APDF analysis will not provide a diagnosis of WRMSD, but it will assess risk from occupational factors associated with WRMSD.

Another ergonomic sEMG assessment tool is the measurement of percent muscular rest (%MR) using gap analysis (Veierstedl 1990). This temporal processing technique measures the total number of times when muscle activity dips below a preset value for a minimum of a preset time. These time lapses are then presented in number of sEMG gaps per minute which can subsequently be converted into %MR based on the length of the recording time. Hansson, Nordander et al. (2000) established optimum parameters for gap duration at less than 0.5 seconds with a threshold level at 0.5% MVC. The reliability of gap analysis using office workers was established by Delisle, Larivière et al. (2009) , and it has been used to analyze muscle activity in repetitive work environments (Veiersted, Westgaard et al. 1993, Hansson, Nordander et al. 2000, Nordander, Hansson et al. 2000, Pinzke, Stål et al. 2001, Ostensvik,

Veiersted et al. 2009) and to compare differences in activity between men and women (Nordander, Ohlsson et al. 2009, Harwood, Edwards et al. 2011, Roland, Jones et al. 2013). Although recommended parameters for minimum %MR or gap rates have not been established in the literature, researchers, though, have used gap analysis to investigate and document MSS development in the trapezius, one of the five muscles of interest (Veiersted, Westgaard et al. 1993, Hägg and Åström 1997, Jensen, Finsen et al. 1999, Hansson, Nordander et al. 2000, Nordander, Hansson et al. 2000). For repetitive work tasks with low muscular load, Veiersted, Westgaard et al. (1993) determined that muscular rest less than 4% has been associated with an increased risk for trapezius myalgia. With use of ergonomic processing techniques of APDF and gap analysis, sEMG becomes an appropriate evaluation tool.

As previously discussed, when compared to other direct measure processing techniques sEMG is the most appropriate evaluation method to evaluate milk work through assessment of the muscle activity. The argument then shifts towards semi-quantitative assessment methods such as Strain Index or the OCRA method. Both the Strain Index and OCRA method have used to evaluate risk associated with ergonomic exposures (Paulsen, Gallu et al. 2015). Both methods place emphasis on use of forcefulness and body posture to establish risk, which directly examine two primary risk factors associated with WRMSD. However, both the Strain Index and the OCRA method fall short to sEMG for assessment of muscle activity. At the time the dissertation study designs were constructed and data was collected, the Strain Index was limited to only be applicable for the lower arm (Moore and Garg 1995), which vastly minimizes the analysis. However, even the new algorithm that was developed to assess the shoulder, SI still falls short because the forcefulness category is subjective. The OCRA method was not limited to only the lower arms, but its measurement of forcefulness with the Borg scale are also subjective. The OCRA method is dependent on rater experience to determine reliable risk assessments as well. Additionally, neither of these semi-quantitative provide muscle activity information, which is the primary interest. Because both APDF and gap analysis have been used to analyze sEMG data from

repetitive work, sEMG is the most appropriate evaluation instrument to examine milk worker muscle activity in large-herd dairies.

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2. CHAPTER 2- METHODS OVERVIEW

This dissertation is a collection of three specific studies, each of which use similar methods, which are described below. The first study investigated muscle activity in the upper extremity associated with milking work overall in large-herd dairy operations. The second study investigated the upper extremity muscle activity associated with the individual milking tasks to describe which tasks were the most difficult and exposed workers to ergonomic risk factors. The final study compares muscle activity associated with milking work in large-herd dairy operations to the upper extremity muscle activity associated with milking work in small-herd dairy operations to identify similarities and differences in the two operation types.

2.1 SUBJECTS AND DATA COLLECTION PROCEDURES

2.1.1 SUBJECTS

For the *first and second studies*, dairy workers were recruited from five large-herd dairy farms in the U.S. state of Colorado. For the *first study*, a total of 29 subjects were enrolled: 28 men and 1 woman. Of those subjects recruited, 25 were enrolled into the *second study*; 24 men and 1 woman. All subjects were Latino (a) aged 18 years or older. To be included in the study, subjects had to be free from muscular pain at time of data collection and had to have at least one year of milking experience. All subjects were compensated \$30 for their participation in the study. The studies were approved by the Institutional Review Board of Colorado State University. Dairy management and all subjects provided approval and written informed consent, respectively.

The *third study* compared the subject population from the *first study* with a group of Italian dairy workers. A total of 39 subjects were recruited from 21 small-herd dairy farms in the Lombardy

region of Italy. All subjects were aged 18 years or older and all were male. Subjects were of mixed ethnic backgrounds including Italian, Romanian, Indian, Tunisian, Pakistani, and Egyptian. To be included in the study, subjects had to be free of muscular pain at the time of data collection and had to have at least one year of milking experience. Subjects were also asked to declare if they had any diagnosed musculoskeletal symptoms (MSS). This study was approved by the Institutional Review Boards of Colorado State University and the University of Milan. Dairy management and all subjects provided approval and written informed consent, respectively.

2.1.2 DATA COLLECTION PROCEDURES

For the *first and third studies*, anthropometric measurements (Figure 2.1-1) were gathered from all subjects including functional overhead reach, standing height, standing height wearing boots, eye level height, shoulder acromial height, forward functional reach, waist height, and grip breadth, which was measured as the circumference between the thumb and middle finger (Rodgers, 1986).

For all three studies, surface EMG (sEMG) with a sampling frequency of 1000 Hz using Biometrics DataLOG (Biometrics, England) was collected from the upper trapezius, anterior deltoid, biceps brachii, wrist flexors, and wrist extensors of all subjects. Subjects were fitted with five bipolar electrodes (Biometrics, LTD) that were attached to the skin with double-sided tape directly over the midsection of the belly of the upper trapezius, anterior deltoid, biceps brachii, wrist flexors, and wrist extensors in the writing dominant upper limb. The standardized location of the sEMG electrode on the muscle belly was determined through palpation as functional movements were performed (Basmajian 1985). One disposable ground electrode was placed on the contralateral clavicle.

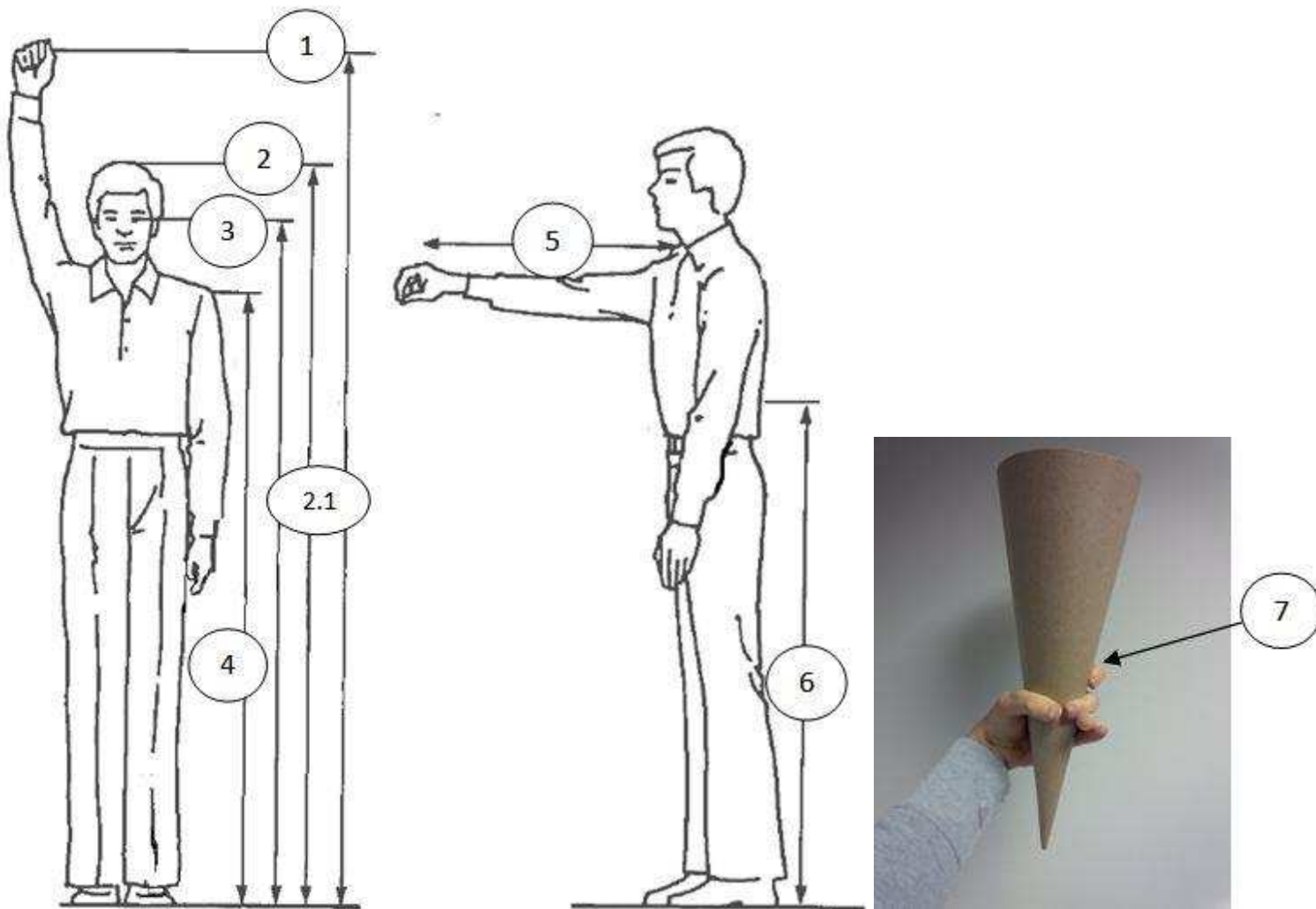


Figure 2.1-1 Anthropometric measurements 1) Functional overhead reach, 2) Standing height, 2.1) Standing height w/boots, 3) Eye level height, 4) Shoulder acromial height, 5) Functional forward reach, 6) Waist height, 7) Grip Breadth (Rodgers, 1986)

The sEMG data were processed using standard techniques (Basmajian 1985). Functional maximum voluntary contractions (fMVC) were collected to normalize the sEMG data to compare the activity of the different muscle groups. Collected sEMG data was DC offset, full wave rectified, and filtered using a bandpass filter set at 10 Hz and 300 Hz. Normalized sEMG data were analyzed using ergonomic assessment variables described further below.

For the *second study*, additional information was gathered to analyze the five manual milking tasks: (1) pre-dipping of the teats with a sanitization solution, (2) stripping of each teat to stimulate milk letdown and inspect for milk quality, (3) wiping of the teats to clean them, (4) attaching the milking cluster to the teats, and (5) post-dipping each teat with a sanitization solution (Doupbrate, Fethke et al. 2012). Three synchronized systems were used to document the beginning and end of each milking task: a digital event marker that created a small voltage change within the sEMG data stream, a written log that contained start/stop times from a stop watch, and a GoPro camera as visual backup system. Data was collected for the length of time it took to milk one pen of cows, 45 to 90 minutes. Pens are the common method to divide a full herd of cattle into manageable groups. A single pen (225 to 275 cows) was used in place of a fixed time frame so that the researchers could easily remove the sEMG equipment from the subjects during the brief break between pens.

For all three studies, subjects were instructed to use the instrumented arm to complete each of the milking tasks that could be completed with either the left arm or the right arm. For example if subjects would normally pre-dip with the left arm (non-instrumented) and then strip with the right arm (instrumented), the subjects would be asked to alternate for the next set of cows so that each task would have sEMG data. Aside from this stipulation workers completed the milking work per their normal routine.

2.2 DATA ANALYSIS & VARIABLES OF INTEREST

For the *first and third studies*, the processed sEMG was used to create muscle activity profiles for the upper trapezius, anterior deltoid, biceps brachii, wrist flexors, and wrist extensors. The muscle activity profiles were constructed for all subjects using the normalized average root mean square (RMS), the amplitude probability distribution function (APDF), and the percent of time for which the muscles rested (%MR). Mean RMS was calculated using a 100 ms moving window with 50% overlap using the RMS processing technique (Basmajian 1985). The static load, mean load, and maximum loads of the APDF were calculated using custom software (Fethke, Anton et al. 2004). The same software was also used to calculate %MR. For the *third study*, sEMG data collected from small-herd dairy workers in Italy was processed identically to sEMG data collected from the large-herd dairies in the U.S.

For the *second study*, similar muscle activity profiles were created for each of the upper extremity muscles. However, the muscle activity profiles were further stratified for each of the five milking tasks. As in the first and third studies, normalized mean RMS, APDF percentiles, and %MR across all subjects were used to construct the muscle activity profiles. However, the variables of interest were calculated using the start/stop times of each task determined from the event marker and the log of stop watch times.

The anthropometric measurements collected for the *first study* were statistically analyzed to determine if there were any correlations with muscle activity variables and if any anthropometric measures could be predictors for the mean RMS, APDF percentiles, or %MR. For the *third study*, the anthropometric measurements were compared between the two study populations to determine if there were any similarities or differences.

2.3 STATISTICAL ANALYSIS

All statistical analyses were conducted using SAS 9.3 (SAS Institute Inc., Cary, NC, USA). Statistical significances were set at $p < 0.05$ *a priori*. Eighty percent power in the statistical models was achieved by determining the appropriate number of subjects through previous published small-herd (Pinzke, Stål et al. 2001, Stål, Pinzke et al. 2003) and laboratory (Jakob, Liebers et al. 2012) sEMG results. The published means for mean RMS and 50th percentile APDF were used in a power calculator to establish the appropriate sample size. In the *first study*, descriptive statistics for the subjects and muscle activity variables were examined. The variables of interest from the muscle activity profiles were analyzed using a random block 26 x 5 (Subject x Muscle) ANOVA with a Tukey's Honest Significant Difference (HSD) post hoc adjustment. Correlations were examined using Pearson's correlation coefficient. Anthropometric variables with statistically significant correlations to mean RMS, APDF percentiles, and %MR were added to ANOVA analysis using the PROC MIXED modeling function in SAS 9.3 (SAS Institute Inc., Cary, NC, USA). Statistically significant interactions were assessed by examining the simple main effects.

For the *second study*, muscle activity profiles for each of the milking tasks were analyzed using a random block 25 x 5 x 5 (Subjects x Muscle x Task) ANOVA with a Tukey's HSD post hoc adjustment. None of the 3 subjects with 1st tier statistical outliers were removed as outliers did not exist across more than one muscle. Statistically significant interactions were assessed by examining the simple main effects. Correlations between mean RMS, 50th percentile APDF, and %MR were examined for each task using Pearson's correlation coefficient. For the *third study*, descriptive statistics for the subjects and muscle activity profiles were examined. Muscle activity profiles were examined using a random block 2 x 86 x 5 (Dairy size x Subject x Muscle) with a Tukey HSD post hoc adjustment. Statistically significant interactions were assessed by examining the simple main effects. Anthropometric measurements were

compared using the Chi squared (χ^2) test and by examining the likelihood ratio test statistic. Correlations between mean RMS, 50th percentile APDF, and %MR were examined for each task using Pearson's correlation coefficient for data collected from both locations.

3. CHAPTER 3- RESULTS OVERVIEW

3.1 STUDY 1

Muscle activity profiles were constructed for the upper trapezius, anterior deltoid, biceps brachii, wrist flexors, and wrist extensors muscles. The analysis of the muscle activity profiles revealed that the biceps brachii had the higher mean RMS and higher 50th percentile of the APDF than all of the other muscles. The upper trapezius had the least %MR and the anterior deltoid had the highest. The correlation analysis indicated that sEMG measures were working as intended as mean RMS and 50th percentile APDF are both average measures of sEMG. Overall, across muscle groups, there was a significant positive correlation between mean RMS and the 50th percentile APDF ($R=0.89$, $p<0.001$). Additionally, %MR had strong negative correlations with the 50th percentile of the APDF ($R=-0.57$, $p<0.001$) and with mean RMS ($R=-0.33$, $p<0.001$).

3.2 STUDY 2

Profiles of muscle activity were created for the upper trapezius, anterior deltoid, biceps brachii, wrist flexors, and wrist extensors muscles for each of five milking tasks. Analysis of the muscle activity profiles revealed that wiping and milk cluster attachment were the most difficult milking tasks. The correlational analysis revealed a statistically significant positive correlation between mean RMS and 50th percentile APDF ($R=0.78$, $p<0.001$). Additionally, %MR had statistically significant negative correlations with mean RMS ($R=-0.18$, $p<0.001$) and 50th percentile APDF ($R=-0.32$, $p<0.001$). Stratification of the data by task revealed a strong, statistically significant positive correlation between mean RMS and 50th percentile APDF for each task ($r>0.69$, $p<0.001$). Percent muscular rest had statistically significant negative correlations with 50th percentile APDF for each task ($r<-0.22$, $p=0.02$), but a statistically significant negative correlation with mean RMS only for milk cluster attachment and stripping ($r<-0.28$,

$p < 0.003$). Stratification of the data by muscle (Table 6.3-10), indicated that mean RMS had a strong positive statistically significant correlation with 50th percentile APDF ($r = 0.62$, $p < 0.001$) for all the muscles. Percent muscular rest had a statistically significant negative correlation with 50th percentile APDF ($r < -0.26$, $p < 0.005$) for all muscles, but a significant negative correlation with mean RMS only for the upper trapezius, wrist flexors, and wrist extensors ($r < -0.21$, $p < 0.03$).

3.3 STUDY 3

Anthropometric measurements were used to compare the dairy worker populations from large-herd dairies in the U.S. state of Colorado with small-herd dairies in the Lombardy region of Italy. The χ^2 test revealed no differences for BMI or functional stature for the two populations. However, eye level height ($p = 0.005$) and forward functional reach ($p < 0.001$) did differ, with the Italian worker population having a longer reach and higher eye level height.

Profiles of muscle activity were created for the muscles of interest for both the small and large-herd operation: upper trapezius, anterior deltoid, biceps brachii, wrist flexors, and wrist extensors. The ANOVA analyses for both mean RMS and 50th percentile of the APDF revealed significant interactions between the size of the dairy operation and the muscle group. The simple main indicated that workers in the large-herd dairies in Colorado had greater activity for the upper trapezius, biceps brachii, and wrist flexors. The ANOVA analysis for %MR revealed that Italian workers in the small-herd dairy had significantly less muscular rest for all muscles excluding the biceps brachii. The correlation analysis determined that overall, across all the muscles, the same statistically significant correlations were present in the workers in the Colorado large-herd dairies and Italian small-herd dairies.

4. CHAPTER 4- DISCUSSION OVERVIEW

4.1 LIMITATIONS

For the *first and second studies*, sEMG data were collected from five different dairies in Colorado. The dairies all had herd sizes (2000+), but were not identical. Differences in herd size led to deviations within the data collection period as the pen size ranged from 225 to 275 cows. The data collection period averaged 52.7 (± 10.8) minutes. Additionally, data collection always commenced at the beginning of each shift with the assumption that data collected at the start of the milking shift were representative of the entire shift. Additionally, it was assumed that there were no differences between how milking work was completed in each of the dairy parlor configurations, which varied across the dairies sampled.

For the *second study*, the parlor configuration limitation, especially for Rotary Parlors, was made more apparent in the task analysis. Rotary parlors have workers constantly performing the same task or set of tasks without breaking the cycle, unlike at other parlor configurations. The task analysis in the *second study* made the parlor configuration limitation more apparent, especially for the rotary parlors. Because workers in Rotary parlors constantly perform the same set of tasks without a break in the cycle, unlike in other parlor configurations, it is possible that data may overestimate required muscle activity and minimize %MR. The *second study* has an additional limitation in that all of the workers were asked to alternate completing the milking tasks using the instrumented arm and the non-instrumented arm. This instruction may have lowered the mean RMS and APDF activity, while possibly increasing the %MR as workers do not normally complete all of the milking work with the same arm, but rather alternate on a normal pattern. Although the muscle rest and activity may have been influenced, the muscle activity

variables are still appropriate to use as subjects would still alternate tasks between arms maintaining typical work-rest cycles.

The *third study* was also affected by the aforementioned limitations and two others: the small-herd dairy workers were instructed to complete all tasks as per their normal routine, and they completed only three of the five milking tasks completed by the workers in the large-herd dairies, teat stripping, teat wiping, and milk cluster attachment. The first limitation may cause an overestimation of muscular rest and underestimation of total muscle activity. The second limitation has a greater impact because the three tasks which the small-herd worker population predominantly participated in have been indicated chiefly in literature as the most strenuous of the milking tasks. Therefore overestimation was possible for muscle activity measures and muscular rest. Finally, the conclusions drawn in these three studies disregard any possible effects that muscle fatigue may have on recorded muscle activity (Dougherty and Rosecrance 2010), even though this could have a direct impact on %MR and APDF values.

In addition to each of the aforementioned limitations, all of the studies suffer from limitations associated with use of sEMG. Albeit being a common analysis technique employed throughout the literature for analyzing muscle activity, sEMG is not without its very specific limitations; these limitations can be divided into data collection and data analysis. From a data collection standpoint there are two primary limitations. First, the integrity of the signal collected is affected by the location of the bipolar electrodes and how the electrodes are held in place. If the electrodes are not placed directly over the belly of the muscle in parallel to the muscle fibers, the signal will most likely be heavily influenced by musculature surrounding the muscle of interest (Basmajian and De Luca 1985). Additionally, if the electrodes are not secured properly, movement artifacts can degrade the signal quality. Secondly, the sEMG signal is affected by the amount of adipose tissue between the electrode and the muscle of

interest. Excess adipose tissue acts as a natural filter, which can remove spectral content from the sEMG signal. Therefore individuals with a higher percentage of body fat can have distorted signals.

From a data analysis perspective, sEMG suffers from two primary limitations; influence of noise and reliability (Basmajian and De Luca 1985). All three papers focus on the temporal component of the sEMG data, which can be affected by noise. Noise can degrade the signal quality due to influences from different sources including high frequency content and movement artifacts. The effects of noise can be limited with digital signal processing techniques, however excessive use of signal processing can limit the amount of viable physiological information left within the sEMG signals. Root mean square (RMS) processing was used to “smooth” the sEMG data as a temporal filter for all of the papers. The window length of the RMS algorithm determines how “smooth” the signal becomes and how much content is removed along with noise. This results are then highly dependent on the quality of the RMS technique. Secondly, sEMG suffers from the limitations of being a linear enveloped Gaussian distribution of noise (Basmajian and De Luca 1985). Unlike other electrical signals, sEMG is non-stationary, which makes it highly variable. It is difficult to reproduce identical sEMG patterns through identical contraction protocols limiting the reliability of sEMG between subjects. This limitation can be overcome through sample size along with high reliability of the normalization techniques. The limitations associated specifically with sEMG are important to note as sEMG is a useful technique, but like all analyses it is not perfect and does have drawbacks.

4.2 FUTURE RECOMMENDATIONS

Future researchers seeking to investigate interventions to alleviate the effects of the known ergonomic risk factors should use bilateral sEMG for a more accurate representation of routine milking activities. This would allow workers to complete their respective milking routines in a more natural manner, without additional instruction or as much exterior distraction. A second consideration for

future researchers is investigating muscle fatigue. The studies reported in this dissertation did not estimate the effects of muscle fatigue nor the impact that muscle fatigue has on the values of the ergonomic sEMG measures. Use of these measures would strengthen the sEMG results and account for nearly all possible physiological impact.

In addition to these recommendations, future researchers should further scrutinize the results from the comparison of muscle activity associated with small-herd dairy operations to muscle activity associated with large-herd operations. The lack of muscular rest demonstrated in the small-herd dairy workers was alarming because of the association that has been investigated between low muscular rest and WRMSD (Veiersted, Westgaard et al. 1993). Simultaneously, the increased muscle activity demonstrated in the large-herd dairy workers was distressing because it supersedes the recommendations for low impact, repetitive work (Jonsson 1982). Future researchers should investigate the causal explanation for why small-herd workers displayed less muscular rest while additionally demonstrating less muscle activity, while large-herd workers displayed an increase in muscular rest with an increase in muscle activity. Further evaluation of this relationship could provide improvement in ergonomic interventions for the dairy workers.

Extending beyond the research community, there are practical recommendations from the results that dairy owners could use to minimize risk of injury. Owners could examine use of physical interventions such as teat scrubbers, lighter milk clusters (Jakob, Liebers et al. 2012), or single suction cups (Jakob and Liebers 2011) to reduce muscular load. Furthermore, dairy owners could examine using administrative interventions such as use of a set job rotation to reduce physical exposure or instituting use of microbreaks to allow for muscular rest. Interventions are necessary to minimize risk of injury.

4.3 CONCLUSIONS

The goals of the studies in this dissertation were to present novel findings about muscle activity across all milking tasks in large-herd dairies, and the similarities and differences between muscle activity associated with small-herd and large-herd dairy operations. These purposes were accomplished by addressing two specific aims with the dissertation research. The *first and second studies* directly examined the first aim by establishing the muscle activity associated with overall milking activities, and the muscle activity associated with the five specific milking tasks completed in a large-herd dairy operation. In the *first study*, the 50th percentile APDF activity values indicate that biceps brachii are at risk for developing WRMSD because the average activity was above the recommended ideal activity level of 10% MVC and the beyond the maximum recommended activity level at 14% MVC. The upper trapezius and wrist extensors were approaching the recommended ideal activity level of 10% MVC. Additionally, the upper trapezius had 6.6% muscular rest, above the 4% associated with trapezius myalgia. In the *second study*, the analysis of the muscle activity profiles revealed that wiping and cluster attachment were the most difficult of the milking tasks as they required the most activity. The 50th percentile APDF values suggest that the milking tasks could place workers at an increased risk for developing MSS and WRMSD. Additionally, the upper trapezius had muscular rest below 4% for all of the milking tasks. This suggests that the upper trapezius was at risk for development of trapezius myalgia. The second aim was addressed initially through the results of the *first study* and through the comparison presented in the *third study*. The results of the studies confirm that milking is strenuous work, whether in a large or small-herd operation. More importantly, the combined results of the *first and second studies* demonstrate that natural downtime between completing milk tasks was essential to minimize impact of the occupational risk factors. When breaks in actively completing milking tasks were removed in *study 2*, the muscle activity increased for all of the muscles groups. The small rests periods between task completions can lower the average muscle activity to recommended levels. In addition to

creating ergonomic interventions that improve milking work, such as decreasing the milk cluster total weight, process interventions which provide additional micro breaks while maintaining productivity could minimize risk of developing WRMSD. In the *third study*, the comparison between the large-herd and small-herd dairy operations revealed that large-herd workers were at greater risk for development of WRMSD as indicated by higher activity levels for the 50th percentile of the APDF. However, small-herd workers had significantly less muscular rest, with an average of 0.6% and may, therefore, be at an increased risk for development of trapezius myalgia. These suggest that interventions that lead to an overall increase in muscular rest are also needed in small-herd environments.

5. CHAPTER 5- UPPER LIMB MUSCLE ACTIVITY AMONG WORKERS IN U.S. INDUSTRIALIZED DAIRY OPERATIONS

5.1 INTRODUCTION

Dairy farming is one of the oldest agriculture practices in human history (Kalumuddin 2011). Throughout the last 200 years, modern milking operations have changed a great deal from their ancestral counterparts in both size and technology used. Small farms of the 1800s with fewer than 10 cows have now evolved into operations with 50-200 cows. What was once considered a large farm of 20-25 cows using efficient, foot powered Mehring milking machines in the 1890s, have now become operations of 1500+ cows with parlor milking systems (USDA 2014). Advances in milking technology combined with economics of scale have led to the industrialization of the modern dairy farm. In the past 50 years, the demand for milk products and the cost of milk production have shifted from small-herd operations (<500 cows) to large-herd (1000-1500) and mega herd (1500+) operations. Dairy farms in the U.S. with large or mega-herds rely on the efficiency of parlor systems to meet the milk demands. In a parlor system, cows move freely to enter stalls, where they are milked simultaneously. Once milking is concluded, the cows are released and the cycle continues with a new set of cows. Currently, large and mega-herd dairy farms in the U.S. consist of 5% of American dairy operations, but produce approximately 65% of the domestic milk (NASS 2013). In 2001, large-herd operations produced 35% of U.S. milk, and in 2009, similar operations had increased production to 56% of U.S. milk. This steady increase in farm herd size over the span of only eight years suggests that large-herd operations are the future for the American milking industry. However, these large milking operations present potential new occupational hazards for the dairy workforce, including musculoskeletal problems.

Work-related musculoskeletal disorders (WRMSDs) are the result of cumulative damage to muscles, tendons, ligaments, and nervous tissue from repeated exposure to occupational risk factors

(Barbe and Barr 2006). WRMSDs have been associated with work tasks that are characterized by high repetition, awkward postures, and forceful exertions (Punnett and Wegman 2004), all of which may be experience in modern milking operations. It isn't surprising, then that dairy work has been associated with WRMSDs (Davis and Kotowski 2007, Patil, Rosecrance et al. 2012) and musculoskeletal symptoms (MSS) in the United States (Doupbrate, Gimeno et al. 2013, Doupbrate, Kolstrup et al. 2013) and in Europe (Stål, Hansson et al. 2000, Pinzke, Stål et al. 2001).

To date, the primary focus of occupational health research within the dairy industry has been on small-herd farms (Nevala-Puranen, Kallionpää et al. 1996, Stål 1999, Stål, Hansson et al. 2000, Pinzke, Stål et al. 2001, Stål, Pinzke et al. 2003, Stål, Pinzke et al. 2003, Perkiö-Mäkelä and Hentilä 2005, Nonnenmann, Anton et al. 2008). Occupational health researchers have concluded that milking tasks on small-herd farms require high muscular load (Stål, Hansson et al. 2000, Stål, Pinzke et al. 2003), are physically demanding (Nevala-Puranen, Kallionpää et al. 1996), consist of highly repetitive motions (Pinzke, Stål et al. 2001, Stål, Pinzke et al. 2003), and are associated with MSS (Nonnenmann, Anton et al. 2008, Kolstrup 2012) and MSDs (Stål, Hansson et al. 2000, Pinzke, Stål et al. 2001, Kolstrup 2012). These risk factors in small-herd dairies can be expected in large-herd dairy farms, maybe even to a greater extent since these operations, unlike small-herd farms, operate 24 hours a day, seven days a week. Researchers have suggested that methods performed on large-herd parlor systems increase the risk of injury (Pratt 1992, MacCrawford, Wilkins et al. 1998), but these enormous dairies have not been as extensively studied as small-herd farms.

Doupbrate, Gimeno et al. (2013) were the first to examine the prevalence of MSS among large-herd dairy farms in the U.S. The authors determined that there was high prevalence of MSS in the upper extremities of large-herd dairy workers. These findings were consistent with findings of research into small-herd operation (Osborne, Blake et al. (2012). However, the findings of Doupbrate, Gimeno et al. (2013) should not be directly compared to small-herd research because of differences in task

specialization and volume of work performed. Small-herd dairy workers perform milking work and often participate in additional dairy work, such as feeding cows, maternity care/birthing calves, and maintaining farm equipment. Large-herd dairy operations, however, tend to hire other workers for the other above-mentioned areas of the dairy (Doupbrate, Gimeno et al. 2013) so the milking workers have less task variety.

All workers in the large-herd dairy parlor perform some combination of the following five milking tasks during an eight to twelve hour shift. The five fundamental work tasks performed by workers in large-herd dairy parlors are (1) pre-dipping of the teats with a sanitization solution, (2) stripping of each teat to stimulate milk letdown and inspect for milk abnormalities, (3) wiping of the teats to clean them, (4) attaching the milking cluster, (5) and post-dipping of each teat with a sanitization solution (Doupbrate, Fethke et al. 2012). A few of these milking tasks assessed in small-herd dairies, such as stripping and attachment (Stål, Moritz et al. 1996), have been described by the workers as strenuous. Nevala-Puranen, Kallionpää et al. (1996) had previously researched dairy work using sEMG and had found that the work was not difficult from their respective sEMG results. However, they had only examined the trapezius and no other muscles. Pinzke, Stål et al. (2001) substantiated through the use of surface electromyography (sEMG) that stripping, wiping, and attachment require high muscular load in the forearm flexors and biceps. Also using sEMG of the upper extremity Stål, Pinzke et al. (2003), determined that some reduction in muscular load of the biceps and forearm flexors could be achieved by using a support arm device to assist with bearing the milk cluster weight. The risk factors from these tasks is even greater in modern, large-herd dairies where these work tasks have been demonstrated to be highly repetitive and offer limited opportunities for rest (Doupbrate, Fethke et al. 2012). However, much less research has been conducted in large-herd operations than in small dairies. Milking tasks in large-herd parlors have not been assessed using sEMG of the upper extremity of dairy workers either individually by comparing one task to another, or by examining the overall effect of the work tasks

together. Furthermore, with dairy production trending away from small-herd operations and towards large-herd operations, it is necessary to investigate the milking work in large-herd parlor operations with direct measures such as sEMG to quantify physical exposure to ergonomic risk factors. (Doupbrate, Kolstrup et al. 2013).

The aim of this research was to quantify the upper extremity muscle activity of workers performing milking work in large-herd dairies, which has only been completed within small-herd dairies. Surface EMG from the trapezius, anterior deltoid, the biceps brachii, wrist flexors and wrist extensors muscles were used to create muscle activity profiles for the combined milking tasks. The biceps brachii and wrist flexors were chosen as they had been previously examined in small-herd research (Stål, Hansson et al. 2000, Pinzke, Stål et al. 2001, Stål, Pinzke et al. 2003). The muscle activity collected in these papers displayed the forearm flexors to have more activity. Full shift dairy studies (Doupbrate and Rosecrance 2010, Rosecrance and Doupbrate 2012) examining ergonomic exposures in dairies examined muscle activity from the anterior deltoid, trapezius, wrist flexors, and wrist extensors. Peak loads were revealed in the anterior deltoid and forearm flexors. From personal visual observations of milking work at five to ten different large-herd dairies in five different states, repetitive patterns were noticed within the different milking tasks. The arms repeated the same similar patterns of shoulder flexion to enter under the teats and then extension out when the task was finished. Additionally, there were similarities observed in how the fingers were constantly flexed to complete all of the tasks. From the findings of previous literature and personal observations, I hypothesize that the anterior deltoid and wrist flexors would be the most active muscles, while the biceps brachii muscle will be the least active muscle. To the best of my knowledge, this is the first study that has quantified muscle activity with sEMG of the upper extremity among large-herd U.S. dairy operations.

5.2 METHODS

5.2.1 PARTICIPANTS

Twenty nine dairy parlor workers were recruited from six large-herd dairy farms in the U.S. state of Colorado. All of the subjects were Latino(a) aged 18 years or older. Twenty eight participants were male; one was female. All subjects described themselves as free from muscular pain at the time of data collection. To maintain homogeneity of the study population, all subjects had a minimum of 1 year experience, participating in the milking tasks of pre-dipping, stripping, wiping, attaching milking clusters, and post dipping. Subjects were compensated \$30 for their participation. This study was approved by the Institutional Review Board of Colorado State University. Dairy management and all subjects provided approval and written informed consent, respectively.

5.2.2 DATA COLLECTION PROTOCOLS

5.2.2.1 Anthropometric Protocol

Several anthropometric measurements were taken from each worker as illustrated in Figure 2.1-1. These measurements included functional overhead reach (1), standing height (2), standing height wearing boots (2.1), eye level height (3), shoulder acromial height (4), forward functional reach (5), waist height (6), and grip breadth, which was measured as the circumference between the thumb and middle finger (7).

5.2.2.2 Surface Electromyography

Surface electromyography (sEMG) with a sampling frequency of 1000 Hz using Biometrics DataLOG (Biometrics, England) was collected from the upper trapezius, anterior deltoid, biceps brachii, wrist flexors, and wrist extensors. Bipolar electrodes (Biometrics, LTD) were attached to the skin with

double-sided tape directly over the midsection of the belly of each muscle of the dominant arm. Skin was prepped using standard protocols (Basmajian and De Luca 1985). The appropriate location of the electrode on the muscle belly was determined by palpitation as functional movements were performed (Basmajian and De Luca 1985). Functional movements had the secondary purpose of allowing the subjects to warm up muscle groups. One disposable reference electrode was placed on the contralateral clavicle. After electrode placement was completed, Hypafix medical tape (Hamburg, Germany) was placed over the electrode securing it in place and minimizing movement artifact. Real-time streaming of sEMG was visually examined to assure that muscle activity coincided with the appropriate functional movements, (e.g. raising and lowering of arm activated the anterior deltoid muscle).

5.2.2.3 Functional Maximum Voluntary Contraction (fMVC) Protocol

Functional maximum voluntary contractions (fMVC) were collected to normalize the sEMG data for appropriate comparison. Prior to commencing fMVC, a 30-second baseline resting sEMG signal was collected to establish a minimum resting muscle activity. Subjects then performed three unique fMVC procedures to obtain functional maximum contractions for the muscles of interest. A minimum of three fMVC trials were administered for each subject for each muscle group. Over a three-second countdown, subjects were told to ramp up to a maximum muscular effort and hold for four seconds (during which they were verbally encouraged to maintain a maximum contraction) and then relax. . Rest periods of one minute were provided between trials in order to minimize fatigue. Upon completion of each trial, a maximum was calculated using the middle three seconds of the root mean square (RMS) processed sEMG trial data. The mean and standard deviation were determined to calculate covariance. If the covariance was above 15% for the three fMVC trials, then additional trials were conducted with a maximum of five total trials.

Functional MVCs for the anterior deltoid and upper trapezius were calculated using the procedures established by Boettcher, Ginn et al. (2008). For the anterior deltoid this was accomplished by raising the arm 120 degrees in the sagittal plane from a relaxed state. Pressure was applied proximally below the elbow to attempt to engage the anterior deltoid muscle. Subjects were instructed to maintain their arm in the elevated position. The upper trapezius fMVC was gathered using the "empty can" method (Boettcher, Ginn et al. 2008). Briefly, the subjects were instructed to place their arm at 90 degree flexion in the scapular plane and internally rotate the arm forcing the palm to face outward away from body centerline. Finally, subjects were instructed to simulate holding an empty soda can. Downward pressure was applied proximally below the elbow, as the subject maintained the arm in in the "empty can" position. Finally, wrist flexors and the wrist extensors fMVCs were obtained simultaneously through a co-contraction with the use of a hand dynamometer (Biometrics G100, England). Subjects were instructed to hold the hand dynamometer in a power grip and keep the elbow in 90 degrees of flexion. The dynamometer handle was adjusted to comply with the variability in hand size among the subjects. Visually examining how the subject held the hand dynamometer as well as subject feedback determined if the hand dynamometer grip needed to be adjusted. Subjects were instructed to close their grip with maximum effort while maintaining elbow flexion. Functional MVCs for the biceps brachii muscle were determined using the values generated from the wrist flexor and extensors procedure.

5.2.2.4 Milking Tasks

All subjects completed the five individual milking tasks: pre-dipping, stripping, wiping, attaching milking clusters, and post dipping. Typically, pre-dipping, wiping, and post-dipping were completed with one hand while stripping and attaching required both hands. With tasks that could be completed using either the right or left arms, subjects were instructed to use the instrumented arm. Aside from this

stipulation, subjects performed the tasks per their normal routine in parallel and herringbone configured milking parlors. However, in rotary type parlors, subjects were instructed to change their normal routines. Typically, during a shift, subjects rotated between three workstations at the end of a pen of cows (pens are used to divide the herd in to smaller, more manageable and organized groups). Pre-dipping and stripping were completed at the first station, wiping and milk cluster attachment were finished at the second station, and post-dipping was completed at the third station. Instead of completing the normal routine and rotating at the completion of a pen of cows, subjects were asked to rotate between the three different workstations every 20 minutes to guarantee each subject completed all the tasks. To develop muscle activity profiles, it was necessary to determine precisely when the milking work was commenced. This was accomplished using a digital event marker. When the subjects began the milking shift, the event marker was triggered to mark within the sEMG stream the start of the milking shift. To have a backup if the event marker failed, a second researcher recorded the start and end times of the milking shift as noted on a timer synchronized with the data loggers. Data was collected for the length of time it took to milk a complete pen of cows, which ranged from 45 and 90 minutes. A single pen of cows, about 225-275 was chosen for the sampling period to allow for the removal of the sEMG equipment from the subjects during their brief break between pens.

5.2.3 *MUSCLE ACTIVITY PROFILES*

Muscle activity profiles were constructed through analysis of the normalized processed sEMG data. The raw sEMG data was demeaned removing any DC offset and then full wave rectified (Basmajian and De Luca 1985). Afterward the rectified sEMG data were digitally filtered with a bandpass filter allowing frequencies between 10 Hz to 300 Hz applied forwards and in reverse to not distort the signal. Muscle activity was normalized using the fMVC data. Functional MVC data were processed with 100ms moving average (Bao, Mathiassen et al. 1995). The maximum value determined from this process was

used to normalize the processed sEMG data. The sEMG data were normalized using the instantaneous maximum value determined from the highest 100ms average. Normalization was completed using an arithmetic process,

$$\%MVC = \frac{(sEMG - Rest)}{(fMax - Rest)} \quad \text{Eq. 1}$$

where $\%MVC$ is the normalized muscle activity, $sEMG$ represents the processed sEMG data, $fMax$ represents the instantaneous maximum value from fMVC trials, and $Rest$ represents the minimum value from the 30 second baseline. Temporal analysis of the sEMG data was accomplished through the RMS processing technique (Basmajian and De Luca 1985). A graphic user interface (GUI) was created using MATLAB 7.10.0 (Mathworks, Natick, MA) to process the sEMG data and obtain mean RMS values. Amplitude probability distribution function (APDF) was then determined for the 10th percentile, 50th percentile, and 90th percentile (Jonsson 1982) using custom software (Fethke, Anton et al. 2004) developed in LabVIEW (National Instruments, Austin, Texas). Percent muscular rest ($\%MR$) of the sEMG was determined with a threshold of 0.5% MVC or less and a minimum gap duration of 0.25 seconds (Hansson, Nordander et al. 2000). The same LabVIEW custom software (Fethke, Anton et al. 2004) was used to determine $\%MR$ values. Muscle activity profiles were constructed for each muscle. The profiles contain the normalized RMS, ADPF, and $\%MR$, which was averaged across all the subjects and provide an estimate of the overall muscle activity and recovery experienced by milking parlor workers during the data collection.

5.2.4 STATISTICAL ANALYSIS

All statistical analyses were administered using SAS 9.3 (SAS Institute Inc., Cary, NC, USA). Eighty percent power in the statistical models was achieved by determining the appropriate number of subjects through previous published small-herd (Pinzke, Stål et al. 2001, Stål, Pinzke et al. 2003) and laboratory (Jakob, Liebers et al. 2012) sEMG results. The published means for mean RMS and 50th

percentile APDF were used in a power calculator to establish the appropriate sample size. Descriptive statistics for the subjects and muscle activity profiles were constructed. Muscle profiles were examined using a random block 26 x 5 ANOVA (Subject x Muscle) with a Tukey Honest Significant Difference post hoc adjustment to determine significant differences in the RMS, APDF, and %MR. Correlations among these three measures were also examined. Statistical significance were set at $p < 0.05$ *a priori*.

5.3 RESULTS

5.3.1 MUSCLE ACTIVITY PROFILES

Muscle activity profiles were constructed for the upper trapezius, anterior deltoid, biceps brachii, wrist flexors, and wrist extensors muscles (Table 5.3-1). The ANOVA analysis of the mean RMS indicated a significant difference (Table 5.3-2) between anterior deltoid and biceps brachii ($p = 0.001$): the biceps brachii muscle had double the activity of the anterior deltoid muscle. Additionally, the activity profiles for the wrist flexors were statistically significantly less active than the biceps brachii ($p = 0.05$). There were no other significant differences in the RMS ($p > 0.125$).

Table 5.3-1: Muscle activity profiles

	Upper Trapezius	Anterior Deltoid	Biceps Brachii	Wrist Flexors	Wrist Extensors
10th Percentile	1.13 (2.07)	0.15 (0.39)	1.21 (2.23)	0.40 (0.60)	0.55 (0.92)
50th percentile	9.28 (6.61)	3.49 (3.71)	14.58 (11.5)	7.41 (5.10)	9.75 (5.70)
90th percentile	31.43 (21.05)	43.37 (36.26)	51.23 (38.86)	36.75 (21.41)	44.11 (31.13)
Mean RMS	13.58 (9.19)	9.79 (3.71)	19.44 (13.87)	12.73 (6.24)	14.02 (7.73)
%MR	6.64 (7.24)	22.77 (12.75)	9.45 (7.73)	13.58 (8.25)	13.16 (6.69)

Note: Mean RMS and APDF percentiles units are %fMVC and %MR units are in a percentage of time

Table 5.3-2: ANOVA analysis of mean RMS

Muscle 1 vs. Muscle 2	Muscle 1	Muscle 2	Difference	Adjusted P-value
Anterior Deltoid vs Biceps Brachii	9.74	19.44	9.70	0.001
Wrist Flexors vs Biceps Brachii	12.73	19.44	6.71	0.05

Note: Units are %fMVC

Table 5.3-3: ANOVA analysis of 50th percentile APDF

Muscle 1 vs. Muscle 2	Muscle 1	Muscle 2	Difference	Adjusted P-value
Anterior Deltoid vs Biceps Brachii	3.50	14.58	11.08	<0.0001
Anterior Deltoid vs Upper Trapezius	3.50	9.28	5.78	0.03
Anterior Deltoid vs Wrist Extensors	3.50	9.75	6.25	0.01
Biceps Brachii vs. Wrist Flexors	14.58	7.40	7.18	0.003
Biceps Brachii vs. Upper Trapezius	14.58	9.28	5.30	0.05

Note: Units are %fMVC

Table 5.3-4: ANOVA analysis of %MR

	Muscle 1	Muscle 2	Difference	Adjusted P-value
Anterior Deltoid vs Biceps Brachii	22.77	9.45	13.32	<0.0001
Anterior Deltoid vs Upper Trapezius	22.77	6.64	16.13	<0.0001
Anterior Deltoid vs Wrist Extensors	22.77	13.16	9.61	0.003
Upper Trapezius vs. Wrist Flexors	6.64	13.58	6.94	0.02

Note: Units are percentage of time

The normalized 50th percentile APDF ANOVA analysis (

Table 5.3-3) indicated that the anterior deltoid had significantly less muscle activity than the biceps brachii ($p<0.001$), upper trapezius ($p=0.03$), and wrist extensors ($p=0.01$), but not less than wrist flexors ($p>0.05$) muscles. Additionally, the biceps brachii had significantly more muscle activity than the wrist flexors ($p=0.003$) and the upper trapezius ($p=0.05$). There were no other statistically significant differences between the muscles when examining APDF ($p>0.09$).

The normalized %MR ANOVA analysis (Table 5.3-4) indicated that the anterior deltoid had statistically more rest than the biceps brachii ($p<0.001$), upper trapezius ($p<0.001$), wrist extensors ($p=0.003$), but not less than wrist flexors ($p=0.11$) muscles. Additionally, the upper trapezius muscle had statistically less rest than the wrist flexors ($p=0.02$). There were no other significant differences among the muscles when comparing %MR ($p>0.11$).

Correlative analysis determined strong, statistically significant positive correlations between RMS and APDF for each individual muscle group ($R > 0.75$, $p < 0.001$). Additionally, strong, significant negative correlations between %MR with APDF ($R < -0.59$, $p < 0.001$) and %MR with RMS ($R < -0.48$, $p = 0.011$) were apparent for each muscle group. Overall, across muscle groups, there was a significant positive correlation (Figure 5.3-1) between RMS and APDF ($R = 0.89$, $p < 0.001$). Additionally, %MR had strong negative correlations (Figure 5.3-2 & Figure 5.3-3) with APDF ($R = -0.57$, $p < 0.001$) and with RMS ($R = -0.33$, $p < 0.001$).

5.3.2 ANTHROPOMETRIC ANALYSIS

Functional stature, shoulder acromial height, functional forward reach, hand grip breadth, BMI, and age were examined to determine if these anthropometric variables would be correlated with normalized RMS, APDF, and %MR. Combining data for all of the muscles revealed that there were significant negative correlations between mean RMS with functional stature ($R = -0.22$, $p = 0.01$) and mean RMS with shoulder acromial height ($R = -0.20$, $p = 0.02$). Normalized APDF had similar statistically significant negative correlations with functional stature ($R = -0.19$, $p = 0.01$) and shoulder acromial height ($R = -0.17$, $p = 0.01$). Normalized %MR had significant positive correlations with functional stature ($R = 0.23$, $p = 0.01$) and shoulder acromial height ($R = 0.22$, $p = 0.01$). There were no other significant correlations between anthropometric variables and normalized RMS, APDF, and %MR.

Functional stature was examined to determine if there was an interactive effect with muscle type for normalized RMS and %APDF. The normalized RMS ANOVA revealed no significant interaction between muscle and functional stature ($p = 0.38$). However, the main effects indicated that functional stature was a statistically significant ($p = 0.009$). The normalized APDF ANOVA also revealed no significant interaction between muscle and functional stature ($p = 0.49$). Additionally, the main effects also revealed functional stature was statistically significant ($p = 0.02$).

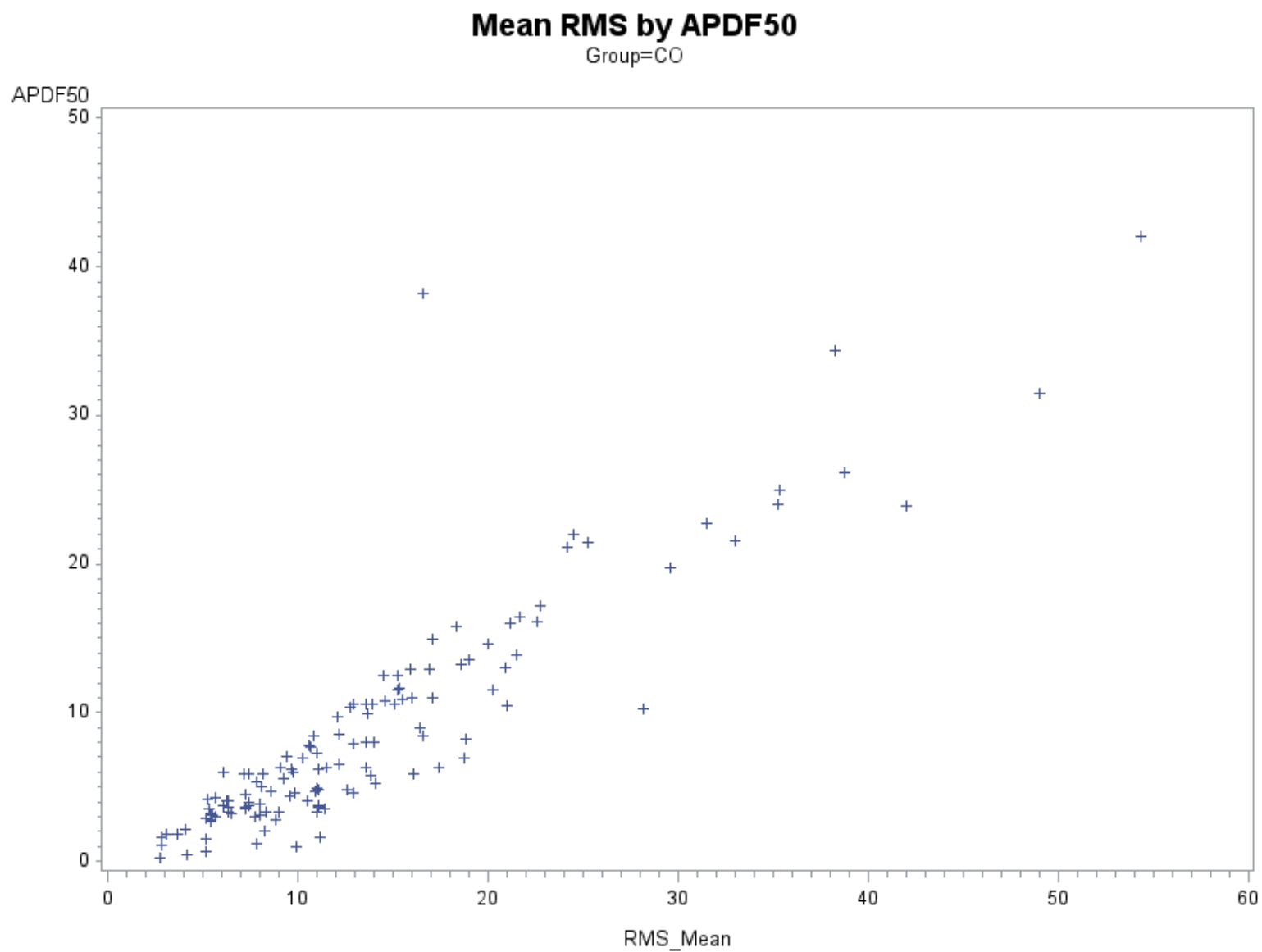


Figure 5.3-1: Correlation between mean RMS and 50th percentile APDF

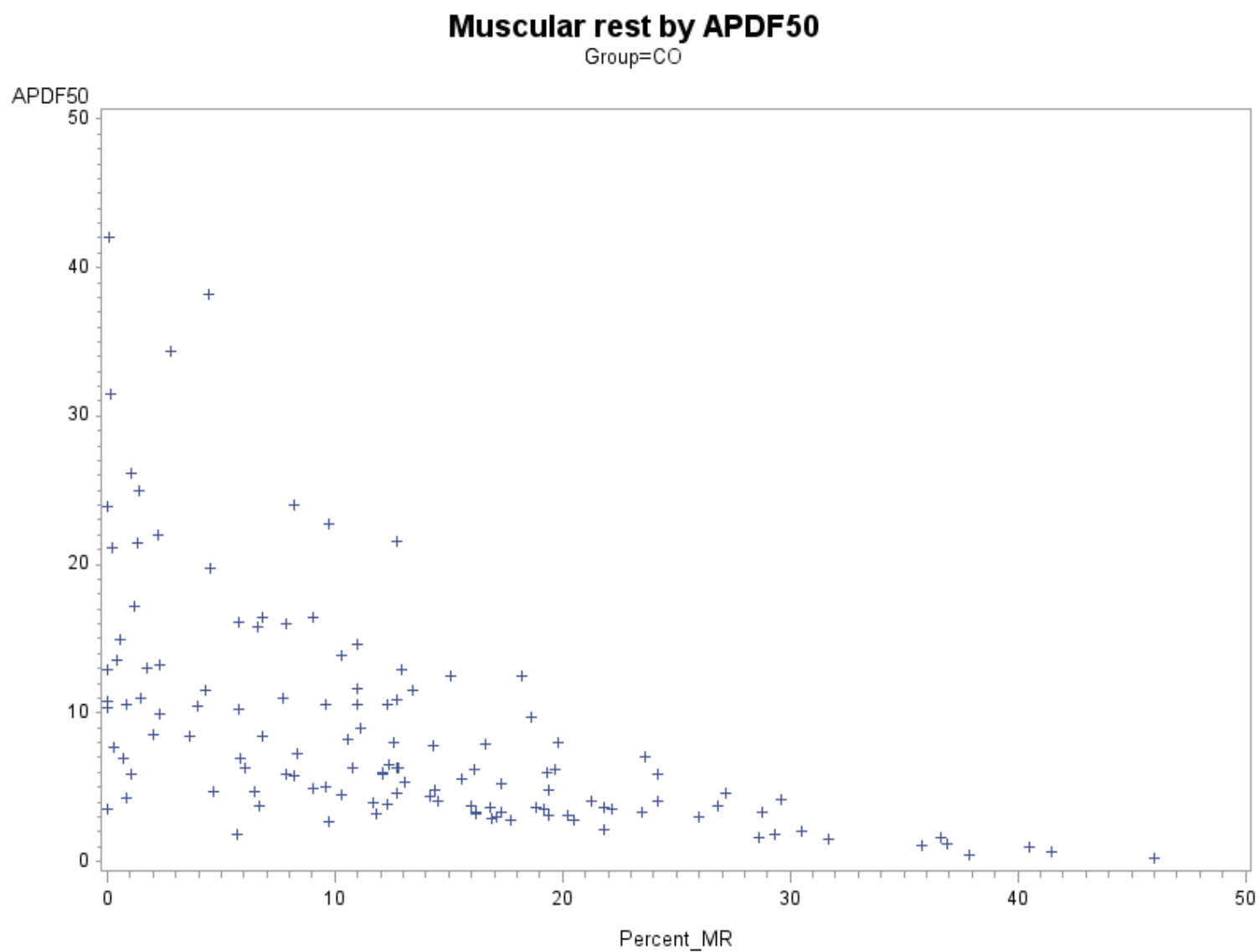


Figure 5.3-2: Correlation between %MR and 50th percentile APDF

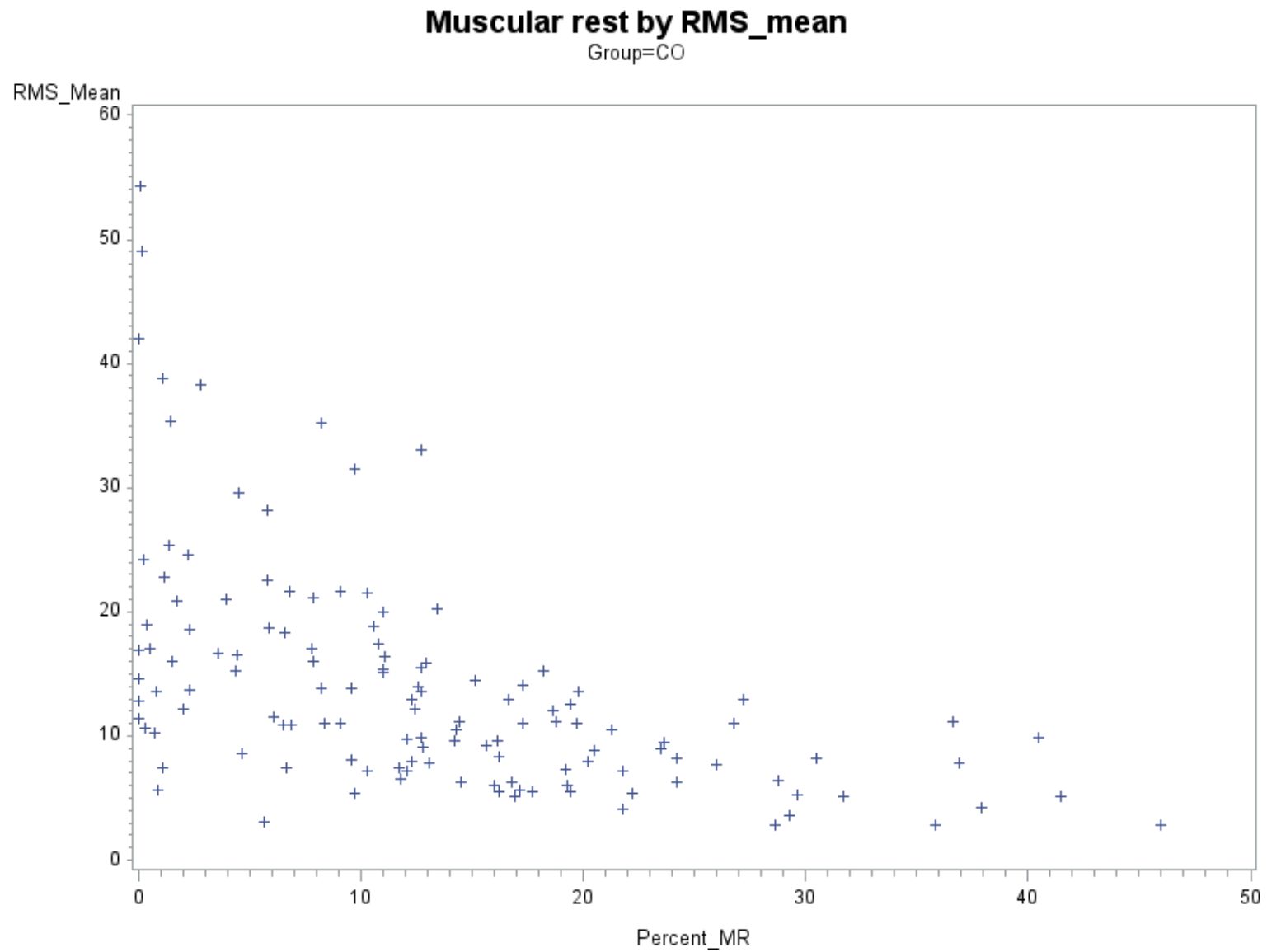


Figure 5.3-3: Correlation between %MR and mean RMS

Functional stature was also assessed to determine if an interaction occurred with muscle type for the normalized %MR. The normalized %MR ANOVA showed slightly different results than the muscle activity measurements. There was no statistically significant interaction between muscle type and functional stature, however the interaction approached significance ($p=0.07$). Functional stature was then dichotomized and the model re-examined. Although using functional stature as a dichotomized variable produced a significantly better model ($p<0.001$), the new analysis did not reveal a significant interaction between muscle and functional stature ($p=0.46$). When functional stature was significantly correlated with %MR, there were no interactive effects.

5.4 DISCUSSION

The primary purpose of this investigation was to quantify muscle activity during milking work in a large-herd dairy environment using normalized mean RMS, 50th percentile APDF, and %MR for the upper trapezius, anterior deltoid, biceps brachii, wrist extensors, and wrist flexors muscles. Additionally, anthropometric variables were collected for exploratory analysis of the subject population and correlational analysis with the muscle activity.

The anthropometric analysis revealed that only functional stature was statistically significant with the muscle activity variables, though without statistically significant interactive effects. However, unlike the muscle activity variables, %MR did demonstrate an approaching significant ($p=0.07$). The approaching significance suggests that with more data there could be an interactive effect between muscle type and functional stature for %MR. From the correlations, the results indicate that taller workers would possibly have less muscle activity and more muscular rest.

Analysis of normalized RMS, APDF, and %MR indicated that the milking activities had different activity requirements for the muscle groups of interest. The results of the correlation analysis indicate that the muscle activity measures are working as intended and thus were expected. Mean RMS and the

50th percentile APDF both measure average muscle activity and are expected to be highly correlated.

Percent muscular rest is a measure of the rest time vs. the total work time, and therefore is expected to be negatively correlated with measures of average muscle activity in repetitive work.

Normalized mean RMS indicated a statistically significant difference between biceps brachii and anterior deltoid muscles which displayed had the highest and lowest values, respectively. From examining these results, our hypothesis, the anterior deltoid and wrist flexors would be the most active muscle and the biceps brachii the least active, was rejected. The biceps brachii muscle was expected to demonstrate less activity than wrist flexors as observed in previous literature (Stål, Hansson et al. 2000, Pinzke, Stål et al. 2001, Stål, Pinzke et al. 2003), but the results revealed that the biceps were more active. Additionally, the anterior deltoid muscle was revealed to have the least amount of muscle activity. Normalized 50th percentile APDF revealed nearly identical results with the anterior deltoid displaying the least amount of muscle activity and the biceps brachii displaying the highest average activity. Although these results contradicted the original hypotheses of the present study, they are not implausible. Lifting and holding an object at 90 degrees flexion in the sagittal plane is less strenuous if using the biceps brachii muscle and holding the elbow in flexion rather than using the anterior deltoid muscle and holding the shoulder in flexion. Although the present study did not examine the effects of fatigue, it is plausible that over time the workers have adjusted to the difficulty of the milking work by using more bicep activity to complete milking tasks that require a held object such as the milk cluster attachment. Additionally, the fMVC for the biceps brachii were gathered using the wrist flexor and extensors protocol. It is probable that the fMVCs gathered for the biceps brachii were lower than what could have been gathered using a biceps centric protocol. The sEMG results of the biceps brachii could then be inflated, which could explain the vast differences seen within the literature.

Reviewing the results of %MR analysis strengthens the notion that workers adapt to the milking work. The anterior deltoid muscle was revealed to have the most muscular rest, while the upper trapezius and the biceps brachii muscles had the least. Although workers may be using different muscles to complete the milking work than originally hypothesized, there is another reason that may account for the vast differences in %MR. An event marker was used to determine the start of the milking shift, but no method was employed to differentiate between times spent actively working and resting. Observationally, brief breaks existed between milking individual rows of cows within herringbone and parallel parlors. Depending on the parlor, some workers were able to completely rest during this period, while other workers had to complete additional dairy work like folding cloth towels for the wiping tasks. Regardless, workers typically kept their arms in a neutral position during these rest periods, and the arms were flexed at the elbow joint activating the biceps muscle while keep the anterior deltoid muscle at rest. This can explain the difference between the measurements of the anterior deltoid and the biceps brachii muscles. However, this does not explain the low level of %MR for the upper trapezius muscle. Because milking work is strenuous and demanding, it is possible that a stressful work environment is created, resulting in the workers keeping their upper trapezius muscle in relative activation. Even though our results rejected our initial hypotheses, they are similar to previous findings from other dairy research groups.

Stål, Hansson et al. (2000) examined muscular load of the biceps muscle, along with the flexor and extensor muscles of the forearms with sEMG within loose housing and tethering milking systems. Tethering milking systems are similar to old hand milking procedure with a cluster device whereas loose housing systems cows enter fixed stalls in a parlor, such as herringbone, parallel, and rotary parlors. The researchers used APDF and %MR to assess the muscle activity. Although the researchers did not statistically compare the muscles, a visual examination revealed possible differences between muscles. The biceps appear, via APDF, to have nearly half the muscular activity as the extensors and flexors, but

there is no notable difference between the muscles when viewing the results of the muscular rest. The large differences seen in APDF along with the minute differences seen in %MR in the aforementioned study suggest that there could be a possible influence from how the subjects actually completed the milking tasks. Pinzke, Stål et al. (2001) examined individual milking tasks in a loose housing milking system, similarly to Stål, Hansson et al. (2000). Specifically, Pinzke et al. (2001) examined the muscular loads of the biceps and forearm flexors associated with drying, pre-milking, and attaching. Although the authors did not compare the muscle groups, there were noticeable differences between the biceps and forearm flexors. The biceps had nearly half the activity for each task except attachment, but unlike Stål, Hansson et al. (2000), the biceps exhibited more time under muscular rest. This difference could be attributed to analysis of specific tasks as both studies used the same procedures to determine muscular rest and APDF, but Pinzke, Stål et al. (2001) divided the activities. Stål, Hansson et al. (2000), like the present study, examined the average muscle activity for the entire milking period, rather than dividing the muscle activity per task. Although the statistical variation between muscular rest and APDF cannot be attributed causes, the values do hold pertinent information.

Amplitude probability distribution function (APDF) has been used to assess the risk of developing muscular problems due to work overload (Jonsson 1982). Recommendations were created for static (10th percentile), mean (50th percentile) and maximum (90th percentile) activity levels to prevent the development of MSS and MSD. The static APDF activity is suggested to be below 2% MVC and should never be above 5% MVC. The recommended level for the mean APDF activity should be below 10% MVC and must always be below 14%. The maximum APDF activity is recommended to stay below 50% MVC and never exceed 70% MVC. In this present study, the biceps brachii had the mean APDF value at 14.58% MVC, while the wrist extensors and upper trapezius were the closest to the recommended level 9.75% and 9.28% MVC (Table 5.3-1). The values presented in this present study differ from those determined by other researchers. Stål, Pinzke et al. (2003) evaluated biceps brachii

and wrist flexors muscles activity during a support assisted and unassisted cluster attachment task. The researchers determined flexor APDF activity was 13% MVC for unsupported attachment and 6.1% MVC for biceps. Another research group that examined muscle activity pertaining to tasks, Pinzke, Stål et al. (2001), determined that biceps brachii activity ranged from 5.9 to 9.8% MVC for the active arm, while wrist flexors activity ranged from 7.5 to 27% MVC for the 50th percentile APDF. However, both of these studies examined specific milking tasks. When studying overall milking tasks, Stål, Hansson et al. (2000) determined that the biceps brachii activity was 3.9% MVC, wrist flexors activity was 7.4% MVC and wrist extensors activity was 8.5% for the 50th percentile APDF. The wrist flexors and wrist extensors activity levels in the study by Stål, Hansson et al. (2000) are comparable to those reported in this study. However, the difference for biceps brachii is large: 3.9% vs. 14.58% MVC. It is possible that this difference could be related to the size of the dairies where the data was collected for this present study used large-herd dairies while the European studies examined small-herd dairies. Alternatively, the difference in biceps activity could also be due to the MVC collection protocol. As stated earlier, the fMVC for the biceps brachii were gathered using the wrist flexor and extensors protocol rather than a biceps specific activity. This protocol could have overinflated the biceps activity.

Although there are no current field studies at dairy farms that have examined muscle activity in large- dairies, German researchers (Jakob and Liebers 2009, Liebers, Jakob et al. 2009, Jakob and Liebers 2011, Jakob, Liebers et al. 2012) recreated a large-herd dairy atmosphere within a laboratory setting to conduct a task-based analysis of milking variables. The researchers conducted an in-depth simulation of large-herd cluster attachment in order to investigate the effects of cluster weight reduction. They ascertained through sEMG that attachment with the common 2.4 kg cluster imposed a considerable load on muscles of the upper extremities (Liebers, Jakob et al. 2009, Jakob and Liebers 2011, Jakob, Liebers et al. 2012). Reducing the mass of the milking cluster to 1.4 kg decreased muscle activity by up to 20% (Jakob, Liebers et al. 2012). The activity was not calculated using APDF, but rather using

normalized integrated sEMG similar to RMS processing. The results those researchers presented were comparable to our RMS findings (Table 5.3-1); biceps brachii 13.21% MVC, upper trapezius 17.09% MVC, wrist flexors, 10.51% MVC, and wrist extensors 13.25% MVC. The anterior deltoid had much higher activity, 23.39% MVC, than what we reported: 9.738% MVC. However, this is expected as Jakob, Liebers et al. (2012) had only examined attachment of the clusters, a task that has the worker's arms at or above shoulder height in order to complete the task, while the muscle activity measurement in this study spans all tasks in the milking process.

Furthermore, dairy industry sEMG has been used to assess many repetitive tasks. A series of papers (Hansson, Balogh et al. 2009, Hansson, Balogh et al. 2010) reported the muscle activity use of the upper trapezius and wrist extensors in several different areas of repetitive work. These included, but were not limited to, car manufacturing, fish processing, poultry processing, letter sorting, laminate processing, meat cutting, mink fur sorting, and parcel sorting. Muscle activity for the upper trapezius ranged from 7% to 46% MVC. The forearm extensors had activity ranging from 6% to 19% MVC. In addition to using muscle load, the authors also examined muscular rest to complete an activity profile. Because the aim of the papers (Hansson, Balogh et al. 2009, Hansson, Balogh et al. 2010) was to explore muscular workload, muscular rest was presented through correlations with muscular load and other parameters examined such as %MR. The authors demonstrated that for wrist extensors muscles there was a strong negative correlation ($R=-0.75$) between the 50th percentile APDF and muscular rest. The upper trapezius demonstrated a strong negative correlation ($R=-0.85$) as well. Significant correlations were also demonstrated between %MR and 50th percentile APDF. The muscular activity findings for repetitive dairy work in the study for this dissertation are similar to those demonstrated by Hansson et al., (2009, 2010).

There has been evidence of a relationship between lack of muscular rest and the development of shoulder disorders in occupational tasks for the upper trapezius (Veiersted, Westgaard et al. 1993). Veiersted, Westgaard et al. (1993) examined the relationship between muscle usage and the development of trapezius myalgia through sEMG analysis. The authors studied workers at a chocolate manufacturing plant who worked on the production or packaging line. Subjects were surveyed for complaints of neck or shoulder pain every 10th week for one year. Muscle activity data was collected at the same interval. Each data collection session was comprised of 10 minutes of sEMG sampling while the subjects worked at their respective habitual work rhythm. The 50th and 90th percentiles of the APDF were used to describe muscular load; muscular rest was defined by gaps of activity under 0.5% MVC lasting less than 0.2 seconds. By comparing the survey data and the sEMG data, the authors determined that subjects who had developed trapezius myalgia, had significantly fewer gaps per minute. The authors determined that as muscular rest increased by an additional gap per minute, the subjects' risk of developing WRMSDs decreased by 6%. Subjects who did not experience WRMSDs had gap rates greater than 10.8 gaps per minute or roughly 4% muscular rest. Hansson, Nordander et al. (2000) revisited the use of %MR to examine the sensitivity of the trapezius when comparing different work tasks completed by hospital cleaners and office workers. The authors compared %MR along with various percentiles of APDF. The repetitive work tasks presented 50th percentile APDF values ranging from 3.6% to 8.1% APDF for the trapezius, all less than those found for large-herd dairy milking. Muscular rest ranged from 1.1% to 13.4% of total work time. Muscular rest for upper trapezius determined from dairy milking was 6.6%, which fits well within the range presented for office and cleaning work tasks. The authors found that %MR was more precise than using various percentiles of the APDF for the trapezius to compare work task differences. Although the development of trapezius myalgia has not been demonstrated in the dairy industry specifically, the risk is present because dairy work is, similar to manufacturing, repetitive (Stål, Pinzke et al. 2003).

Dairy milking work has a high association with both musculoskeletal symptoms (MSS) and WRMSDs. (Stål, Hansson et al. 2000, Pinzke 2003, Davis and Kotowski 2007, Nonnenmann, Anton et al. 2008, Kolstrup 2012, Patil, Rosecrance et al. 2012, Douphrate, Gimeno et al. 2013). Douphrate, Gimeno et al. (2013) determined that in large-herd U.S. dairies, almost three-fourths of the milking workers had MSS in some part of the body. Kolstrup (2012) used a modified version of the Standard Nordic Questionnaire to determine that in Swedish small-herd dairies there was a high prevalence of MSD among workers in their shoulders, hands/wrist, and low back. These investigations examined a broad category of MSS and WRMSDs rather than targeting specific disorders. Patil, Rosecrance et al. (2012) examined the prevalence of carpal tunnel syndrome in large-herd U.S. dairy parlors. Carpal tunnel syndrome has been associated with work tasks involving repetitive motions and forceful upper-limb muscle activity (Barr, Barbe et al. 2004). Patil, Rosecrance et al. (2012) concluded that the prevalence of carpal tunnel syndrome was significantly higher among dairy workers than non-dairy workers. Although the present study did not determine overall wrist flexors and wrist extensors activity to be beyond the recommended levels for the 10th, 50th, and 90th APDF percentiles, the wrist extensor activity was approaching the threshold for 50th (9.75% fMVC) and 90th (44.11% fMVC) percentiles. It is very possible that when examining activity associated with specific milking tasks, the wrist flexors and wrist extensors muscle activity will be beyond the recommended threshold, increasing risk for developing WRMSDs such as carpal tunnel syndrome.

From a practical perspective, these results provide dairy owners with a general direction to minimize risk of injury. The high biceps activity (14.58% fMVC) in combination with low anterior deltoid activity (3.49% fMVC) indicate that workers may be keeping the elbows in high amount of flexion in order to complete the milking work. Therefore to reduce biceps activity, owners should seek to encourage use of microbreaks with full bicep relaxation. Microbreaks lasting less than 1 minute have been demonstrated to provide the same benefit as a longer 5 minute break, but without the added cycle

time (Bennett 2015). A secondary intervention, would be to reduce the weight of the tools being used to complete the dairy work. Jakob, Liebers et al. (2012) examined interventions targeting reducing the weight of the milk cluster attachment. The researchers determined that reducing the weight of the cluster from 2.0 kg to 1.4 kg could reduce activity by nearly 20% in the muscles of the arms, shoulders, and neck. Use of these interventions could possibly reduce muscle activity and risk for developing WRMSDs. Additionally, dairy owners could examine use of standardized rotation among the parlor workers so that each of the milkers participates in the “cow pushing” activities. For example if there are three milkers working in a parlor, two of them are typically full time milkers, and the third milker also acts as a “cow pusher” organizing the cows and assisting their flow into the stalls. By the time the cows have finished entering the stalls and the pusher exits the pen to assist the other milkers, the vast majority of the milking work has already been completed and the pusher only has a few cows to work on. In this example, using a standard rotation between the three positions would lower the overall exposure to the risk factors. Job rotations have been demonstrated to reduce exposure.

5.4.1 LIMITATIONS

Muscle activity measured with sEMG was collected at several different dairies. Each dairy had similar, but not identical herd sizes creating fluctuations in the total data collecting time. Subjects completed the milking work for the length of time required to complete the first full pen of cattle (225-275 cows). The time in between pens provided the researchers time to remove the sEMG equipment without affecting work production. The data collection period was on average 52.7 (± 10.8) minutes. Additionally, data collection always began at the beginning of each shift. This caused observable variability in the pace of work across different dairies as work flow achieved optimal pace at different points of the shift per dairy. Furthermore, during the investigation the subjects were asked to use the instrumented arm to collect muscle activity from each of the milking tasks, which did change how some

of the subjects would milk compared to the normal routine. For example a worker that would normally pre-dip with the left hand and then strip with the right hand was asked to switch hands for a set number of cows in order for sEMG data to be gathered. Finally, this investigation makes the assumption that collecting muscle activity for about 50 minutes at the start of the shift equally represents milking work completed at latter times in the milking shift. Physiologically, we are disregarding any possible effects that muscle fatigue may have on recorded muscle activity, although these could have a direct impact on %MR and APDF values.

5.5 SUMMARY AND CONCLUSIONS

Dairy milking has significant effects on upper extremity muscle activity and muscular rest. The muscle activity of the long head of biceps brachii muscle measured in this study was much higher than the recommended 10% MVC for the 50th percentile APDF (Jonsson 1982). The wrist flexors and upper trapezius were approaching the recommended 10% MVC. These findings suggest that milking tasks at large-herd dairies may increase the risk of workers developing muscular discomfort and possibly disorders. From examining muscular rest findings, the upper trapezius muscle was rested least. However, when compared to previous research (Veiersted, Westgaard et al. 1993) , the upper trapezius muscle is receiving adequate rest for low impact, repetitive work tasks, so risk of myalgia is decreased

Although this investigation presents novel muscular activity information for large-herd dairies, more information is needed to create appropriate interventions. Future studies should focus on determining how the individual milking tasks affect the upper extremity musculature. Small-herd researchers first reported overall muscular activity (Stål, Hansson et al. 2000) and then investigated the effects of specific milking tasks (Pinzke, Stål et al. 2001, Stål, Pinzke et al. 2003). Large-herd researchers should follow the same pattern, especially due to the scarcity of research. Finally, future researchers

examining muscle activity in large and mega-herd dairies should also examine the effects of muscular fatigue.

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6. CHAPTER 6- UPPER LIMB MUSCULAR WORKLOAD ASSOCIATED WITH MILKING TASKS IN LARGE-HERD DAIRY PARLORS

6.1 INTRODUCTION

Work-related musculoskeletal disorders (WRMSDs) are an economic burden that affects employers in the United States (U.S.) with medical costs totaling nearly \$20 billion annually (OSHA 2014). These disorders account for 30% of all nonfatal occupational injuries reported across all industries in the U.S. (BLS 2010). The U.S. Department of Labor defines WRMSDs as injuries or disorders of the neuromuscular and skeletal systems associated with exposure to risk factors found in the workplace (Barbe and Barr 2006). Established risk factors for WRMSDs include awkward postures, highly repetitive movements, forceful exertions, and vibration (Punnett and Wegman 2004, Mukhopadhyay, O'Sullivan et al. 2007, Mukhopadhyay, O'Sullivan et al. 2009, da Costa and Vieira 2010, Farooq and Khan 2012, Gallagher and Heberger 2012, Barbe, Gallagher et al. 2013). Of the total American workforce, 27% are exposed to repetitive motion and nearly 45% are exposed to awkward postures during their work tasks (Tak and Calvert 2011). This evidence suggests that occupational WRMSDs should be expected among workers in several industry classifications, including agriculture.

Researchers have reported that workers in the agriculture industry have a high prevalence of WRMSDs (Osborne, Blake et al. 2012) and musculoskeletal symptoms (MSS), which are often precursors to WRMSDs. Douphrate, Gimeno et al. (2013) reported the prevalence of work related MSS was 76.4% among U.S. large-herd dairy workers, with high prevalence in the upper extremities. Swedish dairy workers have also experienced high prevalence of MSS ranging between 76% to 86% (Douphrate, Kolstrup et al. 2013). Additionally, Patil, Gilkey et al. (2010) have identified carpal tunnel syndrome as a specific WRMSDs among U.S. dairy workers. One explanation for the significant risk of upper-limb disorders among dairy workers is the industrialization of the modern milking operations. These

operations often milk several thousand cows three times per day, which has led to highly repetitive work tasks within the milking parlor.

Workers in large-herd (1000-1500 head) and mega-herd (>1500 head) U.S. milking parlors often complete five very specific milking tasks: (1) “pre-dipping” of the teats with a sanitization solution, (2) “stripping” of each teat to stimulate milk letdown and inspect for milk quality, (3) “wiping” of the teats to clean them, (4) “attachment” of the milking cluster to teats, (5) “post-dipping” each teat with a sanitization solution (Doupbrate, Fethke et al. 2012). In U.S. dairies, milking tasks are performed in dairy parlors with cows lined-up in a parallel, herringbone, or rotary configuration (USDA 2007, Doupbrate, Kolstrup et al. 2013). Herringbone parlors are designed with cows entering each stall at roughly a 45 degree angle. In parallel oriented parlors, cows enter stalls at a 90 degree angle from the walkway with the cows’ rear facing the workers. Rotary parlors require cows to enter individual stalls on a rotating platform with their hind legs facing outward on the circular platform (Doupbrate, Fethke et al. 2012). In rotary parlors, the cows rotate towards the workers, as opposed to the workers moving from stall to stall.

The five described milking tasks have been examined using sEMG in a laboratory environment (Jakob and Liebers 2009, Jakob and Liebers 2011, Jakob, Liebers et al. 2012) and in small-herd dairy parlors (Nevala-Puranen, Kallionpää et al. 1996, Stål, Hansson et al. 2000, Pinzke, Stål et al. 2001, Stål, Pinzke et al. 2003), and in large-herd dairy parlors with the Standardized Nordic Questionnaire. These milking tasks, however, have not been examined with sEMG in large-herd parlors where task specificity and repetition is much higher than in small-herd dairies. Examining the small herd research (Stål, Moritz et al. 1996, Pinzke, Stål et al. 2001, Stål, Pinzke et al. 2003) milk cluster attachment, drying (wiping), and pre-milking (stripping) are demonstrated to require substantial muscle activity from the upper extremities to complete and all of those were labeled difficult work. The laboratory research (Jakob and Liebers 2009, Jakob and Liebers 2011, Jakob, Liebers et al. 2012) focuses primarily on the attaching task.

The authors examine muscle activity associated with the upper extremity and demonstrate that attaching requires higher activity from the anterior deltoid. Surface EMG would then be an appropriate evaluation instrument to examine milk work in large-herd dairies because muscular load has been associated with ergonomic risk factors such as forceful contractions and repetitive motions (Jonsson 1976, Jonsson 1977), and sEMG is the primary method to examine muscle activity.

The primary aim of the research reported here was to quantify, muscular load from the upper extremity musculature of dairy workers during the five primary milking tasks through use of sEMG. Muscle activity profiles for each milking task were created and analyzed using sEMG collected from the upper trapezius, anterior deltoid, the biceps brachii, wrist flexors, and wrist extensors. These muscles were chosen to be studied as they have been thoroughly examined and found to be of importance to complete milking work in small-herd parlors (Stål, Moritz et al. 1996, Pinzke, Stål et al. 2001, Stål, Pinzke et al. 2003) and have been studied in full shift research in large-herd operations (Doupbrate and Rosecrance 2010, Rosecrance and Doupbrate 2012). From the findings of previous small-herd literature examining milking tasks with sEMG (Stål, Moritz et al. 1996, Pinzke, Stål et al. 2001, Pinzke, Stål et al. 2001, Stål, Pinzke et al. 2003, Doupbrate, Gimeno et al. 2013) I hypothesize that milk cluster attachment, stripping, and wiping will be the more difficult milking tasks with greater muscular load, with milk cluster attachment the most difficult with the highest muscular load. To date there are no reports in the peer-reviewed literature that have quantified the sEMG of dairy workers while performing milking tasks in large-herd U.S. dairies.

6.2 METHODS

6.2.1 PARTICIPANTS

Subjects (dairy milking parlor workers) were recruited from three large-herd dairy farms in the U.S. state of Colorado. The three dairy operations milked their cows in parallel, herringbone and rotary

parlor configurations, respectively. All the subjects were Latino(a) aged 18 years or older. A total of 25 workers were enrolled; 24 men and 1 woman. All subjects were free from muscular pain at the time of data collection. To be included in the study, subjects had to have at least one year of milking experience primary milking tasks: pre-dipping, stripping, wiping, attaching milking clusters, and post dipping. Subjects were compensated \$30 for their participation. This study was approved by the Institutional Review Board of Colorado State University. Dairy management and all subjects provided approval and written informed consent, respectively.

6.2.2 DATA COLLECTION PROTOCOL

6.2.2.1 Surface Electromyography

Muscle activity was collected at a sampling frequency of 1000 Hz using Biometrics DataLOG (Biometrics, England) field equipment from the upper trapezius, anterior deltoid, biceps brachii, wrist flexors, and wrist extensors of all subjects. Subjects were fitted with five bipolar electrodes (Biometrics, LTD) that were attached on the skin with double-sided tape directly over the midsection of the belly of each muscle of interest in the dominant upper limb. Skin was prepped using sand-paper and an alcohol wipe to remove dead skin cells. One disposable ground electrode was placed on the contralateral clavicle. The standardized location of the sEMG electrode on the muscle belly was determined through palpation as functional movements were performed (Basmajian and De Luca 1985). Functional movements included shrugging the shoulders to activate the upper trapezius, raising and lowering the dominant arm to activate the anterior deltoid, opening and closing the dominant hand to activate the wrist flexors and extensors, and flexion at the elbow of the dominant arm to activate the biceps brachii. Functional movements had a secondary purpose of allowing the subjects to warm up muscle groups. After electrode placement was completed, Hypafix medical tape (Hamburg, Germany) was placed over each electrode to secure it and to minimize movement artifact. Real time streaming of the sEMG signal was visually examined to assure that muscle activity coincided with the appropriate functional movements, (e.g. raising and lowering of arm with activation of anterior deltoid).

6.2.2.2 Functional Maximum Voluntary Contraction (fMVC) Protocol

The purpose of the functional maximum voluntary contractions (fMVC) was to normalize the sEMG data in order to compare and contrast the activity of different muscle groups. A 30-second baseline resting sEMG signal was first collected to calculate the minimum resting activity to use in the normalization procedure. Subjects then performed a minimum of three fMVC to obtain functional

maximum contractions for the muscles of interest. Over a three second countdown, subjects were told to ramp up to a maximum muscular effort, hold the maximum effort for an additional four seconds during which subjects were verbally encouraged to maintain the maximum contraction, and then to relax. After each fMVC trial was completed, subjects were provided a one minute rest period to minimize muscle fatigue. Upon completion of each fMVC trial, the maximum sEMG was calculated using the middle three seconds of the root mean square (RMS) processed sEMG signal. The mean and standard deviation were determined to calculate covariance between trials. If the covariance was above 15% for the three fMVC trials, additional trials were repeated (up to a maximum of five) until the covariance was below 15%.

Functional MVCs for the anterior deltoid and upper trapezius were calculated using the procedures established by Boettcher, Ginn et al. (2008). For the anterior deltoid this was accomplished by raising the arm 120 degrees in the sagittal plane from a relaxed state. Pressure was applied proximally below the elbow to attempt to engage the anterior deltoid muscle. Subjects were instructed to maintain their arm in the elevated position. The upper trapezius fMVC was gathered using the "empty can" method (Boettcher, Ginn et al. 2008). Briefly, the subjects were instructed to place their arm at 90 degree flexion in the scapular plane and internally rotate the arm forcing the palm to face outward away from body centerline. Finally, subjects were instructed to simulate holding an empty soda can. Downward pressure was applied proximally below the elbow, as the subject maintained the arm in aforementioned position. Finally, wrist flexors and the wrist extensors fMVCs were obtained simultaneously through a co-contraction with the use of a hand dynamometer (Biometrics G100, England). Subjects were instructed to hold the hand dynamometer in a power grip and keep the elbow in 90 degrees of flexion. The dynamometer handle was adjusted to comply with the variability in hand size among the subjects. Visually examining how the subject held the hand dynamometer as well as subject feedback determined if the hand dynamometer grip needed to be adjusted. Subjects were

instructed to close their grip with maximum effort while maintaining elbow flexion. Functional MVCs for the biceps brachii muscle were determined using the values generated from the wrist flexor and extensors procedure.

6.2.2.3 Milking Tasks

All subjects completed the standard five individual milking tasks: pre-dipping, stripping, wiping, attaching milking clusters, and post dipping. Typically, pre-dipping, wiping, and post-dipping were completed with one hand, while stripping and attaching required the use of both hands. For tasks that could be completed using either the right or left arms, subjects were instructed to use the instrumented arm to complete each of the milking tasks. Excluding a stipulation to complete tasks with the instrumented arm, subjects performed the tasks per their normal routine in parallel and herringbone configurations. Rotary configurations required subjects to rotate amongst their workstations every 20 minutes to guarantee each subject completed all the tasks. At the first work station a subject completed pre-dipping and stripping directly after cows entered stalls. The second station had the subject complete wiping and attaching. Finally, at the third station, a subject completed post dipping on cows that had finished being milked. By asking subjects to rotate every 20 minutes, each subject completed all the milking tasks.

To develop muscle activity profiles for each of the milking tasks, it was necessary to accurately document when each milking task began and ended. When the subjects began the milking shift, the event marker was triggered to mark within the EMG stream the start of the work. A second system was used in which a researcher started a stop watch simultaneously to when the event marker was triggered. Furthermore, a third system consisting of a GoPro Camera (San Mateo, California) synchronized with the data stream was used in the event of irregularities within the sEMG data stream. At the start of a repetition of a milking task, one researcher triggered and held down the event marker

during the specific milking task. Additionally, a second researcher simultaneously documented the time code on a stop watch at the beginning and end of the specific milking task. The GoPro Camera system would be recording all the task activities during data collection. Each milking task commenced when the subject's hands would move towards the cow's udder and cross the plane marked by the stall wall. A subject finished a single repetition of a milking task the moment the arms returned from underneath the cow's udder. Once the subject had completed a repetition, the event marker was released signaling the end of the repetition in the sEMG data stream. When the subject completed a full set of task repetitions, ranging from five to ten, the first researcher would signal the second who would write down the completion time as noted on the stop watch. The total number of task repetitions during each of these periods was documented. This process was repeated during the entire data collection period for each of the five milking tasks. Data was collected for the length of time it took to complete one pen of cattle (225 to 275 cows), which ranged from 45 to 90 minutes. A single pen of cows was used in place of a fixed time frame so that the researchers could easily remove the sEMG equipment from the subjects during the brief break between pens.

6.2.3 *MUSCLE ACTIVITY PROFILES*

Muscle activity profiles were constructed through analysis of the normalized processed sEMG data. The raw sEMG data was demeaned removing any DC offset and then full wave rectified (Basmajian and De Luca 1985). Afterward the sEMG data were zero-phase digitally filtered with a bandpass filter allowing frequencies between 10 Hz to 300 Hz. All muscle activity was normalized using the fMVC data. Functional MVC data were processed using a 100ms moving average filter (Bao, Mathiassen et al. 1995). The sEMG data were normalized using the instantaneous maximum value determined from the highest 100ms average. Normalization was completed using an arithmetic process,

$$\%MVC = \frac{(sEMG - Rest)}{(fMax - Rest)} \quad \text{Eq. 1}$$

where %MVC is the normalized muscle activity, *sEMG* represents the processed sEMG data, *fMax* represents the instantaneous maximum value from fMVC trials, and *Rest* represents the minimum value from the 30 second baseline. Analysis of the sEMG data was accomplished through use of the RMS processing technique (Basmajian and De Luca 1985) and the amplitude probability distribution function (APDF) (Jonsson 1982). A graphic user interface (GUI) program was created using MATLAB 7.10.0 (Mathworks, Natick, MA) to process the sEMG data and obtain mean RMS values. The 10th percentile (static), 50th percentile (mean), and 90th percentile (maximum) of the APDF (Jonsson 1982) were established using custom software (Fethke, Anton et al. 2004) developed in LabVIEW (National Instruments, Austin, Texas). Percent muscular rest (%MR) of the sEMG (Petrofsky, Glaser et al. 1982) was determined with a threshold of less than 0.5% MVC and gap duration of at least 0.25 seconds (Hansson, Nordander et al. 2000). Custom LabVIEW software (Fethke, Anton et al. 2004) was used to determine %MR values.

Muscle activity profiles were constructed for each individual muscle group during each of the five specific milking tasks. This was accomplished by determining the mean RMS, ADPF, and %MR across all the subjects. The profiles provided an estimate of the overall muscle activity and recovery experienced by parlor workers per task during the data collection period.

6.2.4 STATISTICAL ANALYSIS

All statistical analyses were conducted using SAS 9.3 (SAS Institute Inc., Cary, NC, USA). To achieve 80% power in the statistical models, the appropriate number of subjects needed in the study was determined using previous published sEMG results from previous small-herd (Pinzke, Stål et al. 2001, Stål, Pinzke et al. 2003) and laboratory studies (Jakob, Liebers et al. 2012). Muscle profiles were assessed using a random block design with a 25 x 5 x 5 (Subjects x Muscle x Task) ANOVA with a Tukey Honest Significant Difference post hoc adjustment to determine differences in the RMS, APDF, and

%MR. Statistically significant interactions were assessed by examining the simple main effects. Data were also stratified by parlor configuration and compared with descriptive statistics. Correlations between mean RMS, 50th percentile APDF, and %MR were examined for each task. Statistical significance was set at $p < 0.05$.

6.3 RESULTS

6.3.1 *MUSCLE ACTIVITY PROFILES*

Profiles of muscle activity were created for the upper trapezius, anterior deltoid, biceps brachii, wrist flexors, and wrist extensors muscles for each of five milking tasks (Table 6.3-1). The ANOVA analysis of the mean RMS did not detect a significant interaction between task and muscle ($p = 0.23$). However, both variables task and muscle were statistically significant as shown by the main effects ($p < 0.001$). Stratification of the mean RMS data by task did not reveal any significant results because the main effects of the majority of the statistical models did not have variable muscle as significant. Stratification of the mean RMS data by muscle (Table 6.3-2) yielded statistically significant models for each of the muscles of interest ($p < 0.001$). For the anterior deltoid model, statistically significant differences were determined between pre-dipping and all of the other milking tasks ($p < 0.01$); pre-dipping had less activity. The biceps brachii model revealed statistically significant greater activity only for wiping with stripping ($p = 0.001$), pre-dipping ($p = 0.002$), and post-dipping ($p < 0.001$). The upper trapezius model revealed a statistically significant difference only between pre-dipping and wiping ($p = 0.002$) with pre-dipping having less activity. The wrist flexors model revealed statistically significant greater activity for wiping compared to the other milking tasks ($p < 0.02$). Additionally, the extensor model revealed statistical differences between post-dipping and stripping ($p = 0.03$) and between pre-dipping and stripping ($p = 0.007$). The wrist extensors model found statistically significant greater activity for wiping compared to all of the milking tasks ($p < 0.05$) except milk cluster attachment ($p = 0.63$).

Additionally, statistically significant differences were revealed between pre-dipping and stripping ($p=0.03$) and between pre-dipping and cluster attachment ($p=0.0003$). No other statistically significant results were determined from the mean RMS analysis. The considered difficulty of each milking task did not necessarily correspond to muscle activity levels.

Table 6.3-1: Muscle activity profiles for the milking tasks.

	Upper Trapezius	Anterior Deltoid	Biceps Brachii	Wrist Flexors	Wrist Extensors
<i><u>Pre-dipping</u></i>					
10th Percentile	4.65 (3.47)	1.47 (1.43)	9.97 (8.89)	3.41 (2.76)	4.70 (2.71)
50th percentile	13.68 (9.06)	9.53 (5.80)	22.61 (21.75)	9.97 (9.55)	13.61 (7.18)
90th percentile	26.81 (15.70)	29.12 (13.68)	45.89 (45.90)	22.65 (17.19)	30.86 (13.27)
Mean RMS	15.02 (10.65)	12.88 (7.57)	23.46 (23.37)	11.67 (10.88)	16.45 (8.76)
%MR	1.24 (2.53)	3.43 (3.40)	0.30 (0.77)	0.85 (1.39)	0.45 (1.07)
<i><u>Stripping</u></i>					
10th Percentile	2.72 (2.20)	0.69 (0.90)	6.88 (10.40)	1.17 (1.35)	2.71 (3.01)
50th percentile	13.34 (7.37)	9.55 (5.42)	15.78 (11.44)	10.37 (12.75)	15.41 (11.88)
90th percentile	35.44 (13.13)	41.24 (9.83)	42.07 (35.71)	42.69 (41.43)	42.46 (24.39)
Mean RMS	18.59 (8.09)	18.38 (5.26)	22.65 (20.14)	19.93 (17.44)	23.75 (14.07)
%MR	1.29 (1.81)	10.87 (10.24)	2.30 (4.62)	10.00 (10.10)	5.98 (9.69)
<i><u>Wiping</u></i>					
10th Percentile	2.73 (2.01)	1.01 (1.15)	9.09 (7.51)	3.48 (3.51)	7.15 (6.04)
50th percentile	14.65 (6.87)	9.40 (5.64)	28.10 (21.29)	16.26 (13.86)	22.28 (13.51)
90th percentile	36.62 (13.11)	48.15 (14.00)	67.90 (51.82)	51.23 (30.05)	50.51 (24.54)
Mean RMS	22.12 (10.72)	23.04 (8.14)	34.98 (24.16)	27.49 (14.89)	30.45 (14.47)
%MR	1.30 (2.07)	8.13 (11.39)	1.24 (4.32)	2.11 (3.62)	1.60 (2.81)
<i><u>Milk cluster attachment</u></i>					
10th Percentile	2.56 (2.60)	1.03 (0.86)	7.65 (6.30)	1.89 (1.32)	6.88 (7.63)
50th percentile	12.89 (7.19)	13.78 (4.28)	24.17 (17.97)	12.11 (12.06)	22.09 (12.30)
90th percentile	29.78 (14.18)	46.90 (11.32)	65.53 (49.55)	34.90 (25.88)	49.19 (25.77)
Mean RMS	14.85 (8.15)	22.30 (6.82)	27.57 (19.18)	14.57 (12.26)	27.10 (16.73)
%MR	2.66 (3.88)	4.50 (4.00)	0.90 (2.07)	2.16 (2.20)	2.24 (4.08)
<i><u>Post-dipping</u></i>					
10th Percentile	3.92 (1.65)	1.33 (1.63)	7.16 (5.99)	2.63 (2.32)	4.76 (2.57)
50th percentile	15.08 (5.77)	12.84 (4.72)	18.33 (16.21)	9.39 (7.21)	14.96 (6.81)
90th percentile	32.94 (18.01)	39.15 (16.86)	42.99 (39.91)	24.60 (17.07)	32.95 (14.12)
Mean RMS	18.99 (9.27)	19.67 (7.25)	19.44 (12.56)	12.84 (9.48)	20.47 (10.44)
%MR	1.50 (2.59)	9.58 (6.71)	1.37 (3.83)	2.51 (3.72)	1.46 (2.95)

Note: Mean and (SD) are shown for each muscle $n=21$ for all milking tasks. Percentiles refer to APDF analysis. Units for mean RMS and APDF are %fMVC. %MR was measured as a percentage of total working time.

Table 6.3-2: Mean RMS of milking tasks stratified by muscle

Task 1 vs Task 2	Task 1	Task 2	Difference	Adjusted P-value
<i>Anterior Deltoid</i>				
Pre-dipping vs. Cluster Attachment	12.88	22.30	9.42	<0.001
Pre-dipping vs. Post-dipping	12.88	19.67	6.79	0.0005
Pre-dipping vs. Wiping	12.88	23.04	10.19	<0.001
Pre-dipping vs. Stripping	12.88	18.38	5.50	0.007
<i>Biceps Brachii</i>				
Wiping vs. Stripping	34.98	22.65	12.33	0.0007
Wiping vs. Pre-dipping	34.98	23.46	11.52	0.002
Wiping vs. Post-dipping	34.98	19.44	15.54	<0.001
<i>Upper Trapezius</i>				
Pre-dipping vs. Wiping	15.02	22.12	7.10	0.0002
<i>Wrist Extensors</i>				
Wiping vs. Pre-dipping	30.45	16.46	13.97	<0.0001
Wiping vs. Post-dipping	30.45	20.47	9.97	0.0007
Wiping vs. Stripping	30.45	23.75	6.69	0.05
Pre-dipping vs. Cluster Attachment	16.46	27.10	10.64	0.0003
Pre-dipping vs. Stripping	16.46	23.75	7.29	0.03
<i>Wrist Flexors</i>				
Wiping vs. Pre-dipping	27.49	11.67		
Wiping vs. Post-dipping	27.49	12.84	14.64	<0.001
Wiping vs. Stripping	27.49	19.93		
Wiping vs. Cluster Attachment	27.49	14.57	12.91	<0.001
Stripping vs. Pre-dipping	19.93	11.67	8.26	<0.001
Stripping vs. Post-dipping	19.93	12.84	7.09	0.03

Note: Only statistically significant results are presented. Estimate units are %fMVC

Table 6.3-3: 50th percentile APDF of milking tasks stratified by muscle

Task 1 vs Task 2	Task 1	Task 2	Difference	Adjusted P-value
<i>Anterior Deltoid</i>				
Cluster Attachment vs. Pre-dipping	13.78	9.53	4.26	0.02
Cluster Attachment vs. Wiping	13.78	9.40	4.38	0.01
Cluster Attachment vs. Stripping	13.78	9.55	4.22	0.02
<i>Biceps Brachii</i>				
Wiping vs. Stripping	28.10	15.78	12.33	<0.0001
Wiping vs. Post-dipping	28.10	18.33	9.77	0.002
Cluster Attachment vs. Stripping	24.17	15.78	8.39	0.01

Wrist Extensors				
Wiping vs. Pre-dipping	22.28	13.61	13.97	<0.0001
Wiping vs. Post-dipping	22.28	14.96	9.97	0.0007
Wiping vs. Stripping	22.28	15.41	6.69	0.05
Cluster Attachment vs. Pre-dipping	22.09	13.61	8.49	0.0006
Cluster Attachment vs. Post-dipping	22.09	14.96	7.13	0.006
Cluster Attachment vs. Stripping	22.09	15.41	6.68	0.01
Wrist Flexors				
Wiping vs. Pre-dipping	16.26	9.97	6.29	<0.004
Wiping vs. Post-dipping	16.26	9.39	6.87	0.001
Wiping vs. Stripping	16.26	10.38	5.89	0.009

Note: Only statistically significant results are presented. Estimate units are %fMVC. Upper trapezius did not have any statistical differences.

Table 6.3-4: 10th percentile APDF of milking tasks stratified by muscle

Task 1 vs Task 2	Task 1	Task 2	Difference	Adjusted P-value
Upper Trapezius				
Pre-dipping vs. Cluster Attachment	4.65	2.56	2.087	0.0002
Pre-dipping vs. Wiping	4.65	2.73	1.92	0.0009
Pre-dipping vs. Stripping	4.65	2.71	1.93	0.0008
Cluster Attachment vs. Post-dipping	2.56	3.92	1.35	0.04
Wrist Extensors				
Stripping vs. Wiping	2.71	7.14	4.44	0.007
Stripping vs. Cluster Attachment	2.71	6.88	4.18	0.01
Wrist Flexors				
Stripping vs. Pre-dipping	1.17	3.41	2.25	0.0001
Stripping vs. Post-dipping	1.17	2.63	1.47	0.03
Stripping vs. Wiping	1.17	3.48	2.31	<0.001
Cluster Attachment vs. Pre-dipping	1.89	3.41	1.57	0.02
Cluster Attachment vs. Wiping	1.89	3.48	1.59	0.01

Note: Only statistically significant results are presented. Estimate units are %fMVC.

The ANOVA analysis of the 50th percentile of the APDF did not indicate a statistically significant interaction between task and muscle. However, like mean RMS, the main effects indicated that both task and muscle were statistically significant ($p < 0.001$) with muscle ($F = 18.63$, $p < 0.001$) demonstrating more responsibility for the variation among mean RMS than task ($F = 4.65$, $p = 0.001$). Stratification of the mean 50th percentile APDF data by muscle (Table 6.3-3) yielded statistically significant models for each muscle ($p < 0.001$). The anterior deltoid model indicated that milk cluster attachment was statistically different than all the other tasks ($p < 0.02$) except post-dipping ($p = 0.96$). The biceps brachii model

indicated that wiping was statistically different than stripping ($p<0.001$) and post-dipping ($p=0.002$). Additionally, milk cluster attachment was also significantly different from stripping ($p=0.01$). The upper trapezius model did not reveal any statistically significant differences. The wrist extensor model indicated that wiping was statistically different from all other milking tasks ($p<0.001$) except milk cluster attachment ($p=1.0$). Additionally, milk cluster attachment was statistically different from all other milking tasks ($p<0.01$) except wiping ($p=1.0$). The wrist flexor model determined that wiping was statistically different from all of the other milking tasks ($p<0.009$) except milk cluster attachment ($p=0.12$). There were no other statistically significant differences indicated in the 50th percentile APDF analysis.

The ANOVA analyses of the 10th (static) and 90th (maximum) percentiles of the APDF did not indicate a statistically significant interaction between task and muscle. However, they each illustrated unique differences. The main effects of the 10th percentile of the APDF revealed that muscle and task were both statistically significant ($p<0.006$). However, muscle demonstrated to be more robust than task ($F= 42.60$ $p<0.001$ vs. $F= 3.62$, $p<0.006$). Stratification of the 10th percentile APDF data by muscle (Table 6.3-4) yielded statistically significant models for upper trapezius, wrist flexors, and wrist extensors ($p<0.004$). The anterior deltoid model approached significance ($p=0.07$) but the biceps brachii muscle was not significant ($p=0.32$). The upper trapezius model revealed that pre-dipping had significantly greater static activity than all of the tasks ($p<0.04$), excluding post-dipping. Additionally, milk cluster attachment displayed significantly less static activity than post-dipping ($p=0.04$). The wrist flexor model revealed that stripping had significantly less static activity than all of the other milking tasks ($p<0.02$) excluding milk cluster attachment ($p=0.57$). Additionally, milk cluster attachment had significantly less static activity than pre-dipping ($p=0.02$) and wiping ($p=0.01$). The wrist extensor model indicated that stripping had significantly less static activity than wiping ($p=0.007$) and milk cluster attachment ($p=0.01$).

Table 6.3-5: 90th percentile APDF of milking tasks stratified by muscle

Task 1 vs Task 2	Task 1	Task 2	Difference	Adjusted P-value
<i>Anterior Deltoid</i>				
Pre-dipping vs. Cluster Attachment	29.12	46.90	17.78	<0.0001
Pre-dipping vs. Post-dipping		39.15	10.03	0.003
Pre-dipping vs. Wiping		48.15	19.03	<0.0001
Pre-dipping vs. Stripping		41.23	12.12	0.0002
Post-dipping vs. Cluster Attachment	39.15	46.90	7.75	0.04
Post-dipping vs. Wiping		48.15	8.99	0.01
<i>Biceps Brachii</i>				
Cluster Attachment vs. Pre-dipping	65.53	45.89	19.64	0.01
Cluster Attachment vs. Post-dipping		42.99	22.54	0.002
Cluster Attachment vs. Stripping		42.07	23.46	0.001
Wiping vs. Pre-dipping	67.90	45.89	22.01	0.003
Wiping vs. Post-dipping		42.99	24.91	0.0006
Wiping vs. Stripping		42.07	25.83	0.0003
<i>Upper Trapezius</i>				
Pre-dipping vs. Post-dipping	26.81	32.94	6.13	0.01
Pre-dipping vs. Wiping		36.62	9.81	<0.0001
Pre-dipping vs. Stripping		35.45	8.64	0.0001
Cluster Attachment vs. Wiping	29.78	36.62	6.84	0.004
Cluster Attachment vs. Stripping		35.45	5.67	0.03
<i>Wrist Extensors</i>				
Pre-dipping vs. Cluster Attachment	30.82	49.19	18.33	0.0001
Pre-dipping vs. Wiping		50.51	19.65	<0.0001
Post-dipping vs. Cluster Attachment	32.95	49.19	16.24	0.001
Post-dipping vs. Wiping		50.51	17.56	0.0003
<i>Wrist Flexors</i>				
Wiping vs. Pre-dipping	51.23	22.65	28.58	<0.0001
Wiping vs. Post-dipping		24.60	26.62	<0.0001
Wiping vs. Cluster Attachment		34.90	16.33	0.02
Stripping vs. Pre-dipping	42.69	22.65	20.03	<0.0001
Stripping vs. Post-dipping		24.60	18.09	0.007

Note: Only statistically significant results are presented. Estimate units are %fMVC.

The main effects of the 90th percentile of the APDF revealed that muscle and task were statistically significant ($F=10.87$ $p<0.001$ vs. $F=11.15$ $p<0.001$). The 90th percentile APDF data was also stratified by muscle and task independently. Stratification by muscle yielded stronger, statistically significant models vs stratification by task ($F>9.28$ vs. $F<5.08$). Stratification of the 90th percentile APDF data by muscle (Table 6.3-5) yielded significant models for each muscle ($p<0.001$). The anterior deltoid

model revealed that pre-dipping had significantly less maximum activity than all of the other muscles ($p<0.003$). Additionally, post-dipping had significantly less maximum activity than milk cluster attachment and wiping ($p<0.03$). The biceps brachii model revealed that both milk cluster attachment and wiping displayed significantly greater maximum activity than all of the other milking tasks ($p<0.01$), but were not different from each other ($p=0.99$). The upper trapezius model revealed that pre-dipping had significantly less maximum activity than all of the tasks ($p<0.01$) excluding milk cluster attachment ($p=0.52$). Additionally, milk cluster attachment displayed significantly less static activity than wiping ($p=0.004$) and stripping ($p=0.02$). The wrist flexor model revealed that wiping had significantly greater maximum activity than all of the other milking tasks ($p<0.02$) excluding stripping ($p=0.47$). Additionally, stripping had significantly greater maximum activity than pre-dipping ($p=0.002$) and post-dipping ($p=0.007$). The wrist extensor model indicated that pre-dipping had significantly less maximum activity than wiping ($p<0.0001$) and milk cluster attachment ($p=0.0001$). Additionally, post-dipping had significantly less maximum activity than wiping ($p=0.0003$) and milk cluster attachment ($p=0.001$).

Table 6.3-6: Simple main effects of muscle by task interaction for %MR stratified by muscle

Task 1 vs Task 2	Task 1	Task 2	Difference	Adjusted P-value
<i>Anterior Deltoid</i>				
Pre-dipping vs. Post-dipping	3.43	9.58	6.14	0.0003
Pre-dipping vs. Wiping		8.13	4.70	0.01
Pre-dipping vs. Stripping		10.87	7.44	<0.0001
Cluster Attachment vs. Post-dipping	4.50	9.58	5.08	0.006
Cluster Attachment vs. Stripping		8.13	6.38	0.0002
<i>Wrist Extensors</i>				
Stripping vs. Pre-dipping	5.98	0.45	5.53	0.002
Stripping vs. Post-dipping		1.46	4.53	0.02
Stripping vs. Wiping		1.60	4.38	0.03
<i>Wrist Flexors</i>				
Stripping vs. Cluster Attachment	10.00	2.16	7.84	<0.0001
Stripping vs. Pre-dipping		0.85	9.15	<0.0001
Stripping vs. Post-dipping		2.51	7.49	<0.0001
Stripping vs. Wiping		2.11	7.89	<0.0001

Note: Units are in percentage of time.

Table 6.3-7: Simple main effects of muscle by task interaction for %MR stratified by Task

Muscle 1 vs Muscle 2	Muscle 1	Muscle 2	Difference	Adjusted P-value
<i>Post-dipping</i>				
Anterior Deltoid vs. Biceps Brachii	9.58	1.37	17.78	<0.0001
Anterior Deltoid vs. Upper Trapezius		1.50	10.03	<0.0001
Anterior Deltoid vs. Wrist Extensors		1.46	19.03	<0.0001
Anterior Deltoid vs. Wrist Flexors		2.51	12.12	<0.0001
<i>Stripping</i>				
Anterior Deltoid vs. Biceps Brachii	10.87	2.30	18.33	<0.0001
Anterior Deltoid vs. Upper Trapezius		1.29	19.65	<0.0001
Anterior Deltoid vs. Wrist Extensors		5.98	16.24	0.009
Wrist Flexors vs. Biceps Brachii	9.99	2.30		<0.0001
Wrist Flexors vs. Upper Trapezius		1.29		<0.0001
Wrist Flexors vs. Wrist Extensors		5.98	17.56	0.05
<i>Wiping</i>				
Anterior Deltoid vs. Biceps Brachii	8.13	1.24	28.58	<0.0001
Anterior Deltoid vs. Upper Trapezius		1.30	26.62	<0.0001
Anterior Deltoid vs. Wrist Extensors		1.60	16.33	0.0001
Anterior Deltoid vs. Wrist Flexors		2.11	20.03	0.0005

Note: Units are in percentage of time.

The ANOVA analysis of %MR revealed a statistically significant interaction between muscle and milking task ($p < 0.001$). The simple main effects of the statistically significant interaction indicated that there were several statistically significant differences. Examining the simple main effects by muscle (Table 6.3-6) indicated that the anterior deltoid, wrist flexors, and wrist extensors muscles ($p < 0.002$) had statistically significant interactive effects. The biceps brachii ($p = 0.74$) and the upper trapezius muscles ($p = 0.85$) did not demonstrate statistically significant interactive effects. For the anterior deltoid muscle, milk cluster attachment was revealed to have significantly less %MR than post-dipping ($p = 0.006$) and stripping ($p = 0.002$). Additionally, pre-dipping had significantly less %MR than all other tasks except milk cluster attachment ($p < 0.01$). For the wrist flexors muscles, stripping was indicated to have significantly more %MR than all of the other milking tasks ($p < 0.001$). For the wrist extensors muscles, stripping was indicated to have significantly more %MR than all of the other milking tasks ($p < 0.03$) except milk cluster

attachment ($p=0.08$), which was approaching a significant difference. Examining the simple main effects by task (Table 6.3-7) revealed that post-dipping, stripping, and wiping ($p<0.001$) demonstrated significant interactive effects. Milk cluster attachment and pre-dipping did not have any interactive effects ($p>0.18$). For both post-dipping and wiping, the anterior deltoid muscle was revealed to have significantly greater %MR than all of the other muscles ($p<0.001$). For stripping, the anterior deltoid muscle was revealed to have greater %MR than all of the other muscles ($p<0.009$) excluding the wrist flexors ($p=0.97$). Additionally, the wrist flexors were indicated to have significantly more %MR than all of the other muscles ($p<0.05$) excluding the anterior deltoids ($p=0.97$). No other statistically significant interactive effects were determined from the simple main effects of the muscle by task interaction.

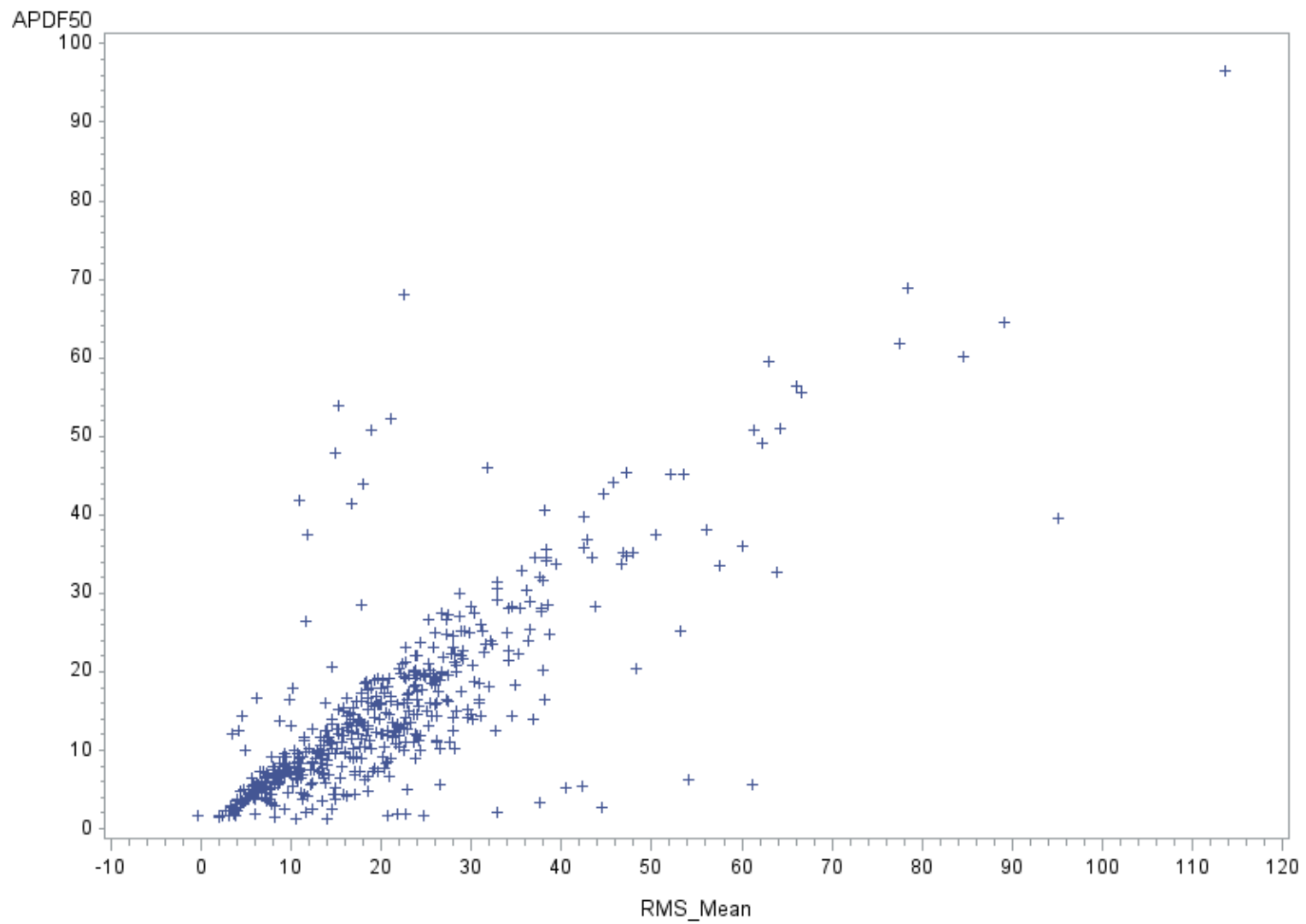


Figure 6.3-1: Correlation between 50th percentile APDF vs. Mean RMS,

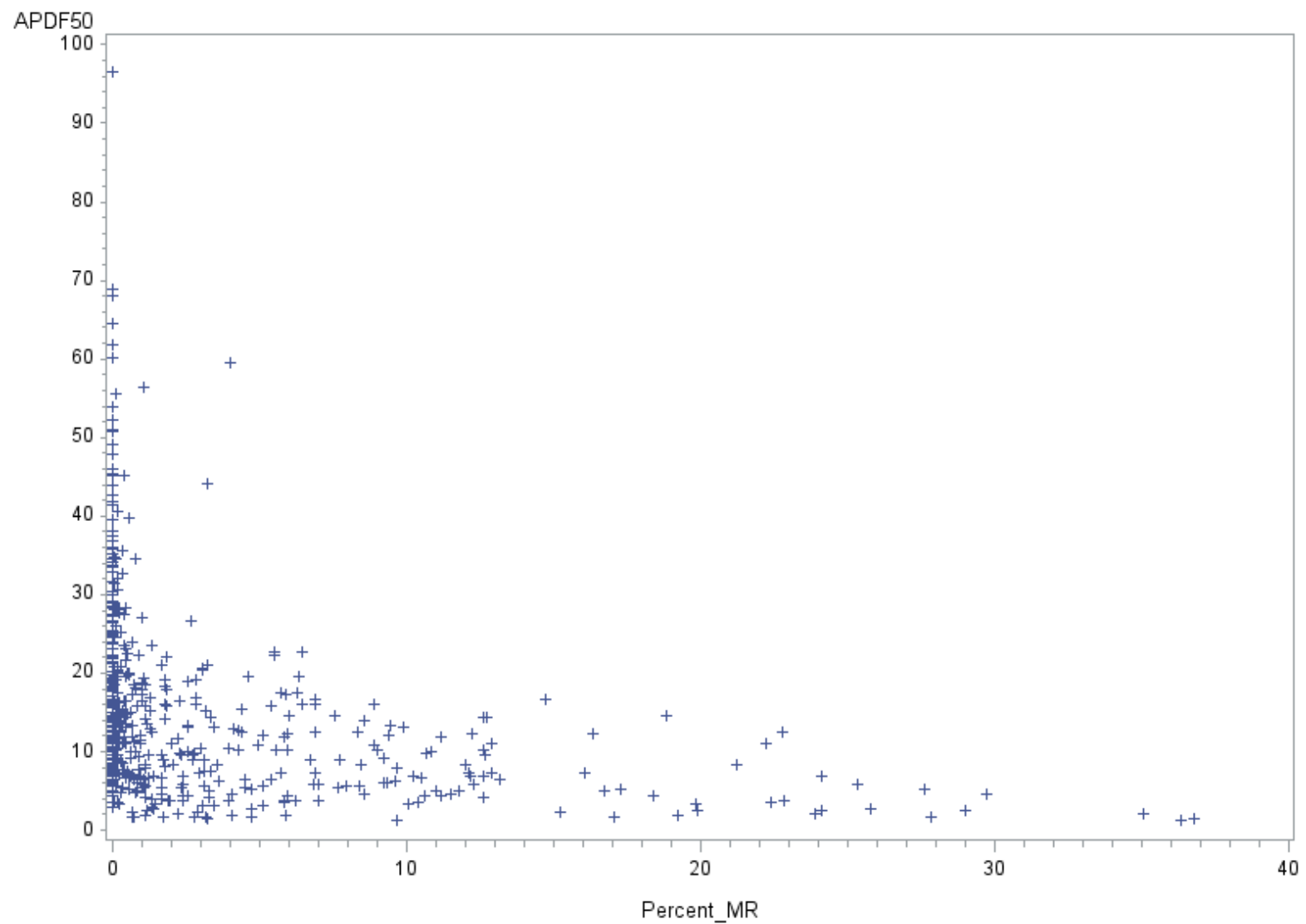


Figure 6.3-2: Correlation between 50th percentile APDF vs %MR

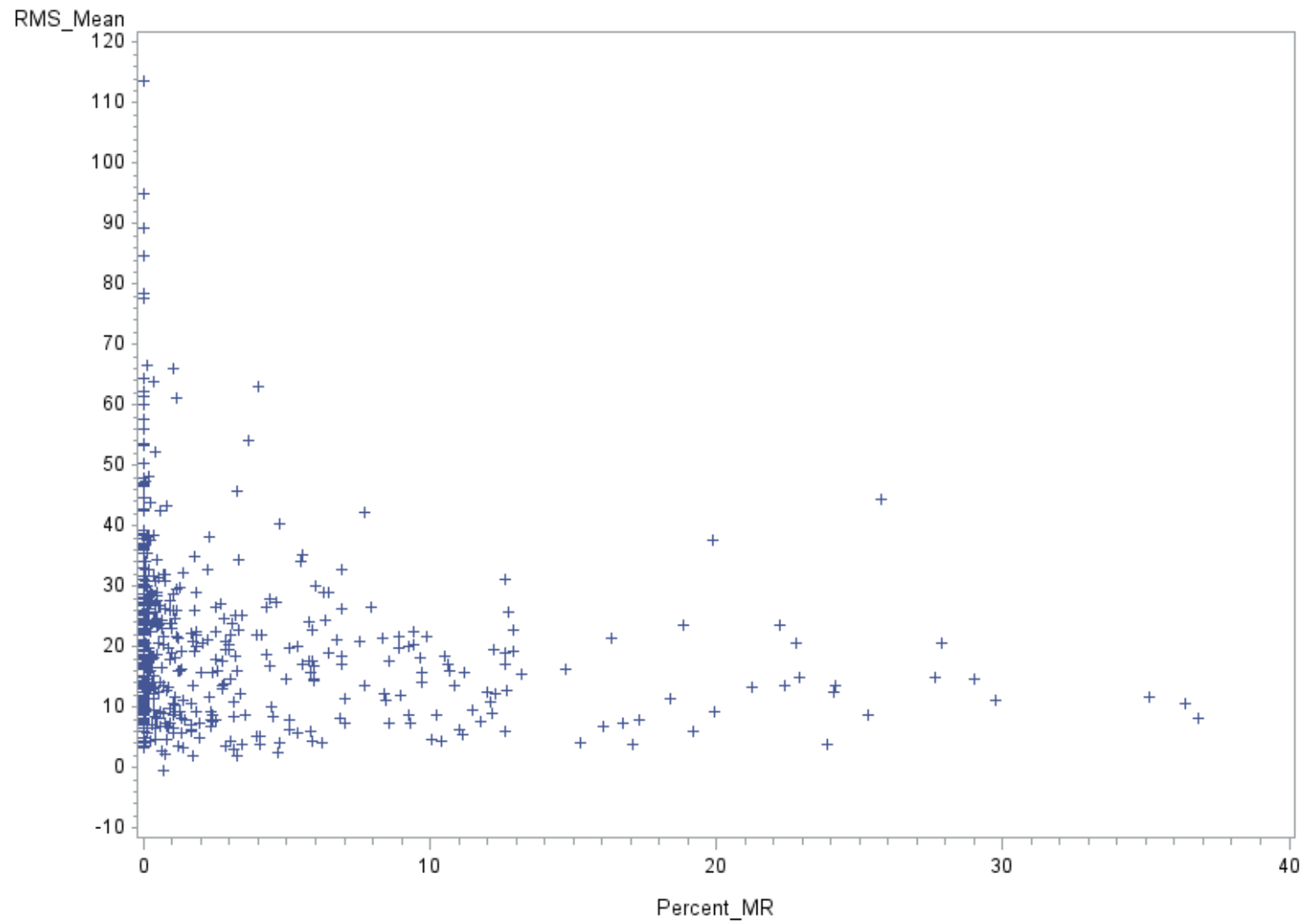


Figure 6.3-3: Correlation between Mean RMS vs. %MR

Table 6.3-8: Overall Correlations of muscle activity profile variables

	Mean RMS	50 th Percentile APDF
%MR	-0.18 (<0.0001)	-0.32 (<0.0001)
50 th percentile APDF	0.78 (<0.0001)	

Table 6.3-9: Correlations of muscle activity profile variables stratified by task

	Mean RMS	50 th Percentile APDF
<i>Pre-dipping</i>		
%MR	-0.15 (0.11)	-0.22 (0.02)
50 th percentile APDF	0.90 (<0.0001)	
<i>Stripping</i>		
%MR	-0.35 (<0.0003)	-0.43 (<0.0001)
50 th percentile APDF	0.74 (<0.0001)	
<i>Wiping</i>		
%MR	-0.14 (0.13)	-0.37 (<0.0001)
50 th percentile APDF	0.73 (<0.0001)	
<i>Cluster Attachment</i>		
%MR	-0.29 (0.003)	-0.37 (<0.0001)
50 th percentile APDF	0.85 (<0.0001)	
<i>Post-dipping</i>		
%MR	-0.13 (0.17)	-0.28 (0.003)
50 th percentile APDF	0.70 (<0.0001)	

Note: Correlations were not statistically compared between tasks

Table 6.3-10: Correlations of muscle activity profile variables stratified by task

	Mean RMS	50 th Percentile APDF
<i>Anterior Deltoid</i>		
%MR	-0.13 (0.18)	-0.38 (<0.0001)
50 th percentile APDF	0.63 (<0.0001)	
<i>Biceps Brachii</i>		
%MR	-0.15 (<0.14)	-0.34 (0.0005)
50 th percentile APDF	0.73 (<0.0001)	
<i>Upper Trapezius</i>		
%MR	-0.28 (0.004)	-0.42 (<0.0001)
50 th percentile APDF	0.78 (<0.0001)	
<i>Wrist Extensors</i>		
%MR	-0.25 (0.01)	-0.36 (0.0002)
50 th percentile APDF	0.87 (<0.0001)	
<i>Wrist Flexors</i>		
%MR	-0.22 (0.03)	-0.26 (0.007)
50 th percentile APDF	0.84 (<0.0001)	

Note: Correlations were not statistically compared across muscles

Correlation analysis determined strong, statistically significant positive correlation (Figure 6.3-3) between mean RMS and 50th percentile APDF ($R=0.78$, $p<0.001$) from an overall view (Table 6.3-8). Additionally, %MR had statistically significant negative correlations with and 50th percentile APDF (Figure 6.3-2) ($R=-0.32$, $p<0.001$) mean RMS (Figure 6.3-3) ($R=-0.18$, $p<0.001$). When stratifying the data by task (Table 6.3-9) a strong, statistically significant positive correlation between mean RMS and 50th percentile APDF was found for each task ($r>0.69$, $p<0.001$). Additionally, %MR had statistically significant negative correlations with 50th percentile APDF for each task ($r<-0.22$, $p=0.02$). However, %MR only had a statistically significant negative correlation with mean RMS for milk cluster attachment and stripping ($r<-0.28$, $p<0.003$). When stratifying the data by muscle (Table 6.3-10), mean RMS had a strong positive statistically significant correlation with 50th percentile APDF ($r=0.62$, $p<0.001$) for all the muscles. Additionally, %MR had a statistically significant negative correlation with 50th percentile APDF ($r<-0.26$, $p<0.005$) for all muscles. However, %MR had a significant negative correlation with mean RMS for only the upper trapezius, wrist flexors, and wrist extensors muscles ($r<-0.21$, $p<0.03$).

6.4 DISCUSSION

The main focus of this investigation was to evaluate the muscular load associated with each of the five milking tasks. This was accomplished by creating muscle activity profiles for the upper trapezius, anterior deltoid, biceps brachii, wrist flexors, and wrist extensors muscles. The profiles included mean RMS, %MR, 10th percentile APDF, 50th percentile APDF, and 90th percentile APDF. The muscle activity profiles were then stratified for each of the milking tasks and evaluated to identify differences between milking tasks and correlations were examined for exploratory analysis.

Muscle activity was quantified through the use of sEMG to identify differences between the milking tasks. The exploratory correlational analysis revealed that the variables used to describe the sEMG were appropriate with significant correlations for non-stratified activity. Mean RMS and 50th

percentile APDF both represent average values of activity and are expected to be strongly correlated. At the same time it would be expected for there to be negative correlations between measures of average muscle activity and %MR. However, when stratifying by both task type and muscle the strength and significance of the %MR with mean RMS drops substantially. As 50th percentile APDF with %MR does not vary in significance it is possible that 50th percentile APDF would be the more appropriate measure for average muscle activity.

The analysis of the muscle activity profiles revealed that there are differences between the milking tasks. Examining mean RMS and APDF percentiles revealed that certain tasks require greater muscular load than others. Wiping presented statistically significant higher muscle activity for many of the muscles compared to other tasks. However, cluster attachment did not consistently reveal significantly greater muscle activity for all muscles. Furthermore, stripping did not consistently separate itself from the other milking tasks. These results suggest that the initial hypotheses were partially rejected. Stripping was not statistically distinguishable on a consistent basis pre-dipping and post dipping to be deemed more difficult. Additionally, cluster attachment was not revealed to be significantly different from wiping rejecting the hypothesis that cluster attachment was the most difficult. However, wiping and cluster attachment were significantly greater than the other tasks on a consistent basis to be deemed more difficult, which is similar to what had been established in previous literature (Stål, Moritz et al. 1996, Pinzke, Stål et al. 2001, Stål, Pinzke et al. 2003, Douphrate, Gimeno et al. 2013).

In addition to field research, my findings are similar to experimental research. German researchers (Jakob and Liebers 2009, Liebers, Jakob et al. 2009, Jakob and Liebers 2011, Jakob, Liebers et al. 2012) replicated the large-herd dairy atmosphere within a laboratory environment to analyze the milking tasks rather than collect field research. The researchers reported muscle activity associated with

milk cluster attachment using a conventional milking unit with a weight of 1.4 kg. Their findings were very similar to those reported in this present study's muscle activity profiles (Table 6.3-1); anterior deltoid 23.39% vs. 22.3% MVC, biceps brachii 13.21% vs. 27.6% MVC, upper trapezius 17.09% vs. 14.84% MVC, wrist flexors 10.51% vs. 14.57% MVC, and wrist extensors 13.25% vs. 27.1% MVC. The results for the anterior deltoid, upper trapezius and wrist extensors muscles from this current paper suggest that field collected data are similar to laboratory simulation. Although there are noticeable differences for the biceps brachii and the wrist flexors muscles, this could be the result of a controlled laboratory environment vs. the milking parlor. Unfortunately, no other comparison can be made as %MR and APDF percentiles were not calculated by Jakob, Liebers et al. (2012), and body posture analysis was not accomplished in this present study.

Pinzke, Stål et al. (2001) studied milking work tasks in a loose housing milking system in European dairy parlors. The authors examined the muscular load associated with stripping, wiping, and milk cluster attachment through use of multiple APDF percentiles. The results indicated that, for the biceps brachii muscle, milk cluster attachment displayed a muscular load with the maximum APDF at 29% MVC, the mean APDF at 14% MVC, and the static APDF at 4.5% MVC. Wiping displayed the maximum APDF at 20% MVC, the mean APDF at 9.7% MVC, and the static APDF at 3.3 %MVC. Stripping was revealed to require a maximum APDF of 12% MVC, a mean APDF of 5.3% MVC, and a static APDF of 1.7% MVC. In this current paper, milk cluster attachment revealed, for the biceps brachii muscle, the maximum APDF at 65.5% MVC, mean APDF at 24.1% MVC, and static APDF at 7.7% MVC. Wiping revealed a maximum APDF at 67.9% MVC, a mean APDF at 28.1% MVC, and a static APDF at 9.1% MVC. Stripping required a maximum APDF at 42.1% MVC, a mean APDF at 15.8% MVC, and a static APDF at 6.9% MVC. Although the biceps brachii muscle presented higher muscle activity values in this current paper, the tasks have similar ratios for each respective paper. The wrist flexors muscles displayed a similar pattern, though not as pronounced. The Pinzke, Stål et al. (2001) investigation presents, for the

wrist flexors muscles, that wiping displayed a maximum APDF at 50% MVC, a mean APDF at 27% MVC, and a static APDF at 11% MVC. Milk cluster attachment required maximum APDF at 45% MVC, mean APDF at 18% MVC, and a static APDF at 6.6% MVC. Finally, stripping exhibited a maximum APDF at 40% MVC, a mean APDF at 20% MVC, and a static APDF at 7.9% MVC. To compare, in this current paper, the wrist flexors muscles revealed wiping to have maximum APDF at 51.3% MVC, a mean APDF at 16.3% MVC, and a static at 3.5% MVC. Milk cluster attachment exhibited a maximum APDF at 34.9% MVC mean APDF at 12.1% MVC, and static at 1.9% MVC. Stripping displayed a maximum APDF at 42.7% MVC mean APDF at 10.4% MVC, and static at 1.2% MVC. Although in this current paper the wrist flexors muscles presented lower muscle activity values, there was a noticeable ratio between the percentiles of APDF that was similar in both investigations. Differences are to be expected between this current study and Pinzke, Stål et al. (2001) because each study used very different herd sizes. This current paper examines U.S. large-herd parlors with more than 1500 cows where Pinzke, Stål et al. (2001) examined Swedish small-herd parlors with less than 500 cows. However, the muscle activity results of this current paper are still similar to previously published literature that assess individual milking tasks through sEMG (Pinzke, Stål et al. 2001).

Although there is no published literature that directly compares the milking tasks in large-herd parlors to the milking tasks in small-herd parlors, the difficulty of milking tasks has been examined in both parlor settings. In Swedish small-herd dairy farms, Stål, Moritz et al. (1996) used mail-in surveys and reported that the most strenuous milking task was stripping, followed by milk cluster attachment. As previously discussed, Pinzke, Stål et al. (2001) examined stripping, wiping, and milk cluster attachment milking tasks in a small-herd environment. The authors determined that milk cluster attachment produced the largest muscular load in the biceps brachii muscle, and wiping produced the highest muscular load in the forearm flexors muscles. Stripping displayed the least amount of muscular load in both muscles suggesting that milk cluster attachment and wiping are more strenuous tasks. Patil,

Gilkey et al. (2010) examined milking tasks in dairy parlors with herds larger than 500 cows. The authors used two ergonomic exposure metrics, the strain index and the hand activity level, to analyze the milking work. The results from the strain index measure indicated that milk cluster attachment, stripping, and wiping were all the most difficult. Douphrate, Gimeno et al. (2013) concluded from worker self-reports that stripping and cluster attachment were the most difficult milking tasks in large-herd operations. Most recently, Silvetti, Gismondi et al. (2014) examined pre-dipping and wiping through the milking of six cows. The authors did not statistically compare the muscle activity associated between the tasks, but from simple observation of the results wiping displayed higher muscle activity in the anterior deltoid muscle (24.8% MVC vs. 13.1% MVC). This suggests that wiping would be more difficult than pre-dipping. The analysis of the muscle activity in this current study suggest that milk cluster attachment, stripping, and wiping are more strenuous than pre-dipping and post-dipping. Additionally from observation, wiping displayed the highest average muscle activity, mean RMS and mean APDF, of all the milking tasks for each individual muscle. These results are similar to what has been previously reported in current literature. Analysis of %MR did not provide clear cut comparisons between the milking tasks. Stripping was revealed to have statistically more %MR than milk cluster attachment in the anterior deltoid. For the wrist flexors, stripping was revealed to have more %MR than both milk cluster attachment and wiping. In the wrist extensors muscles, stripping was revealed to have statistically more %MR than wiping. These results suggest that stripping was less strenuous than milk cluster attachment and wiping. Pinzke, Stål et al. (2001) examined stripping, wiping, and milk cluster attachment through %MR. The authors determined that wiping had statistically less %MR than milk cluster attachment. Observationally, stripping displayed more %MR than both wiping and milk cluster attachment. These results suggest that stripping was the least strenuous task and wiping was the most strenuous, both of which are very similar to the %MR findings of this current paper. Overall, when combining the muscle activity findings of this paper with the %MR findings of this paper, wiping and milk

cluster attachment can be described as the most difficult and strenuous of the milking tasks. However, each of the milking tasks surpasses the recommended activity levels to prevent possible development of MSS and WRMSDs.

Amplitude probability distribution function was developed to analyze and assess the risk of developing muscular disorders (Jonsson 1982). The APDF percentiles have been used to analyze and assess sEMG in work environments (Mathiassen and Winkel 1991, Nordander, Hansson et al. 2000, Fethke, Gerr et al. 2007, Ostensvik, Veiersted et al. 2009) and establish recommendations for muscle activity levels associated with repetitive work. Muscular load recommendations have been developed for repetitive work; the static load (10th percentile) should be below 2% MVC and never above 5% MVC, the mean load (50th percentile) should be below 10% MVC and must never exceed 14%, and the maximum load (90th percentile) should be below 50% MVC and must never exceed 70% MVC. When examining the overall activity for each task, the static APDF load was above 2% MVC for each task but below 5% MVC. The mean APDF load has attaching and wiping above 14% MVC, pre-dipping and post-dipping at 14% MVC, and stripping was at 13% MVC. The maximum ADPF load had all the tasks below 50% MVC, except wiping (51% MVC). However, it is important to recall that this analysis examined the muscle activity associated just with the milking tasks and eliminated any down time between different milking tasks examining rather a work cycle instead of a full work-rest cycle. The specific values returned from the APDF analysis demonstrate a possibility that tasks are above recommended thresholds, though, with inclusion of downtime could drive the actual values below the recommended thresholds. Even though activity could be below recommended APDF thresholds when examining the work-rest cycle, it is important to recall that the milking tasks revealed different levels of activity. These APDF percentile values suggest that cluster attachment and wiping tasks in U.S. large-herd parlors require the most muscle activity and that all of the milking tasks could potentially place workers at an increased risk to develop MSS and WRMSDs.

Interventions have been examined for milk cluster attachment (Stål, Pinzke et al. 2003, Jakob and Liebers 2011). The use of a support arm to hold the milk cluster lowered mean APDF from 14% MVC to 10% MVC in the biceps brachii muscle and reduced the static APDF of the wrist flexors muscles from 6% MVC to 4% MVC (Stål, Pinzke et al. 2003). Jakob, Liebers et al. (2012) determined that reducing the weight of the cluster attachment from 2.4 kg to 1.4 kg reduced muscle activity by up to 20%. Another investigation by the same researchers determined that further changing the task from a single 1.4 kg milk cluster to a system with four individual 300g suction cups reduces overall muscle activity about 30% (Jakob and Liebers 2011). However, interventions have only been examined for the milk cluster attachment task. The results of the current paper suggest that the other milking tasks, primarily wiping, need to be given more attention in order to reduce risk for MSS and WRMSDs development.

As described, varying the milk cluster weight has been evaluated as has use of a mechanical support to assist with cluster attachment. However, there has been little investigation into the other milking tasks. Teat scrubbers (Puli-Sistem, Azzanello, Italy) have been developed to assist with stripping, but the scrubbers still require very similar movements arm movements to accomplish the task, which does not reduce exposure to all of the risk factors. Additionally, stripping could be assisted with use of a single suction cup to initiate milk flow, with a similar design as presented by (Jakob and Liebers 2011). Use of a suction cup, could drastically reduce the reliance on the wrist flexor muscle group as the teats would not need to be squeezed by hand. However, wiping has not been examined directly with interventions. Wiping, which was demonstrated to be one of the most difficult tasks, would require ingenuity to alleviate because the entire udder needs to be cleaned along the specific teat area and the task needs to be completed with high precision at a high rate. Practical interventions should focus on limiting overall exposure through job rotation or increasing number of rest breaks through the shift. Future research should examine these interventions to establish best practices.

6.4.1 LIMITATIONS

Muscle activity was quantified through use of sEMG. The raw data was collected from six different dairies in Eastern Colorado. The dairies all had similar herd size (2000+), but were not identical. Differences in herd size led to deviations within the data collection period. Subjects completed the milking work for the length of time required to complete the first full pen of cattle. This time lasted on average 50 minutes. Differences in collection time allowed for the possibility of additional task data to be collected. More importantly, not all of the dairies had the same parlor configuration design. Two of the dairies used rotary parlors, two used herringbone configurations, and two used parallel design. Because parlor configuration was not used to stratify the data, the analysis assumes that there are no differences between those parlors. There was a safe assumption between herringbone and parallel configurations because of similarities between the designs. However, rotary designs are very different. A limitation occurs in the task analysis because rotary parlors have workers constantly performing the same task or set of tasks without breaking the cycle, unlike the other parlor configurations. It was possible that data from the rotary parlors may overestimate required muscle activity and minimize %MR.

A second set of limitations arose from the completion of the milking tasks. Subjects were instructed to complete the milking tasks using the instrumented dominant arm to make certain the sEMG data represented the milking tasks. This instruction created a few problems that affected the investigation and analysis. First, subjects did not complete an equal number of each milking task. The subjects were asked to complete the work as per normal operation, but some subjects completed more sets of certain tasks compared to other subjects. Secondly, the milking work was routine for the subjects, and normally the non-instrumented arm was used to complete milking tasks. For example, some of the subjects were accustomed to completing pre-dipping with the non-instrumented arm and

wiping with the instrumented arm. Subjects were actively reminded to use the instrumented arm for each task, but there were occurrences during sets of tasks where the non-instrumented arm would be used. These occurrences could have lowered the mean RMS and APDF activity, while possibly increasing the %MR. Additionally, instructing the subjects to only use the instrumented arm also creates in itself another limitation for the task analysis. Constant use of one arm changes the actual milking routine, which may provide an overestimation of the activity required for the tasks and an underestimation of %MR. Finally, the subjects may be less efficient in their movements as the actions are not customary. Use of bilateral sEMG data collection would alleviate these specific limitations in future studies. Lastly, this investigation takes an assumption that the data collected at the start of the shift was representative of the entire shift. Almost all large-herd parlors run milking shifts lasting between eight to twelve hours. Therefore, by collecting at the very start of the shift, the investigation does not account for any effects that muscle fatigue may play on activity requirements. Muscle fatigue could have a direct impact on APDF percentiles and %MR. Future studies should consider collecting data throughout the milking shift that would provide insight to the effect of muscle fatigue.

In addition to limitations in the study protocol, this study also suffers from limitations associated specifically with analyzing sEMG. First, the processed sEMG data has to be normalized in order to compare between subjects and tasks. The normalization procedures are frequently designed to isolate a muscle and ensure that a maximum contraction is created. In this current study, true MVCs were not gathered as functional movements where used to accommodate the field setting, which could possibly generate less activity. More importantly the biceps brachii was not gathered through a biceps specific movement, but rather through the wrist flexors and extensors procedure for the sake of time. The higher levels of activity determined from the biceps brachii could be a result of weaker than expected fMVC, which when normalizing returns an overestimation of the activity. Secondly, the fMVC protocols used isometric contractions to normalize a dynamic contraction. Although this is a common procedure, a

dynamic contraction can produce greater activity than an isometric contraction (Basmajian and De Luca 1985). Normalizing a dynamic activity with isometric fMVCs could lead to a possible overestimation of average activity as a true maximum was not gathered.

6.5 SUMMARY AND CONCLUSIONS

Milk cluster attachment and teat wiping were revealed to be the most strenuous of the five milking tasks when examining the complete muscle activity profiles. Pre-dipping and post-dipping were determined to require the least amount of mean muscle activity. However, all of the milking tasks were revealed to require mean APDF activity that exceeds what is recommended in their respective work cycles. It is possible that when examining the full work-rest cycles for each milking task that average muscle activity decreases and muscular rest would increase. Nevertheless, these results suggest that the milking tasks place workers at an increased risk for developing MSS and WRMSDs, such as tendonitis and carpal tunnel syndrome.

Although this investigation presents novel information regarding milking tasks in large-herd operations, there is still a need for continued endeavors in milk task analysis. Muscle fatigue was not examined and the impact of fatigue was not taken into account. More data are needed to approximate the possible effects of muscle fatigue. In addition to the effects of fatigue, bilateral analysis could also provide an even more accurate representation of the muscle activity associated with the milking tasks because it would not disrupt the worker's normal milking routine. Future dairy research seeking to develop, assess, or compare intervention strategies to assist milkers should consider examining the effects of fatigue.

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7. CHAPTER 7- COMPARISON OF UPPER LIMB MUSCLE ACTIVITY BETWEEN US AND ITALIAN INDUSTRIALIZED DAIRY OPERATIONS

7.1 INTRODUCTION

Dairy farming has been practiced all over the world by humans for thousands of years (Kalumuddin 2011). Although some farms still practice original hand milking techniques, the dairy industry has become modernized with use of vacuum bucket milking and dairy parlor systems (USDA 2014). In addition to having advanced technologically, average herd size in the United States has increased steadily to meet milk demands (USDA and Dairyman 2013). In the last 10 years average U.S. herd size has increased from 123 to 196 cows per farm in order to compete with the growing numbers of large-herd (1000-1500 cows) and mega-herd (1500+ cows) farms (NASS 2013). Conversely, within the European Union average herd size can vary from 3 to 141 cows per farm (Marquer 2014). This is primarily because milk production in the EU is pre-established for each country, and each country is not permitted to exceed that determined value (European Commission, 2013). Yet, regardless of herd size, musculoskeletal disorders (MSDs) among milkers have been prevalent in European (Stal 2000, Pinzke, Stål et al. 2001) and U.S. dairies (Doupbrate, Gimeno et al. 2013, Doupbrate, Kolstrup et al. 2013).

Work-related MSDs develop from repeated exposure to work tasks associated with forceful exertions, high number of repetitions, and awkward body postures (Punnett and Wegman 2004). The modern milking industry exposes dairy milkers to these risk factors. Stal (2000) examined milking in two systems: tethering, similar to old hand milking procedure with a cluster device, and loose-housing, where cows enter fixed stalls in a parlor. The authors determined that high muscular loads in the wrist flexor and extensor muscles in combination with awkward hand positions were present during milking, which could contribute to wrist and hand injuries. The loose-housing system reduced overall muscle activity, but also decreased muscular rest. Pinzke, Stål et al. (2001) expanded Stal (2000) findings by

using surface electromyography (sEMG) and electrogoniometry to examine three specific tasks of the milking work: drying, pre-milking, and cluster attachment. The authors determined that each of the tasks presented with high loads of muscular activity as well as awkward wrist positioning. This combination of risk factors might contribute to developing wrist injuries. Stål, Pinzke et al. (2003) once again examined wrist postures in loose-housing dairy parlors and compared them to modern rotary parlors, where cows enter a stall that is on top of a rotating platform. The authors determined that this newer parlor configuration provided less awkward wrist positions, but increased the repetitiveness of the work tasks. Regardless of milking parlor design, from a muscular standpoint, milking has been documented as strenuous work requiring high muscular load and awkward positions in small-herd dairies.

Loose-housing parlor systems are also used in the U.S. dairy industry. However, they more commonly referred to by the position the cows enter the stalls: herringbone, parallel, and rotary. In a herringbone parlor the cows enter each stall at an angle between 45 to 70 degrees (Figure 7.1-1). In parallel parlors the cows enter stalls at a 90 degree angle from the walkway with the cows' hind legs facing the worker. Rotary parlors require cows to enter individual stalls on a rotating platform with their hind legs facing outward on the circular platform (Doupbrate, Fethke et al. 2012). Muscle strain in U.S. dairy industry workers has also been examined. Doupbrate and Rosecrance (2010) used sEMG to assess muscle force from the upper trapezius, anterior deltoid, and forearm flexors and extensors during a full shift of milking within a loose-housing dairy parlor. Amplitude probability distribution function (APDF), a common measure for average muscle activity (Jonsson 1982), results revealed high peak loads in the anterior

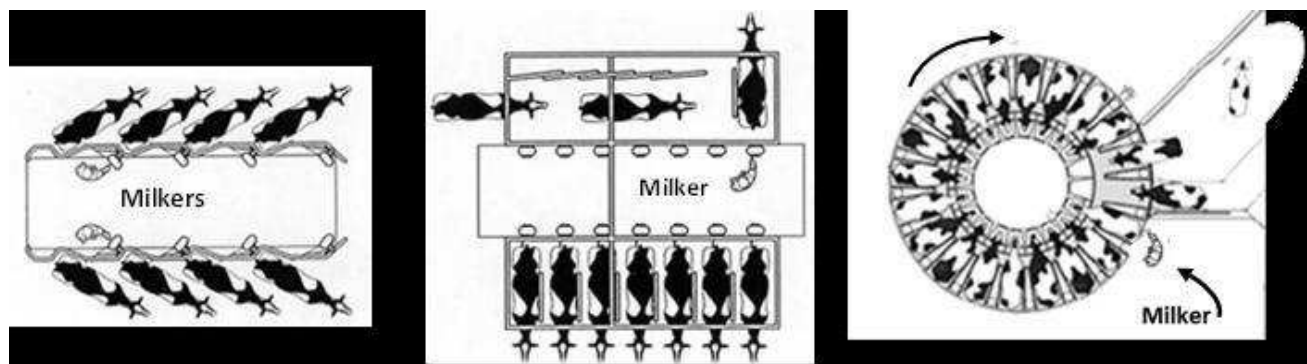


Figure 7.1-1 Dairy parlor configurations (Doupbrate, Kolstrup et al. 2013) (Left) Herringbone configuration, (Center) Parallel configuration, (Right) Rotary configuration

deltoid and forearm flexor muscles. Rosecrance and Doupbrate (2012) re-examined muscle activity in combination with joint positioning over the course of the full milking shift. Exposure variation analysis revealed a majority of the muscle contractions to be less than one second in duration and forceful. From postural analysis the authors determined that workers elevated their shoulder above 45 degrees for roughly 40% of the work shift. Forceful exertions and repetitive motions such as these, combined with awkward postures present an increased risk for MSDs such tendonitis.

Prevalence of MSDs and their precursors, musculoskeletal symptoms (MSS), have been well documented on European (Stal 2000, Pinzke, Stål et al. 2001, Kolstrup 2012) and U.S. (Sung, Zurcher et al. 2005, Doupbrate, Gimeno et al. 2013, Doupbrate, Kolstrup et al. 2013) dairy farms. Additionally, as previously presented, the effects that milking has on upper extremity musculature has also been well documented in both geographies. However, direct comparisons between European and U.S. milking systems have not been undertaken. Dairy systems are similar on both continents as they commonly operate loose-housing dairy parlors. However, differences in herd size between the two regions greatly affect volume of work and task specialization (Doupbrate, Gimeno et al. 2013), posing challenges in comparing small-herd and large-herd findings without direct comparisons to establish similarities and differences. Large-herd dairies, unlike small-herd operations, run 24 hours a day, seven days a week milking the entire herd two to three times per day (USDA 2007). This operational schedule creates an

assembly like procedure that increases the worker population to ergonomic risk factors including repetitive motion and excessive muscular strain. As the United States continues to trend towards large-herd dairies (Doupbrate, Kolstrup et al. 2013) and the European Union maintaining small-herd dairies (Marquer 2014), there is a need to compare the two dairy operations to understand differences and similarities to combat the high prevalence of MSDs that exist.

The most appropriate method to compare the dairy operations would be through the common thread, the milking tasks. The five fundamental work tasks performed by workers in large-herd and small-herd dairy parlors are (1) pre-dipping of the teats with a sanitization solution, (2) stripping of each teat to stimulate milk letdown and inspect for milk abnormalities, (3) wiping of the teats to clean them, (4) attaching the milking cluster, (5) and post-dipping of each teat with a sanitization solution (Doupbrate, Fethke et al. 2012). The aim of this research is to compare muscle activity associated with the milking tasks in large and small-herd dairy operations. Milking tasks have been analyzed in small-herd operations using sEMG (Stål, Hansson et al. 2000, Pinzke, Stål et al. 2001, Stål, Pinzke et al. 2003). Additionally, full shift dairy studies in large-herd environments (Doupbrate and Rosecrance 2010, Rosecrance and Doupbrate 2012) examining ergonomic exposures in dairies assessed muscle activity from the anterior deltoid, trapezius, wrist flexors, and wrist extensors using sEMG. To date, there are no reports in the peer-reviewed literature that quantify and compare muscle activity data gathered from large-herd, Loose-housing parlor systems in the U.S. with muscle activity data collected from small-herd, Loose-housing parlor systems in Europe. The primary aim of the present research was to discern if there are differences between large and small-herd parlor systems (conducted in the U.S. state of Colorado and the Lombardy region of Italy) with regards to muscle activity and muscular rest among milking workers. Because large-herd dairy operations have a greater volume of work, I hypothesize that the large-herd environment will reveal greater muscle activity and less muscular rest than the small-herd environment across the milking tasks.

7.2 METHODS

7.2.1 *LARGE-HERD DAIRY PARTICIPANTS*

Twenty-nine healthy subjects (dairy parlor workers) were recruited from three large-herd dairy farms in the U.S. state of Colorado. All the subjects were Latino(a) aged 18 years or older. Twenty-eight participants were male and one was female. All subjects were free from muscular pain at the time of data collection. To maintain homogeneity of the study population, all subjects were dairy workers performing the following milking tasks: pre-dipping, stripping, wiping, attaching milking clusters, and post dipping. Subjects were compensated \$30 for their participation. This study was approved by the Institutional Review Board at the universities in both countries. Dairy management and all subjects provided approval and written informed consent, respectively.

7.2.2 *SMALL-HERD DAIRY PARTICIPANTS*

Thirty-nine dairy workers were recruited from twenty-one small dairy farms in the Lombardy region of Italy. All the subjects were aged 18 years or older and male. Subjects were of mixed ethnic backgrounds including Italian, Romanian, Indian, Tunisian, Pakistani, and Egyptian. Workers were asked if they had any presence of musculoskeletal symptoms (MSS). All declared they were free from muscular pain at the time of data collection. To maintain homogeneity of the study population, all subjects were dairy workers performing the following milking tasks pre-dipping, stripping, wiping, attaching milking clusters, and post dipping. Dairy management and all subjects provided approval and written informed consent, respectively.

7.2.3 DATA COLLECTION PROTOCOLS

Anthropometric measurements and sEMG data from the anterior deltoid, upper trapezius, biceps brachii, wrist flexors, and wrist extensors were collected using a previously described collection procedure (Mixco, Masci et al. 2015). Anthropometric and sEMG data were collected and processed identically in both locations to ensure consistency in the data from Italy and Colorado.

7.2.3.1 Functional Maximum Voluntary Contraction (fMVC) Protocol

Functional maximum voluntary contractions (fMVC) were collected to normalize the sEMG data in order to appropriately compare muscle groups. A 30 second baseline resting sEMG signal was collected to calculate the minimum resting activity to use in the normalization procedure. Subjects then performed three fMVC procedures (Mixco, Masci et al. 2015) to obtain functional maximum contractions for the anterior deltoid, upper trapezius, biceps brachii, wrist flexors, and wrist extensors muscles. At least three fMVC trials were administered for each subject for each muscle group. Over a three second countdown, subjects were told to ramp up to a maximum muscular effort, hold the maximum effort for four seconds, and then relax. Subjects were verbally encouraged to maintain a maximum contraction. One minute rest periods were provided between trials to minimize muscle fatigue. Upon completion of each trial, a maximum was calculated using the middle three seconds of the root mean square (RMS) processed sEMG trial data. The mean and standard deviation were determined to calculate covariance. If the covariance was above 15% for the three fMVC trials, additional trials were repeated up to a maximum of five trials.

Functional MVCs for the anterior deltoid and upper trapezius were calculated using the procedures established by Boettcher, Ginn et al. (2008). For the anterior deltoid, this was accomplished by raising the arm 120 degrees in the sagittal plane from a relaxed state. Pressure was applied

proximally below the elbow to engage the anterior deltoid muscle. Subjects were instructed to maintain their arm in the elevated position. The upper trapezius fMVC was gathered using the "empty can" method (Boettcher, Ginn et al. 2008). The subjects were instructed to place their arm at 90 degree flexion in the scapular plane and internally rotate the arm forcing the palm to face outward away from body centerline. Finally, subjects were instructed to simulate holding an empty soda can. Downward pressure was applied proximally below the elbow, as the subject maintained the arm in aforementioned position. Wrist flexors and wrist extensors' fMVCs were obtained simultaneously through a co-contraction with the use of a hand dynamometer (Biometrics G100, England). Subjects were instructed to form a power grip around the handle of the hand dynamometer and keep the elbow in 90 degrees of flexion. Subjects were instructed to grip with maximum effort while maintaining elbow flexion. Functional MVCs for the biceps brachii muscle were determined using the values generated from the wrist flexor and extensors procedure.

7.2.3.2 Milking tasks

Subjects in large and small herd dairies had relatively similar milking routines. All of the large-herd dairy subjects completed five individual milking tasks: pre-dipping, stripping, wiping, attaching milking clusters, and post dipping. Italian subjects predominantly completed stripping, wiping, and attachment of milking clusters. Typically, pre-dipping, wiping, and post-dipping were completed with one hand while stripping and attaching required the use of both. For tasks that could be completed using either the right or left arm, subjects were instructed to use the instrumented arm. Aside from this stipulation, subjects performed the tasks per their normal routine in parallel and herringbone configured milking parlors. In rotary type parlors subjects were asked to rotate amongst the three different workstations. At the first work station, a subject completed pre-dipping and stripping directly after cows entered stalls. At the second station, the subject completed wiping and attaching. Finally, at the third

station, the subject completed post dipping on cows that had been milked. By asking subjects to rotate every 20 minutes, each subject completed all the milking tasks.

To develop muscle activity profiles, it was necessary to document when the milking work was commenced. This was accomplished with the use of an event marker and a stopwatch. When the subjects began the milking shift, the event marker was triggered to mark the start within the EMG stream. A stopwatch was simultaneously started to document the total time of milking work. Data was collected for the length of time it took to completely milk a pen of cattle (225-275 cows), between 45 and 90 minutes. Once milking work was concluded the time was documented and the stopwatch turned off. The sample period was a single pen of cows rather than a fixed time frame to allow for the removal of the EMG equipment from the subjects during their short breaks in between pens when milking activity was paused.

7.2.4 MUSCLE ACTIVITY PROFILES

Muscle activity profiles were constructed through analysis of the normalized processed sEMG data. The processed sEMG data was normalized using the fMVC data. Functional MVC data were processed with 100ms moving average (Bao, Mathiassen et al. 1995). The instantaneous maximum value determined from the moving average was used to normalize the processed sEMG data. Normalization was completed using an arithmetic process,

$$\%MVC = \frac{(sEMG - Rest)}{(fMax - Rest)} \quad \text{Eq. 1}$$

where %MVC was the normalized processed sEMG data, *sEMG* represents the collected data, *fMax* represents the instantaneous maximum value from fMVC trials, and *Rest* represents the minimum value from the 30 second baseline. Temporal analysis of the sEMG data was accomplished through use of the RMS processing technique (Basmajian and De Luca 1985). A graphic user interface (GUI) program was

created using MATLAB 7.10.0 (Mathworks, Natick, MA) to process the sEMG data and obtain mean RMS values. Amplitude probability distribution function (APDF) was determined for the 10th percentile (static), 50th percentile (mean), and 90th percentile (maximum) (Jonsson 1982) using custom software (Fethke, Anton et al. 2004) developed in LabVIEW (National Instruments, Austin, Texas). Percent muscular rest (%MR) of the sEMG was determined with a threshold of less than 0.5% MVC and gap duration of at least 0.25 seconds (Hansson, Nordander et al. 2000). The same LabVIEW custom software (Fethke, Anton et al. 2004) was used to determine %MR values. Muscle activity profiles were constructed for each individual muscle. This was accomplished by determining the mean RMS, ADPF, and %MR across all the subjects. The profiles provide an estimate of the overall muscle activity and recovery experienced by the dairy workers during the given time period.

7.2.5 STATISTICAL ANALYSIS

All statistical analyses were conducted using SAS 9.3 (SAS Institute Inc., Cary, NC, USA). Descriptive statistics for the subjects and muscle activity profiles were conducted. Muscle profiles were examined using a random block 2 x 57 x 5 ANOVA (Location x Subject x Muscle) with a Tukey Honest Significant Difference post hoc adjustment to determine differences in the RMS, APDF, and %MR. Statistically significant interactions between muscle and dairy location were assessed by examining the simple main effects. Anthropometric population differences were completed using Chi squared (χ^2) test and by examining the likelihood ratio test statistic. Correlations between mean RMS, 50th percentile APDF, and %MR were also examined. Statistical significance was set at $p < 0.05$ *a priori*.

7.3 RESULTS

7.3.1 ANTHROPOMETRIC ANALYSIS

The χ^2 test indicated that the two subject populations had statistically significant differences for categorical eye level height ($p=0.005$) and forward functional reach ($p<0.001$). Functional overhead reach was approaching a statistically significant difference ($p=0.06$). There were no statistically significant differences between the two subject populations for functional stature, acromial stature, weight, or BMI ($p>0.19$). These results indicate that the two study populations are relatively similar except that milkers in the small-herd dairies in Italy have longer reach than the milkers in the large-herd dairies in Colorado

7.3.2 MUSCLE ACTIVITY PROFILES

Profiles of muscle activity were created for the muscles of interest: upper trapezius, anterior deltoid, biceps brachii, wrist flexors, and wrist extensors (Table 7.3-1). The mean RMS ANOVA analysis detected a significant interaction ($p<0.001$) between the size of the dairies, and the muscles of interest when examining the fixed effects. The simple main effects of the statistically significant interaction (Table 7.3-2) revealed significant differences for the biceps brachii ($p<0.001$), upper trapezius ($p=0.002$), and the wrist flexors ($p<0.001$) between the two dairy types. The anterior deltoid ($p=0.43$) and the wrist extensors ($p=0.50$) muscles were not significantly different between the locations. In each of the significant findings, the muscle activity values were determined to be higher in large-herd operations than small-herd operations. This finding was expected as large-herd dairy workers experience a higher volume of work because of larger herd size.

Table 7.3-1: Muscle activity profiles per muscle

<i>Small Herd</i>	Upper Trapezius	Anterior Deltoid	Biceps Brachii	Wrist Flexors	Wrist Extensors
10th Percentile	0.66 (1.18)	0.16 (0.88)	0.076 (0.69)	0.15 (1.52)	0.23 (1.85)
50th percentile	6.28 (4.29)	3.60 (3.99)	4.38 (2.73)	2.51 (2.67)	9.23 (5.58)
90th percentile	19.50 (12.27)	29.61 (24.31)	19.75 (9.94)	35.85 (48.81)	43.43 (36.76)
Mean RMS	8.46 (5.35)	8.26 (5.23)	6.86 (4.02)	5.64 (4.12)	14.60 (7.78)
%MR	0.59 (1.22)	4.98 (5.88)	5.36 (10.10)	4.67 (4.55)	5.67 (3.36)
<i>Large Herd</i>					
10th Percentile	1.13 (2.07)	0.15 (0.39)	1.21 (2.22)	0.54 (0.92)	0.40 (0.59)
50th percentile	9.28 (6.61)	3.49 (3.71)	14.58 (11.5)	7.41 (5.10)	9.75 (5.70)
90th percentile	31.44 (21.04)	43.36 (36.26)	51.22 (38.86)	44.11 (31.13)	36.74 (21.40)
Mean RMS	13.58 (9.19)	9.74 (3.71)	19.44 (13.87)	12.73 (6.24)	14.02 (7.73)
%MR	6.64 (7.24)	22.77 (12.75)	9.45 (7.34)	13.58 (8.25)	13.16 (6.69)

Note: Note: Mean and (SD) are shown for each muscle $n=26$ for Large herd and $n=40$ for Small herd. Percentiles refer to APDF analysis. Units for mean RMS and APDF are %fMVC. %MR is measured as a percentage of total working time.

Table 7.3-2: Simple main effects of dairy size X muscle interaction for mean RMS analysis

Muscle	Large-herd estimate	Small herd estimate	Difference	Adjusted P-value
Anterior Deltoid	9.6228	8.2492	1.3736	0.42
Upper Trapezius	13.4744	8.0310	5.4434	0.002
Biceps Brachii	19.3237	6.8501	12.4736	<0.001
Wrist Flexors	12.6175	5.6311	6.9864	<0.001
Wrist Extensors	13.9036	15.0619	-1.1583	0.50

Note: Estimates units are %fMVC.

Table 7.3-3: Simple main effects of dairy size X muscle interaction for 50th percentile APDF

Muscle	Large-herd estimate	Small herd estimate	Difference	Adjusted P-value
Anterior Deltoid	3.4412	3.4806	-0.03938	0.98
Upper Trapezius	9.2232	5.9917	3.2315	0.02
Biceps Brachii	14.5270	4.3477	10.1793	<0.001
Wrist Flexors	7.3509	2.5741	4.7767	0.004
Wrist Extensors	9.6947	9.4415	0.2532	0.85

Note: Estimates units are %fMVC.

Amplitude probability distribution function was evaluated at the 10th, 50th, and 90th percentiles.

The ANOVA analysis 10th percentile APDF revealed that dairy size ($p=0.01$) and muscle ($p=0.008$) were statically significant, but the analysis did not reveal a significant interaction between dairy size and muscle. However, the ANOVA analysis of the 50th and 90th percentiles of the APDF did reveal statistically

significant interactions ($p<0.001$ and $p=0.03$ respectively). For the 50th percentile APDF, the simple main effects of the statistically significant interaction (Table 7.3-3) revealed statistically significant differences for the biceps brachii ($p<0.001$), the upper trapezius ($p=0.02$), and the wrist flexors ($p=0.0004$). The anterior deltoid ($p=0.97$) and the wrist extensors ($p=0.84$) were not significantly different when comparing the two dairy types. The analysis of simple main effects for the 90th

Table 7.3-4: Simple main effects of dairy size X muscle interaction for 90th percentile

Muscle	Large-herd estimate	Small herd estimate	Difference	Adjusted P-value
Anterior Deltoid	43.3692	29.3831	13.9862	0.06
Upper Trapezius	31.4385	18.1549	13.2836	0.08
Biceps Brachii	51.2288	19.8454	31.3834	<0.001
Wrist Flexors	36.7462	31.8438	4.9024	0.51
Wrist Extensors	44.1115	45.1353	-1.0237	0.89

Note: Estimates units are %fMVC.

Table 7.3-5: Simple main effects of dairy size X muscle interaction for %MR

Muscle	Large-herd estimate	Small herd estimate	Difference	Adjusted P-value
Anterior Deltoid	22.7527	4.8699	17.8828	<0.001
Upper Trapezius	6.6225	0.6185	6.0039	0.004
Biceps Brachii	9.4296	5.4977	3.9319	0.06
Wrist Flexors	13.5620	7.1109	6.4511	0.002
Wrist Extensors	13.1400	1.9615	11.1785	<0.001

Note: Estimates are a percentage of total collection time

Table 7.3-6: Correlations of muscle activity profile variables

<i>Small Herd</i>	Mean RMS	50th Percentile APDF
%MR	-0.29 (<0.001)	-0.30 (<0.001)
50th percentile APDF	0.90 (<0.001)	
<i>Large Herd</i>		
%MR	-0.53 (<0.001)	-0.57 (<0.001)
50th percentile APDF	0.90 (<0.001)	

Note: Correlations were not statistically compared across herd size

percentile APDF (Table 7.3-4) revealed statistically significant differences only for the biceps brachii muscle ($p<0.001$). The anterior deltoid ($p=0.06$) and the upper trapezius (0.08) were both approaching a significant difference, while the wrist flexors ($p=0.50$) and extensors ($p=0.87$) were not significantly

different between the two sizes of dairies. The findings from the 50th percentile APDF were as expected because of the higher volume of work seen in large-herd operations. Like mean RMS, the muscle activity from large-herd operations was almost double that of small-herd operations. The 90th percentile APDF was associated with the peak muscle activity during the work (Jonsson 1982). The findings of the 90th percentile APDF indicate that, except for the biceps brachii muscle, there are no differences between peak muscle activity required for dairy work be it a small-herd operation or a large-herd operation.

The %MR ANOVA analysis also indicated a significant interaction between herd size and muscles ($p<0.001$). The simple main effects of the statistically significant interaction (Table 7.3-5) indicated that there were statistically significant differences for each of the muscles ($p<0.004$) when comparing dairy types, except the biceps brachii ($p=0.06$), which was approaching significance. The %MR values were at least twice as large for the Colorado based large-herd dairies as the Italian small-herd dairies. These results were not expected as large-herd dairies have a higher volume of milking work and a faster work pace compared to small-herd dairies, and therefore less resting time for workers.

The correlation analysis determined that overall, across all the muscles, the same statistically significant correlations were present in both Coloradan large-herd dairies and Italian small-herd dairies (Table 7.3-6). In the small-herd dairies, mean RMS had a strong positive, statistically significant correlation with 50th ($R>0.89$, $p<0.001$) percentile APDF. Additionally, both mean RMS and 50th percentile APDF had a statistically significant negative correlation with %MR ($R<-0.29$, $p<0.001$; $R<-0.29$, $p<0.001$). Evaluating the individual muscles, mean RMS, and 50th percentile APDF had strong, statistically significant positive correlations ($R>0.75$, $p<0.001$) for each muscle at both locations. However, when examining individual muscles, %MR only had negative correlations with mean RMS and 50th percentile APDF for the biceps brachii ($R=-0.35$, $p=0.03$; $R=-0.42$, $p=0.01$) and the wrist flexors ($R=-0.40$, $p=0.01$; $R=-0.35$, $p=0.03$) muscles for the Italian small-herd dairies. In large-herd dairies, %MR had statistically

significant negative correlations with both mean RMS ($R < -0.48$, $p < 0.001$) and 50th percentile APDF ($R < -0.59$, $p < 0.001$) for each muscle. Mean RMS and 50th percentile APDF should have a strong positive correlation as they are both measures of mean muscle activity. The results show that the analysis was working as intended. Additionally, %MR should also be expected to have a negative correlation with measures of mean muscle activity. The lack of correlations for specific muscle groups in the Italian small-herd dairies was appropriate, as low %MR values were determined for the anterior deltoid, wrist extensors, and upper trapezius (Table 7.3-5).

7.4 DISCUSSION

The primary purpose of this investigation was to determine if there were differences in muscle activity during milking work between Coloradan large-herd operations and Italian small-herd operations. This was accomplished by analyzing the mean RMS, APDF percentiles, and %MR of the upper trapezius, anterior deltoid, biceps brachii, wrist flexors, and wrist extensors associated with milking work. Additionally, the two subject populations were compared to distinguish anthropometric differences.

Surface EMG was used to quantify muscle activity to compare the effects of milking activities in large and small-herd dairies. The analysis of mean RMS, APDF percentiles, and %MR indicated that the milking activities affected the muscles of interest differently based on the herd size. The mean RMS analysis and 50th percentile APDF revealed that in the large-herd dairies in Colorado, there was great muscle activity for the biceps brachii, upper trapezius, and the wrist flexors. Percent muscular rest further provides a clear difference between the large and small-herd dairy farms. Subjects from the large-herd farms had at least double the amount %MR compared to small-herd farms. Because the anthropometric analysis revealed only a difference in categorical forward functional reach and eye level height, but not functional working height, the differences in muscle activity cannot be attributed to the physical differences between the subject populations. Additionally, having a longer forward functional

reach, as demonstrated for the Italian subjects, would allow for less shoulder flexion and in turn less anterior deltoid flexion. However, nearly identical anterior deltoid activity was indicated by both mean RMS and 50th percentile APDF. Furthermore, %MR revealed that the Italian subjects had nearly five times less rest for the anterior deltoid muscle. This contributes to the conclusion that differences seen among the muscle activity could be due to the differences between the large-herd and small-herd dairies.

The average herd size for the Coloradan dairies was about 2200 cows and the Italian dairies averaged about 350 cows. Aside from this large difference in average herd size between the two, milking practices differed as well. Italian dairies milked their cows only twice per day whereas in the Coloradan dairies the cows were milked three times per day. The increased herd size means more cows to milk per hour and thus a faster work pace (Doughrati and Rosecrance 2010). This could explain the increased muscle activity presented at the large-herd operations. Although work pace has not been examined directly within the dairy industry, looking to research in similar work environments may help here.

Work pace has been examined in light assembly work, with mixed results. Bosch, Mathiassen et al. (2011) examined the effect that work pace had on muscular load requirements in simulated light assembly work. The authors created a repetitive work task that simulated industrial assembly. The task was completed at a low work pace that simulated “normal” work flow, as defined by industrial time standards, and at a high work pace, which simulated realistic industrial work flow. The authors determined that the increased work pace did not create an increase in upper extremity muscular load required to complete the tasks. Gooyers and Stevenson (2012) examined how the upper extremity muscles are affected by increasing work pace of the speed fastening assembly process. Subjects completed 120 minutes of simulated fastening at shoulder and waist height. The authors examined

three different work rates: 7, 14, and 21 fasteners per minute. The analysis indicated that increasing the work pace caused an increase in 50th percentile APDF for the upper extremity musculature. Although neither of the assembly processes are identical to dairy work, the repetitive nature of the assembly tasks and the low muscular loads reported are similar to milking tasks. Therefore, it becomes difficult to state that increased work pace is an explanation for the differences in muscle activity reported between large and small-herd dairies.

The difference in muscle activity not only corresponds with the larger herd size, but also with the work pace. The large-herd parlor workers had at least twice as much %MR as the small-herd parlor workers. This finding was unexpected because of the work pace and workload differences between large and small-herd operations created by the large differences in herd size. The largest differences in %MR were found in the anterior deltoid (22.8% vs 4.9%), upper trapezius (6.6% vs 0.62%), and wrist extensors (13.1% vs 2.0%) muscles, where only upper trapezius muscles displayed a statistically different level of activity between the large and small-herd operations. The low levels of %MR displayed by the Italian subjects may be a result of a high reported prevalence of musculoskeletal symptoms (MSS) among European dairy workers (Stål, Moritz et al. 1996, Pinzke 2003, Doupbrate, Kolstrup et al. 2013). It was not unrealistic for the Italian subjects to report having MSS and possibly musculoskeletal symptoms disorders (MSDs). Percent muscular rest has been used to study and document the development of MSS in the upper trapezius muscles (Veiersted, Westgaard et al. 1993, Hägg and Åström 1997, Jensen, Finsen et al. 1999, Hansson, Nordander et al. 2000, Nordander, Hansson et al. 2000). For repetitive work tasks with low muscular load, %MR less than 4% has been associated with an increased risk for trapezius myalgia (Veiersted, Westgaard et al. 1993). Italian subjects had %MR less than 1% for the upper trapezius. It was therefore possible for there to be a presence of MSS in the upper trapezius muscle.

Another possible reason for the major differences in %MR is the actual milking work. Coloradan subjects performed all five the milking tasks, whereas Italian subjects focused mainly on performing only stripping, wiping, and attaching, regarding as the most strenuous of the five milking tasks (Stål, Moritz et al. 1996, Pinzke, Stål et al. 2001, Stål, Pinzke et al. 2003, Douphrate, Gimeno et al. 2013). Stål, Moritz et al. (1996) reported that milkers thought that stripping was the most strenuous milking task followed by cluster attachment. Pinzke, Stål et al. (2001) compared the muscle activity required to complete several of the milking tasks in small-herd operations and determined that attaching had a higher 50th percentile APDF for biceps brachii muscles (14% MVC) than stripping (5.3% MVC), and wiping (9.7% MVC). For the forearm flexors muscles, wiping had the highest 50th percentile APDF at 27% MVC. Wiping demonstrated to have the least amount of %MR. Douphrate, Gimeno et al. (2013) concluded that, from worker self-reporting, that stripping and cluster attachment were the most difficult milking tasks in large-herd operations. Masci et al, (2014) demonstrated with use of the Strain Index (Moore and Garg, 1995) that in Italian dairies, wiping, stripping, and milk cluster attachment are strenuous. The researchers also used the Borg perceived effort scale (Borg, 1998) which revealed that the perceived effort from the workers matched the Strain Index high effort results. In our analysis, the Italian subject population primarily completed only the most difficult of the milking tasks, while Coloradan subjects completed all of the milking tasks. The difference in milking work could explain the high difference in %MR. Percent muscular rest requires that muscle activity drop below 0.5% MVC for at least 0.25 seconds to be documented. If only the most difficult milking tasks are being completed, the total variation in muscle activity may not drop preventing %MR documentation. This was noticeable as the muscles that presented statistically higher activity, mean RMS and 50th percentile APDF, in the large-herd subjects also had greater variability. Therefore it was probable that the difference in %MR can be attributed to the difference in tasks performed. Additionally, it was important to note that Italian workers were required to perform parlor operation tasks in addition to the milking work. These activities included pushing cows into the

parlor, cleaning the pit floor, and completing antibiotics injections. Performing these activities throughout the data collection could also attribute to the low %MR. Lastly, and most importantly, it is possible that the threshold for the %MR calculations at 0.5% MVC may be too low and inappropriate for the tasks being analyzed. Additionally, the threshold may require too precise of a measurement that may not be achievable using sEMG. The threshold had been used by previous researchers (Veiersted, Westgaard et al. 1993, Hägg and Åström 1997, Jensen, Finsen et al. 1999, Hansson, Nordander et al. 2000, Nordander, Hansson et al. 2000) and additionally found to be most appropriate at 0.5% MVC (Hansson, Nordander et al. 2000), but the tasks examined were not as complex as milking tasks. The results were unexpected as the common interpretation of the relationship between muscle activity and rest when comparing two activities would be inverse, i.e. higher activity has lower rest. It is possible that by increasing the threshold to 5% MVC would be more appropriate for examining milking tasks using sEMG.

Dairy milking has been demonstrated to be difficult and strenuous work in both large-herd and small-herd operations (Stål, Moritz et al. 1996, Pinzke, Stål et al. 2001, Sung, Zurcher et al. 2005, Kolstrup 2012). There was a high association for MSS and MSDs in dairy work in both large and small-herd operations (Stal 2000, Pinzke 2003, Sung, Zurcher et al. 2005, Davis and Kotowski 2007, Kolstrup 2012, Patil, Rosecrance et al. 2012, Doupbrate, Gimeno et al. 2013). This study demonstrated that although there are clear differences between large-herd dairy farms in Colorado and small-herd dairy farms in Italy, dairy milking was difficult work regardless of location. There were no differences in four of the five muscles for 90th percentiles APDF, which represents the maximum activity during the collection period (Jonsson 1982). Although the 10th percentile was not statistically comparable between operations, observationally, the values for each muscle did not appear to be drastically different.

7.4.1 LIMITATIONS

Muscle activity measured with sEMG was collected at multiple dairies in two different countries: the U.S. and Italy. The participating dairies within each country were similarly sized, but not identical which created fluctuations in the total data collecting time. Subjects completed the milking work for the length of time required to complete the first full pen of cattle. This time lasted on average 50 minutes in Coloradan operations and roughly 70 minutes in Italian operations, which could have impacted the sEMG analysis. Additionally, data collection always commenced at the beginning of each shift in operations. This caused observable variability in the pace of work across different dairies; work flow achieved optimal pace at different points of the shift per dairy. Another set of limitations arose from the actual completion of the milking tasks. While the small-herd dairy subjects were instructed to complete the milking tasks as per their normal routine, the large-herd subjects were instructed to complete the milking tasks with the instrumented arm to ensure that the collected sEMG represented the milking tasks. This created three problems. First, milking work becomes routine for many of the workers, and subjects in the large-herd dairies sometimes forgot to use the instrumented arm. For example, in some parlors pre-dipping was completed with the non-dominant arm and wiping immediately after with the dominant (instrumented) arm. This was minimized by reminders from the researchers, but the limited number of occurrences may have lowered the overall muscle activity and increased the %MR. A second problem arose from requiring the subjects to always use the instrumented arm to complete the milking tasks. If the work was normally completed by alternating arms, then the data collection was not an accurate portrayal of the milking tasks, and constant use of one arm may also inflate muscle activity and minimize muscular rest. The third problem developed when comparing the data. Because small-herd subjects performed the milking work per their normal routine, it was possible that the non-instrumented arm was used to complete the milking work instead of the instrumented arm. If the instrumented arm was then not used for this period of time, the muscle activity data collected does not

represent milking work. Therefore the muscle activity may have been underestimated and %MR overestimated. To overcome this problem, future research should examine milking tasks bilaterally. Finally, this investigation assumes that collecting muscle activity for about an hour at the start of the shift equally represents milking work completed throughout the milking shift. Large herd operations have workers complete the milking tasks during eight to twelve hour shifts. Physiologically, we are disregarding any possible effects that muscle fatigue may have on recorded muscle activity, which could have a direct impact on %MR and APDF values. Future research should consider the impact that fatigue may play by examining latter portions of the shift or using full shift data.

In addition to limitations through the study design, limitations also arise from use of sEMG. First, signal quality and strength can be affected drastically by electrode placement, amount of adipose tissue, and processing techniques (Basmajian and De Luca 1985). Secondly, sEMG is a highly variable signal with low reliability that relies on signal processing techniques to allow researchers to interpret and translate what is occurring within the sEMG signal. Within the context of this paper, %MR is affected by both sets of limitations. Percent muscular rest was established by contractions having a value below 0.5 %fMVC and lasting at least 0.25 seconds. The highly irregular results between the large and small herd parlors when examining both %MR and muscle activity together suggest that surface electrodes may not be able to reliably detect a threshold of 0.5% fMVC. Misplacement of electrodes would affect the ability of low contractions to be accurately detected. More importantly, the natural variability seen in nonstationary signals such as sEMG creates low reliability which increase the requirement of accurately detecting a threshold of 0.5% fMVC. Finally, the %MR is directly affected by the precision of the collected MVC. The closer an MVC is to the muscles true maximum, the more manageable it becomes for the %MR algorithm to operate. However, in this study fMVCs were used in place of MVCs. Therefore the %MR algorithm could have difficulty appropriately detecting activity at such a low threshold. Furthermore, these limitations are then compounded as the normalization process uses a static

contraction, which does not generate a true maximum contraction when analyzing dynamic contractions. These limitations suggest that it is probable that using 0.5% fMVC is too low of a threshold for the analysis used in this current paper.

7.5 SUMMARY AND CONCLUSIONS

Dairy milking in Coloradan large-herd operations demonstrated higher mean RMS, 50th percentile APDF, and %MR than Italian small-herd operations. The differences in mean RMS and 50th percentile APDF suggest that large-herd dairy workers may be more at risk to develop injuries caused through extended high average muscle activity (Jonsson 1982). However, %MR suggests that small-herd dairy workers are more susceptible to developing injuries caused by lack of muscular rest, such as trapezius myalgia (Veiersted, Westgaard et al. 1993). Milking is difficult work in small and large-herd operations and both subject populations are at risk for injury.

Although this investigation presents a novel comparison between small and large-herd operations, more information is still needed to accurately compare milking between operations. Fatigue measures were not examined and their impact was not accounted for. Large herd operations run longer milking shifts than small-herd parlors, therefore examining the impact of muscular fatigue and differences between operations would be beneficial. Task based analyses should also be conducted to determine how each task compares in small and large-herd operations. Through a task based analysis, appropriate interventions could be applied more effectively. Future dairy researchers examining differences between small and large-herd operations should focus on comparing dairy operations through task-based analyses.

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