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Making Milking Easier –

Reducing Physical Strain of Parlor Workers During Milking Cluster Attachment

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To my parents

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Summary

Milking personnel have been affected by musculoskeletal disorders for many years. In parlor workers the shoulders, wrists and lower back are most affected. As the procedure of milking cluster attachment has been reported to be the most strenuous during milking, we took a three-step approach to reduce the physical strain of this task.

In the first step, we used the computer-assisted recording and long-term analysis system (CUELA) to record flexion angles of multiple joints during milking. The posture of 30 milkers was evaluated on 15 farms. Milking parlor types evaluated included the Herringbone 30°, the Herringbone 50°, and the Parallel as well as the Rotary parlor. The 5^{th}, 50^{th} and 95^{th} percentiles of the data recordings were classified against ISO Norms and it was found that joint flexion angles were concerning. The statistical analysis revealed a significant interaction between milking parlor type and a working height coefficient, which reflected the ratio between the subject's height and the effective udder height (udder height + depth of pit). By using model predictions, we calculated working height coefficients that could improve joint flexion angles. These working height coefficients were calculated for each parlor type and used within the newly developed "milking health formula" to calculate the ideal depth of pit, under the consideration of the milker's height, milking parlor type and udder height.

As the working heights recommended within the milking health formula were relatively low for all parlor types, and the recommendations made for the Herringbone 30° were broad, we aimed to further validate our findings by using surface electromyography to monitor muscle contraction intensities of 16 milkers (nine females, seven males). The second step of this thesis was performed in a laboratory setting where the milking cluster was attached to an artificial udder. It was important to ensure that the milking health formula enabled a consistent setting of working heights for milkers of different body heights, as well as ensuring that lower working heights reduced muscle contraction intensities of the upper limb and shoulder muscles. The results showed that lower working heights decreased muscle contraction intensities of the shoulder muscles, but not of the lower and upper arms. Further, since the subjects body height had no effect on muscle contraction intensities, it can be concluded that the formula offers an effective way to set comparable working heights for milkers of different body heights.

Posture of milkers is not only affected by working heights, but also by the horizontal reaching distance between the milker and the cows' udder. It has recently been assumed that milking stall dimensions are currently too small for dairy cows and that they should be increased to ensure their welfare. This could however increase the reaching distance between the udder and the cow and thus negatively affect ergonomics. In the third step of the thesis, we therefore used surface electromyography, in both a Herringbone 30° and a Side by Side milking parlor, to investigate the effect of increased milking stall dimensions on muscle contraction intensities of the upper limb and shoulder muscles during milking. Nine male subjects milked 30 cows twice per parlor type, where the milking stall dimensions were large on one side of the milking parlor and standard sized on the other. Milking stall dimensions had no effect on muscular contraction intensities in the Side by Side parlor and a controversial effect in the Herringbone 30° parlor. The contraction intensities in the right lower and upper arm were higher when cows were milked in standard sized milking stalls, but were higher in the left upper arm when cows were milked in large milking stalls. The effect of milking stall dimensions on the work environment should therefore be further investigated.

In conclusion, the current project has developed a method to calculate beneficial working heights for a variety of milking parlor types. These derived recommendations have been further validated and it was shown that lower working heights reduced muscular load of the shoulder muscles.

Zusammenfassung

Seit vielen Jahren werden bei Melkern und Melkerinnen Erkrankungen des Bewegungsapparates festgestellt. Bei Melkern, die in Melkständen arbeiten sind die Schultern, Handgelenke und der untere Rücken am stärksten von diesen Beschwerden betroffen. Das Ansetzen des Melkzeugs ist beim Melken die anstrengendste Tätigkeit. Deshalb versuchten wir die Arbeitsbelastung des Melkpersonals bei dieser Tätigkeit in einem dreistufigen Ansatz zu reduzieren.

In einem ersten Schritt verwendeten wir das computerunterstützte Erfassung- und Langzeit-Analyse (CUELA) System, um die Beugewinkel verschiedener Gelenke beim Melken zu erfassen. Auf 15 Landwirtschaftsbetrieben wurde hierzu die Haltung von insgesamt 30 melkenden Personen untersucht. Die Untersuchung umfasste die Melkstandtypen Fischgräte 30°, Fischgräte 50°, Side by Side und Melkkarussell. Das 5te, 50te und 95te Perzentil der erfassten Daten wurde jeweils nach ISO-Normen klassifiziert. Hierbei wurden besorgniserregende Beugewinkel der Gelenke festgestellt. Die statistische Analyse ergab eine signifikante Wechselwirkung zwischen dem Melkstandtypen und einem Arbeitshöhekoeffizienten, der sich aus der Körpergrösse der melkenden Person und der effektiven Höhe des Euters (Euterhöhe + Tiefe der Melkgrube) ergibt. Mit Hilfe von Modellschätzungen bestimmten wir Arbeitshöhekoeffizienten, durch die die Beugewinkel der Gelenke verbessert werden konnten. Diese Arbeitshöhekoeffizienten wurden spezifisch für die einzelnen Melkstandtypen berechnet und konnten in der neu entwickelten "Milking Health Formel" eingesetzt werden, um die ideale Melkgrubentiefe in Abhängigkeit der Körpergrösse der melkenden Person, des Melkstandtyps und der Euterhöhe zu berechnen.

Da die durch die Milking Health Formel empfohlenen Arbeitshöhen für alle Melkstandtypen relativ tief und die Empfehlungen für den Fischgräten 30° Melkstand noch unpräzise waren, prüften wir in einem zweiten Schritt unsere Ergebnisse durch den Einsatz von Oberflächen-Elektromyographie. Wir untersuchten hierzu die Intensität der Muskelkontraktion von 16

melkenden Personen (9 Frauen, 7 Männer) unter Laborbedingungen. Die Probanden setzten das Melkzeug hierzu auf drei unterschiedlichen Arbeitshöhen an einem Kunsteuter an. Die Milking Health Formel ermöglichte eine konsistente Einstellung der Arbeitshöhen für melkende Personen unterschiedlicher Körpergrössen. So konnte untersucht werden, ob die niedrigeren Arbeitshöhen zu einer Entlastung der oberen Extremitäten und Schultern des Melkers führen. Die Ergebnisse zeigten, dass die tieferen Arbeitshöhen die Intensität der Muskelkontraktion der Schultern, nicht jedoch der Unter- und Oberarme senkten. Da die Körpergrösse des Melkers weiterhin keinen Einfluss auf die Intensität der Muskelkontraktionen hatte, konnten wir schlussfolgern, dass die Formel es effektiv ermöglicht vergleichbare Arbeitshöhen für Personen unterschiedlicher Körpergrösse einzustellen.

Im dritten Teil dieser Dissertation untersuchten wir mit Hilfe von Oberflächen-Elektromyographie, sowohl im Fischgräten 30° Melkstand als auch im Side by Side Melkstand, den Einfluss vergrösserter Melkplatzabmessungen auf die Intensität von Muskelkontraktionen in den oberen Extremitäten und Schultern. Dieser Versuch wurde durchgeführt, da ein Zusammenhang zwischen dem horizontalen Abstand der melkenden Person zum Kuheuter und der Ergonomie in Melkständen festgestellt wurde. Zudem wurde die Vermutung geäussert, dass die derzeitigen Melkstandabmessungen für die Kühe zu klein sind und im Hinblick auf das Wohlbefinden der Milchkühe vergrössert werden sollten. Grössere Melkplätze könnten jedoch dazu führen, dass die horizontale Entfernung zwischen Melker und Kuh sich vergrössert und die Ergonomie des Melkers somit beeinflusst. In der dritten Studie melkten daher neun Personen 30 Kühe je zwei Mal im Fischgräten 30° und zwei Mal im Side by Side Melkstand. Hierbei waren die Melkplatzabmessungen der Kühe jeweils auf einer Seite des Melkstands gross, während Sie auf der anderen Seite Standardmass hatten. Die Melkplatzmessungen hatten beim Side by Side Melkstand keinen und beim Fischgräten 30° Melkstand einen widersprüchlichen Einfluss auf die Intensität der Muskelkontraktionen. Die Intensität der Muskelkontraktionen im rechten Unter- und Oberarm waren höher, wenn die Kühe in Standard Melkplätzen gemolken wurden, während im linken Oberarm die Intensität der Muskelkontraktionen höher waren, wenn die Kühe in grossen Melkplätzen gemolken wurden. Der Einfluss der Melkplatzabmessungen auf die Arbeitsbedingungen im Melkstand sollte daher noch genauer untersucht werden.

In der vorliegenden Arbeit wurde eine Methode entwickelt, mit der ergonomisch vorteilhafte Arbeitshöhen für unterschiedliche Melkstandtypen berechnet werden können. Diese Empfehlungen wurden validiert und es wurde gezeigt, dass tiefere Arbeitshöhen die Belastung der Schultermuskulatur reduzierten.

1 General Introduction

Dairy farmers commonly suffer from a high workload, which comprises from physiological strain, psychological stress and time (Umstätter et al., 2016). In dairy farming, the highest proportion of workload, namely 29%, is expended during milking (Schick, 2007). The current thesis will therefore focus on the evaluation and improvement of the physical strain on milking personnel.

1.1 History of Milking

The dairy industry has successively aimed at improving labor efficiency as well as ergonomics during milking, and as such has developed from labor intensive manual milking, over milking machines with buckets, to stanchion systems and now to milking parlors, with a rising interest in automated milking systems (Pinzke, 2016). These developments have all been accelerated by the desire to relieve the physical strain during milking, as well as animal management. Scientific evidence shows, that since 4000 BC, cows have been milked for human consumption (Copley et al., 2003). At first cows were milked manually; however, this was very labor intensive and involved high physical strain, particularly of the hands and wrists, therefore over the course of time cow milking has increasingly become automated. In 1860 L.O. Colvin invented the first hand milking machine, which at this time consisted of a hand-driven vacuum pump (Colvin, 1860; Herrmann, 2010), however this device was not successful as it did not release the vacuum. It was not until the invention of the pulsator in 1895 and the first commercial milking machine in 1907, that machine milking could replace manual milking (Blaxter, 1983). These milking machines were originally attached to the udder in a position where the milker was seated on a stool next to the cow. To date these stanchion systems are used in dairy farms with fewer cows kept in tie-stalls (Douphrate et al., 2009). This causes high physical strain, particularly in the back and knees of milkers. The dairy industry has always aimed at increasing work efficiency in which the first labor studies were carried out in milking parlors in the 1950's (Chetwynd, 1956). With the industrialization of the dairy industry, herd sizes increased and cows have been increasingly milked in milking parlors (MacDonald et al., 2007). Hereby the cows stand elevated of the milker (usually in a pit) and the milker attaches the cluster in a standing position. This enables work not only to become more comfortable, but also increases efficiency as several cows can be milked at the same time (Douphrate et al., 2009).

In 1990, 97% of Swiss dairy farms milked their cows in a stanchion system, whilst only 3% milked in milking parlors. In 2015, 55% of farms used milking parlors, and only 45% milked their cows in a stanchion system (BLW, 2013). Automated milking systems have been available to commercial farms since 1992 (Umstätter, 2002). A recent study reported that 50.7% of farms with a loose-housing system in Scania (southern Sweden), milked with a robotic milking system in 2013 (Pinzke, 2016). The study further stated that male dairy farmers using robotic milking systems reported less complaints of the shoulder, whilst females reported less discomfort in the lower back, compared to milkers with parlor or stanchion systems (Pinzke, 2016). However, to date only few farms in Switzerland are equipped with these automatic or robotic milking systems and a large number of cows' are still milked in milking parlors on a daily basis. It therefore remains relevant to improve the work environment of milkers specifically in milking parlors.

Milking parlor types currently commercially available include the Herringbone 30°, Herringbone 50°, Side by Side, Autotandem (or Tandem), or Rotary (inside- or outside milkers) parlors. The attachment of the milking cluster differs between parlor types and therefore results in distinctive postures (Figure 1.1). In the Autotandem, the Herringbone 30° and most inside milking Rotary parlors, the cluster is attached anterior to the hind legs, whilst cluster attachment in the Herringbone 50°, the Side by Side and most outside milking Rotary parlors is performed posteriorly, through the hind legs (Figure 1.1). Further, depending on the angle and position of cluster attachment, the reaching distance varies between parlor types (Tuure and Alasuutari, 2009).

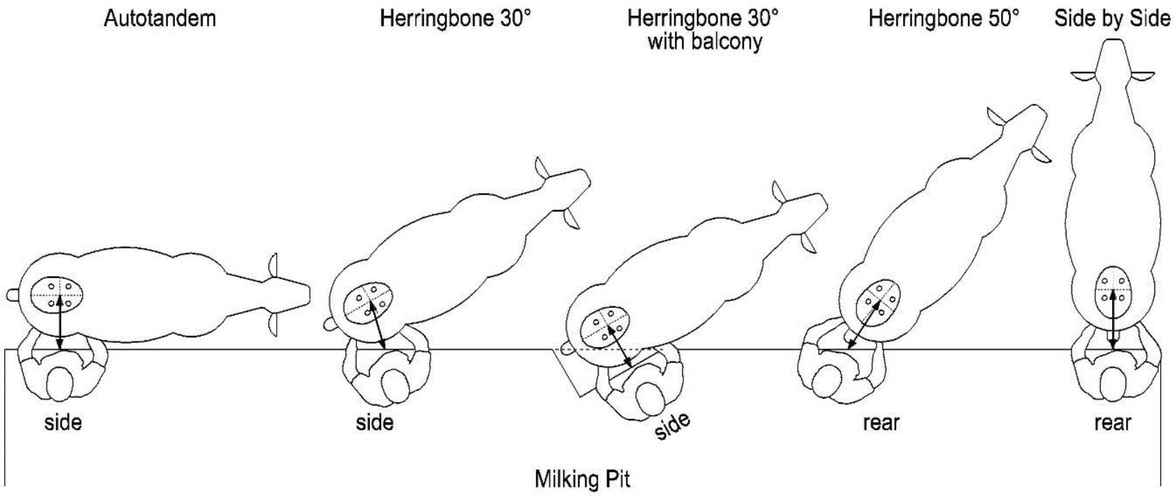

Figure 1.1 Position of milking cluster attachment in a variety of milking parlor types. The cluster is attached from the side in the Autotandem and the Herringbone 30° parlor and from the rear in the Herringbone 50° and the Side by Side parlor. The arrows indicate the horizontal reaching distance.

1.2 Work Related Health Problems in Dairy Farmers

Reports on musculoskeletal disorders have been well documented in the scientific literature (Stål et al., 1998; Stål et al., 2004; Jakob, 2010; Karttunen and Rautiainen, 2011; Lunner Kolstrup, 2012; Patil et al., 2012; Douphrate et al., 2013; Karttunen and Rautiainen, 2013; Douphrate et al., 2014; Pinzke, 2016). Yet the aim to improve certain working conditions, effectively resulted in a shift of musculoskeletal problems. Machine milking in stanchion systems, where the milker is seated on a stool, has soon been recognized to cause problems in the knees. Early studies have therefore investigated the force experienced by the knee joint during milking and advised to decrease the horizontal distance between the cow and the milker (Ekholm et al., 1985; Nisell, 1985). However, it was not long until the idea of milking in a standing position evolved and milking in parlors became more popular. While earlier studies reported that milking in parlors was considered light work for the cardiovascular system (Nevala-Puranen et al., 1996) and peak muscular loads of the upper limbs were decreased compared to stanchion systems (Stål et al., 2000), it soon became apparent that muscular-skeletal disorders of the upper limb remained. Neck, shoulder, wrists and hands were most affected in milking parlor operators (Douphrate et al., 2009). Tuure and Karttunen (2007) reported that one out of three milkers in Finland suffered from complaints in the neck and shoulder regions. Particularly females have been reported to be prone to the pronator syndrome (Stål et al., 1998; Stål et al., 2004) and the carpal tunnel syndrome (Patil et al., 2012). Further, the frequency of cows handled per time unit amplified in loose housing systems compared to stanchion systems, and thus the acute risk of injury by dairy cows also increased (Douphrate et al., 2009). Karttunen and Rautiainen (2011) stated a decline in working ability of 39% among Finnish dairy farmers (44% among females, 32% among males). Although this results in a loss of efficiency, farmers are reluctant to invest in an ergonomic work environment. Previous studies have therefore developed a cost benefit analysis on investments of ergonomic assistance devices in milking parlors (Douphrate and Rosecrance, 2004).

1.3 Optimizing Work Environments for Milking Parlor Operators

Research has continuously aimed at improving ergonomics in milking parlors in order to reduce musculoskeletal disorders in milking personnel (Pinzke et al., 2001; O'Brien et al., 2007; Douphrate et al., 2009; Liebers et al., 2009; Tuure and Alasuutari, 2009; Douphrate and Rosecrance, 2010; Karttunen and Rautiainen, 2011; Douphrate et al., 2013; Silvetti et al., 2014). This research involved time studies, the evaluation of muscular loads and the assessment of posture. Hereby studies have primarily published recommendations on three aspects: reducing cluster weight, benefits of specific parlor types, and ideal working heights.

1.3.1 Cluster Weight

The milking cluster is lifted and held in a repetitive and static manner. This procedure puts the milker under an even higher physical strain when milking clusters are heavy. Researchers have therefore investigated the effect of reducing cluster weight. Jakob et al. (2009) have found that light clusters (1.4 kg) reduced physical load compared to heavier clusters (2.4 kg). Milking companies are aware of this and yet most clusters distributed commercially are relatively heavy, as clusters weighing up to 3.5 kg are commonly used in commercial farming (Jakob et al., 2009). This is due to farmers in praxis reporting that heavier clusters were beneficial in that they ensured a better emptying of the cow's udder. Researchers have conversely mentioned benefits of light milking clusters for dairy cows, such as reduced cluster on time (Rasmussen and Madsen, 2000) and less agitated behavior (Ohnstad, 1998). This indicates, that light clusters might be beneficial for milkers and dairy cows.

A milking cluster typically consists of the four teat cups that collect milk in a central claw. Over the years, this claw has increased in size, which makes it more difficult to hold. A milking system that directly transports the milk from the teat cups to the milk line, without collecting it in the claw, is also commercially available (Multilactor, Siliconform, Türkheim, Germany). Hereby the milker attaches each teat cup separately and therefore only uses one hand to attach the milking units and needs to lift no more than 0.3 kg per teat cup, thus reducing the muscular load during milking, compared to light conventional clusters (Jakob and Liebers, 2010). Despite the benefits and the commercial availability, this milking system is not widely distributed in practice, which is mostly due to the reluctance of farmers to invest in ergonomic assistance devices during the milking procedure.

1.3.2 Evaluating Benefits of Specific Parlor Types

With multiple different parlor types commercially available, it soon became of interest to ascertain which parlor type is the best. This question however, cannot be answered easily and must be considered as a multifactorial approach. Despite appreciating good posture in milking parlors, the time spent during milking and the space requirements will also have a high relevance in the evaluation of milking parlor types. It is aimed to reduce labor time during milking as this decreases the time the milker is exposed to the physical stress.

The time spent during milking is dependent on the milking parlor type and is mainly determined by the walking distance between cows, which decreases with increasing angle of the cow to the milking pit (Figure 1.1). The angle at which the cow stands towards the milking pit further influences posture, as it affects the way the milking cluster is attached (Figure 1.1). In Autotandem parlors the cluster is attached from the side and the milker stands parallel to the cow. In the Herringbone 30° the milker attaches the milking cluster from the side of the cow, but needs to rotate the upper body in order to reach the udder (Figure 1.1). In Side by Side and Herringbone 50° parlors, the cluster is attached from behind the cow, between the hind legs. This results in increased reaching distances. In the Side by Side parlor, the milker stands parallel to the cow, whereas the milkers' body is slightly rotated in the Herringbone 50° (Figure 1.1).

The space requirements for these milking parlors depend on the positioning of cows. The closer the cows are positioned next to each other, the less space is required and walking distances between cows are decreased, but the accessibility of the udder is reduced. Closer positioning of milking stalls not only results in decreased space allowances for buildings, but also reduced walking distances for milkers, thus resulting in increased cow milking frequencies per hour in Side by Side and Rotary parlors (Vos, 1974; Smith et al., 1998). However, the visibility of the cow is reduced and the cluster attachment procedure is different. The horizontal reaching distances vary between parlor types (Figure 1.1) and thus the floor heights of milking parlors in which the cluster is attached posteriorly, such as the Side by Side (1 m) or Herringbone 50° (0.95 m) parlors are currently built with deeper milking pits than in Tandem (0.85 m) or Herringbone 30° (0.85 m) parlors (DeLaval, 2011).

1.3.3 Estimation of Ideal Working Heights

Working heights have been addressed in multiple studies on milking parlor ergonomics (Vos, 1974; Pinzke et al., 2001; Tuure and Alasuutari, 2009; Jakob et al., 2012). However, comparing the information available on working heights for different milking parlor types shows that recommending correct working heights for workers in milking parlors has been difficult. Overall recommendations point at the need to work in a standing position with a straight back where the udder base is at level with the shoulder (Liebers et al., 2009) or between shoulder and elbow (Vos, 1974). In addition to a good posture, such relatively high working heights also ensure a good visibility of the udder. On the other hand, they cause disadvantageous joint flexion angles of the upper limbs, as well as higher muscular loads during the lifting of the milking cluster. To the present time there is a lack of precise recommendations that enables a simple calculation of ergonomically beneficial working heights in milking parlors. This Information is not only required for the ergonomic installation of milking pits on commercial farms, but also to make precise comparisons across or within research studies.

1.4 Optimizing Milking Stall Dimensions for Dairy Cows

Former studies have reported that the horizontal reaching distance between dairy cows and milkers influenced the postures of milking personnel. Median forward reaching distances of males lie at 0.74 m and of females lie at 0.69 m (Lange and Windel, 2013) and the variation of horizontal udder distance has been reported to be low and lie between 0.4 m to 0.5 m with an average of 0.45 m ± 0.028 m (Tuure and Alasuutari, 2009). Vos (1974) described the optimum working area to be in a horizontal distance between 0.25 m and 0.5 m and therefore advised cows to be positioned as close to the edge of the platform as possible.

This can be controlled better in smaller milking stalls. However, the milking parlor is not only the working environment for milking personnel, but also for dairy cows. Considering the welfare of dairy cows in milking parlors is not only important for ethical reasons, but also because stress reduces oxytocin release and inhibits milk let down (Rushen et al., 2001). Size recommendations of milking stalls have, to date, not been of concern in previous research and standard stall dimensions have been used for decades. Due to breeding for high yielding dairy cows, their body size has increased (Hansen, 2000a; Schönmuth and Löber, 2006), without any size development appreciated in the building of milking parlors. Therefore, it is presumed that milking stalls may have become too small for dairy cows and it is currently being discussed to increase them in order to accommodate for improved cow welfare.

If milking stall dimensions are increased, this may allow dairy cows to stand further away from the edge of the platform and therefore increase horizontal reaching distance between milker and cow. It must therefore be ensured that the milkers’ health does not suffer from an improvement of cow comfort. A solution for this problem is commercially available in form of self-indexing gates, which adjust milking stall dimensions for each cow (Moreau, 1994). However, farmers are reluctant to spend money on such ergonomic investments.

1.5 Ergonomic Workplace Evaluation

The International Ergonomics Association (2016) defines ergonomics (i.e. human factors) as “the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance”.

As such, providing an ergonomically favorable work environment has proven to be effective in improving work satisfaction, reducing absences through injury or health disorders and therefore increasing productivity (Vink et al., 2006). Several methods of ergonomic workplace evaluation are available to provide information regarding the work environment and potential areas of improvement. These methods include the subjective yet well-established Ovako Working posture Assessment System (OWAS) (de Bruijn et al., 1998), and the Rapid Upper Limb Assessment (RULA) (McAtamney and Nigel Corlett, 1993). Both methods are based on the evaluation of angular joint positions, which are not measured, but assessed via subjective observation. Although these methods are useful in a practical setting, more precise and objective measurement methods, such as posture and muscular force have become available and are widely applied in research. These measurement systems mostly enable tracing back motions by a visual display on the computer. Available systems include the motion capture systems Simi Motion (Simi Reality Motion Systems GmbH, Unterschleißheim, Germany), the gyroscope, accelerometer and magnetometer based systems cEYEberman (Kassel University, Kassel, Germany), as well as the gyroscope and accelerometer based computer-assisted recording and long-term analysis system CUELA (IFA, Bonn, Germany), which all have their benefits and limitations. Magnetometers often suffer from time drift, which is facilitated particularly by the exposure of the sensors to large amounts of iron, that are commonly found in a farm environment (Cai et al., 2001). Further, the use of camera based methods is often restricted due to the conflict between a limited visibility within the workplace and a need of the camera to observe target points (or markers), which are placed on the subject. An additional method used to measure physiological workload and as such has been widely established in research is electromyography. It measures muscular exertion and can therefore provide an objective feedback on the muscular force required for a particular work procedure (Konrad, 2006). Electromyography provides a high flexibility due to wireless transmission of data recordings and very precise measurements.

Work environments can further be assessed virtually. Improved software computer programs enable the modelling and evaluation of work environments, without the need to perform laboratory or praxis experiments. These model calculations are implemented in computer-aided design (CAD) work environments, and provide evaluations that are based on calculated joint flexion angles in combination with lifted loads e.g. Siemens Jack™ (Pennsylvania University, USA) or the computer supported anthropometric mathematical system for occupant simulation (RAMSIS) (Seidl, 1997). Although very interesting, objective, and thus effective, software base their recommendations purely on model calculations rather than true measurements. It therefore makes sense to use the software to evaluate beneficial postures and then verify those findings in experimental trials and so reduce the workload during the experimental period. A further limit in using model-based software is the lack of accountability for non-modelled data (such as cow behavior) within the simulation of work environments.

One method alone can only evaluate particular aspects of the work environment, such as joint position, muscular force, or duration of physical strain. The evaluation of the work environment should follow at least one of the three principles: neutral joint flexion, reduction of muscular force or the avoidance of static postures. Consequently, it is advisable to combine measurement methods for an overall interpretation and recommendation.

1.6 Aims of Research

The PhD thesis aimed to develop guidelines to improve ergonomics in milking parlors. This was undertaken in a three step approach. In the first study we aimed to evaluate ergonomics on commercial farms and use this data to develop a formula for recommending working heights for different milking parlor types. In the second study we aimed to investigate if lower working heights could reduce muscular contraction intensities and further validate the usability of the formula developed in the first study. Hereby, we further aimed to increase the precision of the working heights recommended for the Herringbone 30°parlor. In the third study we aimed to evaluate the effect of increased milking stall dimensions of dairy cows on the contraction intensities of four upper limb and shoulder muscles in milkers during milking cluster attachment in a Herringbone 30° and a Side by Side milking parlor.

2 Improving Ergonomics in Milking Parlors: Empirical Findings for Optimal Working Heights in Five Milking Parlor Types

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2.1 Interpretive Summary

To address the high levels of musculoskeletal disorders experienced by milking parlor operators, the CUELA system was used to record postures and movements in five different milking parlor types. The angular degree data were used to develop parlor-specific constant factors that accounted for the milker's body height and the cow's udder height. These constant factors can be used in the new milking health formula, which has been developed in the present study. This formula facilitates the calculation of ideal depth of pit in individual cases. By this it contributes to the improvement of ergonomics during milking.

2.2 Abstract

Milking postures have shifted from seated milking in tethered stalls to milking in a standing position in parlors. However, the musculoskeletal workload of dairy farmers remains high. Previous studies have shown that different working heights affect ergonomics, but they could not objectively evaluate and quantify the workload. The aim of the present study was to assess the effect of working height in different milking parlor types on the milker's workload during the task of attaching milking clusters. Computer-assisted recording and long-term analysis of movements were used to record positions of joints and body regions while performing certain tasks in terms of angular degrees of^joints (ADJ) according to the neutral zero method. The 5th, 50th, and 95th percentiles described the distribution of angular degree values measured for each joint. The ADJ were evaluated according to international standards and other scientific literature on the issue to assess the muscular load. The workload was compared between 5 parlor types (auto tandem, herringbone 30°, herringbone 50°, parallel, and rotary) on 15 farms with 2 subjects per parlor and 1 milking period per subject. The working height was defined as a coefficient based on the milker's body height, the floor level, and the cow's udder height. The data recorded during the attachment task were analyzed using generalized linear mixed-effects models taking into account the hierarchical experimental design. The results indicated that the interaction of the cow's udder height, the milker's body height, and the parlor type had a larger effect on ergonomics than each parameter had independently. The interaction was significant in at least 1 of the 3 percentiles in 28 out of 31 ADJ. The postural differences between parlor types, however, were minor. A milking health formula was created to calculate the ideal depth of pit by considering the parlor type, the milker's height, and the mean herd udder height. This formula can be used to develop individual recommendations for future parlor construction.

Keywords: guideline, milking health formula, posture, workload, herringbone

2.3 Introduction

Dairy farmers display high levels of musculoskeletal disorders; thus, the present study aimed at analyzing and improving posture during milking. The milking process represents a large part of the daily work routine on dairy farms, and despite position being improved compared with milking in stanchion systems, it has been associated with awkward postures (Jakob et al., 2009). Although milking may not be perceived as strenuous because it has been considered light work for the cardiovascular system (Perkiö-Mäkelä and Hentilä, 2005), several questionnaire-based studies showed that a large percentage of dairy farmers suffer from musculoskeletal problems, particularly disorders associated with the wrists and hands (Stål et al., 1996; Kauke et al., 2010; Kolstrup et al., 2010). Pinzke (2003) reported 83% of men and 90% of women to be affected by such problems, which is in line with Douphrate et al. (2009), who stated that 80% of dairy farmers suffer from musculoskeletal disorders. In addition, Karttunen and Rautiainen (2011) reported a decline in working ability, which was caused by these problems, in 39% of dairy farmers.

Health and efficiency considerations have influenced dairy husbandry in the past. As a consequence of dairy farm automation and industrialization, herd sizes have increased and milking is commonly performed in parlors. Previous research assessed the muscular load of the upper extremities during milking in parlors compared with that during milking in a tethered system and showed that the peak loads in milking parlors were decreased (Stål et al., 2000). Despite the expectation that milking in parlors reduced the physical load, problems in the neck, shoulder, and upper extremities of milkers remained (Arborelius, 1986; Jakob et al., 2012).

Tuure and Alasuutari (2009) reported that 1 out of 3 milkers who worked in a loose-housing barn were affected by problems in the upper limb, such as the neck and shoulder regions. Previous ergonomic research has focused on assessing the workload of the elbow, shoulder, and hip regions, but results also demonstrated a significant effect on the torsion and side bending of the trunk when milkers had to operate heavy milking clusters (Jakob et al., 2009).

Liebers and Caffier (2006) also identified severe strains on the milkers' knees, upper limbs, and lower backs. Specific research investigated the ergonomic benefit of support arms, because milking clusters were lifted in a static posture and could weigh up to 3 kg, yet surprisingly little effect was seen (Stål et al., 2003). Conversely, the distance between the udder and the milker has been reported to cause a leverage action of up to 9 N·m, indicating a high muscular load during the attachment task (Jakob et al., 2007). Pinzke et al. (2001) described the attachment task as the most strenuous task, because it involved the lifting and attaching of the milking cluster. Furthermore, Kauke et al. (2010) reported that 14% of survey participants perceived cluster attachment to be most strenuous. These results were in line with other international studies that indicated that the attachment task negatively affected ergonomics (Stål et al., 1996, 2003; Jakob et al., 2012). Whereas all tasks during milking were carried out in the udder region, and thus the working height was relatively similar, the attachment task was particularly interesting, as the milker spent 0.2 min/cow and milking procedure on attaching the milking cluster (Schick, 2000). During this period of time, the milker had to lift the cluster, which weighed between 2.6 and 3.1 kg, to the udder base; thus the task is physically more demanding than other tasks carried out during milking, such as premilking, stimulation, swiveling the milking cluster, or dipping or spraying the teats.

Ergonomics during milking were determined by multiple factors, such as parlor type, cow dimension, udder base height, parlor height, and milker height, and were linked strongly to the horizontal distance between the cow and the milker (Jakob et al., 2009). Of the few studies that have assessed the ergonomic differences in milking parlor systems, Stål et al. (2003) reported improved wrist positions in rotary systems compared with herringbone and tethered systems, indicating ergonomic differences between parlor types. Results from early studies suggested that ergonomics could be improved when floors were adjusted to a height at which the milker's elbows were considered to be at an ideal level during the working procedure (Billon et al., 1985; Stål and Pinzke, 1991). Jakob et al. (2012) further stated that muscle activity was lowest when light milking clusters were used and the teat ends were at shoulder level. Hence, some parlors were equipped with adjustable floors to enable ideal ergonomic posture for milkers of different heights. However, studies have shown that udder base height varies between 22 and 69 cm (Jakob et al., 2009), with a mean of 56 cm depending on the age and breed of the cows (Jakob, 2011). Jakob et al. (2009) reported that such factors could cause a variation of the ideal floor height for good posture of up to 50 cm. Furthermore, Billon (2009) found that the ideal depth of pit could vary between parlor types and advised that pits in parallel parlors should be higher than other pits. Tuure and Alasuutari (2009) further indicated differences between parlor types, as they reported horizontal reaching distance in herringbone 30° (HB 30°), autotandem (ATD), and parallel (PAR) parlors to vary between 36 and 58 cm. As body heights vary between milkers, a practical guide is needed for adjusting floors to the ideal working height at which the milker can work in an optimized ergonomic posture. Research, therefore, needs to identify methods to improve ergonomics in milking parlors to reduce the negative effect of milking postures on the musculoskeletal system of milkers. The present study aimed to analyze ergonomics in different milking parlor types and develop individual recommendations on working heights to improve posture in a variety of milking parlors.

2.4 Materials and Methods

2.4.1 Body Posture Recording with the CUELA System

Computer-assisted recording and long-term analysis (CUELA) was used to record musculoskeletal motions. The CUELA system has been used to assess ergonomics in different professions, such as nursing (Freitag et al., 2007) and flight attendance (Glitsch et al., 2007), and in several work environments, such as visual display unit workplaces (Ellegast et al., 2012b), places that require the pulling and pushing of waste containers (Backhaus et al., 2012), offices (Ellegast et al., 2012a), and animal facility washrooms (Kiermayer et al., 2011). Additionally, the CUELA system was validated in a milking parlor environment during a feasibility study (Kauke et al., 2009).

The CUELA system uses movement sensors (ADXL 3D accelerometers 103/203, Analog Devices, Norwood, MA; and muRata ENC-03R gyroscopes, Murata, Tokyo, Japan) to record the inclination and torsion of joints. Positions of joints are recorded in terms of angular degrees of joints (ADJ) according to the neutral zero method (Ryf and Weymann, 1995). The system further records how long each posture is maintained (Ellegast, 1998).

2.4.2 Experimental Design and Subjects

The study was performed in a commercial setting on a total of 15 farms. The following parlor types were assessed on 3 farms each: HB 30°, herringbone 50° (HB 50°), ATD, PAR, and rotary (ROT). Each farm was sampled by monitoring 2 different subjects (milkers) for the duration of 1 full shift of milking (6 subjects per milking parlor type). Ultimately, each cow on every farm was milked by 2 milkers. All 30 subjects (4 female, 26 male) were experienced professional milkers and accustomed to milking in the investigated environment. The subjects were familiar with both the cows and the parlor. All subjects were introduced to the CUELA system and participated voluntarily. The CUELA system was attached during 1 milking period per subject and recorded the movement of monitored joints and body parts with a continuous sampling rate of 50 Hz. Subject, parlor, and udder details are displayed in Table 2.1.

Table 2.1 Subject and milking parlor specifications (mean ± SD) and height coefficients (minimum and maximum values) by parlor type.

	Subject (milker)					Milking parlor			Height coefficient	
Item	Age (yr)	Height (cm)	Shoulder height (cm)	Weight (kg)	Dominant hand (right/left/both)	Depth of pit (cm)	Scaffold height (cm)	Milking cluster (kg)	Minimum	Maximum
Parlor type										
Auto tandem	34 ± 14	172 ± 7	142 ± 8	81 ± 21	3/2/1	90.4 ± 1.7	164.9 ± 7.6	2.9 ± 0.6	0.72	1.09
Herringbone 30°	36 ± 12	177 ± 4	146 ± 4	81 ± 12	6/0/0	92.4 ± 4.0	155.2 ± 8.6	2.6 ± 0.4	0.70	0.96
Herringbone 50°	46 ± 5	176 ± 4	146 ± 4	77 ± 7	4/2/0	92.0 ± 3.1	165.6 ± 3.7	3.1 ± 0.2	0.71	0.94
Parallel	36 ± 10	176 ± 5	146 ± 5	75 ± 16	5/1/0	99.1 ± 7.3	169.4 ± 3.9	2.7 ± 0.0	0.71	0.98
Rotary	33 ± 11	176 ± 4	146 ± 5	83 ± 11	5/1/0	91.6 ± 3.8	168.4 ± 8.0	2.6 ± 0.6	0.67	0.93

2.4.3 Data Processing

The ADJ data were processed with the CUELA specific statistical software WIDAAN (Winkel Daten

Analyze, IFA, Sankt Augustin, Germany). The subjects were filmed simultaneously to the data recording. The WIDAAN software links the video to the CUELA data and visualizes the movements in a motion figure. This facilitated the precise separation of events and, therefore, allowed us to define specific tasks or phases during milking, such as cluster attachment, stimulation, premilking, dipping or spraying, and swiveling the milking cluster. The data were subsequently assigned to the specific tasks. Only the task "attachment" was evaluated in the data analysis. A standard rating was available for 25 joint movements; each movement could result in various joint positions that were expressed as ADJ and were rated as acceptable, conditionally acceptable, or not acceptable in regard to ergonomics (Drury, 1987; McAtamney and Corlett, 1993; European Commission, 2005; Hoehne-Hückstädt et al., 2007; Institute for Occupational Safety and Health of the German Social Accident Insurance, 2013). Only the 25 rated joint movements monitored during the attachment task were considered in the analysis (see Table 2.2).

Table 2.2 Percentage of „not acceptable" angular degrees of joints (ADJ) in the 5th, 50th, and 95th percentiles for joints and body regions or movements, expressed as means across all milking parlor types.

Joint / body region	**Sensor number**	**Movement**	**5th**	**50th**	**95th**
Head	15	Inclination forward	73	45	17
	16	Inclination sideward	68	51	68
Cervical spine	5	Lateral flexion	53	33	57
	6	Flexion / extension	92	68	40
Trunk movements	22	Flexion / extension	39	20	7
	23	Lateral flexion	2	1	4
	21	Torsion	0	0	0
Back bending	19	Lateral inclination	2	0	1
	20	Inclination	46	30	19
Knee joint	13 (left)	Flexion / extension	42	48	71
	14 (right)		51	58	78
Shoulder joint	28 (left)	Ad-/abduction	9	31	53
	29 (right)		33	62	82
	30 (left)	Flexion / extension	11	39	71
	31 (right)		17	45	75
	32 (left)	Inward / outward rotation	25	12	13
	33 (right)		17	6	25
Cubital joint	3 (left)	Flexion / extension	94	70	19
	4 (right)		100	77	23
Lower arm	34 (left)	Pronation / supination	23	4	27
	35 (right)		14	9	30
Wrist	9 (left)	Radial / ulnar duction	50	28	24
	10 (right)		13	3	16
	7 (left)	Flexion / extension	3	0	2
	8 (right)		0	0	5

2.4.4 Height Coefficient

A height coefficient was created to present the ratio between working height and milker's height by using the formula: (individual udder base height + floor level)/milker's individual height. This height coefficient was used to account for the effects of the milker's body height and the cow's udder height in the statistical analysis. The 5th, 50th, and 95th percentiles (WIDAAN output) of the ADJ express the measuring incidence of a specific posture. These were statistically evaluated to find differences in both the median (50th percentile), the 5 lowest (5th percentile), and the 5 highest (95th percentile) percent of measured postures.

2.4.5 Statistical Analysis

The generalized linear mixed-effects model (Pinheiro and Bates, 2000) was used to evaluate the target variables. Statistical differences were evaluated separately for the 5th, 50th, and 95th percentiles of each ADJ. The statistical analysis was performed in R 1.9.1 (R Development Core Team, 2006), and parlor type (factor with 5 levels: ATD, HB 30°, HB 50°, PAR, and ROT), height coefficient (continuous), and all possible 2-way interactions between parlor type and height coefficient were fixed effects. Milkers nested in cows and in farms were included as random effects. The residuals and random effects were checked graphically to ensure that they met the model assumptions.

2.4.6 Proportion of not Acceptable Postures

The raw data were further analyzed by calculating the percentage of acceptable, conditionally acceptable, and not acceptable ADJ in all percentiles of the 25 rated joint movements. The proportion of not acceptable postures across all parlors was calculated to establish which joints were largely affected by poor working posture.

2.4.7 Model Development

The statistical output from recordings and analysis of the rated joints and body parts were used in a mathematical model to calculate the ADJ at specific constant factors between 0.7 and 1.0 (in intervals of 0.05). The generalized linear mixed effects model not only calculates the significance of the model components, but also the significance of their interaction. In this case the interaction was significant, and the estimates that were calculated by R could be used in a function:

$$\text{Estimate of the angular degree at a specific constant factor} = \text{estimate intercept} + \text{estimate milking parlor type} + \text{estimate height coefficient} \times \text{specific constant factor which will be calculated} + \text{estimate height coefficient} \times \text{estimate interaction.}$$

The statistical data were used to assess the most acceptable posture by summarizing the numbers of ADJ that were rated as acceptable (Deutsche Gesetzliche Unfallversicherung, 2013) at a specific constant factor. The numbers of acceptable ADJ across all ADJ in the 5th, 50th, and 95th percentiles were counted and summarized for each milking parlor type and height coefficient. If 100% of all modeled ADJ were acceptable, this would result in a total of 25 positive occurrences in each of the 3 percentiles and a maximal score of 75. The estimates of the height coefficients resulting in the most acceptable postures were used as a constant factor in the milking health formula.

2.5 Results

2.5.1 Empirical Data

A significant ($P < 0.05$) interaction of parlor type and height coefficient was observed in 22 out of 31 (50^{th} percentile) or 25 out of 31 (5th and 95th percentiles) ADJ (the levels of significance are stated in Table 2.A1). In contrast, few ADJ were influenced significantly by only 1 of the main effects (parlor type or height coefficient). The height coefficient was significant ($P < 0.05$)

in 3 out of 31 ADJ (in the 5th, 50th, and 95^{th} percentiles: knee flexion left; shoulder adduction right; in the 5th and 50th percentiles: lower arm pronation left). The parlor type was significant ($P < 0.05$) in 2 out of 31 ADJ (thoracic spine inclination forward in the 50th and 95th percentiles; shoulder adduction left in the 5th percentile).

2.5.2 Proportion of Not Acceptable Postures

Table 2.2 shows the percentage of not acceptable ADJ of the rated joint movements across all parlor types in the 5th, 50th, and 95th percentiles. It was apparent that the cubital joint flexion toward the left and right, the cervical forward bending, the flexion of the right knee, the forward head inclination, and the adduction of the right shoulder were not acceptable in the 50^{th} percentile over 50% of the time and that the flexion of the left knee and the right shoulder were not acceptable over 40% of the time (Table 2.2).

2.5.3 Model Calculation

The numbers of acceptable ADJ across the rated joint movements at a specific constant factor are listed in Table 2.3. These numbers were created by using model data. It was apparent that the ROT parlor had the lowest number of acceptable ADJ (41 acceptable out of 75 total ADJ) when the most acceptable ROT-specific constant factor was considered. The PAR parlor had 1 more acceptable ADJ (42 out of 75) at its most acceptable constant factor than the ROT parlor. The HB 50° parlor had the largest number of acceptable ADJ (49 out of 75). However, the ATD parlor had the most acceptable ADJ across different constant factors, followed by HB 50°. The total number of acceptable ADJ across all constant factors was lowest in PAR (257 acceptable ADJ). According to the definition of the constant factor, the ideal working height in each parlor type was dependent on the coefficient of the milker's body height and the udder base height and varied across parlor types. Therefore, it was apparent that body height had a lesser effect in the ATD parlor than in the ROT parlor as the number of acceptable ADJ varied less with differing constant factors (for further details see Table

2.3 and Table 2.A1). Despite using modeled data, it was not possible to create a situation in which all ADJ were acceptable in any parlor type.

Table 2.3 Number of acceptable angular degrees of joints (ADJ) across all joint movements in regard to the 5th, 50th and 95th percentiles at a specific constant factor (modeled data) (maximum value per constant factor when all ADJ are acceptable is 75)[1].

	Constant factors							
Parlor type	0.7	0.75	0.8	0.85	0.9	0.95	1	∑
Auto tandem	44	45	45	**46**	45	45	39	307
Herringbone 30°	**42**	41	40	**42**	**42**	40	**42**	289
Herringbone 50°	48	**49**	46	42	37	39	36	297
Parallel	**42**	40	38	38	33	34	32	257
Rotary	39	**41**	40	36	34	35	34	259

[1] The values in bold show the largest number of acceptable ADJ for the individual parlor type.

2.5.4 Development of the Milking Health Formula

A formula that facilitated the individual calculation of the ideal depth of pit was developed:

$$\textit{Ideal Depth of Pit (cm)} =$$

$$\textit{Individual Milker Height (cm) x Parlor-Specific Constant Factor – Herds Mean Udder Height (cm).}$$

The optimal parlor-specific constant factors for each parlor type are indicated in Table 2.3.

2.6 Discussion

The data indicated a strong interaction between the milking parlor type and the height coefficient (i.e., the proportion of the udder base height and the floor level to the milker's body height) regarding ergonomics during the attachment task. Results from the present study revealed that the ideal working height varied between milkers and parlors, as the ideal constant factor of udder base, floor level, and milker's body height differed between parlor types. The HB 50° enabled milkers to maintain the highest number of acceptable body postures (49) at the ideal constant factor (constant factors: 0.75), whereas ROT allowed for the lowest number of acceptable body postures (41) at the most acceptable constant factor (constant factor: 0.75; Table 2.3). The ATD was shown to be the most beneficial parlor when multiple milkers of varying heights work in the same parlor. This was reflected by the highest number of acceptable ADJ (45/46) among different constant factors (0.75, 0.8, 0.85, and 0.9). However, if a parlor is operated by 1 milker alone or by milkers of similar heights, the ideal depth of pit can be calculated by using the new milking health formula and the constant factors that were established as a result of our study. The ideal constant factors in Table 2.3 can be used to identify the best possible working position and thus improve ergonomics for each parlor type.

The milking health formula [Ideal Depth of Pit (cm) = Milker's Height (cm) x Parlor-Specific Constant Factor – Mean Udder Height (cm)] can therefore be used as a guideline for future milking parlors, as well as to set the correct working height in parlors with adjustable floors. This formula accounts for variable heights in milking personnel as well as variable mean udder heights. Furthermore, it takes into account the effect of horizontal reaching distance in the different parlor types, which has been reported to differ between HB 30°, PAR, and ATD parlors (Tuure and Alasuutari, 2009).

Ideal working height for the attachment task has been discussed in previous research, and authors suggested working height in HB 30° parlors to be best when the milker's shoulder is level to the teat end (Jakob et al., 2012). The current study found HB 30° and ATD parlors to be relatively tolerant across different working heights, thus suggesting that neither working at shoulder or at elbow level would cause bad posture. Nevertheless, a higher coefficient, and thus a deeper milking pit (higher depth of pit), resulted in more acceptable ADJ particularly in ATD but also in HB 30° parlors, thus indicating a benefit of working with the udder at shoulder level in these parlor types. The milking health formula, however, recommended the depth of pit in HB 50°, PAR, and ROT parlors to be smaller; this is in line with the findings of Stål and Pinzke (1991), who recommended the elbow to be 30 cm above the floor level of the cow. The differences in ideal working height could be explained by the reaching distance, which is larger in PAR than in the other parlor types. Billon (2009) stated that different working heights are recommended for the different parlor types and points out that pits of PAR parlors should be higher. The current study also suggested higher pits for PAR parlors and recommended differing ideal working heights for the milking parlor types, which is in line with the recommendations made by Billon (2009).

Douphrate et al. (2013) reported that PAR parlors required milkers to attach the milking cluster from behind the cow, which required an increased reaching distance compared with parlors, such as ATD or HB 30°, in which the milker attached the cluster from the side. The shoulder-udder distance in the ATD parlor is smaller than in HB 30° parlors, as the angular position of the cow makes it necessary for the milker to reach over the platform (Douphrate et al., 2013). The ROT parlors in the current study were inside milkers. The cows were stood at a 30°angle and milked from the side. Due to the round platform in ROT parlors, the udder-shoulder distance was increased compared with a normal HB 30° parlor. In outside-milking ROT parlors cows are milked from behind, thus we would expect the shoulder-udder distance to be similar to that in a PAR parlor.

Although not directly addressed, the shoulder-udder distance is indirectly reflected by the individual recommendations of the milking health formula. It appeared that with increased shoulder-udder distance, such as in the PAR parlors, the ideal working height is higher and thus the depth of pit is smaller than when the shoulder-udder distance is decreased. For each parlor type, we identified a parlor-specific constant factor that is multiplied by the milker's height in the developed formula.The ideal constant factors can result in a variation of the ideal depth of pit between different parlor types of up to 16 cm for a person at 160 cm of height and up to 19 cm for a person at 190 cm of height. Although the formula developed in the current study is useful to optimize the parlor-specific working height, it does not necessarily imply that the resulting ergonomics are satisfactory and eliminate the occurrence of musculoskeletal problems in dairy workers. Due to opposite ideal constant factors of different joints, certain joints will operate at a not acceptable level when the movements and positions of other joints are acceptable. The interactions of the left shoulder, the elbows, and the cervical spine illustrate this issue. Whereas the elbows operate in an acceptable posture when the constant factor is 1.0 and in a not acceptable posture when the constant factor is 0.7, the shoulder joint operates in a conditionally acceptable posture when the constant factor is 0.7 but in a not acceptable posture when the constant factor is 1.0. Further, the bending of the cervical spine is acceptable when the constant factor is 0.7 and not acceptable when the constant factor is 1.0 in most parlor types. These findings are in line with previous research that reported opposite interactions between joints (Jakob et al., 2009). Hence, despite the consideration of the ideal constant factor, certain joints will operate in nonideal working postures during parts of the milking procedure. It is not possible for all joints to simultaneously be at an acceptable ergonomic posture during milking.

The ideal constant factors were calculated by counting the numbers of ADJ in an acceptable ergonomic range (according to norms and ergonomic literature) in the 5th, 50th, and 95th percentiles. Although this approach gives a useful estimate of the quality of the working posture, the interpretation has proven difficult. The 50th percentile, for instance, represents the median level of postures at a specific ADJ; however, certain joints might cause severe problems if they remain at strain for a short period of time. For example, overbending a joint may result in similar or more severe pain than holding a joint in an uncomfortable position for an ongoing period of time, thus it is important to also consider the 5th and 95th percentiles. To give practical recommendations, it was justifiable to simplify the data by considering the range of postures (5th, 50th, and 95th percentiles). However, considering the 25th and 75th percentiles and the direction of movements would allow for a more detailed assessment and thus analysis of certain milking parlor elements, such as cradle bars. Future research should aim at considering such elements to improve existing parlors by making small adjustments.

Across all 5 examined parlor types, only 43 to 49 out of 75 ADJ represented an acceptable posture at the recommended ideal constant factors. Therefore, it can be concluded that even when workers were milking at an ideal working height, only 57.3 to 65.3% of all ADJ were in an acceptable ergonomic range throughout the 5th, 50th, and 95th percentiles. Hence, the working conditions can be improved, but it is impossible to develop a milking parlor that is acceptable for all joints. This may be due to the distance between the udder and the milker, which requires the milker to reach out and lift the milking cluster to attach it to the udder and so load weight on shoulders, elbows, and wrists. Tuure and Alasuutari (2009) assessed this criterion and emphasized the importance of appropriate parlor dimensions for improved ergonomics. When planning and constructing milking parlors, farmers should therefore specify details on musculoskeletal problems so that special attention can be paid to joints of concern for the particular farmer (see Table 2.A1). Due to technical challenges, the horizontal reaching distance could not be measured directly in our study; however, the milking health formula considered heights of milker and udder and took the parlor type into account. Hence, the distance was included indirectly in the formula.

The 50th percentile indicated high levels of not acceptable postures in the knees [48% of the left knee (sensor 13) and 58% of the right knee (sensor 14); Table 2.2] and supported earlier findings that reported a high physical strain on the knees during milking (Liebers and Caffier, 2006). Previous research stated that high levels of upper limb and lower back disorders were the result of milking postures (Liebers and Caffier, 2006). The percentage of not acceptable postures in the trunk (flexion: 20%, lateral flexion: 1%, torsion: 0%) and back bending (lateral inclination: 0%, inclination: 30%) do not confirm these findings. In contrast, the present study found high percentages of not acceptable postures in the shoulder and arm regions (see Table 2.2).

The ideal depth of pit recommended in the present study appears to be lower than that identified in previous research (e.g., Jakob et al., 2009) and provides advanced information on ideal working height in different milking parlor types. Furthermore, the milking health formula can be used to calculate the ideal depth of pit. Future research should focus on the validation of the milking health formula in an experimental setting.

2.7 Conclusion

The present results are of benefit for farms with adjustable floors, as they facilitate an easy calculation of the ideal working height and can be used to improve posture during milking. The depth of pit in milking parlors should therefore be constructed according to the ideal working height, which predominantly depends on a combination of the parlor type and the height coefficient between the udder base height, the floor level, and the milker’s body height. Ergonomics of the parlor types ROT and PAR were disadvantageous compared with those of HB 30° or ATD, and ergonomics of HB 50° were the most advantageous when the individually recommended working heights were applied. However, the differences between parlor types were minor, whereas the differences in the interaction of parlor type and height coefficient were significant. Some joints or body regions were in an opposing relationship to each other, which indicated that ergonomics cannot be improved for all joints that are involved in any given posture. However, the results of our study can be used to give individual recommendations and improve ergonomics in parlors with the help of the milking health formula that was established in the current study.

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2.9 Appendix

Tab. 2.A1: Model calculation presenting parlor-specific angular degrees of joints (ADJ) at each constant factor with P-values for the interaction of parlor type × height coefficient; *P < 0.05, **P < 0.01, ***P < 0.001; n.s. = not significant). The ADJ values were color coded according to the BGI/GUV-I 7011 (Anhang 3) and scientific literature [gray (green) = acceptable, white (yellow) = conditionally acceptable, black (red) = not acceptable; Drury, 1987; McAtamney and Corlett, 1993; ISO, 2000; European Commission, 2005; Hoehne-Hückstädt et al., 2007; Deutsche Gesetzliche Unfallversicherung, 2013). ATD = autotandem parlor; HB 30° = herringbone 30° parlor; HB 50° = herringbone 50° parlor; PAR = parallel parlor; ROT = rotary parlor.

Joint flexion angle	Percentile	Parlor type and constant factor															Interaction parlor type x height coefficient
		ATD			HB 30°			HB 50°			PAR			ROT			
		0.7	0.8	1.0	0.7	0.8	1.0	0.7	0.8	1.0	0.7	0.8	1.0	0.7	0.8	1.0	
Cubital joint flexion left	5	29	34	42	29	31	36	26	30	36	12	31	68	22	31	48	***
	50	46	51	62	55	54	52	43	51	67	28	44	75	47	52	62	***
	95	62	67	76	77	75	69	60	71	93	44	59	89	68	76	93	***
Cubital joint flexion right	5	23	24	26	39	35	26	18	28	49	11	18	30	16	25	45	***
	50	51	48	43	56	58	64	44	51	63	40	47	60	34	40	53	***
	95	76	70	58	71	77	90	73	74	76	76	79	83	54	56	59	***
Cervical bending right	5	-20	-14	-3	-8	-10	-16	-13	-12	-9	-14	-11	-4	-12	-11	-10	**
	50	-12	-6	7	2	1	-1	-6	-1	8	-7	-3	6	-4	1	9	*
	95	-6	3	19	12	12	13	4	9	20	3	7	14	8	11	16	**
Cervical bending forward	5	-3	-11	-26	-18	-19	-20	-9	-18	-36	-7	-10	-16	-11	-16	-25	*
	50	6	-1	-16	-6	-6	-6	4	-6	-27	8	2	-9	-1	-5	-12	**
	95	19	10	-7	7	7	8	17	6	-14	22	14	-1	15	10	1	*
Wrist flexion left	5	-21	-25	-31	-31	-26	-16	-19	-24	-32	-9	-15	-26	-20	-28	-45	**
	50	-15	-12	-6	-21	-10	10	-9	-9	-10	-1	-4	-9	-9	-15	-26	***
	95	7	8	10	13	14	17	13	14	16	7	8	10	10	11	13	n.s.
Wrist flexion right	5	-31	-26	-16	-35	-27	-10	-11	-19	-33	-17	-19	-22	-26	-27	-29	***
	50	-15	-11	-4	-20	-11	5	-1	-4	-11	4	0	-6	-15	-18	-23	***
	95	12	16	25	3	12	30	24	19	10	24	26	31	5	-3	-17	***
Wrist radialduction left	5	-28	-24	-17	-33	-25	-7	-19	-24	-33	-17	-28	-51	-22	-23	-24	***
	50	-20	-15	-4	-23	-15	1	-12	-14	-20	-9	-18	-37	-6	-4	-1	***
	95	-10	-2	14	-6	-2	5	-1	0	1	3	-7	-26	6	10	18	***
Wrist radialduction right	5	-22	-17	6	-21	-16	-7	-7	-12	-20	-13	-18	-26	-2	-3	-6	***
	50	-14	-9	2	-15	-9	4	1	-5	-16	1	-4	-15	4	2	-1	***
	95	0	4	12	-7	0	14	9	4	-5	19	12	-3	13	10	4	***
Knee flexion left	5	9	7	3	10	8	5	7	5	1	13	11	8	5	3	0	n.s.
	50	13	10	4	16	13	7	11	8	2	20	17	11	12	8	2	n.s.
	95	16	14	8	22	20	15	16	14	8	28	26	21	20	17	12	n.s.
Knee flexion right	5	7	7	6	0	8	22	-1	3	12	17	13	3	6	5	2	***
	50	13	11	7	7	12	23	1	6	16	25	19	7	12	9	4	***
	95	18	16	13	15	21	32	11	13	19	34	29	18	24	18	7	***
Head inclination forward	5	14	6	-10	-3	-2	-4	11	-1	-24	8	0	-17	10	0	-18	**
	50	21	12	-6	3	3	4	17	4	-21	14	5	-14	16	7	-11	***
	95	33	24	5	15	17	20	30	17	-8	31	18	-6	38	25	-2	***
Head inclination sideward	5	-27	-19	-1	-12	-15	-22	-13	-13	-12	-30	-23	-11	-7	-7	-7	**
	50	-17	-8	11	3	0	-5	-8	0	15	-17	-11	1	3	9	20	**
	95	-7	-4	-24	17	16	15	4	14	34	-5	1	13	21	24	30	**
Dorsal bending right	5	-8	-5	0	-3	-3	-2	-5	-4	-1	-7	-9	-12	2	1	-2	*
	50	0	1	1	2	2	3	2	3	3	-6	-6	-5	6	7	7	n.s.
	95	6	6	7	6	7	7	7	7	8	-1	-1	0	11	12	12	n.s.
Dorsal bending forward	5	8	4	-5	0	1	2	8	4	-5	5	2	-4	4	-1	-10	**
	50	11	7	-2	2	3	5	12	8	-1	8	5	-1	8	3	-6	***
	95	15	10	0	5	6	7	15	11	2	11	8	2	12	7	-3	***
Dorsal torsion right	5	-1	-1	-3	-2	-3	-5	-5	-3	1	-6	-4	1	-1	-2	-3	***
	50	3	2	0	0	1	2	-1	0	3	-3	-1	5	3	2	0	***
	95	7	6	3	3	4	6	4	4	5	0	3	8	6	6	5	***
Trunk inclination forward	5	5	6	8	5	5	5	7	5	1	1	-2	-8	12	6	-5	***
	50	11	11	12	8	9	9	11	10	5	6	2	-6	16	11	3	***
	95	15	15	15	12	12	13	15	14	11	11	7	-2	22	16	5	***
Lateral trunk inclination right	5	-7	-6	-6	-8	-7	-7	-5	-5	-4	-11	-11	-10	0	0	1	n.s.
	50	-2	-1	0	-2	-1	0	1	1	2	-6	-6	-5	6	6	7	n.s.
	95	2	4	7	6	5	2	3	6	11	0	0	0	12	12	13	*
Shoulder adduction left	5	-14	-16	-18	-25	-27	-29	-36	-37	-40	-13	-14	-16	-32	-34	-36	n.s.
	50	-7	-5	-1	-18	-17	-13	-19	-17	-14	-7	-5	-2	-12	-10	-7	n.s.
	95	-5	4	22	-7	-7	-5	-17	-6	16	13	8	-3	-1	6	20	***
Shoulder adduction	5	-27	-20	-6	-15	-8	6	-13	-11	3	-38	-31	-17	-7	0	14	n.s.

right	50	-13	-5	12	1	10	27	0	9	26	-9	0	17	2	11	28	n.s.
	95	2	10	27	20	28	46	19	27	45	15	23	41	133	22	39	n.s.
Shoulder flexion left	5	14	29	60	29	37	53	44	41	35	28	35	49	33	38	47	***
	50	26	42	73	52	55	60	53	60	75	38	45	57	56	64	80	**
	95	35	53	88	68	68	67	63	76	103	47	55	69	73	80	94	***
Shoulder flexion right	5	24	31	47	45	47	51	28	30	34	45	38	24	41	52	73	***
	50	44	51	66	56	64	82	59	52	38	67	64	56	54	61	76	***
	95	56	64	81	66	78	103	70	65	57	74	78	84	65	69	77	***
Shoulder rotation left	5	-12	-13	-17	-23	-24	-28	-7	-8	-12	-12	-14	-17	-27	-29	-32	n.s.
	50	1	-1	-4	-8	-10	-13	12	10	6	-2	-3	-7	-14	-16	-19	n.s.
	95	20	21	24	7	8	11	25	26	29	5	6	9	24	25	28	n.s.
Shoulder rotation right	5	-4	2	14	12	-14	-66	-12	-9	-2	-18	-16	-12	1	7	18	***
	50	15	18	24	23	1	-43	9	8	7	3	7	16	16	19	25	***
	95	47	44	38	30	27	20	37	34	28	58	55	49	36	33	27	n.s.
Lower arm pronation left	5	-30	-28	-23	-44	-41	-34	-27	-27	-29	-20	-33	-60	-35	-43	-59	***
	50	-3	-7	-15	-12	-16	-24	-4	-8	-16	-22	-26	-34	-6	-10	-18	n.s.
	95	15	17	20	34	24	3	-6	15	57	10	5	-7	46	42	35	***
Lower arm pronation right	5	-28	-32	-42	-17	-17	-16	-23	-31	-49	-26	-37	-59	-30	-26	-17	***
	50	8	-1	-19	-8	6	33	3	-10	-35	-6	-11	-20	-7	-8	-9	***
	95	37	28	8	12	30	67	30	20	2	34	32	28	19	12	-3	***

3 Lower Working Heights Decrease Contraction Intensity of Shoulder Muscles in a Herringbone 30° Milking Parlor

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3.1 Interpretive Summary

Muscle contraction intensities were evaluated during milking at three working heights in a Herringbone 30° milking parlor. Four upper limb and shoulder muscles were monitored bilaterally by using surface electromyography in seven men and nine women. Contraction intensities of the *deltoideus anterior* and *upper trapezius* were lower when the working height was fitted to the lowest setting. These differences were not found in the *flexor carpi ulnaris* or the *biceps brachii*.

3.2 Abstract

Musculoskeletal disorders have been a main concern in milkers for many years. In order to improve posture, a formula was developed in a previous study, to calculate ergonomically optimal working heights for various milking parlor types. However, the working height recommendations based on the formula for the Herringbone 30° parlor were broad. To clarify the recommendations for the optimal working height we investigated the impact of working height on upper limb and shoulder muscle contraction intensities.

We evaluated 60 milking cluster attachment procedures in a Herringbone 30° milking parlor in seven men and nine women. Specifically, we examined the impact of working height on muscle contraction intensity of four arm and shoulder muscles bilaterally (*flexor carpi ulnaris*, *biceps brachii, deltoideus anterior* and *upper trapezius*) by using surface electromyography. The working heights (low, medium and high), which reflect the ratio of the subject's height to the height of the udder base, were used in the milking health formula to determine and fit individual depth of pits.

Data were evaluated for each muscle and arm side in the functions "holding" and "attaching". Statistical analysis was performed using linear mixed effects models, where muscle contraction intensity served as a target variable, whereas working height coefficient, sex, subject height and repetition were treated as fixed effects, and repetition group, nested in working height, nested in subject were considered as random effects. Contraction intensities decreased with decreasing working height for the *deltoideus anterior* and *upper trapezius* but not for the *flexor carpi ulnaris* or the *biceps brachii* muscles in both holding and attaching arm functions. We found that milking at a lower working height reduced muscle contraction intensities of the shoulder muscles. Women showed higher contraction intensities than men, whereas subject height had no effect. The study demonstrated that a lower working height decreased muscular load during milking. These lower working heights should be used within the recommendations made by the milking health formula for the Herringbone 30°. Working heights could be adjusted effectively for milkers of varying body height. Future studies should therefore use the milking health formula as a tool to objectively compare and improve the accuracy of the working height coefficients.

Keywords: milking health formula, ergonomics, labor, dairy cow, physical load, electromyography.

3.3 Introduction

Due to ongoing reports of high levels of musculoskeletal problems in milking parlor operators (Jakob, 2010; Patil et al., 2012; Douphrate et al., 2013; Douphrate et al., 2014), research has aimed to evaluate risk factors during milking, such as posture (Jakob et al., 2012; Cockburn et al., 2015; Jakob and Thinius, 2015) and physical load (Liebers et al., 2009). Milking personnel has generally been advised to work in a position in which the teat ends are at shoulder level (Jakob et al., 2009; Jakob et al., 2012). Contrarily, in a recent study, we found that raising the floor level for the milker would decrease the lifting height and, thus, benefit posture (Cockburn et al., 2015). In the same study, we also provided recommendations regarding differing working heights (WH) for a variety of parlor types (Autotandem, Herringbone 30°, Herringbone 50°, Parallel and Rotary) and developed guidelines that were implemented in the milking health formula (Cockburn et al., 2015). These recommendations enabled the calculation of WH under consideration of the parlor type, the cows' mean udder height and the milker's body height.

The WH recommendations provided by the milking health formula resulted in considerably lower WH than those currently used in a commercial setting, especially for Herringbone 30° and Side by Side parlors (Cockburn et al., 2015). Liebers et al. (2009) recommended a WH, where the udder is at shoulder level; considering a median male milker of 1.75 m with a shoulder height of 1.45 m, this results in a WH coefficient of 0.8 (Lange and Windel, 2013). Furthermore, the recommended WH coefficient for the Herringbone 30° parlor was very broad (between 0.7 and 0.9). The lower WH recommended by the milking health formula could be favorable not only in improving posture but also for reducing muscle contraction intensity and, thus, the physical demand during milking. Therefore, additional information was needed to refine the recommended WH coefficients that had been derived from on-farm experiments for this milking parlor type.

The present study aimed to investigate the effect of WH on upper limb and shoulder physical workload, by evaluating muscle contraction intensities during the milking procedure. We further expected to improve the precision of the milking health formula's optimal WH coefficient for the Herringbone 30° parlor in a laboratory setting. A secondary aim of this study was to investigate the milking health formula's ability to set comparable WH for subjects of different body heights.

3.4 Materials and Methods

3.4.1 Experimental Setting

The study was carried out in the experimental milking parlor of Agroscope in Tänikon, Switzerland. This experimental milking parlor was a 2 x 5 Herringbone 30° parlor with a balcony depth of 0.1 m (Figure 3.1; GEA Farm Technologies GmbH, Bönen, Germany). It was equipped with an adjustable floor and the cluster-positioning arm Posilactor (GEA Farm Technologies GmbH, Bönen, Germany), which allowed for a variation of WH and a steady positioning of the milking clusters. We decided to use cluster-positioning arms because they help standardize and smoothen the movements between subjects. The milking clusters we used were the GEA "Classic 300" (GEA Farm Technologies GmbH, Bönen, Germany) and weighed 2.6 kg. The short milk tubes were made of silicon, which improves handling (Siliconform, Türkheim, Germany).

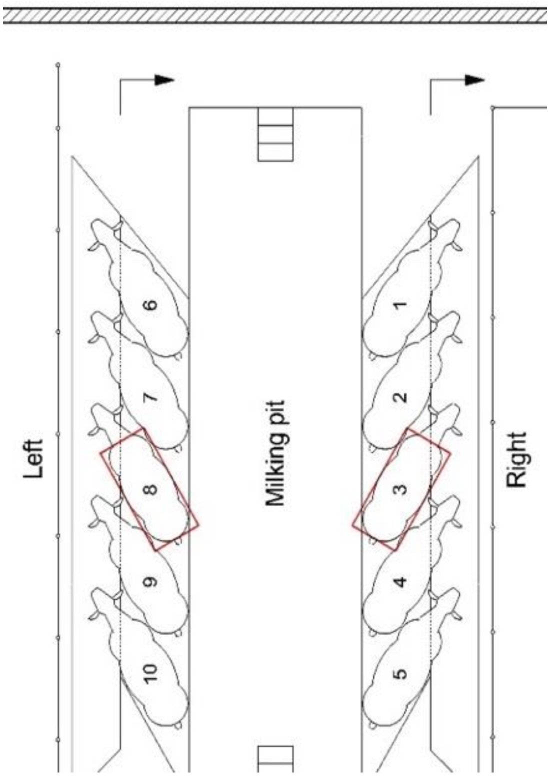

Figure 3.1 Setup of the experimental milking parlor. Two artificial udders were positioned at milking stall numbers 8 and 3.

Subjects were monitored whilst attaching a milking cluster to an artificial udder (IC KUH, Bad Bentheim, Germany). This udder was placed in a self-constructed wooden stand with an udder base height of 0.55 m (Figures 3.2 and 3.3). The wooden stand was equipped with true-to-scale hind legs with size proportions that reflected the mean size of cow legs at our research farm. The artificial udders were positioned in the middle of the left and right sides of the milking parlor (Milking stalls 3 and 8, Figure 3.1).

Figure 3.2 Artificial udder used in the experiment.

3.4.2 Subjects

The study was registered with the Swiss Ethics Commission of the Canton of Thurgau, Switzerland. Seven men and nine women with milking experience, but without a daily routine, participated in the trial. We chose milkers without work routine to exclude habituated work procedures and, thus, be able to instruct a particular milking cluster attachment technique. All milkers were in good health, had a body mass index below 30 and participated voluntarily. Women measured between 1.68 and 1.89 m (mean 1.76 ± 0.06 m), and men measured between 1.74 and 1.89 m (mean 1.81 ± 0.05 m) in height.

3.4.3 Working Heights

Three WH were individually installed for each subject (Figure 3.3). These were determined by using WH coefficients, which reflect the ratio of the height of the udder base + depth of pit to the height of the milker (Formula 1). The milking health formula (Cockburn et al., 2015) was used to calculate the individual depth of pit to ensure the correct WH (Formula 1). In the formula, the WH coefficient was set as a constant factor, and the height of the artificial udder (0.55 m) agreed with the herds' mean udder height. The WH coefficients 0.72 (low), 0.775 (medium) and 0.82 (high) were used in the formula to determine depth of pit for each subject at the three WH. A larger WH coefficient resulted in an increased depth of pit and thus a higher WH (Figure 3.3).

Formula 1

$$Depth\ of\ Pit\ [m] = (Subject\ Height\ [m] * Coefficient^1) - (Herd\ Mean\ Udder\ Height\ [m])$$

$$Coefficient^{\ 1} = \frac{(Udder\ Base\ Height\ [m] + Depth\ of\ Pit\ [m])}{Subject\ Height\ [m]}$$

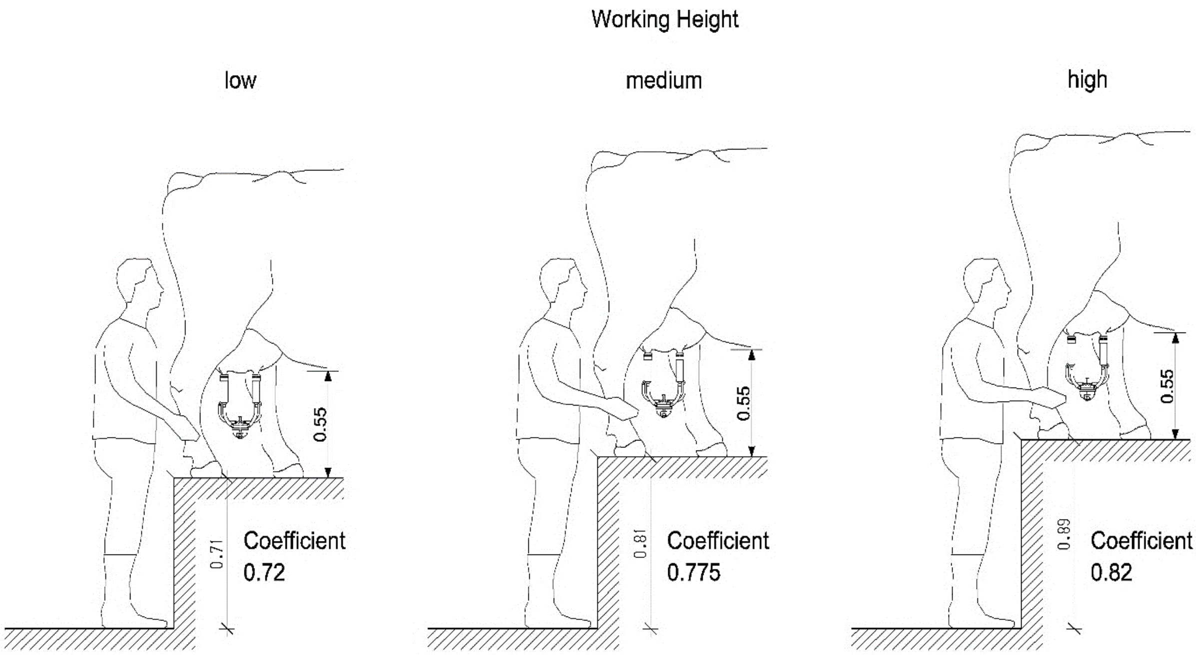

Figure 3.3 Three working height coefficients with a representative milker (body height of 1.75 m) in a Herringbone 30° parlor.

3.4.4 Measuring Devices

The Trigno™ wireless surface electromyography (sEMG) system was used to record upper limb and shoulder muscular activation of subjects during the work routine (Delsys, Boston, USA). Each sensor measured 37 x 26 x 15 mm and weighed 14 g. Two bar electrodes and two reference bar electrodes were installed parallel within the sensor. One sensor was placed on each monitored muscle. Prior to sensor placement, the skin was prepared by shaving an area slightly bigger than the sensor and cleaning it with alcohol pads (70%).

In total, eight sensors were placed bilaterally on *flexor carpi ulnaris*, *biceps brachii*, *deltoideus anterior* and *upper trapezius*, parallel to the muscle fibers according to the Seniam guidelines (Hermens et al., 1999). These muscles were selected due to their role during the attachment of the milking cluster. The cluster is held in the palm of the hand and as such requires wrist flexion, which is provided by the *flexor carpi ulnaris*. The *biceps brachii* is responsible for elbow flexion, which is relevant for lifting and holding of the cluster. The main function of the *deltoideus anterior* is shoulder abduction and flexion and thus this muscle plays a vital role when the cluster is moved forward, away from the milker's body underneath the cow's udder. During this movement, the shoulder may also be lifted, which is facilitated by the *upper trapezius*.

Signal quality was checked prior to data collection using the EMGworks acquisition software (Delsys, Boston, USA). The software was further used to record the data with a standard sampling rate of 1926 Hz. At all times, an observer was present during the experiment. The observer documented the initiation of a new attachment procedure by swinging an accelerometer when the subject pressed the button to release the milking cluster. Therefore, an EMG sensor was attached to the observer's hand and preset as an accelerometer with a standard sampling rate of 184.1 Hz. As the sEMG and accelerometer data were recorded with the same software package, the accelerometer was used to mark the starting point of the attaching procedure in the sEMG data. The experimental procedures were filmed using Mobotix M15 conventional cameras (Mobotix AG, Langmeil, Germany) to be able to go back and evaluate ambiguous occurrences in sEMG data.

3.4.5 Experimental Procedure

Data recordings took place between 9.30 AM and 12.30 PM. The experimental procedure consisted of three elements:

1. Maximum Voluntary Contraction

Each subject's recordings took place on the same day. Initially, the subject completed two unilateral (MVC) per monitored muscle (i.e., 16 MVC in total). The duration of each MVC was 3–5 seconds (Konrad, 2006) and the resistance was applied manually by the experimenter. The MVC of the *flexor carpi ulnaris* was performed by asking the subject to turn the ventral side of the lower arm upwards, while the upper arm remained parallel to the trunk. The subject was then asked to flex the wrist upwards against a resistance with a joint angle at roughly 120° whereby 180° was a straight joint. The MVC of the *biceps brachii* was performed by asking the subject to perform an elbow flexion against resistance at approximately 90°. The MVC of the *deltoideus anterior* was performed by asking the subject to lift the lower and upper arm forward against a resistance, whilst the elbow joint remained straight and the ventral side of the elbow and the radial side of the hand were facing upwards. The angle of the shoulder was hereby roughly at 150° whereby 180° was a straight joint. The MVC of the *upper trapezius* was performed by asking the subject to lift the shoulder upwards against the resistance whilst the elbow, shoulder and wrist joints remained straight. If the maximal sEMG signal of the two contractions differed by more than 10%, a third contraction was performed. The mean sEMG activity of these two contractions served as a reference for the experimental data and allowed for a comparison between and within subjects (see below). If a third contraction was performed, the mean was calculated from the 2 highest contractions.

2. Training the Attachment Technique

The subjects were instructed to attach the milking cluster with a defined technique to ensure that the attachment task was carried out similarly between the subjects. The arm that was furthest away from the cow's hind leg was always used to lift and hold the milking cluster, whilst the arm that was closest to the hind leg was used to attach the teat cups. Accordingly, the cluster was held in the left hand on the right side of the milking parlor and in the right hand on the left side of the milking parlor (holding), whilst the contralateral hand was used to attach the teat cups to the teat (attaching).

Initially, the cluster faced the floor and was held by a string, which was automatically released once the subject pressed the start button on the milking terminal. The subject was instructed to use the holding hand to swing the milking cluster and turn it around so that the teat cups faced upwards. Hereby the milk tubes were blocked and, therefore, air inlet was prevented due to the bending of the short milk tubes. The cluster was then shifted underneath the artificial udder (holding), and the teat cups were attached laterally in a U-shape (attaching), anterior to the artificial hind legs. The teat that was furthest away from the milker was hereby attached first. Subjects were instructed not to look at the teats whilst attaching the milking cluster. Instead, they were trained to hold the teat cup with their thumb and middle finger and use their index finger to feel the location of the teat and guide it into the cup (Figure 3.4).

Figure 3.4 Milking cluster attachment technique.

Every subject was given 15 minutes to practice the milking cluster attachment in the instructed way prior to the recording period. The recording period began when the subjects confirmed that they felt comfortable and familiar with the attachment procedure.

3. Recording Period

Each subject was asked to attach the milking cluster 60 times. Each repetition started with the pressing of the start button, which released the milking cluster and was documented by the observer swinging the hand with the accelerometer. Each attachment procedure was followed by a 20 second recovery phase. The time for cluster attachment was not limited. Five repetitions were carried out on each side of the milking parlor, with one minute recovery phase between sides. This procedure was then repeated once, resulting in 20 repetitions per WH, with 10 repetitions on each side of the milking parlor. A new WH was installed after every 20 repetitions. We chose this procedure to represent milking a group of five cows, which reflected milking in a practical setting. The WH as well as the parlor sides on which the data recording started were randomized between subjects. Six combinations of WH settings were therefore available. Each subject had a new combination of WH and started the milking on a new (right or left) side of the milking parlor.

3.4.6 Data Analysis

The data were processed in the software package EMGworks Analysis (Delsys, Boston, USA). sEMG and accelerometer data were processed simultaneously. Non-physiological data, which can occur through movement of the sensors (for example when they get caught on clothing or rails), appear as artefacts (peaks) in the raw sEMG data. Thus, the raw data were visually checked for artefacts, and attachment procedures with artefacts were omitted (sEMG sequences with artefacts were not evaluated) in the analyses. The percentage of omitted data was 1%. Artefacts were defined as any visible shift < 5 ms with an increased amplitude based on the baseline sEMG. As the raw sEMG was measured in Volts and, accordingly, had positive and negative values that equalize to zero, the root mean square values of the raw data were calculated with a window length of 0.25 ms (using one of the functions in the EMGworks analysis software), roughly averaging 481.25 sampling points, to create positive values, which were then used for further analysis. Hereby, the offset of the data was also removed, which ensured that all data of relaxed muscles originated from zero. No additional filters were used. R version 3.1.0 (R Core Team, 2013) was used to normalize the RMS data to each subject's muscles' individual MVC by calculating the percentage of the mean MVC amplitude values. All sEMG data were subsequently reported as a percentage to provide mean contraction intensities.

The accelerometer traces consist of the X-, Y- and Z-axis. The initial change before the peak of the acceleration traces (which was the result of the observer marking the beginning point) on the Z-axis was used as the starting point of the attachment procedure, whereas the end point was established where the sEMG activity of the *deltoideus anterior* decreased almost to zero. The *deltoideus anterior* is responsible for the forward/upward lifting of the arm. When this muscle's activity decreases, the subject will not be able to hold the cluster underneath the udder, hence it was chosen as an end point of the attaching procedure.

The time intervals between the starting and end points were compared with the time intervals of the attachment procedure on the videos to assure correct data alignment. The mean muscle contraction intensities during the attachment procedure were calculated with the software package EMGworks. This data set was then pasted into an Excel spreadsheet (Microsoft Office, 2013). The data were lined up with the additional data representing WH, subject height, side of the milking parlor, arm function and repetition. Repetitions were coded from one to five. Hereby, five repetitions were carried out on one side of the milking parlor and represented the milking of one group of cows. These five repetitions were considered as a "repetition group" (12 in total, resulting in 60 attachment procedures). Files were separated into the arm holding the milking cluster and the arm attaching the teat cups. Thus for right and left muscles, 30 repetitions were evaluated for both the attaching and holding arm.

3.4.7 Statistics

Statistical analysis was performed separately for all 4 recorded muscles (on both sides) and two arm functions (holding and attaching functions of the right and left *flexor carpi ulnaris*, *biceps brachii*, *deltoideus anterior* and *upper trapezius*) in R version 3.1.0, resulting in 16 models. A generalized linear mixed effects model ("lme" method, Pinheiro and Bates, 2000) from the package "nlme" (Pinheiro et al., 2016) was fitted, where the mean contraction intensity was set as the outcome variable. WH coefficient (factor with three levels), sex (factor with two levels), subject height (continuous), repetition (continuous) and their interactions were treated as fixed effects. Repetition group (six repetition groups, each comprising five attachment procedures), nested in repetitions per WH (10 repetitions per WH), nested in subject (30 repetitions per subject) were considered as random effects.

After fitting the model, the residuals were checked graphically for normal distribution and homogeneity of variance. To satisfy these assumptions, all mean contraction intensities were logit transformed. In a few cases, it was necessary to remove outliers to ensure normally distributed residuals (outliers removed: one in the left *biceps brachii* [holding], two in the right *flexor carpi ulnaris* [attaching]).

The dredge function (package MuMin) was used to find the best model based on the smallest Bayesian Information Criterion and largest model weight (w_i) (Bartoń, 2013). The model weight can be interpreted as the probability for a specific model to be optimal in the set of considered models given the data, where the w_i's of all models in a set add up to one (Symonds and Moussalli, 2011). Here, our set included the maximum model as described above and all simpler models including the null model (with an intercept only; so-called all-subset approach). The evidence ratio (ER_0) reflects how many times the chosen model was more likely compared with the null model (Symonds and Moussalli, 2011). This approach in choosing a model is an alternative to frequentist *p*-value based testing and therefore no *p*-values are presented.

3.5 Results

WH had no effect on contraction intensity of the *flexor carpi ulnaris* or the *biceps brachii* during either the holding or the attaching function. However, contraction intensity increased with WH and was highest at the high WH for both the holding and the attaching arm functions in the left and right *deltoideus anterior* and *upper trapezius* (Table 3.1; Figures 3.5 and 3.6). Only figures for the holding function of the right *deltoideus anterior* and the right *upper trapezius* were presented because the patterns we found were similar across the right and left sides, as well as the holding and attaching arm functions. Subject height had no effect on contraction intensity in any of the monitored muscles (Table 3.1). Sex had an effect on many of the monitored muscles; during the attaching arm function, muscular contraction intensities were higher in women than in men in the left and right *flexor carpi ulnaris*, the right *biceps brachii* and the left and right *deltoideus anterior* (Table 3.2). This effect was also found in both left and right *deltoideus anterior* and *upper trapezius* for the holding arm function (Tables 3.1 and 3.2; Figures 3.5 and 3.6). Contraction intensity decreased with increasing repetition in the right *flexor carpi ulnaris* during the holding arm function. In addition, there was an interaction of sex and repetition in the right *deltoideus anterior*, where contraction intensity decreased over time in women but not in men (Figure 3.5). For the attaching arm, contraction intensity decreased over time in the left *flexor carpi ulnaris*, the left and right *deltoideus anterior* and the right *upper trapezius*.

Table 3.1 Fixed effects of the best model from the model selection table. Fixed effects in bold can be found in Figures 3.5 and 3.6. WH=Working height, S=Sex, R=Repetition, x=Interaction, 0=Null model. w_i describes the probability that the chosen model is the best model. ER_0 describes how many times the chosen model is more likely than the model that includes only the intercept (null model). All data were logit transformed.

	Function	Holding the milking cluster				Attaching the milking cluster			
Side	Muscle	*Flexor carpi ulnaris*	*Biceps brachii*	*Deltoideus anterior*	*Upper trapezius*	*Flexor carpi ulnaris*	*Biceps brachii*	*Deltoideus anterior*	*Upper trapezius*
Left	Fixed effects	0	0	WH + S	WH + S	WH + R	0	WH + S + R	WH
	w_i	0.39	0.65	0.53	0.67	0.50	0.54	0.66	0.67
	ER_0	1	1	5250	6740	12.1	1	6600	6670
Right	Fixed effects	R	0	WH + S x R	WH + S	S	S	WH + S + R	WH + R
	w_i	0.48	0.60	0.59	0.67	0.39	0.50	0.40	0.60
	ER_0	4,200	1	5,880	6,660	3.1	10.2	4,030	6,000

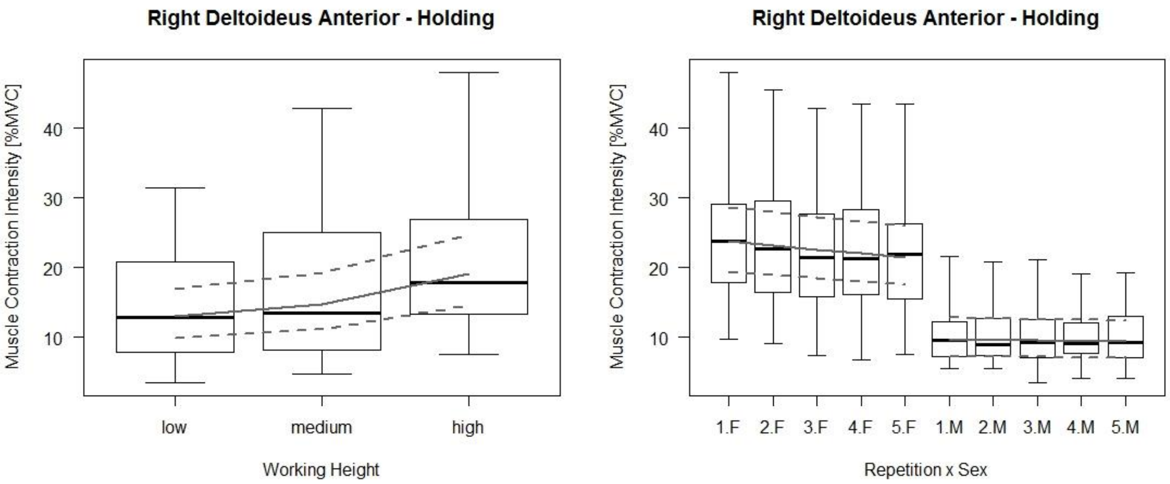

Figure 3.5 Contraction intensity of the right deltoideus anterior. Box plots show raw data: The thick black line indicates the median. The upper box indicates the 75th percentile, the lower box indicates the 25th percentile. The whiskers show the minimum and maximum. Lines: model prediction with upper and lower 95% confidence interval.

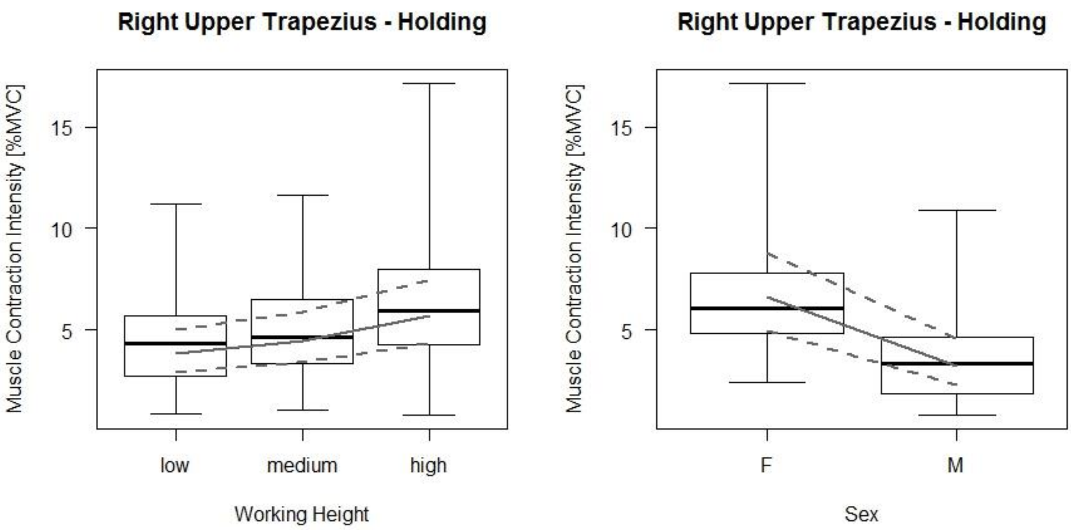

Figure 3.6 Contraction intensity of the right upper trapezius. Box plots show raw data: The thick black line indicates the median. The upper box indicates the 75th percentile, the lower box indicates the 25th percentile. The whiskers show the minimum and maximum. Lines: model prediction with upper and lower 95% confidence interval.

Table 3.2 Estimated muscle contraction intensity [%MVC] of male and female subjects for each arm, according to 3 working heights and 2 arm functions. Estimates are based on the model assumption including the fixed effects sex and working height, not on the best model. Bold italics indicate high levels of muscle contraction intensities. Working heights: L=low, M= medium, H= high.

Target Variable			*Flexor carpi ulnaris*						*Biceps brachii*						*Deltoideus anterior*						*Upper trapezius*					
	Sex		Male			Female			Male			Female			Male			Female			Male			Female		
Arm Side	Function	Working Height	L	M	H	L	M	H	L	M	H	L	M	H	L	M	H	L	M	H	L	M	H	L	M	H
Left	Holding	Estimate	15.5	14.6	15.1	***27.9***	***28.0***	***26.1***	16.5	16.2	18.0	***24.9***	***27.0***	***28.2***	7.5	8.5	11.0	15.8	16.2	***21.5***	2.5	2.7	3.4	4.6	4.9	6.0
		Lo. CI	10.3	9.2	9.6	20.0	19.8	18.3	11.5	10.9	12.2	15.1	15.9	16.7	6.1	6.9	8.8	13.2	13.3	19.6	2.2	2.3	3.0	3.5	3.6	4.4
		Up. CI	***22.7***	***22.3***	***23.1***	***37.1***	***38.0***	***35.7***	***23.0***	***23.5***	***25.8***	***38.1***	***41.8***	***43.3***	9.1	10.6	13.5	18.9	19.6	***25.6***	2.9	3.1	4.0	6.2	6.7	8.2
	Attaching	Estimate	8.8	8.7	9.8	19.8	19.5	18.5	3.8	3.9	4.4	8.0	8.1	8.5	8.5	9.7	11.65	15.7	17.8	***21.5***	3.7	4.0	5.0	4.3	5.2	7.6
		Lo. CI	6.2	5.9	6.7	14.9	14.3	13.6	3.1	3.2	3.6	4.9	4.9	5.1	7.4	8.3	10.0	13.6	15.3	18.6	2.4	2.9	3.8	3.4	4.1	6.0
		Up. CI	12.3	12.6	14.1	***25.8***	***25.9***	***24.7***	4.4	3.6	5.5	12.6	13.3	13.8	9.8	11.3	13.5	18.1	***20.6***	***24.7***	4.1	5.3	6.8	7.6	6.0	9.5
Right	Holding	Estimate	11.7	11.6	13.3	***23.3***	***25.2***	***23.8***	12.2	12.6	14.0	16.5	19.0	18.7	7.9	8.6	12.5	18.7	***21.6***	***26.1***	2.6	3.0	3.7	5.1	6.0	7.8
		Lo. CI	7.2	6.8	7.9	17.1	18.2	17.1	10.0	10.1	11.2	12.6	14.2	14.0	6.5	6.9	10.1	14.4	16.5	***20.2***	1.7	1.9	2.4	4.1	4.8	6.2
		Up. CI	18.3	19.0	21.5	***30.9***	***33.9***	***32.2***	15.0	15.7	17.4	***21.4***	***24.8***	***24.5***	9.7	10.7	15.3	***23.8***	***27.8***	***33.0***	3.9	4.7	5.8	6.3	7.5	9.7
	Attaching	Estimate	8.1	8.0	8.4	17.7	17.9	19.2	3.1	3.0	3.6	7.3	7.2	7.8	3.1	3.0	3.6	***22.6***	***24.4***	***29.0***	3.8	4.6	5.8	5.0	6.7	9.7
		Lo. CI	5.5	5.2	5.5	13.1	12.9	13.9	2.6	2.5	3.0	5.1	4.9	5.3	2.6	2.5	2.9	16.8	17.8	***21.5***	2.5	2.9	3.7	3.8	5.0	7.3
		Up. CI	11.7	5.5	12.7	***25.6***	***24.2***	***26.0***	3.6	3.6	4.3	10.3	10.4	11.2	3.6	3.6	4.2	***29.8***	***32.5***	***37.9***	5.7	7.2	9.0	6.7	9.0	12.9

3.6 Discussion

3.6.1 Working Height

The results of the current study showed that mean contraction intensities decreased bilaterally with decreasing WH in the *deltoideus anterior*, which is responsible for the forward/upward lifting of the arm, and the *upper trapezius*, which facilitates the lifting of the shoulder. For these muscles, contraction intensities were lowest when the milking cluster was attached with a low WH. This indicates that a lower WH may reduce physical strain of the shoulder muscles. No such effects were observed for the *flexor carpi ulnaris* or the *biceps brachii*, which are responsible for wrist flexion and elbow flexion, respectively. This finding shows that physical strain of the shoulder regions can be reduced by the correct usage of the milking health formula, which recommends lower WH. Although the muscular loads of these regions were lower than those of the *flexor carpi ulnaris* and the *biceps brachii*, milkers are primarily affected by shoulder problems, thus making it worthwhile to give these areas a closer consideration (Lunner Kolstrup and Jakob, 2016). However, the current study exclusively evaluated the effects in the Herringbone 30° parlor, so we cannot make statements regarding other milking parlor types.

Whereas mean contraction intensities reported for the *deltoideus anterior* and the *biceps brachii* in the current study were relatively similar to those found in a previous study, the values for the *upper trapezius* were lower in our study (Liebers et al., 2009). However, previous research recommended WH at which the teat ends were at shoulder level, which was roughly equivalent to the high WH used in our study (Liebers et al., 2009; Jakob et al., 2012). Jakob et al. (2012) used an artificial udder that was fixed on a metal stand and shaped, but the proportions were not representative of a cow's leg. Their setup might have led to different postures or arm positions during cluster attachment and therefore to different results than those found in our study, in which a true-to-scale hind leg held the artificial udder. This could be relevant when the milker is working at a lower WH at which the elbow and shoulder joints are more extended compared to a higher WH (Figure 3.3).

The current study evaluated 2 WH at which the udder was below eye level (low and medium WH). This reduced contraction intensities, but visibly checking the udder became more difficult; as it was only possible if the milker tilted the head and neck. It would instead also be achievable for the milker to bend his knees. Subjects in the current study were instructed not to look at the teats whilst attaching the milking cluster but, instead, to hold the teat cup with their thumb and middle finger and use their index finger to guide the teat into the cup. In order to reassure healthy cows, it is strongly recommended to examine the udder and teat condition prior to milking. However, the udder is visibly checked during the pre-milking and cleaning procedure, which is carried out prior to attaching the milking cluster. Although this task usually takes longer than the actual attaching of the cluster, it is carried out without a load and, thus, is associated with low physical stress. This agrees with former studies that found the attachment task to be most strenuous (Pinzke et al., 2001), which is why we focused particularly on this task in the current study. A recent work by Douphrate et al. (2013) further reported that 40% of Herringbone parlor operators perceived attaching as the most difficult milking task vs. 30% for Parallel and 29% for Rotary parlor operators. However, if milking parlors are built with a smaller depth of pit and, thus, a lower WH, solutions to enable udder visibility without a tilted head, such as camera/display solutions, could offer additional support in future milking parlors.

In the current study, muscular contraction intensities were higher in the holding arm than in the attaching arm. Stål et al. (1998) reported musculoskeletal disorders to be dominant in the hand used to hold the milking cluster. This supports the assumption that the high muscular contraction intensities during the holding of the milking cluster may represent a risk factor for musculoskeletal disorders. The milking clusters used in the current study weighed 2.6 kg, despite former studies reporting that lighter clusters (1.4 kg) positively affect ergonomics (Jakob et al., 2012). We chose to use these clusters because it was important to find differences between WH configurations, and a heavier cluster made it possible to show this effect more clearly. Mean contraction intensities in the current study were relatively high compared to Jakob et al. (2012). This may be due to the fact that only subjects without milking routine were in our trial, as their muscles were not trained for the attaching procedure. It is likely that a lower level of practice results in higher muscle contraction intensities, despite a normalization to each subject's individual MVC.

3.6.2 Sex

An untrained subject requires a higher muscular activation to lift a load than a trained subject (Strasser et al., 2013). Similar explanations can be applied to the higher muscular activity in women than in men. Strasser et al. (2013) described absolute maximum strength in men to be 30% higher than in women. This explains the sex-related findings of the current study, in which women presented higher muscular contraction intensities in all of the monitored muscles (Tables 3.1 and 3.2). Jonsson (1978) suggested limit values for muscular load, stating that the static load level "must not exceed 5% of MVC, the mean load level should not exceed 10% and must not exceed 14% of MVC". Hence, the muscular loads in our female milkers were considerably beyond the highest threshold, especially those of the *flexor carpi ulnaris*, *biceps brachii* and *deltoideus anterior* (Table 3.2). In regard to an ergonomic workplace design, it should be discussed if this work may be too strenuous for most women, especially as studies have previously reported a high prevalence of musculoskeletal disorders in female milkers (Stål et al., 1998; Stål et al., 2004).

3.6.3 Repetition

We considered repetition in the statistical model primarily to account for information regarding the study design and so give a better estimation of the other variables. However, repetition had an effect in many of the best models, where mean contraction intensity decreased with increasing repetition number (Table 3.1). This finding agrees with a former study, which found a decrease in handling time with increasing repetition (Liebers et al., 2009). In our study, this effect was interacted with sex in the right *deltoideus anterior* in the attaching arm function, during which contraction intensities in women decreased with increasing repetition, whereas those in men did not. This decrease may indicate that the females improved the efficacy of the movement and, therefore, reduced physical strain over the repetitions, which could be due to selecting subjects without work routine. However, no kinematic analyses were conducted in the current study, which would have helped to detect potential change in the range of motion throughout the consecutive repetitions.

3.6.4 Subject Height

The milking health formula was created as a tool to calculate ideal depth of pits for subjects of varying body heights (Cockburn et al., 2015). Although considered in the statistical model, subject height had no effect on mean contraction intensities in any of the monitored muscles. Thus, we can conclude that the setting of depth of pits, under consideration of the subject height, offered an effective and objective way to compare WH between subjects with varying body heights. We can therefore consider the use of the milking health formula validated, yet should continue increasing the precision of the WH coefficients within the formula (Cockburn et al., 2015). Thus, the use of the milking health formula is valuable not only for farm practice but also for researchers, as it offers an objective and precise method for setting and comparing different WH.

3.7 Conclusion

The WH coefficient used in the milking health formula for the Herringbone 30° parlor should be medium or low to reduce contraction intensity of shoulder muscles. However, physical strain of the upper limbs does not seem to be affected by WH. Subject height had no effect on muscle contraction intensities. Future studies should use the milking health formula as a reference tool to improve comparability between studies. Mean contraction intensities were generally higher in women than in men, therefore, it is important for women to be aware of the high physical strain during milking.

3.8 Acknowledgements

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4 Effect of Milking Stall Dimensions on Upper Limb and Shoulder Activity in Milkers

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4.1 Interpretive Summary

The current study aimed at investigating the effect of enlarged milking stall dimensions for dairy cows on the muscle contraction intensity of the upper limbs and shoulders in milking personnel. Surface electromyography was used to assess the activity of four bilateral muscles that are used for cluster attachment during the milking of cows in standard sized and large milking stalls in a Herringbone and Side by Side milking parlor. Milking stall dimension had a small effect on the contraction intensity of the measured muscles in the Herringbone and none in the Side by Side parlor.

4.2 Abstract

Previous studies have reported health issues of the upper limbs in milking personnel. It has become apparent that the welfare of cows in milking parlors may be impaired due to the limited size of each milking stall relative to the increasing size of the cows. This study investigated the effect of increased milking stall dimensions on the muscle contraction intensity in milking personnel during milking. The study was performed in an experimental milking parlor, which allowed for the adjustment of the individual cow standing area for milking (milking stall). Nine experienced milkers performed two shifts of milking in each a Herringbone and a Side by Side milking parlor. The milking stall dimensions were large on one side and standard on the other. Sides were switched between measuring shifts. Surface electromyography was used to monitor muscle contraction intensity of forearm (*flexor carpi ulnaris*), arm (*biceps brachii*) and shoulder (*deltoideus anterior*; upper *trapezius*) muscles of each side. Statistical analysis was performed separately for the Herringbone and Side by Side parlor for each muscle, using mean contraction intensity as the target variable in a linear mixed effects model. Contraction intensity differed in regard to milking stall dimensions, but the conclusions that can be drawn from the results are limited. In the Herringbone parlor, contraction intensity of the left *biceps brachii* was smaller when cows were milked in standard sized instead of large milking stall dimensions, whereas the opposite effect was found for the right *biceps brachii*. No such effect was found in the Side by Side parlor. Increasing milking stall dimensions did not consistently increase contraction intensity in the measured muscles. However, the results may be different when milkers handle herds larger than 30 cows, which results in longer milking shifts.

4.3 Introduction

Since the 1950 cows have increasingly been milked in milking (1). Hereby, the cows enter the parlor mostly at floor level and the milker stands in a pit, where he or she usually attaches the milking cluster in a standing position. To date, the most common milking parlor type is the Herringbone 30°. In this parlor type, cows stand at an angle of 30° to the milking pit. The milker attaches the milking cluster in front of the hind legs. The Side by Side milking parlor is more space efficient, as cows stand parallel at a 90° angle to the milking pit. The milking cluster is attached to the udder from between the hind legs. Hence, the working position varies between the two parlor types (2). The Herringbone parlor leads to a laterally flexed posture but allows the milker to be relatively close to the udder, whereas the Side by Side parlor results in an increased reaching distance but allows for a straight posture.

Ergonomic workplace evaluation has been dealt with for many years, as milkers' health has continuously been affected. Thinius and Jakob (2) have reported the upper limb and shoulder regions to be the second most affected body parts (neck: 54%, shoulders: 46%, and hand/wrists: 45%) after the lower back (70% of the examined milkers). Milkers have further been reported to be prone to the carpal tunnel syndrome and the pronator syndrome (3). As an example, 16.6% of milkers were reported to develop the carpal tunnel syndrome compared with 3.6% of non-parlor workers, which is possibly caused by repetitive static movements and vibration (4). When attaching the cluster, the milker holds the milking cluster in one hand and uses the other hand to attach the teat cups to the teats. Hereby, the cluster is held in the palm of the hand and the fingers are extended (3). The cluster, which weighs between 2 and 3.5 kg, is held in a static posture. Stål, Hagert (3) reported that 23 out of 30 women were affected by the pronator syndrome causing them pain, numbness, tingling, weakness and clumsiness of the forearms.However, cow welfare has recently also been taken into consideration for milking parlor design. There is anecdotal evidence from researchers and consultants that the dimensions of milking stalls are currently too small in respect to the size of dairy cows, and welfare of the animals may therefore be compromised. Indeed, the dimensions of the individual cow standing area (milking stall) for milking parlors have not been adapted in the past 20 years. In the same time, dairy cows have increased in size as a result of breeding for a higher milk yield (Hansen, 2000a). Schönmuth and Löber (2006) reported an increase of sacral height in Holstein–Friesian heifers by 0.12 m from 1.37 to 1.49 m between 1980 and 1996.

A larger space allowance may increase cow welfare, as it would enable the cow to stand more comfortably. However, the distance between the milker and the cow’s udder may also increase because the cow may not choose to stand lined up to the hock rails, but may rather stand at a distance and, consequently, be further away from the milker. Tuure and Alasuutari (2009) showed that an increased distance between the cow’s udder and the milker caused a poor working posture. In that case, if the size of milking parlors was increased, milking cows may affect the health and safety of milking personnel as it becomes more difficult for the milker to reach the udder. In response to this issue, most milking technology companies now offer the option to install indexing milking stalls, which enable individual milking parlor dimensions and, accordingly, a better position of each cow (Moreau, 1994). When investing in new milking parlors, particularly small farms are often on a limited budget. As a result, ergonomics are not prioritized strongly enough despite the risk of musculoskeletal disorders of the upper limbs and compromised health (Douphrate et al., 2013). This issue has been recognized by Douphrate and Rosecrance (2004), who developed a cost benefit analysis that included direct and indirect costs of injuries in milking personnel. They stated that ergonomic benefits included an increase in productivity and product quality and a decrease in injury (Douphrate and Rosecrance, 2004).

The current study aimed to evaluate the effect of milking stall dimensions on milkers’ upper limb and shoulder muscle contraction intensity – as estimated from surface electromyography (sEMG) activity – during milking. Therefore, the contraction intensity of eight upper limb and shoulder muscles largely used for cluster attachment was monitored in nine professional milkers during the milking of the same set of cows in standard sized and large milking stalls in both Herringbone and Side by Side milking parlors. We expected that muscle contraction intensity will increase with larger milking stall dimensions, due to an increased distance between the milker and the cow.

4.4 Materials and Methods

4.4.1 Milking Parlor

The research was carried out in the experimental milking parlor of Agroscope in Tänikon, Switzerland. This experimental milking parlor could be converted between a Herringbone (Figure 4.1) and a Side by Side milking parlor, and milking stall dimensions were adjustable (Figure 4.2). We performed ergonomic measurements in two settings. In the first setting, the parlor type was a Herringbone 30° (2 x 5) with standard exit, and each of the nine subjects was measured during two full shifts of milking (repetitions; January and February 2015). For the second setting, the parlor was converted to a Side by Side parlor (2 x 5) with rapid exit, and another two repetitions were recorded for the same nine subjects (March and April 2015).

Figure 4.1 Herringbone 30° Milking parlor. The milkers stand in the pit shown on the left picture.

Between repetitions, milking stall dimensions were adjusted from standard to large on one side of the parlor, and vice versa on the other side (Table 4.1). Therefore, one side of the milking parlor had large milking stall dimensions (Herringbone: 1.53 m x 1.25 m; Side by Side: 1.83 m x 0.73 m) and the other had standard sized milking stall dimensions (Herringbone: 1.41 m x 1.15 m; Side by Side: 1.70 m x 0.68 m) (Table 4.1 and Figure 4.1). The infrastructure, including the building and milking clusters, were the same in all settings and repetitions; however, due to the differing parlor types, the bars and defecation plates differed between Herringbone and Side by Side. Originally, we had considered testing the effects of small vs. large milking stall dimensions, but a pilot study showed that small milking stalls were inappropriate in regard to cow welfare in that most cows did not fit into smaller milking stalls. Therefore, we decided to evaluate the differences between standard and large sized milking stalls instead.

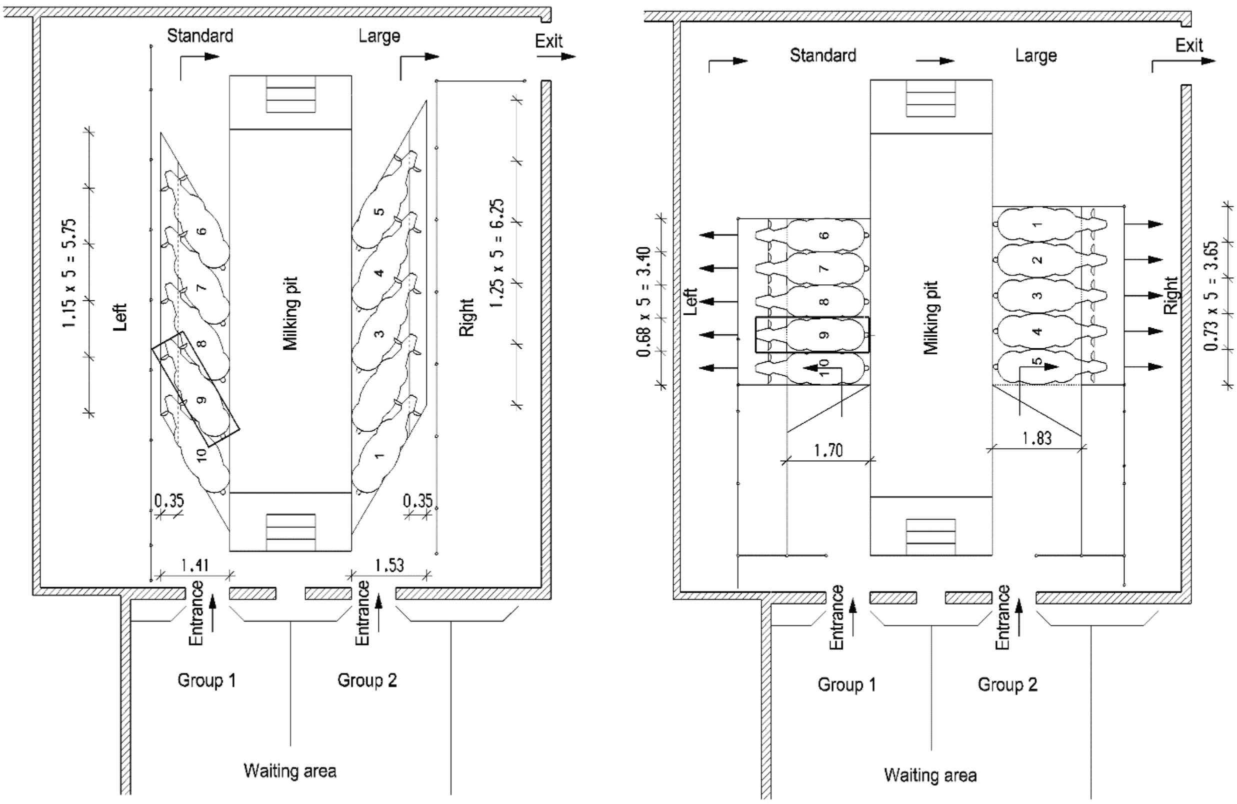

Figure 4.2 Illustration of the experimental milking parlor. The left image shows the parlor as a Herringbone parlor, and the right image shows the parlor as a Side by Side parlor. The left side of the parlor shows the standard sized milking stall dimensions, and the right side shows the large milking stalls.

Table 4.1 Experimental Design – Details on size dimensions of milking parlors and experimental setting. Length and depth include head area (0.35m).

Milking Parlor		**Unit**	**Herringbone 30°**		**Side by Side**	
Side	Dimension		Repetition 1	Repetition 2	Repetition 1	Repetition 2
Left	Length	[m]	1.91	1.62	1.83	1.70
	Depth	[m]	1.53	1.41	-	-
	Width	[m]	1.25	1.15	0.73	0.68
	Area	[m^2]	1.91	1.62	1.34	1.16
	Area	[%]	118	100	116	100
Right	Length	[m]	1.62	1.91	1.70	1.83
	Depth	[m]	1.41	1.53	-	-
	Width	[m]	1.15	1.25	0.68	0.73
	Area	[m^2]	1.62	1.91	1.16	1.34
	Area	[%]	100	118	100	116

The experimental milking parlor was equipped with an adjustable platform. Milking clusters used were GEA “Classic 300” (GEA Farm Technologies GmbH, Bönen, Germany) and weighed 2.6 kg. The short milk tubes were made of silicon (Siliconform, Türkheim, Germany). The Herringbone was equipped with Posilactors (GEA Farm Technologies GmbH, Bönen, Germany), whereas the Side by Side was equipped with Posiballs (GEA Farm Technologies GmbH, Bönen, Germany). Both Posilactors and Posiballs were installed to ensure a correct positioning during attachment of the milking cluster.

4.4.2 Subjects

The Swiss Ethics Commission of the Canton of Thurgau approved the experiment. Nine male subjects took part in the experiment. The subjects provided written informed consent to participate in the study. This agreed with the consent procedure of the ethics commission. Subject height ranged between 1.69 and 1.93 m (mean 1.76 m ± 0.094 m) and mean arm length (measured from the *digitus medius* to the *acromion* process) of the right and left arms were 0.79 m ± 0.048 m and 0.79 m ± 0.044 m, respectively. Eight subjects were right handed and one subject was bilateral. All of them were experienced milkers. They were in good health, had a normal body mass index of below 30 and participated voluntarily. Each subject was required to milk 30 cows per each of the four milking sessions. The floor height was adjusted to the body height of each subject. To do so, the “milking health formula” was used to adjust the floor height to a comparable relative level (Cockburn et al., 2015). We used an adjustment coefficient of 0.775 for both parlor types. The herd’s mean udder base height was measured prior to the main experiment and was 0.56 m ± 0.054 m. Consequently, the depth of pit (standing surface of the milker to standing surface of the cows) for each subject was calculated as:

$$Depth\ of\ pit = (Subject\ Height * Coefficient) - (Herd\ Mean\ Udder\ Height)$$

4.4.3 Cows

The Veterinary Office of the Canton of Thurgau approved the experiments. Milking was part of the cows' daily routine and the farm staff ensured good animal welfare. The herd, consisting of 50 lactating dairy cows, was housed in one loose barn and separated in three groups. Groups 1 and 2 each consisted of 15 healthy dairy cows in lactation. These groups were housed in similar conditions with deep litter bedding. Breeds included cross bred Holstein x Fleckvieh and Brown Swiss. The mean udder heights were 0.56 m (± 0.059) in Group 1 and 0.56 m (± 0.052) in Group 2. The two groups were herded into separate compartments of the waiting area. Group 1 always entered the milking parlor on the left side, whereas Group 2 always entered the parlor on the right side (Figure 4.2). Thus, human subjects milked each of the 30 cows once with standard sized milking stalls and once with large milking stalls in both the Herringbone and the Side by Side parlor (in total, 120 milking's per subject).

4.4.4 Observations

An observer documented the initiation of a new attachment procedure by swinging an accelerometer when the subject pressed the button to release the milking cluster. The observer documented the initiation of pre-milking, udder cleaning and attaching the milking cluster, and noted the cow's position in the milking parlor (Figure 4.2) and the cow number by using the app "Timekeeper" (SIA Devitude, Liepāja, Latvia).

4.4.5 Measuring Devices

The Trigno™ wireless sEMG system (Delsys, Boston, USA) was used to record activity of subjects during the working routine. Each sensor measured 37 mm x 26 mm x 15 mm and weighed 14 g. Two bar electrodes and two reference bar electrodes were installed parallel within the sensor. One sensor was placed on each monitored muscle. Prior to sensor placement, the skin was prepared. In total, eight sensors were placed bilaterally on the *flexor carpi ulnaris* (FC), the *biceps brachii* (BB), the *deltoideus anterior*

(DA) and the upper *trapezius* (UT) muscles, parallel to the muscle fibers as described by Konrad (2006). These muscles were selected due to their role during the attachment of the milking cluster. The cluster is held in the palm of the hand and as such requires wrist flexion, which is provided by the FC. The BB is responsible for elbow flexion, which is relevant for lifting and holding the cluster. The DA is in control of shoulder abduction and flexion and thus plays a vital role when the cluster is moved forward, away from the milker's body underneath the cow's udder. During this movement, the shoulder may also be lifted, which is facilitated by the UT muscles.

Signal quality was checked prior to data collection using the EMGworks Acquisition software (Delsys, Boston, USA). The software was further used to record the data with a standard sampling rate of 1,926 samples per second. Additionally, one Trigno™ sensor was attached to the observers hand and preset as an accelerometer with a standard sampling rate of 184.1 samples per second. As the sEMG and accelerometer data were recorded with the same software package, the accelerometer was used to mark the beginning point of the attaching procedure in the sEMG data. For that, the observer swung the accelerometer as soon as the milker pressed the button to release the milking cluster. The experimental procedures were filmed using Mobotix cameras (Mobotix AG, Langmeil, Germany) to be able to go back and evaluate ambiguous occurrences in the sEMG data.

4.4.6 Experimental Procedure

Each subject completed two unilateral maximal voluntary isometric contractions (MVC) per monitored muscle prior to each evening milking (16 MVC in total). The duration of each MVC was 3–5 seconds (Konrad, 2006), and the resistance was applied manually by the observer. The MVC of the FC was performed by asking the subject to turn the ventral side of the lower arm upwards, while his upper arm remained parallel to his trunk. The subject was then asked to flex his wrist upwards against a resistance with a joint angle of roughly 120°. The MVC of the BB was performed by asking the subject to perform an elbow flexion against resistance of roughly 90°. The MVC of the AD was performed by asking the subject to lift his lower and upper arm forward against a resistance, whilst the elbow joint remained straight and the ventral side of the elbow and the radial side of the hand were facing upwards. The angle of the shoulder was hereby roughly at 150°. The MVC of the UT was performed by asking the subject to lift his shoulder upwards against the resistance, whilst the elbow, shoulder and wrist joints remained straight (180° angle). If the maximal sEMG signal of the two contractions differed by more than 10%, a third contraction was performed. The mean sEMG activity of those two contractions served as a reference for the experimental data and allowed for a comparison between and within subjects. If a third contraction was performed, the mean was calculated from the two highest contractions. All experimental milkings were conducted during the evening milking at 4:00 p.m. A farm staff member who was familiar with the milking parlor and the animals was present during all milkings.

For each milking, the subject was required to pre-milk the cow, clean the udder, press the button to release the milking cluster, and to attach the milking cluster. The subject was asked to milk cows consecutively (1–5 and 6–10; Figure 4.1). Subjects were not instructed to hold the cluster in a specific way, as we wanted to prevent any effects due to a change of their habitual working routine.

4.4.7 Data Analysis

The data were processed in the software package EMGworks Analysis (Delsys, Boston, USA). The sEMG and accelerometer data were processed simultaneously. Non-physiological data, which can occur through movement of the sensors (for example, when they get caught on clothing or rails), appear as artefacts (peaks) in the raw sEMG data. Thus, the raw data were visually checked for artefacts, and attachment procedures with artefacts were omitted (sEMG sequences with artefacts were not evaluated) in the analyses (percentage of omitted data: Herringbone 1.09%, Side by Side 10.88%). Artefacts were defined as any visible shift < 5 ms with an increased amplitude, based on the baseline sEMG. The greater numbers of artefacts in the Side by Side parlor can be explained by sensors being moved by the string that lifts up the milking cluster; this string was not present in the Herringbone parlor. As the raw sEMG was measured in Volt, the root mean square values of the raw data were calculated with a window length of 0.25 ms (using one of the functions in the EMGworks Analysis software), by roughly averaging 481.25 sampling points, to create positive values. These were then used for further analysis. Hereby, the offset of the data was also removed, which ensured that all data of relaxed muscles originated from zero. No additional filters were used.

The acceleration data consisted of three axis (x, y and z). Only the z-axis was used in the analysis. The initial change before the peak of the acceleration traces (that was the result of the observer marking the starting point) on the z-axis was used as the starting point of the attachment procedure (Figure 4.3), and the end point was established where the sEMG activity of the DA decreased to almost zero (Figure 4.3). The DA is responsible for the forward/upward lifting of the arm. When this muscle activity decreases, the subject will not be able to hold the cluster underneath the cow's udder, hence it was chosen as an end point of the attaching procedure. Although holding and attaching hands were identified from video, the attaching procedure strongly varied between subjects. In consequence, the first arm (left or right) that showed a relaxation (decrease in muscular activity) was considered as the end point. The time intervals between the starting and the end points were compared with the time intervals of the attachment procedure on the videos to assure correct data alignment. The mean and max muscle contraction intensities during the attachment procedure as well as the duration of each attachment procedure were calculated with the software package EMGworks (Figure 4.3). This data set was then pasted into an Excel spreadsheet (Microsoft Office 2013, Redmond, USA). The data were lined up with the additional information on cow number, cow position in the milking parlor and repetition. Finally, R version 3.1.0 (R Core Team, 2013) was used to normalize the sEMG data to every subject's muscles' individual MVC by calculating the percentage of the subject's mean MVC amplitude values. After this calculation was completed, the measured data were reported as a percentage, referred to as "normalized" and reflected as %MVC.

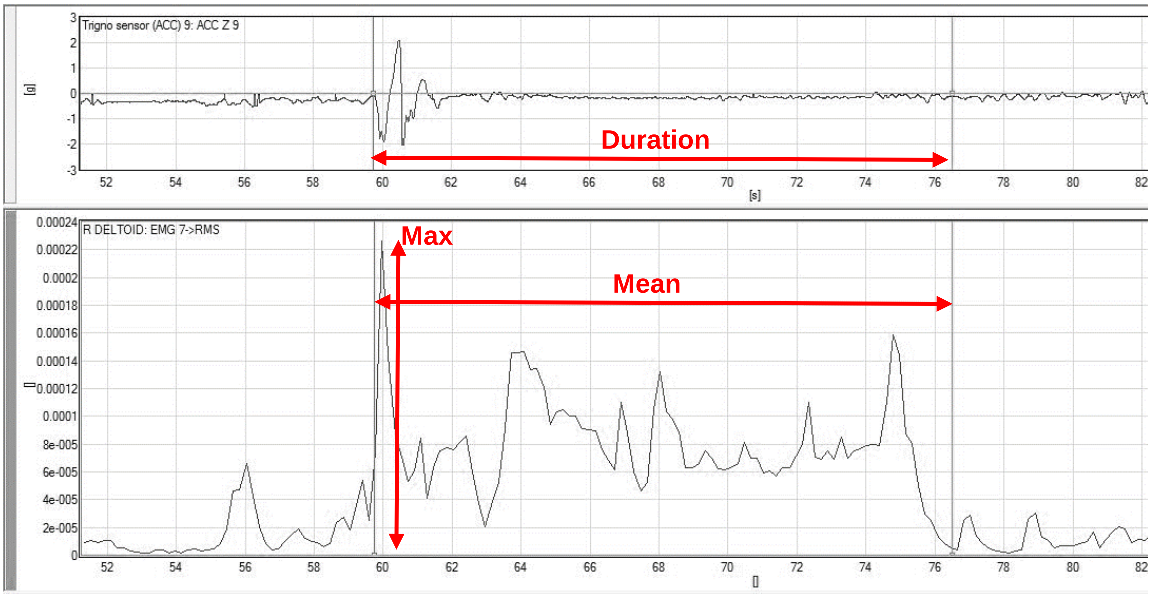

Figure 4.3 The starting point of the attachment procedure was set at the initial change of the accelerometer's x-axis (top plot). The end point was set after the first decrease of muscular activity to almost zero of the deltoideus anterior (bottom plot).

4.4.8 Statistics

Statistical analysis was performed separately for the mean, maximum (max) and duration values in the Herringbone and the Side by Side milking parlors and for each muscle on each side in R version 3.1.0, resulting in 34 models. A linear mixed effects model was fitted in which mean and max normalized muscular contraction and duration were used as the target variables. Milking stall dimension (factor with two levels: standard, large), subject height (continuous), udder height (continuous) and repetition (continuous) and all their potential interactions were used as fixed effects. The model included parlor side, nested in subjects, and nested in measuring period, subject identity and cow identity as crossed random effects.

The model was fitted using the lmer function in R (package = lme4; Bates et al., 2015). After fitting of the model, the residuals were checked graphically for normal distribution and homogeneity of variance. To satisfy these assumptions, all normalized values of muscle contraction intensity (%MVC/100) and durations were logit or log transformed, respectively. In a few cases, it was necessary to remove outliers to ensure normally distributed residuals (numbers of outliers removed per target variable were between 0 and 4).

The dredge function (package = MuMin) was used to find the best model based on the smallest Bayesian Information Criterion (BIC) and largest model weight (w_i) (Bartoń, 2013). The model weight can be interpreted as the probability for a specific model to be optimal in the set of considered models given the data, where the w_i's of all models in a set add up to 1 (Symonds and Moussalli, 2011). Here, our set included the maximum model as described above and all simpler models including the null model, with an intercept only; so-called allsubset approach. Two models with a difference in BIC of less than 2 can be considered equivalent (Raftery, 1995; Symonds and Moussalli, 2011), and the simpler model of two such models was chosen during model selection when models had similar probability as advised for the Akaike Information Criterion (Richards et al., 2011). The evidence ratio (ER_0) reflects how many times the chosen model was more likely compared with the null model (Symonds and Moussalli, 2011). This approach in choosing a model is an alternative to frequentist p-value based testing and, therefore, no p-values are presented.

4.5 Results

Milking stall dimensions were included in the best model in five out of 17 models in the Herringbone milking parlor and none of the 17 models in the Side by Side milking parlor (Table 4.2). The null model was the best model in most cases (Table 4.2). Model estimates and confidence intervals for the mean and max muscle contraction intensities are presented in Table 4.3.

4.5.1 Herringbone

4.5.1.1 Milking Stall Dimension

The muscular activity of the right FC was lower when cows were milked in the large milking stalls than in the standard sized milking stalls (Figure 4.4). No such effect was found in the left FC. The muscular activity of the right BB was affected by milking stall dimension (Figure 4.4). Further, muscular activity increased over time (with repetition) when cows were milked in the large, but not in the standard sized milking stalls. However, the muscular activity within the right BB was lower when cows were milked in large milking stalls than when cows were milked in standard sized milking stalls (Figure 4.4).

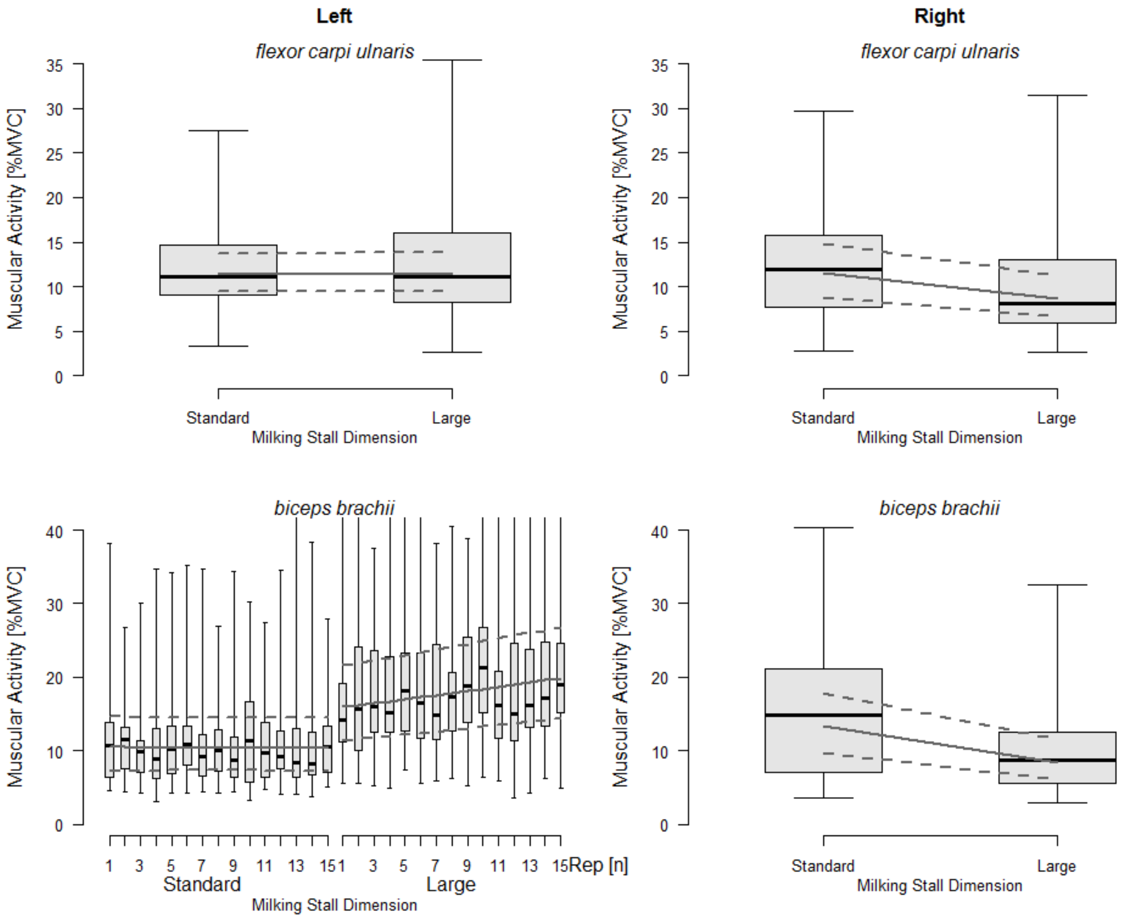

Figure 4.4 Mean muscular activity of the left and right flexor carpi ulnaris and biceps brachii. Box plots show raw data: The thick black line indicates the median. The upper box indicates the 75th percentile, the lower box indicates the 25th percentile. The whiskers show the 95th and the 5th percentiles. Lines: Model prediction with upper and lower 95% confidence interval.

Table 4.2 Fixed effects included in the optimal model for the target variables, the model weight (w_i) based on the BIC and the evidence ratio in relation to the null model (ER_0).

			Herringbone				**Side by Side**			
Muscle	**Side**	**Target Variable**	**Fixed Effects**	**Transformation**	**w_i[1]**	**ER_0[2]**	**Fixed Effects**	**Transformation**	**w_i[1]**	**ER_0[2]**
flexor carpi ulnaris	Left	Mean	-	Logit	0.766	1	-	Logit	0.586	1
		Max	-	Logit	0.368	1	-	-	0.682	1
	Right	Mean	Milking stall dimension	Logit	0.634	12.19	-	Logit	0.554	1
		Max	-	Logit	0.813	1	-	Logit	0.631	1
biceps brachii	Left	Mean	Milking stall dimension x Repetition	Logit	0.594	4,630	-	Logit	0.308	1
		Max	Milking stall dimension	Log	0.474	3.27	-	Logit	0.782	1
	Right	Mean	Milking stall dimension	Logit	0.649	59.00	-	Logit	0.257	1
		Max	Milking stall dimension	-	0.815	22.63	Repetition	Logit	0.479	2.71
deltoideus anterior	Left	Mean	Height	Logit	0.320	2.58	Height	Logit	0.386	2.37
		Max	Height	Logit	0.532	17.16	-	Logit	0.721	1
	Right	Mean	Udder Height	Logit	0.126	160	-	Logit	0.310	1
		Max	-	Logit	0.721	1	-	Logit	0.721	1
upper *trapezius*	Left	Mean	-	Logit	0.809	1	-	Logit	0.258	1
		Max	-	Logit	0.833	1	-	Logit	0.518	1
	Right	Mean	-	Logit	0.436	1	-	Logit	0.768	1
		Max	-	Logit	0.554	1	-	Logit	0.692	1
All		Duration	Repetition	Logit	0.521	4.9	Repetition	Logit	0.866	17.55

[1]The model weight (w_i) describes the probability that the chosen model is the best model within the set of models (allsubset evaluation). [2]The evidence ratio to the null model (ER_0) describes how many times more likely the model is compared with the null model (with an intercept only).

Table 4.3 Estimates and confidence intervals for the mean muscle contraction intensities and duration of the attachment process derived from a model calculation that includes milking stall dimension and any significant fixed effect, as well as all random effects and their interaction. The information is presented for each parlor type, milking stall dimension, muscle and side. Bold letters indicate where milking stall dimension was included in the best model. No values are given for the mean values of the left biceps, as the best model included an interaction, thus results of this model are presented in Figure 4.3.

Target Variable			*flexor carpi ulnaris*				*biceps brachii*				*deltoideus anterior*				upper *trapezius*				Duration	
Unit			*[%MVC]*				*[%MVC]*				*[%MVC]*				*[%MVC]*				[s]	
Parlor Type	Arm side		Left		Right		Left		Right		Left		Right		Left		Right		Both	
	Milking stall dimension		Std.	Lrg.	Std.	Lrg.	Std.	Lrg.	Std.	Lrg.	Std.	Lrg.	Std.	Lrg.	Std.	Lrg.	Std.	Lrg.	Std.	Lrg.
Herringbone	Mean	Estimate	11.4	11.6	**11.5**	**8.7**	F4.3	F4.3	**15.4**	**9.2**	19.6	20.5	20.4	21.2	7.1	7.8	9.9	9.4	14.8	14.8
		Lo. CI	9.3	9.5	**8.6**	**6.7**	F4.3	F4.3	**10.8**	**6.4**	15.4	15.8	16.2	16.9	5.6	6.2	7.4	7.0	13.0	13.1
		Up. CI	14.0	14.0	**15.1**	**11.5**	F4.3	F4.3	**21.6**	**12.8**	24.8	26.0	25.6	26.3	8.9	9.7	13.2	12.4	16.8	16.8
	Max	Estimate	49.2	46.1	43.6	42.8	**36.8**	**52.6**	**50.8**	**32.5**	55.3	51.7	54.1	56.4	29.0	30.1	34.8	30.3	-	-
		Lo. CI	40.1	37.5	30.8	30.1	**25.9**	**41.7**	**39.6**	**21.8**	47.3	43.6	44.8	47.1	23.3	24.2	27.5	23.5	-	-
		Up. CI	58.1	54.9	58.2	57.2	**47.6**	**64.2**	**61.3**	**46.2**	63.1	60.1	63.2	65.4	36.1	37.3	43.5	38.4	-	-
Side by Side	Mean	Estimate	11.9	12.0	9.4	8.8	14.4	14.8	10.3	9.9	16.8	16.8	19.4	18.9	11.3	10.5	10.7	10.9	18.0	17.8
		Lo. CI	9.2	9.4	6.9	6.5	9.9	10.3	6.8	6.5	13.9	13.9	15.4	14.9	9.0	8.4	8.8	9.0	16.4	16.1
		Up. CI	15.0	15.0	12.3	11.5	20.8	21.1	15.3	14.6	20.4	20.1	24.3	23.7	13.9	12.9	13.3	13.4	19.9	19.5
	Max	Estimate	50.9	50.6	50.2	47.7	46.9	44.7	41.8	38.7	54.1	49.9	60.7	59.5	36.4	35.7	34.1	35.0	-	-
		Lo. CI	41.6	41.9	37.5	35.8	28.6	27.2	26.4	23.7	44.8	40.6	47.1	46.0	30.1	29.8	27.7	28.7	-	-
		Up. CI	60.0	60.0	62.9	60.9	65.9	64.0	60.1	57.2	64.0	59.3	73.1	72.2	42.9	42.1	41.1	42.1	-	-

4.5.1.2 The Effect of Working Height

Left DA activity decreased with subject height in both the mean and max values of the muscle contraction intensity. Mean contraction intensity of the right DA increased with udder height (Figure 4.5).

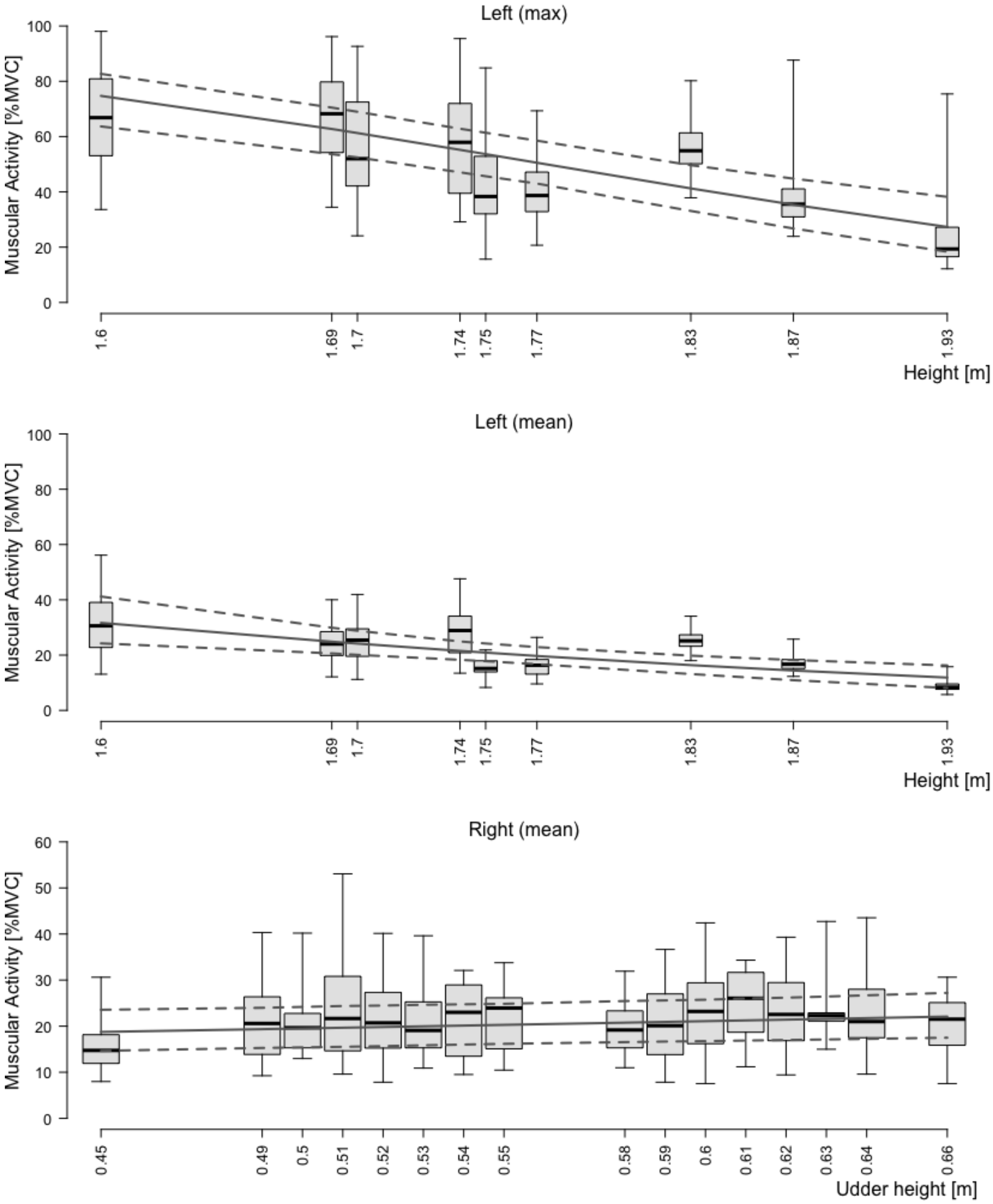

Figure 4.5 Muscular activity of the left and right deltoideus anterior during the procedure "attaching the milking cluster." The thick black line indicates the median. The upper box indicates the 75th percentile, the lower box indicates the 25th percentile. The whiskers show the 95th and the 5th percentiles. The lines between the box plot indicate the model prediction with the upper and lower confidence intervals.

4.5.2 Side by Side

Muscular activity was affected by subject height. The DA activity was lower in tall subjects than in short subjects. This trend of decreasing muscular activity is demonstrated in Figure 4.6. Further, repetition had an effect on the muscular activity of the BB. According to the best model, the maximum muscular activity of the BB decreased with repetition (Table 4.2).

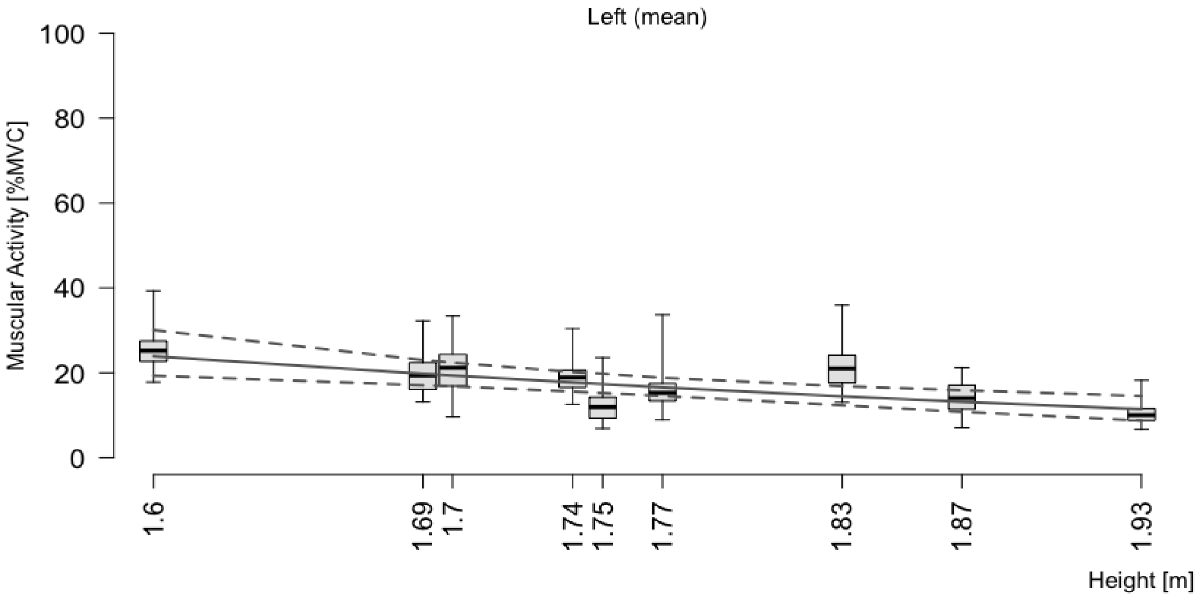

Figure 4.6 Muscular activity of the left *deltoideus anterior* during milking cluster attachment in the Side by Side parlor. The thick black line indicates the median. The upper box indicates the 75th percentile, the lower box indicates the 25th percentile. The whiskers show the 95th and the 5th percentiles. The lines between the box plot indicate the model prediction with the upper and lower confidence intervals.

4.5.3 Duration

The duration of the attachment procedure also had an effect in both milking parlor types. The duration decreased with increasing numbers of repetitions in both Herringbone and Side by Side parlors (Figure 4.7).

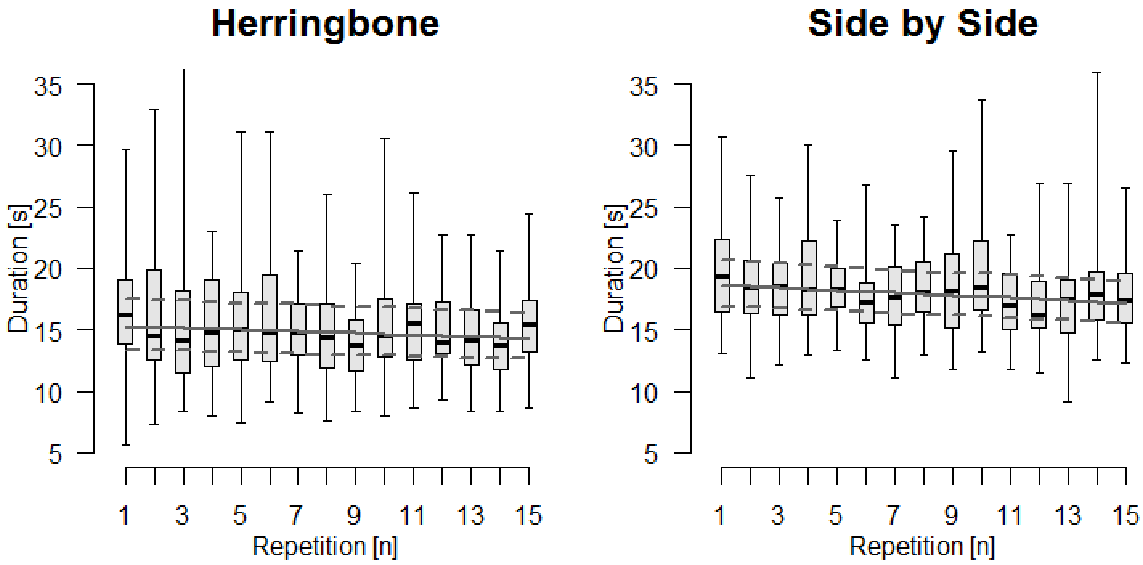

Figure 4.7 The duration of the procedure "attaching the milking cluster" decreased with increasing repetition in the Herringbone and Side by Side milking parlors. The thick black line indicates the median. The upper box indicates the 75th percentile, the lower box indicates the 25th percentile. The whiskers show the 95th and the 5th percentiles. The lines between the box plot indicate the model prediction with the upper and lower confidence intervals.

4.6 Discussion

The discussion will primarily focus on the findings for the Herringbone parlor, as only two variables, height and repetition, were found to have an effect in the Side by Side parlor. The parlor type will only be mentioned when the Side by Side is discussed.

4.6.1 Effect of Milking Stall Dimension

The effects found for FC and BB in the Herringbone parlor were contradictory. Whereas in the right arm muscular activity was lower when cows were milked in large milking stalls than when they were milked in standard sized milking stalls, the opposite effect was found in the left arm. In the left arm, muscular activity was higher when cows were milked in large milking stalls as compared with standard sized milking stalls. Thus, no recommendations can be drawn from the findings. It can be assumed that the differences were due to the different arm functions in particular in this study where all milkers except one were right handed. One arm is always used to hold the milking cluster, whilst the other arm is used to attach the teat cups, and thus the loads between the two arm functions can vary. A shift of muscle contraction intensity is common and could explain the contradicting findings. Nevertheless, we measured only the main muscles involved in the milking procedures, and it may well be possible that we missed recording a shift of muscular activity from the FC to the *flexor carpi radialis* or other muscles. Milking stall dimension had no effect on the muscular activity of the DA or UT.

It was obvious that size differences between dairy cows caused problems during milking. Whereas some of the large cows did not fit into the standard sized milking stalls and had to be removed prior to the trial, some of the small cows caused problems when they were milked in large milking stalls as the subjects had to stretch underneath the hock rail to clean the udder or attach the milking cluster. This should be taken into account when evaluating workplace safety, as the hock rail is designed to prevent the subject from being kicked and cannot fulfil its purpose when the subject stretches underneath it. Further, it can partly explain why no consistent effects were found. Not all cows were too small for the large parlors and some of the small cows stepped back, lining up to the hock rail, thus reducing the horizontal reaching distance between subject and cow.

4.6.2 Effect of Working Height

Subject height had an effect on mean and max muscular activity of the left DA in the Herringbone and on the mean muscular activity of the left DA in the Side by Side parlor. No such effect was found for any of the other muscles. This result shows that the individually calculated depth of pit was largely effective and enabled a comparison between subjects of differing heights. The left DA is responsible for the forward and upward lifting of the arm, thus this muscle is likely to have been influenced by the horizontal reaching distance, which could not directly be accounted for in the setup of the current study. Further, we found an indication that short milkers were used to looking at the udders whilst milking, whereas tall milkers did not show this behavior.

Udder height affected the mean activity of the right DA in the Herringbone parlor. This effect could be due to the right arm being mostly used to attach the teat cups, which resulted in an increased necessity of vertical lifting with increasing udder height.

4.6.3 Effect of Repetition

In both the Herringbone and the Side by Side parlors, duration of the attachment procedure decreased with increasing repetition. This effect may be due to subjects getting used to the milking routine in the experimental milking parlor and, thus, working more efficiently towards the end of milking. The overall means of duration did not differ between milking stall dimensions. Further, max muscular activity of the right BB in the Side by Side parlor decreased with increasing repetition. This finding also suggests that milkers got used to milking in the experimental milking parlor. However, more interestingly, in the Herringbone parlor, muscular contraction intensity of the left BB increased with increasing repetition in the large milking stalls but not in the standard sized milking stalls, indicating fatigue when cows were milked in the large milking stalls.

4.6.4 Effect of Repetition on the Duration of Cluster Attachment

The attachment duration decreased with increasing repetition in both parlor types. This result could be due to the observer effect and/or the milker getting accustomed to milking in the experimental parlor, resulting in a decrease of stress and thus relaxation over time. Although milkers carry out additional tasks in a practical setting, such as cleaning and pre-milking the teats as well as disinfecting the teats post-milking between attachment procedures, milking is a highly repetitive work (Pinzke et al., 2001). Whereas the number of repetitions in our measuring periods was relatively small, in a commercial setting milkers can be required to milk for multiple hours, and thus the conclusions that can be drawn from the current study may lead to a too optimistic picture for large farms.

The duration of the attachment procedure was on average 16 seconds in the Herringbone and 18 seconds in the Side by Side parlor. Although we were not able to statistically compare between parlor types, we observed that the longer durations of attachment procedures in the Side by Side parlor were due to the ergonomic assistance available in the parlor. When the milker pressed the start button, the milking cluster was let down by a string, which took roughly three seconds. The durations of the attachment procedure in the Side by Side parlor were considerably longer than the 10 seconds per cow reported for a Side by Side parlor (O'Brien et al., 2007), whereas the durations in the Herringbone parlor were shorter than the 20 seconds per cow reported for a 2 x 7 Herringbone parlor (Hansen, 2000b). This discrepancy is due to the current study focusing on sEMG measurements rather than labor.

4.6.5 Comparison with Surface Electromyography in Former Studies

To date, there has been little use of sEMG to assess muscular activity in milking parlors. Jakob et al. (2012) investigated the milking routine in six female milking parlor operators and reported that their mean muscular activity was between 10 and 15 %MVC during the attachment of the milking cluster. Douphrate and Rosecrance (2010) used sEMG to evaluate the performance of milking tasks in the forearm flexors and extensors, as well as the DA and UT muscles, and found mean peak loads of 58 %MVC in the forearm flexors and 49 %MVC in the DA. This agrees with the findings in our study (Table 4.3). In order to prevent injury, it has been recommended that maximum contraction intensities remain below 50 %MVC, and mean MVC should not exceed 10% and must not exceed 14% of MVC (Jonsson, 1978; Jonsson, 1982). Staying within the recommended ranges, could, therefore work towards the prevention of musculoskeletal disorders that have been reported for milkers, such as carpal tunnel and pronator syndromes (Stål et al., 1998; Patil et al., 2012) and disorders of the shoulders, neck and wrists (Thinius and Jakob, 2014). We found that peak loads occurred especially during the beginning of the attachment procedure when the cluster was initially lifted and turned over. Thus, it is worthwhile to consider the possibility to optimize this part of the milking procedure with an automated turning of the milking cluster.

Silvetti et al. (2014) stated muscular activity in the DA to be between 12 and 13 %MVC and in the BB between 7 and 8 %MVC during the tapping task in a Side by Side parlor. The tasks of cluster attachment and tapping are not fully comparable as the load in the tapping procedure is much lower than in the attaching procedure, although the postures are relatively similar.

Muscular activity in our study was higher than in that by Silvetti et al. (Silvetti et al., 2014), which is likely due to the greater load of the milking cluster (Table 4.3). The DA activity levels, were reported to be between 21 and 25 %MVC during udder cleaning Silvetti et al. (2014), whereas we found lower mean values of between 20 and 21 %MVC in the Herringbone parlor and between 17 and 19 %MVC in the Side by Side parlor during the cluster attaching procedure in the present study (Table 4.3). This finding indicates that the cluster weight may have a small effect on the contraction intensity of the DA muscles.

4.6.6 Muscular Activation Levels

All muscle contraction intensities were very close to or even exceeded the limit values suggested in the literature and, thus, could be responsible for the musculoskeletal disorders of milking personel (Jonsson, 1978). The FC plays a role in the development of the carpal tunnel syndrome and the pronator syndrome, which often affect milkers (Stål et al., 1998). In the current study, the mean muscular activity ranged between 9 and 12 %MVC and the max values ranged between 43 and 51 %MVC. The BB plays a vital role in holding the milking cluster while it is being attached, as its muscle contraction intensities ranged between 9 and 14 %MVC. The DA is responsible for shoulder flexion and thus the forward lifting of the arm, which in our setting was used to place the milking cluster underneath the udder. Mean contraction intensities of this muscle were the highest among the measured muscles (between 17 and 21 %MVC) and exceeded the maximum recommended intensities of 14 %MVC (Jonsson, 1978). This could explain why many milkers suffer from shoulder problems (Thinius and Jakob, 2014). The UT showed lower muscular activity than the other muscles; this could be due to optimized working heights in our study compared with previous studies, reducing the need to lift the shoulder. Indeed, looking at the data we found a relaxation of the UT when the arm was shifted forward to attach the milking cluster.

4.6.7 Milking Techniques

In order to ensure a routine work situation, all subjects were required to attach the milking clusters in the same way they would on their own farms. The attaching procedures were too variable to systematically evaluate potential differences between the holding and attaching arm. Although most subjects held the milking cluster in one hand and used the other hand to attach each of the teat cups, some changed the holding side depending on the side of the milking parlor, and a few subjects switched the holding hand during the attachment procedures. However, this behavior was accounted for in the statistical model as we had a crossover design and the milker was considered in the random effects, resulting in the evaluation of the differences of milking stall dimensions within the milker.

4.7 Conclusion

There is no evidence from the current study that larger milking stalls systematically increase muscle contraction intensity in the upper limbs and the neck of the milker for 30 cows per milking session. With regard to milkers' upper limb muscle contraction intensities, cows could therefore be provided with more space if it is found that larger milking stalls in milking parlors favor their welfare.

4.8 Acknowledgements

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5 General Discussion

Research has aimed to improve the work environment in milking parlors for many years. Recommendations usually resulted in a posture that enabled working with a straight back, discouraged trunk torsion, reduced muscle contraction intensities and increased joint flexion angles (Nevala-Puranen et al., 1996; Pinzke et al., 2001; Jakob et al., 2009; Silvetti et al., 2014; Pinzke, 2016). However, recommendations have always been limited in their area of application and the comparability between studies has proven difficult. Further, practical guidelines for the fitting of depth of pits were not available. A holistic approach that enabled a constant comparison between studies and parlor types, as well as a consideration of the whole body was missing. Against this background, the present thesis aimed to improve ergonomics in milking parlors. In a first study (Chapter 2) the CUELA system was used to assess joint flexions during milking cluster attachment in five different milking parlor types. In the second study (Chapter 3), electromyography was used to experimentally investigate if lower working heights reduced muscular contraction intensities of four upper limb and shoulder muscles in a Herringbone 30° milking parlor. The third study (Chapter 4) evaluated the effect of increased milking stall dimensions of dairy cows on human ergonomics.

The following discussion will focus on the main findings of the three studies. Subchapter 5.1 addresses two different measuring methods (CUELA and electromyography) used in the presented PhD thesis to evaluate posture and muscular load during milking. Benefits and faults of the developed milking health formula will be discussed in subchapter 5.2, specifically focusing on working heights, the consideration of peak loads, and the precision of the recommendations. Subchapter 5.3 will discuss the validation of the milking health formula's recommendations for the Herringbone 30° parlor, particularly considering the need to view the udder and the technique of milking cluster attachment. The effect of increasing milking stall dimensions of dairy cows on the work environment of milking personnel will be discussed in subchapter 5.4, focusing on the choice of subjects and recommendations on milking stall dimensions. The need for future research will be addressed in subchapter 5.5.

5.1 Justification of Measurement Methods

In the first study (Chapter 2), the computer-assisted recording and long-term analysis system (CUELA; IFA, Bonn, Germany) was used to measure angular degrees of joints during milking. This holistic and unique approach allowed us to analyze the ergonomic situation in a variety of milking parlor types, and enabled the detection of interactions between working heights and milking parlor types. The CUELA system provided very precise measurements of joint angles during the work procedure. However, combining the variety of joints and ideal joint positions measured by the sensors is challenging when used to develop recommendations. To ensure the correct adjustment and calibration of sensors, the use of the CUELA system further requires expertise and therefore is high in cost. Due to the large amount of sensors and the precision of measurements, the CUELA system was relatively heavy and occasionally got caught on rails, water hoses or ropes within the milking parlor. This potentially influences the comfort and posture of milking personnel during the recordings.

We therefore decided to use an alternative measuring system in the other two studies. In the second and third study (Chapters 3 and 4), we used surface electromyography to evaluate muscle contraction intensities in four upper limb (*flexor carpi ulnaris*, *biceps brachii*) and shoulder (*deltoideus anterior*, upper *trapezius*) muscles (bilaterally). Surface electromyography has widely been used in human factor research. Adequate information is available on the correct experimental procedure, data evaluation, interpretation and reporting of electromyography data (Hermens et al., 1999; ISEK, 1999). The amplitude of surface electromyography data is variable between and within subjects, measuring environment, and measuring day. It is however reported that such undesired effects can be avoided by normalizing the data to the subject's individual isometric maximum voluntary contractions of each muscle (ISEK, 1999). Movement artefacts or electrical emission can also affect electromyography recordings (Hermens et al., 1999). However, the electromyography sensors used in the current experiment, in contrast to other electromyography systems, had no cables and contained a measuring and a reference bar electrode within each sensor. Consequently, the above mentioned undesired effects of the surface electromyography were reduced. Additionally, the recording software included a tool that detected electric emissions and poor skin preparation. We were therefore able to ensure sufficient data quality prior to the onset of the recording period. The electromyography sensors used in the current study (Delsys, Boston, USA) were small and could be worn under normal work clothes, ensuring good comfort for subjects. As a result, the amount of data that was contaminated with artefacts and therefore omitted from the analyses was very low (< 2 %). Only the data collected in the Side by Side parlor showed higher contamination rates of 10 %. This was likely due to the assistance rope holding the milking cluster in the Side by Side parlor, that occasionally nudged the sensors during the attachment of the milking clusters.

The combination of both the measurements of joint flexions with the CUELA system, as well as the measurement of muscular contraction intensities with surface electromyography, offered a holistic approach to evaluate ergonomics. Using a second measuring method was valuable to validate and improve the precision of our previous results.

5.2 Benefits and Faults of the Milking Health Formula

In the first study (Chapter 2) joint flexions during milking cluster attachment were assessed in five different milking parlor types, aiming to develop a formula which enabled the calculation of beneficial working heights. Thirty milkers were monitored on 15 commercial farms. The results indicated that most joints were used in poor postures during milking cluster attachment. Differences between parlor types were minor. Instead, results showed interactions between parlor type and working height coefficients, which represent the ratio between the udder height + depth of pit and the milkers body height. Therefore, it was evaluated for each parlor type, which working height coefficients achieved the largest number of joint flexion angles in a beneficial range. The calculation of the ideal depth of pit for subjects of varying body heights ensures optimal working heights during milking. These working height coefficients can further be used within the newly developed “milking health formula”. The milking health formula offers parlor specific recommendations on working heights by facilitating the calculation of individual depth of pits (Cockburn et al., 2015). The following subchapters will discuss aspects of these results.

5.2.1 Low Working Heights

Working heights reflect the ratio of the milkers height to the cows udder base, to which the milking cluster must be lifted (Figure 3.3). As such working heights have a large impact on ergonomics in milking parlors. The recommendations for working heights derived from the first study (Chapter 2) were relatively low compared to working heights currently used praxis (DeLaval, 2011). Previous studies have advised working heights where the udder is at shoulder level (Vos, 1974; Jakob et al., 2009). However, research that compared multiple parlor types in a holistic approach was missing. We therefore conducted an experiment using the same assessment criteria on multiple commercial farms to evaluate posture and successively developed working height recommendations for five milking parlor types (Chapter 2). Interestingly, results showed that recommendable working heights for the Side by Side and Herringbone 50° parlors were lower than those for the Autotandem, or Herringbone 30°, which was opposite to the recommendations currently applied in the industry (DeLaval, 2011).

Considering that milking personnel are predominantly affected by musculoskeletal disorders of the upper limbs and shoulders (Stål et al., 1998; Pinzke et al., 2001; Patil et al., 2012; Lunner Kolstrup and Jakob, 2016), it could be argued that these joints deserve more attention than others and thus a higher weighting when evaluating the correct working heights. However, we decided not to give preference to a particular body region, and weighted each joint similar in the first study (Chapter 2), in order to prevent a shift of musculoskeletal problems. However, we chose to evaluate upper limb and shoulder muscles in the second study (Chapter 3), in which we were able to confirm that muscle contraction intensities decreased with lower working heights. Though, not only the weighting of particular body regions, but also the evaluation of peak loads had an influence on the recommended working heights.

5.2.2 Consideration of Peak Loads

Both, the flexion and extension of joints can be harmful to the musculoskeletal system, thus it is important to consider peak loads. In the first study (Chapter 2) we chose to evaluate the 50th, 5th and 95th percentiles and weighted the postures of the percentiles similarly, despite the postures of the 95th and 5th percentile being maintained over a much shorter time period. The 50th percentile states the median flexion angle, whilst the 5th and 95th percentiles represent the lowest and highest 5 %. The 50th percentile is being maintained the longest and thus should be considered as the static part of the attachment procedure. However, particularly research investigating muscular contraction intensities has shown that muscular peak forces are often the cause for acute injury (Jonsson, 1978), which have been reported to be high in milkers (Karttunen and Rautiainen, 2013; Kuta et al., 2015). The 5th and 95th percentiles describe these extreme postures and should therefore be considered as similarly hazardous to the health of milking personnel as the 50th percentile. It may however be argued that the precision of the recommended working height coefficients should be improved.

5.2.3 Precision of the recommendations

The recommended working height coefficients in the first study (Chapter 2) were based on model calculations from measurements in a large-scale praxis experiment. The data underlining the working height coefficients within the milking health formula therefore provide a good basis for recommendations on ideal depth of pits. However, as the data was obtained within a practical environment, working heights varied between subjects, farms and milking parlor types. Additionally, parlor types, cows and milking techniques varied between milkers. It was therefore particularly valuable to gain further insight on the ideal working height coefficients in a laboratory setting. A large scale experiment was needed to define parameters of interest, as well as to evaluate and determine working heights. The working height coefficients that were evaluated in the first study (Chapter 2) differed by 0.05. We considered this a reasonable step between working heights, especially considering that the number of joint angles in a positive range were relatively close. However, we can only make recommendations for the evaluated working height coefficients. Future research should be encouraged to use the milking health formula as a reference tool to objectively evaluate, improve and recommend the working height coefficients for the different milking parlor types. In this way the milking health formula could be increased in precision. We recognized this need to improve the precision, particularly for the Herringbone 30° parlor, which was therefore in the focus of the second study (Chapter 3).

5.3 Validation for the Herringbone 30°

The working height coefficients recommended in the first study (Chapter 2) were relatively low across all milking parlor types. Additionally, the recommendation for the ideal working height coefficient in the Herringbone 30° was broad (between 0.7 and 0.9). Due to this, the Herringbone 30° in particular was further assessed to investigate if muscular loads could be decreased with lower working heights. In the second study (Chapter 3) we therefore aimed to evaluate the effect of three different working heights within the Herringbone 30° in a laboratory setting, aiming to investigate if lower working heights reduced muscular contraction intensities of upper limb (*flexor carpi ulnaris*, *biceps brachii)* and shoulder muscles (*deltoideus anterior*, upper *trapezius*). The study was carried out in a Herringbone 30° parlor that was equipped with an adjustable floor. Seven men and nine women were required to attach the milking cluster to an artificial udder at three different working heights (low, medium, high). Results of the second study confirmed the benefit of low working heights. Particularly the muscle contraction intensities of the shoulder muscles were reduced when milking clusters were attached at lower working heights. Further, muscle contraction intensities were higher in women than in men. Subject height had no effect on muscle contraction intensities, which proves that the milking health formula can be used to effectively set comparable working heights for subjects of different body heights.

This additional project was considered essential, because the lower working heights recommended by the milking health formula prevented the opportunity of viewing the udder during the attachment of the milking cluster. Derived thereof the following subchapters will discuss the need to view the udder during the attachment procedure, as well as the influence of milking cluster techniques on ergonomics.

5.3.1 Viewing the Udder

Milking consultants found it vital to ensure a good visibility of the udder, thus previous recommendations resulted in working heights where the udder was at shoulder level. A visual control of the udder is inevitable. However, the udder visibility must not be ensured during the procedure of milking cluster attachment, which has been reported to be the most strenuous task during milking (Pinzke et al., 2001). Further, the health and cleanliness of the udder must be checked prior to the attachment of the milking cluster, to prevent any contamination of the milk. It is therefore more sensible to check the teats and udder prior to the attachment of the milking cluster, during the pre-milking and cleaning of the udders. Hereby the milker will also have to tilt his head or flex his knees to view the udder, but is not additionally burdened by the load of the milking cluster. In order to facilitate the attachment of the milking cluster without visual feedback it is advised to instead utilize tactile feedback. Hereby the teat cups are held at the top, between the thumb and the middle finger, whilst the index finger is used to guide the teat into the teat cup (Figure 3.4). We instructed our subjects in the second study (Chapter 3) to follow this particular procedure and the subjects easily adapted to attaching the milking cluster without visual feedback. Thus, the study is valid under these circumstance and the recommended working heights should be used without viewing the udder during milking cluster attachment.

5.3.2 Milking Cluster Attachment

Particularly in the second and third study (Chapters 3 and 4) we found large differences in the way milking clusters were commonly attached and had to make a conscious decision on how to deal with cluster attachment techniques during the experimental procedure and data evaluation. The technique of cluster attachment has not yet been closely considered in studies investigating ergonomics in milking parlors, and it has become apparent that the technique of lifting, holding and attaching the milking cluster varies widely.

Good practice in Europe advises a technique in which the milker bends the short pulsation tubes whilst attaching the milking cluster. This is only possible if three of the short pulsation tubes are held in one hand, whilst the other hand holds the remaining teat cup and prevents air inlet. However, although this method of attaching the cluster is effective, it is rarely used in praxis, because it is very strenuous especially as the claw of the milking cluster has become larger over the years. Although most milkers hold the cluster in the hand that is furthest away from the hind leg and alternate the arm used to hold the milking cluster, some milkers always hold the cluster with the same hand, independent of the milking parlor side. Stål et al. (1998) reported musculoskeletal disorders to be dominant in the hand used to hold the cluster during milking cluster attachment, which agrees with the findings in our second study (Chapter 3) in which muscular loads were higher in the holding than the attaching arm.

The method of teat cup attachment also varies between milkers. Although teat cups should be held at the top, so that the index finger can be used to guide the teat into the teat cup, many milkers hold the teat cup at the lower end and, thus, feel it is necessary to view the udder whilst attaching the teat cups. All these differences affect posture and muscular load during the attachment procedure. Therefore, it is important that future research will consider and state the attachment procedure precisely to improve the comparability between studies.

In the second study (Chapter 3) we required subjects to use a defined attachment technique, that can often be found in a practical setting, to avoid the influence of such undesired effects. This was only possible because we used milkers that did not milk on a daily basis and thus their muscles had not adapted to a particular attaching technique. This decision was based on a study by Stål et al. (1998) that reported the arm used to hold the milking cluster to be more affected by musculoskeletal disorders than the arm used to attach the milking cluster. In the third study (Chapter 4) we however used professional milkers, as we considered this necessary in order to assure good cow welfare during the trials. As the muscles of these milkers were adapted to their attachment technique, we asked milkers to milk the cows in the same way they would milk on their own farms and therefore without a defined attachment technique. Because milking techniques differed largely between subjects (switching the holding and attaching arm between parlor sides, within the attachment procedure or not switching at all), the holding and attaching arms could not be consistently defined in the data analysis. We therefore chose to evaluate the left and right arm instead of the holding and attaching arm. Future studies should however be encouraged to investigate different attachment methods in order to recommend the most ergonomic ones.

5.4 Parlor Unit Dimensions from the Milkers Perspective

In the third study (Chapter 4) we investigated the effect of milking stall dimensions on the muscle contraction intensities of two upper limb (flexor carpi ulnaris, biceps brachii) and two shoulder (deltoideus anterior, upper trapezius) muscles in a Herringbone 30° and a Side by Side milking parlor. It is currently being discussed if milking stall dimensions are too small for dairy cows and should be increased. As the horizontal reaching distance from the milker to the cows udder has been reported to affect ergonomics (Vos, 1974), we found it necessary to investigate if increased milking stall dimensions, will allow the cow to stand further away from the milker and thus cause discomfort for the milking personnel. Professional milkers were monitored while attaching the milking cluster in a Herringbone and a Side by Side milking parlor using electromyography. The milking parlor used allowed for size modifications of the milking stall dimensions and adjustment of floor height. The results showed that the milking stall dimensions had no effect on the muscular contraction intensities of the upper limb muscles in the Side by Side parlor. Whereas in the Herringbone 30° parlor cow space had an effect, however led to different outcomes depending on the side of arm measured. Instead it was found that contraction intensities of the *anterior deltoid* muscle, which is responsible for the forward/upward lifting of the cluster, decreased with subject height. The findings of the third study (Chapter 4) need to be discussed further with a particular focus on the choice of subjects and recommendations on milking stall dimensions.

5.4.1 Choice of Subjects

In the third study (Chapter 4) subjects were required to milk cows and it was important to ensure adequate cow handling. Therefore, we chose to use subjects with work routine. However, undertaking the trial in a more controlled manner with subjects that have no work routine, but therefore distinct attachment procedures such as in the second study (Chapter 3), could have increased the precision of the results and therefore enabled better recommendations. The milking techniques varied between milkers, thus despite having predominantly right handed (and one bilateral) subjects the hand used to hold the milking cluster was not the same between subjects. However, this has been accounted for in the statistical model, where subjects have been considered as a random effect. Thus calculations were made within the subject. Additionally, although the subjects were experienced milkers with work routine, not all of them were accustomed to the low working heights set for them. While taller milkers adapted well to the working height, as they were used to working at relatively similar working heights on their own farms (with non-adjustable standard floor heights), subjects smaller in height reported to feel uncomfortable due to a lack of udder visibility. As a result, milkers smaller in height were more uncomfortable with the inability to view the udder and were often observed to tilt their heads or bend over to view the udder during cluster attachment. This explains why subject height had an effect on muscular load in the third study (Chapter 4) but not in the second study (Chapter 3), in which subjects were instructed not to look at the udder.

5.4.2 Recommendations on Milking Stall Dimensions

We could find neither benefit nor disadvantage of either small or large milking stall dimensions for milkers. The muscular contraction intensities in the right lower and upper arm were higher when cows were milked with standard sized milking stalls, but were higher in the left upper arm when cows were milked were milked with large milking stalls (Figure 4.3 and Table 4.3). Estimated mean contraction intensities of the lower and upper left arm were higher than in the right arm. It can therefore be assumed that the left arm was mostly used to hold the milking cluster, whilst the right arm was used to attach the teat cups. This assumption is based on the results of our second study (Chapter 3) where contraction intensities were higher in the holding than in the attaching arm, and previous research stating that the holding arms were more affected by musculoskeletal disorders (Stal et al., 1998). This indicates that the large milking stalls relieve physical strain in the attaching, but increase physical strain in the more demanding holding arm function. However, we believe that muscle contraction intensity alone is not sufficient to assess the effect of large milking stall dimensions on the milker's work environment. More research is needed to ensure the recognition and removal of health and safety hazards, when cows are being milked in large milking stalls. This became apparent, particularly because small milkers bend underneath the hock rails in order to reach the udder (Figure 5.1). This behavior is not advisable and must be avoided, because the hock rail can no longer fulfil its purpose of protecting the milker from kicks. Further, we found that driving large cows into the parlor with standard sized milking stalls was difficult because they did not fit into the provided milking stalls. Therefore, it has not proven sufficient to evaluate contraction intensities of the upper limb and shoulder muscles exclusively to investigate the effect of increased milking stall dimensions on the milkers ergonomics. Future studies should consequently investigate the effect of milking stall dimensions on workplace safety in a more holistic approach.

Figure 5.1 Milker bending with head positioned behind the hock rail during milking cluster attachment. The large milking stall dimensions put the milker at risk of being kicked.

5.5 Need for Future Research

Future research should aim at improving the accuracy of optimal working height coefficients used within the milking health formula, focusing particularly on the working height coefficients for the Herringbone 50°, Autotandem and Side by Side milking parlors. Evaluations should focus on posture and muscular contraction intensities of the upper limbs and lower back. Milkers would further benefit from the development of ergonomic assistance devices, such as camera solutions enabling udder view at a lower working height. As the turning of the milking cluster has shown to be very strenuous, mechanical devices assisting with this particular procedure during cluster attachment could reduce peak forces of muscular contraction intensities.

The effect of large milking stall dimensions on muscular loads in the upper limbs and shoulder muscles were contradictory and should be further investigated. Further, it is necessary to evaluate risk factors during milking with large milking stall dimensions. Hereby studies focusing on the assessment of safety hazards, the time spent on driving cows into the milking parlors and the measurement of psychological stress in milkers could provide valuable information for future recommendations on milking stall dimensions.

5.6 General Conclusion

The thesis has elaborated a practical guideline for the fitting of correct working heights in a variety of milking parlor types. We have developed and validated the use of the milking health formula for a research and commercial environment. The working heights recommended within the developed milking health formula are lower than previously suggested. However, the derived recommendations have been further validated and the reduction in muscular load of the shoulder muscles has been reproduced with a second measuring system in the Herringbone 30° parlor, proving the beneficial effect of lower working heights.

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7 List of Publications

Cockburn, M., P. Savary, M. Kauke, M. Schick, U. Hoehne- Hückstädt, I. Hermanns and R. Ellegast 2015 improving ergonomics in milking parlors: Empirical findings for optimal working heights in five milking parlor types. Journal of Dairy Science. 98(2):966-74. doi: 10.3168/jds.2014-8535.

Cockburn, M., M. Schick, P. Savary, N. A. Maffiuletti, L. Gygax, and C. Umstätter 2017 Lower working heights decrease contraction intensity of shoulder muscles in a Herringbone 30° milking parlor. Journal of Dairy Science. 100(6):1-12. doi: 10.3168/jds.2016-11629.

Cockburn, M., M. Schick, P. Savary, N. A. Maffiuletti, L. Gygax, and C. Umstätter (Submitted to Ergonomics) Effect of milking stall dimensions on upper limb and shoulder activity in milkers.

Zweifel, U. and Cockburn, M. 2016 Auf der Suche nach mehr Ergonomie. Schweizer Landtechnik (5):31.

Cockburn, M. 2016 Elektromyographische Untersuchungen im Melkstand - Untersuchungen zu Arbeitshöhen und Melkplatzabmessungen. 4.Tag der Ergonomie des Ergonomie Kompetenznetzwerks, Friedrichshafen.

Cockburn, M., Savary, P. and Schick, M. 2016 In: Böttinger, S., Zick, M., Wörner, E., Schempp, T. (eds.), VDI-MEG Kolloquium Landtechnik 41 – Arbeitswissenschaften. Hohenheim, Germany: 113-120.

Cockburn, M. 2016 Elektromyographie im Melkstand - Untersuchungen zu Arbeitshöhen und Melkplatzabmessungen, Wissenschaftliche Gesellschaft der Milcherzeugerberater, Bad Hersfeld.

Cockburn, M. 2015 Arbeitshöhe anpassen - Melker entlasten. *Elite Milcherzeuger Magazin* (4):68-70.

Cockburn, M., Savary, P. and Schick, M. 2015 Optimierung der Arbeitshaltung beim Anhängen des Melkzeuges. *Agroscope Transfer* (102):1-8.

Cockburn, M., Umstätter, C, Savary, P. & Schick, M. 2015 Elektromyographie im Melkstand - Messungen in Praxis- und Laborbedingungen. 3.Tag der Ergonomie des Ergonomie Kompetenznetzwerks, Friedrichshafen.

Cockburn, M., P.Savary, M.Schick 2014 Ergonomic fitting of Hock Rail Height in Milking Parlours. International Conference of Agricultural Engineering, Zürich. Ref: C0580.

Cockburn M., P.Savary, and M.Schick 2014 Optimierung der Grubentiefe im Melkstand - Empfehlungen für die Praxis. Profilait, Zollikhofen.

Cockburn, M., Umstätter, C, Savary, P. and Schick, M. 2015 Physische Arbeitsbelastung beim Melken. 5. Tänikoner Melktechniktagung. Ettenhausen.

Cockburn, M., P. Savary, M. Kauke and M. Schick 2014 Physische Arbeitsbelastung beim Melken. Ergonomie Kompetenz Netzwerk, Ludwigshafen.

Gansow, M., Kauke, M., Savary,P., Höhne-Hückstedt and Schick, M. 2013 Analysis and assessment of workload during milking routines in various types of milking parlours. 4.Tänikoner Melktechniktagung: 49-51.

8 List of Tables

9 List of Figures

10 List of Abbreviations

Chapter 1	
OWAS	Ovako Working posture Assessment System
RULA	Rapid Upper Limb Assessment
CUELA	Computer-assisted recording and long-term analysis system
CAD	Computer-aided design
RAMSIS	Computer supported anthropometric mathematical system for occupant simulation

Chapter 2	
HB 30°	Herringbone 30°
ATD	Autotandem
PAR	Parallel
ADJ	Angular degrees of joints
HB 50°	Herringbone 50°
ROT	Rotary
CUELA	Computer-assisted recording and long-term analysis
WIDAAN	Winkel Daten Analyse

Chapter 3	
WH	Working height
sEMG	Surface electromyography
MVC	Maximal voluntary isometric contractions
w_i	Model weight

Chapter 4	
sEMG	Surface electromyography
FC	*Flexor carpi ulnaris*
BB	*Biceps brachii*
DA	*Deltoideus anterior*
UT	*Upper trapezius*
MVC	Maximal voluntary isometric contractions
BIC	Bayesian Information Criterion
w_i	Model weight
ER_0	Evidence ratio

Chapter 5	
CUELA	Computer-assisted recording and long-term analysis system

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12 Curriculum Vitae

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