Changes in motor variability during a repetitive deboning process: Effects of work experience and neck-shoulder discomfort

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The prevalence of musculoskeletal disorders among workers in the meat processing industry is found to be high and work-related neck and upper limb disorders are common problems among slaughterhouse workers. Motor variability may play a role in the etiology of musculoskeletal disorders. In parallel, age and work experience are known to influence motor strategies. This study introduces nonlinear approach for assessing motor variability in ergonomics for the first time. In combination with linear methods the effect of work experience and discomfort in terms of standard deviation coefficient of variation (variability), approximate entropy, sample entropy (regularity), and correlation dimension (dimensionality) were estimated. Workers with high experience were characterized by having smaller amount of variability compared to low experienced subjects. Discomfort in the neck-shoulder region resulted in lower amount of variability and higher complexity for the head-shoulder displacement, while the amount of variability increased and the regularity and complexity decreased for the elbow-hip displacement. The result could probably be linked to compensatory mechanisms in response to neck-shoulder discomfort.

1. INTRODUCTION

Meat processing involves a considerable amount of manual operations and several studies have demonstrated that workers performing meat processing tasks are at high risk of contracting work-related musculoskeletal disorders (WMSD) [1-4]. In the meat processing industry WMSD most commonly affects the upper extremities including shoulder and neck [5-8] and the key physical risk factors includes repetitive movements, lack of recovery, and awkward postures [6].

There is a lack of quantitative field studies [2, 9]. Most knowledge about WMSD due to slaughterhouse operations is from experimental studies investigating the effect of cutting force [10] and muscle activity [11, 12] during specific limb movements, rather than during functional and in vivo work activities [9]. Quantitative biomechanical analysis can be used to identify motor patterns during work. Differences in motor patterns and motor control among subjects have been suggested as an explanation to why some workers develop WMSD while others, performing the same work task, do not [12, 13]. In parallel, age and work experience are known to influence motor strategies [12, 14]. A recent laboratory study by Madeleine et al. [15] demonstrated that experienced butchers have a larger variability than novices and suggested that motor patterns change with learning and experience. Variability is a central characteristic of all human movement because of its role in motor learning and control [16]. Motor variability is explained by the complexity and constraints that interact to produce a desired movement. Evidence has suggested a possible beneficial effect of varying load, magnitude, rate, frequency, or application site, in the prevention of WMSD [17, 18]. To understand the nature and complexity of the motor variability, a collection of different types of variability measures need to be considered. These quantities can be computed using both linear and nonlinear approaches.

Linear descriptors such as standard deviation and coefficient of variation are commonly used to characterize the amount of variability in a movement [19] and to date, variability in ergonomics has only been measured by means of these linear descriptors [20]. However these approaches do not furnish information about the true structure of motor variability and does not directly characterize the complexity, irregularity, or predictability of the kinematic signals [21]. Nonlinear techniques focus on understanding how variations in a movement pattern change over time. Thus, the idea of combining linear and nonlinear techniques is theoretically very sound and could potentially expand our knowledge on the amount and structure of variability in ergonomics, and thereby providing valuable information about the risk of developing WMSD.

Nonlinear methods have mostly been used to examine variability in biological rhythms such as heart rate or blood pressure [19]. When techniques from nonlinear dynamics have been used in human movement, it has been in connection with research on gait [21] and postural control [22,23]. Investigations into the nature and complexity of a data time series have suggested that a collection of techniques should be used, including linear techniques, along with non linear estimators such as approximate entropy or/and correlation dimension [19].

This field study focused on motor techniques and variability among slaughterhouse workers performing an identical work task. The purpose was to assess motor variability in relation to the subjects' work experience and reported discomfort in the neck-shoulder region using both linear and nonlinear techniques.

2. METHODS AND MATERIALS

Subjects

18 male slaughterhouse workers, performing the task of deboning on a daily base, volunteered to participate in the study. The mean (SD) age was 34.9 (9.4) years, height was 175.1 (9.6) cm, the weight 79.6 (12.9) Kg and their average experience with the task was 2.1 (2) years. Only right handed workers were included in the study. The study was conducted in conformity with the Declaration of Helsinki Experimental Setup.

Experimental Setup

The experimental setup included video recordings of subjects manually deboning fore-ends from pigs (weight: 11Kg/fore-end). The operation consisted in performing multiple cuts to remove three inner bones (shank, humerus and blade) and lasted, under normal conditions, approximately 35-50 seconds/fore-end. The deboning process is repeated approximately 450 times (but up to 530 times) per day. Each subject was video recorded at their daily workplace while deboning at least 6 fore-ends to ensure consistent kinematics data. Prior to recordings each subject received an introduction to the experiment. The workers discomfort in the neck-shoulder area was assessed using a modified version of the standardised Nordic Questionnaire for analysis of musculoskeletal symptoms [24]

Kinematics data was collected using a regular Sony digital video camera (sampling rate at 25 Hz) placed on a tripod perpendicular to the worktable. Markers were placed on the right side of the head, the right shoulder, right elbow and the right hip. A reference recording was performed prior to the experiment, in which the subjects were placed in an upright anatomical position, so the relative motion of the markers could be calculated.

Data Analysis

WINanalyze (vers. 1.3, Mikromak GmbH, Berlin, Germany) was used to digitalize the recorded video sequences. From the recorded data, four representative bouts of approximately 35-50 sec for each subject were chosen for analysis. The tracking procedure revealed that most workers rotated the trunk while working, resulting in unreliable horizontal coordinates [25]. Only the vertical coordinates from the data were therefore suitable for analysis

All further data analysis was conducted in MATLAB (MathWorks, Natick, MA). The digitalized coordinates were low-pass filtered (Butterworth, 2th order, cut-off frequency 5 Hz). To describe relative work posture, distances between the four recorded markers were normalised accordingly to the recorded reference. Data were offset corrected with respect to the upright position (Figure 1). The duration of each cycle (deboning of one fore-end) was calculated as the length of the data series, starting at the first cut and ending when the fore-end left the workbench.

Figure 1: Illustration of the three distances used: Head-Shoulder; Shoulder-Hip and Elbow-Hip

Quantifying motor techniques and variability

The range of motion (ROM) for the vertical displacement of the head-shoulder, shoulder-hip and elbow-hip relative motion was calculated. The mean and the 10^{th}, 50^{th} and 90^{th} percentile of the displacement were also computed. To quantify the motor variability by means of classical linear techniques, standard deviations (SD) and coefficients of variation (CV) were calculated. A set of different nonlinear methods was used to estimate the complexity (approximate entropy (ApEn) and sample entropy (SaEn)) and the fractal nature (correlation dimension (CD)) of the kinematic time series.

ApEn and SaEn are derived from concepts of traditional entropy and have been used as a measure of complexity in many physiological applications [22, 26, 27]. ApEn and SaEn both quantify the probability that runs of patterns, that are close for m observations, remain close on the next incremental comparison [28]. The output is a single nonnegative number, where larger values indicate more uniform structure in the data [29]. The embedding dimension, m, and the tolerance distance, r, were, in the present study, chosen to m=2 and r=0.2xSD, on the basis of other human movement studies using ApEn and SaEn [19, 29, 30, 30]. ApEn differs from SaEn in that its calculation involves counting a self-match for each sequence of patterns [28, 31].

The CD is an approximation of how data points of a dynamical system are organized within a state space [21]. The CD is a measure of the dimensionality of a dynamic system and aims at establishing a stable value to which the estimated CD converge for increasing values of m. The CD is typically considered to be an accurate and sensitive measure as it is more directly related to system structure [27].

Statistical analyses

To analyze which effect discomfort had on the kinematic data, subjects were divided into either a symptomatic or an asymptomatic group. The symptomatic group consisted of subjects that had reported occurrence of discomfort in the neck-shoulder region with in the past week.

To analyze which effect work experience had on the data, subjects were divided into either a low or a high experienced group. The low experienced group was defined as workers with less than one years experience with the task. This is in accordance with previous studies [32, 33]. Subject information is presented in Table 1.

Table 1: Subject information

Parameter	Work Experience		Discomfort	
	Low	High	With	Without
N	7	11	6	12
Age (yrs)	28,1 (6,4)	40,9 (7,5)	35 (6,8)	36,4 (10,5)
Height (cm)	175,9 (13,7)	174,6 (6,6)	180,2 (4,4)	172,6 (10,7)
Weight (kg)	83,3 (14,0)	77,3 (12,0)	80 (11,2)	79,4 (13,9)
Experience on job (yrs)	0,4 (0,2)	3,1 (2,0)	3,1 (2,7)	1,5 (1,5)
Deboning time (s)	56 (19,5)	39 (6,9)	34,8 (0,39)	47,3 (1,57)

Multivariate analysis of variance (MANOVA) in SPSS version 15.0 was preformed. Mean (SD) is reported. The level of significance was set at $P < 0.05$.

Depended variables: Mean, SD, 10th, 50th and 90th percentile, ROM, CV, CD, ApEn and SaEn.

Fixed factors: Work experience and discomfort in neck-shoulder within the past week.

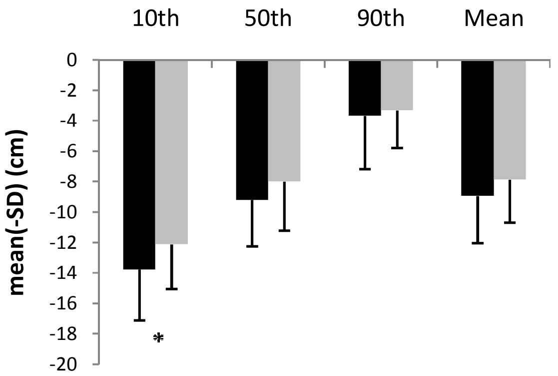

Figure 2: Mean (-SD) of the 10th, 50th and 90th percentile and mean for head-shoulder for both ■ low experience ■ high experience workers. * Indicates statistical differences (p<0.05)

Results

Effects of Work Experience

The work cycle duration was significantly longer (*F*= 18.06; *P*<0.001) for the low experienced workers compared with the high experienced workers (Table 1). For the work cycle duration, there was also a significant interaction between discomfort and work experience (F = 5.0, P = 0.028), the duration was shorter in presence of discomfort compared with no discomfort for workers with low experience (respectively, 39.3 (4.6) s vs. 57.3 (2.9) s, P<0.05) and decreased from low to high experience in presence of discomfort (respectively, 39.3 (3.5) s vs. 32.5 (4) s, P<0.05).

The effect of work experience on the amplitude parameters is reported in figure 2. For the head-shoulder position, the ROM (F=5.7; P=0.02) and 10th percentile (F=4.5; P=0.038) were significantly higher for low experience workers compared compared with the high experienced workers, respectively for ROM, 20 (4.8) cm vs. 17.1 (4.6) cm.

The effect of work experience on SD and CV are presented in Table 2. The low experienced workers had significantly larger SD for the head-shoulder displacement compared with the high experienced

		Experience	
		Low	High
Head - shoulder	SD(cm)	**3,94 (0,82)***	**3,39 (0,78)***
	CV	-0,47 (0,18)	-0,55 (0,38)
Shoulder - hip	SD(cm)	3,38 (0,67)	3,53 (0,94)
	CV	-0,21 (1,58)	-0,16 (3,06)
Elbow - hip	SD(cm)	6,61 (1,29)	6,50 (1,62)
	CV	0,89 (0,64)	2,7 (8,71)

Table 2: Mean (SD) for standard deviation (SD) and coefficient of variation (CV) for low and high experience workers. *Significant group differences (P < 0.05)

workers (F=7.6; P=0.008).

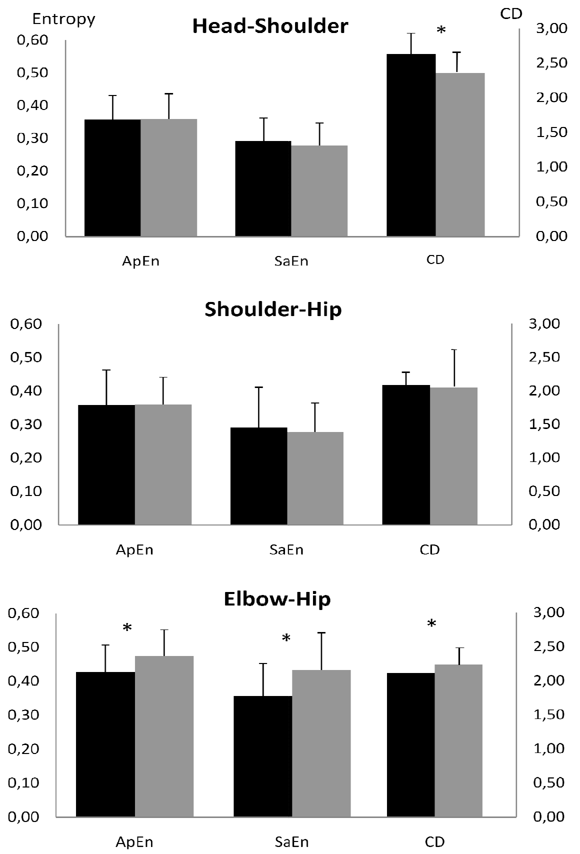

Figure 3: Mean (SD) of approximate entropy (ApEn), Sample entropy (SaEn) and Correlation dimension (CD) for head-shoulder, shoulder hip and elbow-hip ■ low experience ■ high experience workers. * Indicates statistical differences (p<0.05)

Figure 3 presents the effect of work experience on the nonlinear parameters. ApEn for head-shoulder displacement was smaller for the low experienced group compared with high experience workers (F=4.5; P=0.037).

Effects of Discomfort

Discomfort played a role on the work cycle duration (*F*= 9.3; *P*=0.003). The symptomatic workers had shorter cycle time duration compared with asymptomatic workers (Table 1).

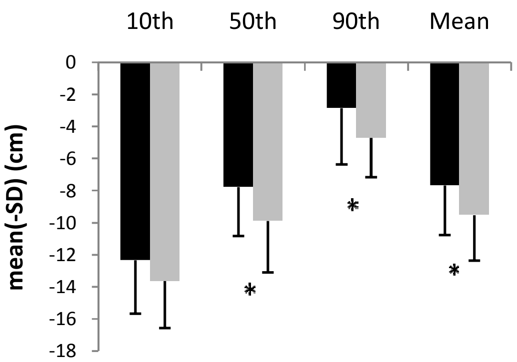

Figure 4: Effect of Discomfort. Mean (-SD) of the 10th, 50th and 90th percentile and mean. * Indicates statistical differences (p<0.05). ■ Asymptomatic ■ Symptomatic

Figure 4 presents the effect of discomfort on the head-shoulder displacement. The symptomatic workers had larger mean (F= 5.9; P=0.017), 50th (F= 7.1; P=0.01) and 90th percentile values (F= 4.3; P=0.041) compared with asymptomatic workers.

		Discomfort	
		Symptomatic	Asymptomatic
Head - shoulder	SD(cm)	3,54 (0,79)	3,64 (0,86)
	CV	**-0,39 (0,11)***	**-0,58 (0,36)***
Shoulder - hip	SD(cm)	3,48 (0,52)	3,47(0,97)
	CV	**0,14 (3,34)***	**-0,34 (2,11)***
Elbow - hip	SD(cm)	**7,17 (1,16)***	**6,26(1,44)***
	CV	0,81 (0,23)	1,98 (6,68)

Table 3: Group means for standard deviation (SD) and coefficient of variation (CV) for symptomatic and asymptomatic groups. *Significant group differences (P < 0:05)

The effect of discomfort on SD and CV are presented in Table 3. CV were greater for the asymptomatic workers compared with the symptomatic workers for the head-shoulder displacement (F=4.9; P=0.03) and the shoulder-hip displacement (F=3.9; P=0.05), while it was opposite for the SD of the elbow-hip displacement (F=6.9; P=0.011).

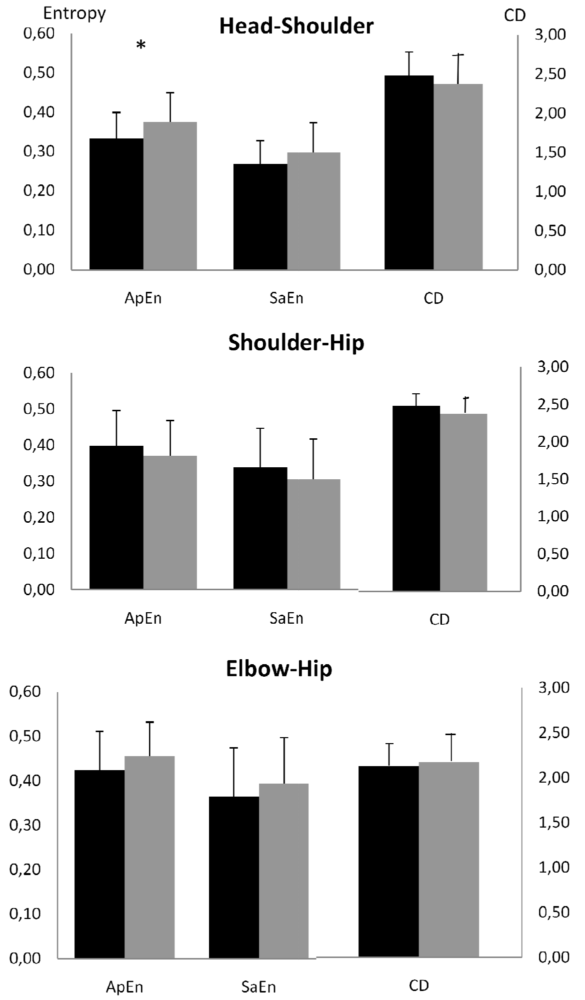

Figure 5 : Mean (SD) of approximate entropy (ApEn), Sample entropy (SaEn) and Correlation dimension (CD) for head-shoulder, shoulder-hip and elbow-hip ■ asymptomatic ■ symtomatic workers. * Indicates statistical differences (p<0.05)

The effect of discomfort on the nonlinear parameters is presented in Figure 5. ApEn, SaEn and CD were higher for the symptomatic workers compared with the asymptomatic workers for the elbow-hip displacement (respectively, F=4.9; P=0.03, F=7.8, P=0.007; F=8.0, P=0.006). CD for the head-shoulder displacement was also significantly larger for the asymptomatic workers compared with the symptomatic workers (F=3.8; P=0.048).

4. DISCUSSION

In this study, both linear and non-linear approaches were used for the first time to quantify and characterize changes in motor variability of kinematics data in response to the subjects work experience and reported discomfort in the neck-shoulder region. A longer work experience mainly led to changes of the displacement of the head and shoulder positions e.g. decrease in range of motion and amount of variability (SD). Discomfort mainly affected the head-shoulder and the elbow-hip displacement leading to lower amount of variability (CV) and higher complexity (CD) for the head-shoulder displacement, in contrast to greater amount of variability (SD) and decreased regularity (ApEn and SaEn) and complexity (CD) in the displacement of elbow-hip.

4.1 Methodological consideration

The present field study was conducted in a slaughterhouse. A deboning task considered as strenuous was investigated. The task was fairly complex, and simpler tasks may not lead to similar findings.

The study population was small but sufficient to generate new information related to motor variability in occupational settings. Especially age differed between low and high experienced workers, and can be considered as a cofounder.

Data were not collected across days or weeks, so conclusions regarding the nature of within- and between subject variations are limited to the conditions studied. With respect to kinematics, it should also be emphasized that analysis was carried only out in the vertical direction. Regardless of limitations, the study should be viewed as a contribution towards better understanding of the change in motor variability during a deboning process.

4.2 Effect of work experience

In the present study, low experienced workers had longer work cycle durations than the more experienced workers. This finding is in line with previous reports on cycle durations among inexperienced and experienced butchers in laboratory [12] and in field studies [34].

To become skilled at a certain task, the learner must acquaint to the best way to coordinate his body movements [35]. Several studies have described that an increase in skill level may be associated with increasing movement variability, both within and between individuals [36], In contrast to these studies, longer work experience resulted in decreased amont of motor variability in the displacement of the head and shoulder positions in the present study. Despite the evidence described for trend in increasing movement variability with increasing skill level, it is possible that such effect could be attributed to specific task constraints or specific nature of the task dynamics [37]. When comparing the present result to laboratory studies, it is important to keep in mind that the unknown extend of motor transfer can in part account for differences in motor variability. Madeleine et al. [15] simulated a cutting process and controlled factors that in a field study would be suspected to affect motor behaviour, e.g. work organisation, physical factors and physical environment. The variability observed in this study could be characterising as the reel variability during deboning and as a combination of the basis variability observed in experimental studies and the additional factors mentioned above.

In this study, the greater amount of variability among low experienced workers might also be explained by the fact that deboning is a task with high demands on productivity and precision. A worker with low experience might want to ensure correct cuts, resulting in frequent bending of his head to achieve a bettwe work precision. Moreover, this idea is supported by the larger ROM and increased of the 10^{th} percentile of the vertical distance for the head-shoulder.

4.3 Effect of Discomfort

Discomfort resulted in statistically significant increase of the vertical distance for the head-shoulder. This indicates that workers with discomfort in the neck-shoulder region operated in a posture where the head was either more flexed or shoulders were more elevated compared with the workers not reporting discomfort These findings are in line with other findings that reported on differences in the neck and shoulder posture among symptomatic and asymptomatic office workers [38].

In addition to this, the head-shoulder data revealed smaller amount of variability (CV) and increase of complexity (CD) for the symptomatic subjects than for the asymptomatic subjects. This could be an indication of discomfort being associated with a more stereotypic working posture in the unpleasant area for symptomatic workers. On the other hand greater complexity was found for the elbow-hip positions. Keeping in mind that discomfort was reported in the neck-shoulder region, this might be explained by compensatory mechanisms.

The amount of variability was smaller and regularity and complexity greater near the discomfort area for asymptomatic workers compared with symptomatic workers. In order to fulfil the deboning task, compensatory mechanisms, involving changes in the relative positions of head-shoulder and elbow-hip took place as depicted by changes in the reported amplitude and variability parameters.

4.4 Variability, is it good or bad?

From a motor control point of view, variability cannot be trivially divided into either good or bad, since it depends on whether variability interferes with the movement or not [39]. The notation of variability in a traditional sense focuses on variation in movement sequences and their outcome. Increased variability relative to some a priori standard should then reflect a problem of control or some sensory-motor mismatch [40]. With respect to a task-specific performance variable, motor variability has been addressed as "good" when the variable was not affected or "bad" when it was changed [39] .The present results underlined the difficulty in defining motor variability as either good or bad. For the symptomatic subjects the larger amount of variability and less regularity observed in the elbow-hip positions could be a result of the constrained and stereotypic observations (less amount of variability) seen between the head and shoulder positions. Then, the observed variability could be interpreted as a negative trend. On the other hand, the variability seen among the asymptomatic subjects could be interpreted as a positive trait and as it may avoid discomfort.

Discomfort may reflect a step towards pain [32]. Kilbom and Persson [18] found, through a prospective study design, that workers using a more dynamic pattern of movements had a lower risk of developing WMSD. In line with this, motor variability is modulated by neck-shoulder pain [15]. Then a higher amount of variability and lower complexity among asymptomatic workers may prevent WMSD development as reported earlier [15, 16],

5. CONCLUSION

The present study provides new quantitative, biomechanical descriptions of the deboning tasks. Besides using traditional kinematic variables and linear techniques for estimating motor variability, the paper introduces for the first time a nonlinear approach for assessing variability in ergonomic.

Workers with high experience in deboning were characterized by having smaller range of motion and amount of variability compared to low experience workers. Discomfort in the neck-shoulder region resulted in lower amount of variability and higher complexity for the head-shoulder displacement while the amount of variability increased and the regularity and complexity decreased for the elbow-hip displacement. This can probably be explained by compensatory mechanisms in response to neck-shoulder discomfort.

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Changes in motor variability during a repetitive deboning process: Effects of working experience and neck-shoulder discomfort

Worksheets

Master thesis by
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10th semester – Spring 2008
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Preface

This collection of worksheets is submitted as a fulfillment of the requirements for the degree *Master of Science in Biomedical Engineering*. The worksheets are written by group 1086a at the Department of Health, Science and technology, Aalborg University, Denmark, during the 10^{th} semester on biomechanics specialty in the period December 1^{st} 2007 to April 25^{th} 2008. The worksheets support the article entitled: *Changes in motor variability during a repetitive deboning process: Effects of working experience and neck-shoulder discomfort*, and both productions are addressed to fellow students at the Department of Health, Science and Technology, the project supervisors, and others interested in motor variability and biomechanics.

Aalborg University, April 2008

Tine Marie Toftgaard Madsen

Content

1 Background & motivation

This worksheet will present a short introduction to the present study. **Section 1.1 -** contains background information. **Section 1.2** - Present the motivation for the study. **Section 1.3** Present the objective of the study. *Work commenced: 15-12-07 Ended: 12-02-08*

1.1 Background

Human movement studies have been of great importance for the understanding of a range of clinical conditions. One clinical condition, much in need of additional research, is musculoskeletal disorders (MSD). MSD is a common cause of work-related disability among workers and it is one of the most frequent causes of sick leave and disability pensioning, with substantial financial consequences due to workers' compensation and medical expenses [1]. MSD include a wide range of inflammatory and degenerative conditions affecting the muscles, tendons, ligaments, joints, peripheral nerves, and supporting blood vessels [2]. The physical work features that are frequently cited as risk factors for MSD, based on both experimental science and epidemiologic studies [2, 3], include rapid work pace and repetitive motion patterns, insufficient recovery time, heavy lifting and forceful manual exertions and cold as well as non-neutral dynamic or static body postures. [2]

1.1.1 Musculoskeletal disorders in meat processing

MSD occur in certain industries and occupations with rates up to three or four times higher than the overall frequency. High-risk sectors include nursing facilities, air transportation and food processing [2, 4]. Meat processing involves considerable manual operations and several studies have demonstrated that workers performing meat processing tasks are exposed to high risk of MSD [4-8]. MSD in the meat processing industry most commonly affects the upper extremities including shoulder and neck [6, 8, 9] and the key risk factors includes repetitive movements, lack of recovery, awkward postures and the tools being used [10]. Knives are frequently used to perform cuts in meat processing and it is not unusual for a worker to perform 12,000 or more cutting motions per 8 hour shift [11]. These cutting tasks are often characterised by highly repetitive movement patterns which use the same muscle groups and require forceful muscle exertions [12, 13] and this can become problematic where repetition occurs for long periods or where work speed increases so that recovery time is lost [14].

1.1.2 Laboratory vs. field studies

Laboratory studies have the advantage of randomized trials, control over the interventions and other experimental conditions, and, often, the use of control groups. However, these studies may suffer from the use of study subjects who are different from workers of interest, they may not always involve representative work tasks, and they may involve duration and intensity of exposure to risk that is often much lower than is typical in workplaces. On the other side, field study results are often difficult to interpret because they may involve multiple interventions, low levels of control over potentially confounding factors that occur naturally in the work environment, and limited availability of true control groups not treated with the intervention. Given the tradeoffs between laboratory and field studies, it is clear that both are needed to gain a more complete picture of the effectiveness of interventions to control work-related musculoskeletal disorders.

1.1.3 Practical ergonomics

There are few conclusive scientific studies whose findings can be applied directly and confidently to the meat industry. For example reveals a review by Tappin et al. (2006) that while a lot of work has been done on biomechanical risk factors affecting the upper limbs during meat processing, most of this has been done in laboratories, rather than in actual plants with all the other operational considerations [14]. Most studies of slaughterhouse operations, primary kinematics, are studies of specific limb movements or specific manoeuvres [13, 20], rather than of the dynamic and complex functional work activities existing in a working plant.

Interventions that aim to reduce the risk of musculoskeletal injury in industry by changing the physical work load depend among other things on quantitative guidelines. Thus one approach to combating MSD is to improve understanding of MSD risk factors through quantitative biomechanical characterization of manual tasks. Quantitative, biomechanical characterizations of manual tasks will lead to identification of appropriate ranges for kinematics, which will in turn, facilitate proper design of manual tasks. Additionally, the methodology could be used to assess manual performance of skilled tasks for proper healthy technique, or be used to evaluate progress through a course of rehabilitation. {{83 Sommerich, C.M. 1996}}

1.2 Motivation

This study is motivated by the serious impact MSD have on workers in meat processing industry and the lack of quantitative industry specific studies whose results can be applied directly to the industry. Quantitative biomechanical analysis can be used to identify motion patterns during work. The method could be used to evaluate routine work and result in specific quantitative suggestions to a "healthier" technique if necessary. Ergonomists that usually performs intervention at work places, often relay on qualitative estimates of exposure and thus an evaluation of risk factors are often based on a subjective opinion. Ideally ergonomists needs quantitative techniques to assess exposure that are easy and quick to use.

The majority of existing epidemiologic studies compare occupations or work operations that differ more in exposure than what would be feasible to achieve within a particular job operation.[15] Thus these studies offer only vague suggestions on the patterns of variation with in specific job operations. Only few studies have investigated whether symptomatic and asymptomatic persons have different postures data [16].

Workers in meat processing are exposed to high risk of MSD and this could be the reason for the comprehensive replacement of the work force in a meat processing plant. But why can some workers work in many years with out developing MSD when colleagues performing the same tasks do. It is known that experience plays an important role in the threshold and reporting of perceived discomfort [17] as well used motor variability because it is suggested, among other things, to a broader distribution of loads among different body tissues [18].

1.2.1 Objective

This study will be a field study focusing on a biomechanical analysis of a slaughterhouse operation repetitively preformed daily. The purpose is primary to assess quantitative information on posture and relate it to MSD and work experience by looking at changes and kinematics and motor variability. Secondary the purpose is to present how this quantitative information could be used in practical ergonomics and guidance.

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2 Literature retrieval

This worksheet will present the literature retrieval preformed to gain information about slaughterhouse work, biomechanical studies on musculoskeletal disorder and motor variability. Work commenced: 08-12-07. Ended: 23.0108

A literature retrieval was preformed to gain background information about slaughterhouse work, biomechanical studies on musculoskeletal disorders and methods for describing variability in movement. Primary it was done to by database searches (mainly in Dads and Medline) and different abstracts were conducted. In all cases, attempts were made to obtain primary literature. Additional chain searches based on relevant articles were done and requests were made of other supplementary data.

2.1 Strategy of the search

The keywords used in the search of the literature were inspired by and found in relevant literature. The search was divided into two parts. The first part focused on musculoskeletal disorders, primary among slaughterhouse workers and biomechanical measures of this (search 1). The second part focused on motor variability in relation to working experience (search 2) and MSD (search 3). The primary keywords for the three searches are illustrated in figure V and VV.

		Abattoir
		OR
		Slaughterhouse
Strain Injury	A	OR
OR	N	**Meat Plant**
Disorder	D	OR
		Slaughter Plant
		OR
		Meat Industry

Search 1

	A	**Motor**

Variability N OR

D **Movement**

AND AND

Experience

OR

Employment

OR

Skill

OR

Expertise

OR

Novice

Search 2

Disorder

OR

Strain Injury

Search 3

3 Pre-analyses

This worksheet contains a summary of the literature retrieval on motor variability. Section 3.1 – Introduction to motor variability and its association with musculoskeletal disorders and work experience. Section 3.2 – Present the overall methods used in the literature to quantify motor variability. Work commenced: 15.12-07. Ended: 10.03-08

3.1 Motor variability

Human movement is variable and variability occurs both within and between individuals [1].Variability is a central characteristic of all human movement because of its role in motor learning and control and has long been considered central to the study of movement and posture [2]. Variability exists because of the many complex systems and constraints that must interact in order to produce movement [3]. Motor variability is inherent in almost every level of analysis of a movement and several types of variability have been observed in the quantities used to describe human performance including kinematic (e.g. joint angle), kinetic (e.g. forces and moments), spatio-temporal (e.g. stride interval) as well as electromyography measurements [4].

3.1.1 Musculoskeletal disorders and motor variability

Variability has been suggested to play an important role in preventing musculoskeletal disorders [5], and evidence has suggested a possible beneficial effect of varying load magnitude, rate, frequency, or application site in the prevention and treatment of overuse injuries [3]. Possible mechanisms for the positive influence of variability could include a broader distribution of stress over different parts of the tissue, distribution of loads among different locations within the same tissues, or loading of the same tissues or locations at different times [3, 5]). Additionally, changes in the characteristics of the load due to variability might expose the affected area to a greater variety of force magnitudes, rates, and directions, thus potentially reducing or slowing the detrimental effects of repeated loading by permitting a longer adaptation time for tissues between loading events. [3]. Under circumstances where repetitive loading could cause overuse musculoskeletal injuries, inherent movement variability could be viewed as an internal protective mechanism that alters the application of the loading characteristics, thus minimizing the accumulation of trauma. [3]

Typically pain in muscles limits the ability to perform movements and it has been demonstrated that pain in the muscles influences motor control strategies via central mechanisms [6] and have effects on motor patterns during isometric and dynamic contraction [7, 8] In addition studies have suggested that differences in motor patterns and motor control between subjects could be an explanation to why some workers develop MSD while others performing the same work task do not. ([9, 10] Kilbom and Persson (1987) found, through a prospective study design, that workers using a more dynamic pattern of movements ran a lower risk of developing MSD than those making use of more static postures during work [11]. In consistent with this finding it is frequently reported that motor variability can be modulated by muscle pain and that the size of the motor variability may

have important clinical implications and the risk for development of MSD [12]. For example, was low back pain shown to be associated with increased lumbar muscle co-activation [8], altered muscle recruitment patterns are associated with pain disorders of the shoulder and cervical spine [13] and decreased amplitude of arm movement during repetitive work was observed in persons with neck-shoulder complaints [12, 14].

3.1.2 Working experience and motor variability

Long exposure seems to increase the risk of musculoskeletal disorders [15]. On the other hand experience plays an important role in the threshold and reporting of perceived discomfort [16]. For example in a 2 year follow up among workers with at least 12 months of job experience the duration of employment did not predict sickness absence due to musculoskeletal disorders ([17]. This is in consistent with studies showing that novice workers have been found to be at an increased risk of musculoskeletal disorders[15], and that they have reported much higher discomfort levels than their experienced co-workers [16]. An explanation may be that experienced subjects have more efficient motor patterns, which reduce discomfort. In contrast to a worker that is unfamiliar with a task, as a novice worker might be, the technique will be less efficient and requiring greater muscular effort than required by an experienced worker. A novice worker may also not have the specific muscle conditioning necessary to perform the job and the combined effect is an increased level of muscle fatigue [18]. In a resent study Madeleine et al. (2008) demonstrated that experienced butchers have a larger kinematic variability than novices and they suggest that motor patterns change with learning and experience. [19]

3.2 Quantifying motor variability

Evidence from motor control analyses and musculoskeletal measurements indicate the potential for significant variability during repeated performance of a specific task. This variability may influence the interpretation of the result of ergonomic risk assessments [20]. [21]There are numerous methods for representing variability and to understand the nature of and complexity of the motor variability a collection of different types of variability measures could be considered.[3] These quantities can be computed using both linear and non-linear approaches.

Linear methods for quantifying motor variability originating from descriptive statistics are considered most appropriate for quantifying the total variability within a system.[5] A linear approach to analyse biological signals does not directly characterize their complexity, irregularity or predictability and the analysis of variability has therefore undergone considerable growth during recent decades. Methods based on non-linear dynamics and chaos theories may reveal subtle abnormalities that may not be uncovered by the linear measures of variability. [22]

Nonlinear methods have mostly been used to examine variability in biological rhythms such as heart rate or blood pressure but may also be useful in examine human movement and its complexity [5]. Techniques from nonlinear dynamics used in human movement have been most evident in research on gait [23] and postural control [24, 25]. The use of nonlinear dynamics has the potential to provide new insights into the complexities of human movement [5]. To date, variability in ergonomics has only been measured by means of linear descriptors. This calls for the use of non-linear approach.

3.2.1 Choice of techniques

There are numerous methods and quantities for representing variability. Investigations into the nature and complexity of a data time series have suggested that a collection of techniques should be used, including linear techniques [5]. Studies using non-linear methods are summarized in Table 3.1.

Authors, year	Measure	SD	CV	LyE	CD	ApE	SaE	SG
Challis, 2006[26]	Maximum isometric moment		X			X		X
Christou,2002[27]	Knee-extension force and muscular contractions	X	X					
Dingwell, 2006[28]	Kinematics of upper body motions during walking	X		X				
Sosnoff,2006[29]	Isometric force output	X	X			X		
Button, 2003 [30]	Elbow (joint) displacement	X						
Dingwell, 2000[31]	Dynamic stability during walking (Kinematics)			X				X
Cavanaugh, 2005[32]	Postural Control					X		
Harbourne, 2003[25]	Center of pressure data			X	X	X		X
Kuursala et al. 2002 [33]	Heart rate and blood pressure				X	X	X	
Buzzy, 2003[23]	Kinematic gait parameters	X	X	X	X			
Granata et al, 1999[20]	Lifting motions, trunk moments, and spinal loads						X	
Tuzcu et al. 2005[34]	Heart rate						X	
Georgoulis2006[35]	Anterior cruciate ligament deficient knee during walking					x		
Gour et al, 2007[36]	Movement patterns of peak-dose levodopa-induced dyskinesia						X	
Vaillancourt,2006[37]	control of force output	X				X		
Donker,2007[38]	Center-of-pressure trajectories/postural control	X		X	X		X	
Roerdink, 2006[39]	Center-of-pressure	X		X	X		X	X

Table3. 2 Summary of some studies using nonlinear technique; Standard diviation (SD), Coefficient of variation (CV), Lyapunov Exponent (LyE), Correlation dimension (CD), Approximate entropy (ApE), Sample Entropy (SaE) and Surrogation (SG)

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4 Problem Statement

This worksheet will present the objectives and delimitation of the project. Section 4.1 – What is the expectation to the study on basis of the literature? **Section 4.2** – The hypothesis **Section 4.3** – Delimitations of the study. Work commenced: 04.01-08. Ended: 01.04-08

4.1 Expectation

To be able to state a hypothesis the following expectations have been reached on the basis of the examined literature.

Discomfort

The assumption underlying discomfort in this study is that it reflects the early perception of MSD and therefore it is expected that posture and movement among the symptomatic slaughterhouse workers will show reduced variability in accordance to the literature (e.g [1]).

Experience

The literature indicates that experienced workers besides having a greater efficiency in their performance also have greater flexibility [3].It is therefore expected that slaughterhouse workers with experience (more than one year) will have increased motor variability than novice workers.

4.2 Hypotheses

The magnitude and structure of ***motor variability*** *in a* ***repetitive task*** *increases with increased* ***working experience*** *and decreases with* ***discomfort in the shoulder-neck region****.*

4.2.1 Specification of keywords

Motor variability:

In this study motor variability is variability in recorded kinematic video data quantified by both linear and nonlinear methods.

Repetitive task:

Manual deboning of a fore-end from a pig, by cutting and removing three inner bones.

Working experience:

In accordance with previous studies experienced workers have at least 1 year experience with the task [2, 5]

Discomfort in the shoulder-neck region:

Discomfort is reported subjective by using the Nordic questionnaires for the analysis of musculoskeletal symptoms. The occurrence of discomfort is with in the previous week (7 days).

4.3 Delimitations

The study is delimited to focus only on one slaughterhouse operation (boning), in an effort to find an equivalent work operation that is preformed by several workers and thus is comparable across subjects.

The kinematic data used in the study is delimited to concern 2D video recordings on the basis of the difficult work surroundings in the slaughterhouse and to be true to what can be expected of an ergonomist and thus the transfer to practical ergonomic intervention.

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5 Description of the experiment

This worksheet will describe the experiment conducted in this project. A detailed experimental protocol can be seen in appendix A (in Danish) Section 5.1 – A presentation of the subjects, their job and how the were recruited. Section 5.2 – Short description of the data collection. Work commenced: 15.01-08. Ended: 10.02-08

5.1 General design

This field study was conducted on a large Danish pig slaughterhouse which, under the present study, employed a total of 1200 butchers, meat cutters and meat byproduct workers. 45.000 pigs were slaughtered and processed pr day. The present study was conducted in the section of fore-end deboning and trimming were a total of 116 workers were employed.

5.1.1 Subjects

18 out of the 58 workers that preformed deboning operations volunteered in participating in the study. The characteristics for the subjects can be seen in table VV. All subjects worked 37 hours per week with four beaks per day (three breaks of 15 minutes and one break of 30 minutes). Piecework allows the worker to bone up to 220% each day, which is consisting with deboning approximately 530 fore-ends on a day. 100% efficiency corresponds to the national minimum wage.

5.1.2 Job description

Fore-end deboning is a slaughterhouse operation where 3 interior bones from the fore-end of a pig are rend free by manual cutting (Figure X). Fore-end deboning is done individually by the workers at their own work bench. As earlier mentioned is deboning piecework, which in principle, is paced individually. But the job is offend done at high speed, with high precision demands and high forces of both cutting and assisting hand. Each worker handled approximately 450 fore-ends (at 11Kg) pre day. Deboning a fore-end is the hardest operation in the slaughterhouse and the operation is back-breaking work. The large number of uniform movements wears down the neck, shoulders, back and arms of the slaughterhouse workers.[1]

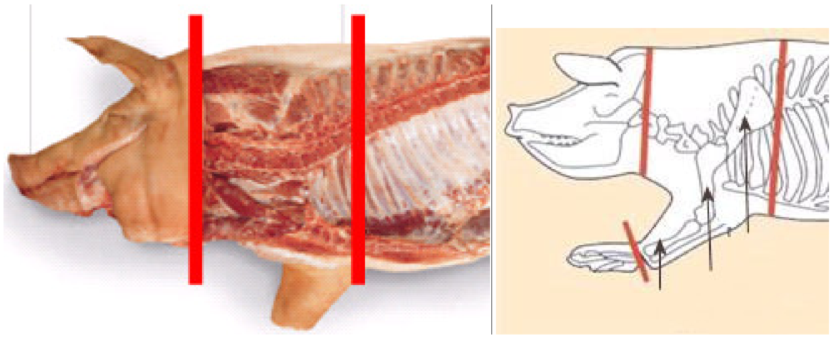

Figure 2: ***Left:*** **A fore-end.** ***Right*****: Three bones are manually removed (shank, humerus and blade)**

5.1.1 Recruiting of subjects

In preparation for recruiting subjects to the study an introductory meeting were held for all 116 slaughterhouse workers in the fore-end section. At the meeting the experiment and its purpose were presented.

After the meeting workers volunteered as subjects and 18 workers were chosen to participate in the experiment after the following inclusion criteria:

- Work operation: Deboning fore-ends

  In the section of fore-end operations other work operations than deboning was preformed. To ensure that all subjects perform identically work operation only subjects working the deboning operations were included in the experiment.

- Right handed.

  To ensure as identical work operations as possible only right handed workers were included in the experiment.

5.2 Data collection

The data registration was collected at the workers daily work station and was divided into two parts. First a registration of the prevalence of discomfort in musculoskeletal system using questionnaires and second a registration of kinematics using 2D video recordings. Before the experiment a pilot collection of data were conducted. The more detailed experimental protocol (in Danish) can be seen in appendix A.

5.2.1 Questionnaires

A standardized questionnaire was used to map the symptoms in the shoulder and neck region and collect personal data and work history. The questionnaire was largely based on the Nordic questionnaires for the analysis of musculoskeletal symptoms [2] and included questions on sickness absence, occurrence of MSD in the previous 12 months (1-year prevalence)and 7 days, age, gender, height, weight, shift work.

5.2.2 Kinematic data

The camera was positioned to the right of the workers workstation, pendicular to the worktable. A reference object of known length was placed in the field of view and was also recorded in order to calibrate data afterwards. To facilitate the later digitizing, orange markers were placed on black elastic band and affixed head, upper extremity and pelvis (Figure 5.1).

Figure 5.1

A commercial Sony digital video camera (Handycam DCR-DVD2025E) where used to record at least 6 processing of a fore-end per subjects. 6 processing were chosen to ensure uninterrupted data with e.g. breaks. The limit of video rate was set at 720x480 pixels for maximal quality of video resolution at sampling rate 25 Hz. The video sequences were saved as MPEG on mini dvd.

Bibliography

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6 Preprocessing & data set description

This worksheet will describe the preprocessing and present the collected data. Section 5.1 – The preprocessing in motion analysis program is presented Section 5.2 – The data set is described with respect to the subject characteristics and recording information. Work commenced: 12.02.08. Ended: 08.03.08

Following data collection, the video image of each trial was transferred to a computer as MPEG files. The recorded video was viewed for interruption, resulting in a reduction in data series to four cycles of deboning for analysis. In addition it was revealed that most workers rotated the trunk while working, resulting in unreliable horizontal coordinates [1]. Only the vertical coordinates from the data were therefore suitable for analysis.

6.1 Preprocessing

WINanalyze version 1.3 video motion analysis program, developed by Mikromak GmbH, was used automatically to extract trajectories of object movement. The MPEG files were conducted into the required file format. The frame rate of AVI file was 29 frames/s. In order to acquisition process, these files then were converted into

24 bit "true color" of its size from 720x576 pixels. An object with known dimension was used to be a reference for calibration frame. Marker points were targeted and semitracked. Y coordinate data were then extracted and exported as tex-files.

To test the accuracy of the extracted data, two points of known distance were tracked in a random file sequence. Min and max were subtracted and the data had an uncertainty of 0.41 cm.

6.1.1 Subject characteristics

Parameter	Mean	Standard Deviation
Age(years)	34.9	12.3
Height (cm)	175.1	42.2
Weight(kg)	79.6	22.1
Experience on job (years)	2.1	2.0
Experience meat cutting (years)	7.3	7.9

Data from six subjects with discomfort with in a week from data collection and data from 12 subjects without is used. Table 5.1 summarizes the characteristics of the six affected subjects. Table 5.2 summarizes the characteristics for the 12 non-affected subjects.

Subject no	Age	Work experience	Data length 1	Data length 2	Data length 3	Data length 4	Data length (av)
1	34	1 year<	602	625	732	729	672
2	34	1 year<	802	811	744	799	789
3	23	<1 year	1.061	1.089	1.096	920	1.042
9	44	1 year<	833	921	841	797	848
10	33	<1 year	946	877	899	974	924
15	42	1 year<	934	954	936	932	939

Table 5. 3: The characteristics for each shoulder-neck subjects

Subject no	Age	Work experience	Data length 1	Data length 2	Data length 3	Data length 4	Data length (av)
4	25	<1 year	2.163	2.226	2.067	2.278	2.184
5	18	<1 year	2.046	2.149	2.000	1.660	1.964
6	42	1 year<	1.162	1.158	938	1.133	1.098
7	56	1 year<	1.107	1.137	1.148	1.119	1.128
8	35	<1 year	1.098	1.119	1.065	1.007	1.072
11	34	1 year<	756	766	887	768	794
12	29	<1 year	916	951	965	908	1.373
13	34	<1 year	1.035	956	1.020	1.034	1.238
14	52	1 year<	742	652	661	836	1.117
16	35	1 year<	745	698	721	722	1.120
17	40	1 year<	679	629	694	674	1.119
18	37	1 year<	1.020	947	1.085	1.234	1.127

Table 5.4: The characteristics for each non-affected subject.

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7 Data analysis

This worksheet will describe the procedure and measures used to quantify motor technique and variability during the data analysis. Section 7.1 The initially proceedings prior to analysis. Section 7.2 Linear quantification of motor variability Section 7.1 Non-Linear quantification of motor variability. Work Commenced: 08.03.08. Ended:

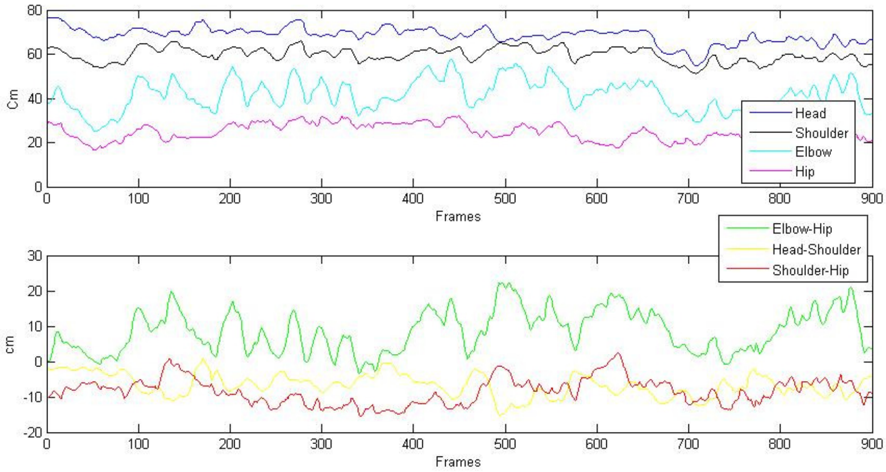
7.1 Initially proceedings

Data time series of the vertical positions of the head, shoulder, elbow and hip marker were exported to tex files from WINanalyse. These tex files were imported in to MATlab (MATLAB 7.0, TheMathWorks, USA) for further analysis. Initially the digitalized coordinates were low-pass filtered (Butterworth, 2th order, cut-off frequency 5 Hz).

To describe relative work posture, distances between the four recorded markers were offset corrected with respect to the upright position (figure 7.1 and 7.2). Velocity and acceleration were computed for each distance.

Figure 7.3 The three distances between positions chosen to describe work posture relative to the up right position.

Figur 7.4- ***Top:*** **Signals from the four markers** ***Buttom:*** **Distance signals in respect to the offset of the upright position**



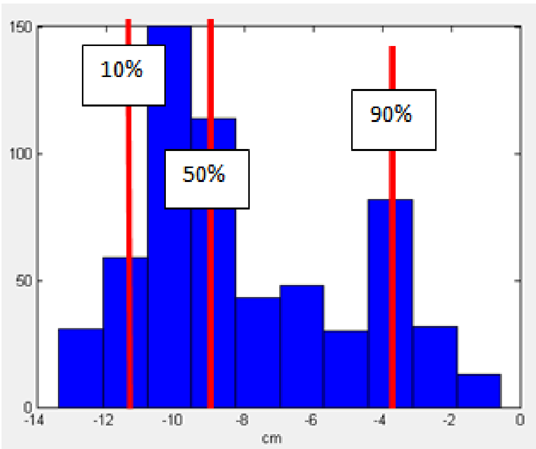
7.2 Kinematics variables

7.2.1 Range of motion

Range is simply the difference between the greatest and the least values. The range is a good indicator of the spread of the data, with a large range implying that the data are spread over a large interval and a small range indicating that the values are more concentrated [1]

7.2.1 Percentiles

Percentiles is the value for which e.g. for the 10th percentile, 10 % of the observations lie below. In this study the 10^{th}, 50^{th} and 90^{th} percentile is calculate. This is illustrated on a histogram of the distribution of a head-shoulder data series in figure 7.3.



Histogram for head-shoulder distance (Subject no 1, 1. trial) Figure 7.5

6.2 Linear quantification of Motor variability

There are numerous methods and quantities for representing variability. To understand the nature of and complexity of the motor variability a collection of different types of variability measures could be considered. These quantities can be computed using both traditional linear and non-traditional nonlinear approaches. In the following sections the most commonly used approaches are described.

Traditional methods for quantifying motor variability originating from descriptive statistics are considered most appropriate for quantifying the total variability within a system [1]. These methods are linear and the variability of variables across trials is commonly quantified using the following described quantities.

3.1.1 Standard deviation

The most common strategy for characterizing variability in motor control is to calculate the standard deviation (SD) of a given movement parameter. The SD characterizes how spread out a distribution of the data is. [2] If the SD is small it is usually reported but is implicitly or explicitly dismissed as a reflection of system noise. In this situation, the mean of the distribution tends to provide the primary source of information about the order in the data. [2]

3.1.3 Coefficient of variation

Range and standard deviation are absolute measures of variability. The most common quantity that represents a relative variability measure is the coefficient of variation (CV). [3]

$$CV = \frac{SD}{Mean}$$

3.2 Non-traditional methods

Non-traditional methods for quantifying motor variability use techniques from the study of nonlinear dynamics to isolate chaotically variability[3]. The introduction of the concepts and methods of nonlinear dynamics and chaos theory to motor control has opened the door to interpretations of movement variability other than simply being equivalent to noise [2]. Nonlinear methods have mostly been used to examine variability in biological rhythms such as heart rate or blood pressure also may be useful in examine human movement and its complexity [1].Techniques from nonlinear dynamics used in human movement have been most evident in research on gait [4]and postural control [5, 6]. The use of nonlinear dynamics has the potential to provide new insights into the complexities of human movement [1].

To characterize the dynamic of a system, a state space has to be reconstructed. This can be done using Time-delay embedding or spatial embedding. These procedures are not described in this worksheet. Characterization of the reconstructed attractor can be done by the nonlinear measures e.g. Correlation Dimension

3.2.3 Correlation Dimension

The correlation dimension (CorrDim) is one of the most fundamental quantities in chaotic time-series analysis. [7]It is a measure of the dimensionality of a dynamic system and approximates the fractal dimension of the region in the state space in which the dynamical system is located [1]. It can be used to evaluate how data points in a time series are arranged within a state space, which is not possible to visualize. The CorrDim statistic aims at establishing a stable value to which the estimated correlation dimensions converge for increasing values of embedding dimensions. In this it reconstructs the phase space of the attractor of a process in detail. [4]

The CorrDim is calculated by usage of the correlation integral Cr. The correlation dimension can be viewed as the likelihood that a set of random points on the trajectories are closer than a given distance r. It is not important what the value of C_r is at any particular single value of r , but how C_r changes with r. The correlation integral is given by [1, 7]:

$$C_r = const \sum_{i=1}^{N} \sum_{j=1}^{N} \theta(r - |x(i) - x(j)|)$$

Often C_r is determined for the range of distances and afterwards log (C_r) is plotted as a function of log (r). For a sufficiently high embedding dimension the linear part of the slope of this plot will be an estimate of CorrDim. Therefore CorrDim is given by [7]:

$$CoD = \lim_{r \to 0} \frac{d \log (C_r)}{d \log(r)}$$

3.2.4 Approximate Entropy

Approximate entropy (ApEn) is derived from concepts of traditional entropy and has been used as a measure of complexity in many physiological applications. Entropy, as it relates to dynamical systems, is the rate of information production. [8]ApEn focuses on quantifying the order in a dataset and measures the logarithmic likelihood that runs of patterns in a time series, over an observer chosen number of sequential observations, remain similar in succeeding intervals of similar length.[1] ApEn is a statistic that is designed to identify patterns of change, from orderly to random, in sequential data. It is a model-independent statistic that distinguishes datasets on the basis of regularity, and quantifies the amount of regularity in time series with a single number. [7]This number is a nonnegative number, with larger values indicating greater serial randomness and smaller values corresponding to more structure in the data. [9]

The following is a description of the calculation of ApEn. It is based on [8, 10-12].

Given any sequence of data points u(i) from i = 1 to N, it is possible to define vector sequences x(i), which consist of length m and are made up of consecutive u(i), specifically defined by the following:

$$x(i) = (u [i], u [i + 1], \dots u [i + m - 1])$$

In order to estimate the frequency that vectors x(i) repeat themselves throughout the data set within a tolerance r, the distance d(x [i],x [j]) is defined as the maximum difference between the scalar components x(i) and x(j). Explicitly, two vectors x(i) and x(j) are 'similar' within the tolerance or filter r (i.e. d(x [i],x [j]) = r) if the difference between any two values for u(i) and u(j) within runs of length m are less than r (i.e. |u(i + k) - u(j+k)| = r for 0 = k = m). Subsequently, $C_i^m(r)$ is defined as the frequency of occurrence of similar runs m within the tolerance r:

$C_i^m(r)$ = (number of j such that d(x [i],x [j]) = r)/(N - m - 1), where j = (N - m - 1)

Taking the natural logarithm of $C_i^m(r)$, $F^m(r)$ is defined as the average of ln $C_i^m(r)$:

$F^m(r) = S_i \ln C_i^m(r)/(N - m - 1)$ where S_i is a sum from I = 1 to (N - m - 1)

$F^m(r)$ is a measure of the prevalence of repetitive patterns of length m within the filter r.

Finally, approximate entropy, or ApEn(m,r,N), is defined as the natural logarithm of the relative prevalence of repetitive patterns of length m as compared with those of length m + 1:

ApEn(m,r,N) = $F^m(r) - F^{m+1}(r)$

Thus, ApEn(m,r,N) measures the logarithmic frequency that similar runs (within the filter r) of length m also remain similar when the length of the run is increased by 1. Thus, small values of ApEn indicate regularity, given that increasing run length m by 1 does not decrease the value of $F^m(r)$ significantly (i.e. regularity connotes that $F^m [r] \sim F^{m+1} [r]$). ApEn(m,r,N) is expressed as a difference, but in essence it represents a ratio; note that $F^m(r)$ is a logarithm of the averaged $C_i^m(r)$, and the ratio of logarithms is equivalent to their difference.

Approximate entropy can de depended on record length; therefore the data in this study is in organized in 5 intervals with same length (N=500) and then the average is the ApEn value given in the results.

3.2.5 Sample Entropy

Sample Entropy (SampEn) is based on ApEn and is also a measure of regularity in data. SampEn was developed to overcome certain limitations of the ApEn method. The main difference is that SampEn simply excludes self-matches in the definition of ApEn and does not employ a templatewise strategy for calculating probabilities.[13] Larger SampEn values indicate greater independence, less predictability, hence greater complexity in the data. SampEn is largely independent of record length and displays relative consistency under circumstances where ApEn does not. [8]

3.2.6 Choice of embedding dimension (m) and tolerance distance (r)

In this study the embedding dimension is set to m=2 and the tolerance distance to r=0.2xSD, on the basis of other human movement studies using ApEn and SaEn [1, 9, 14,] The actual value of the embedding dimension depends on the structure of the data and the choice of the embedding dimension (m) can be crucial for reconstructing and interpreting the state space. In general if m is too small then the embedded manifold is folded onto it self, and elements characterizing the dynamics are lost to the analysis. [7] Conversely, if m is to large then the structure of the attractor is dispersed through a high dimensional space and the time series is indistinguishable from noise.

The most popular method for choosing the optimal embedding parameters are based on the method of false nearest neighbors (FNN) [3]. Random test for the data using the method of FNN can be seen in figure 7.56 and it ague to certain point that m=2 is okay.

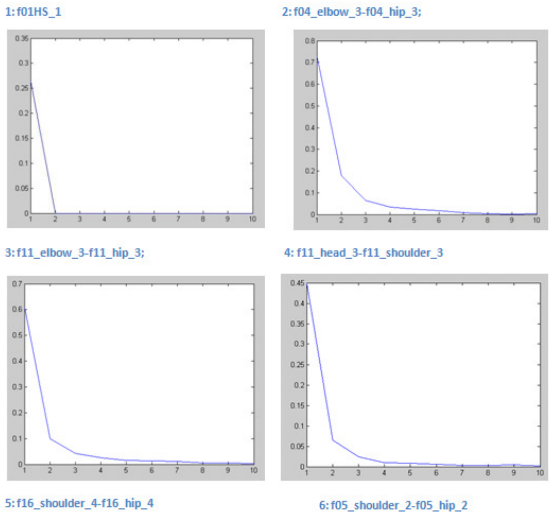


Fig.7.56

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8 Results

This worksheet will present the results obtained through the survey and data analysis. A discussion on the results is given in worksheet no 10. Section 7.1 – A presentation of the survey response Section 7.2 – Results of the statistics of the cutting time Section 7.3 - The results of the statistics of work experience Section 7.4 - The results of the statistics of discomfort in the shoulder-neck region

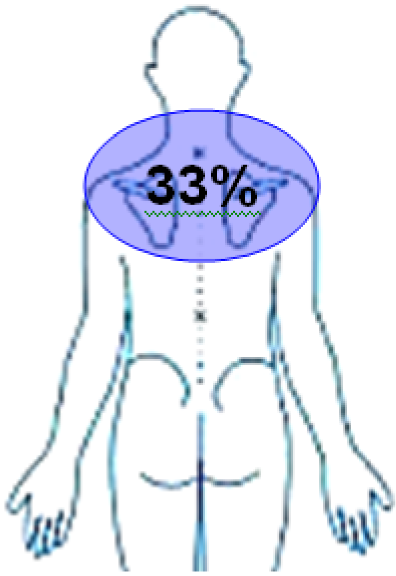
7.1 Survey responses

The 18 subjects participating in the present study reported their antrometric data, work-related data and the occurrence of discomfort in different body parts using a questionnaire. The total response of the 18 questionnaires is made up in appendix WW. Accordingly to the hypothesis only work experience in boning and the occurrence of discomfort in the shoulder-neck region is used from the questionnaire in the present study. The grouping of these survey variables is illustrated in table 1. Discomfort in the shoulder-neck region had occurred among 33% of the subjects with in the past week (figure 1).

Discomfort in the shoulder-neck region	Number of subjects
Symptomatic	6
Asymptomatic	12

Work Experience	Number of subjects
Low (under 1 year)	7
High (more than 1 year)	11

Tabel 1: Between-Subjects Factors

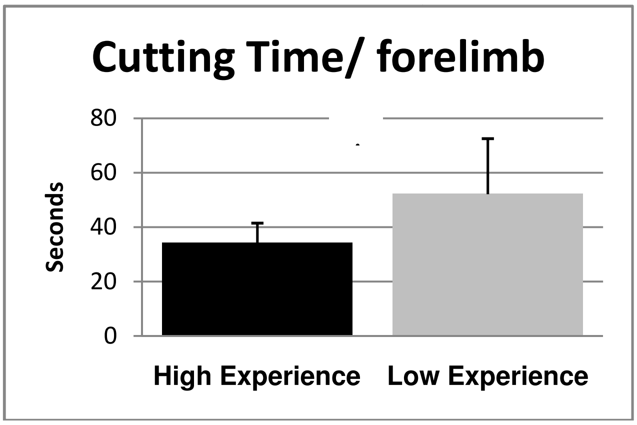


Figur 6: 33% of the subjects had experienced discomfort in the neck-shoulder region with in the past week

7.2 Duration of cutting and boning

Figure 2 and 3 illustrate the influence of work experience and discomfort in the shoulder-neck region on the duration of cutting and boning a single forelimb. A main significant effect for experience (*F*= 18.06; *P*<0.001; figure 2) and discomfort (*F*= 9.27; *P*<0.005; figure 3) was found. The low experienced group had a higher mean cutting time than the high experienced group. The group of workers with discomfort in the shoulder-neck region had a lower mean cutting time than the asymptomatic group. For the duration of cutting and boning, there was a significant interaction between discomfort and work experience (*F*= 5.04; *P*<0.05).

Additional experience and discomfort had also tended to have a significant effect on the standard deviation of the duration (respectively, (*F*= 3.28; *P*<0.1) and (*F*= 3.11; *P*<0.1), there. Workers with no discomfort had higher SD than workers with discomfort (2.87sec 2.2 vs. 1.92sec 0.97) and workers with low experience had higher SD than workers with high experience (3.12sec 2.4 vs. 2.19sec 1.47).



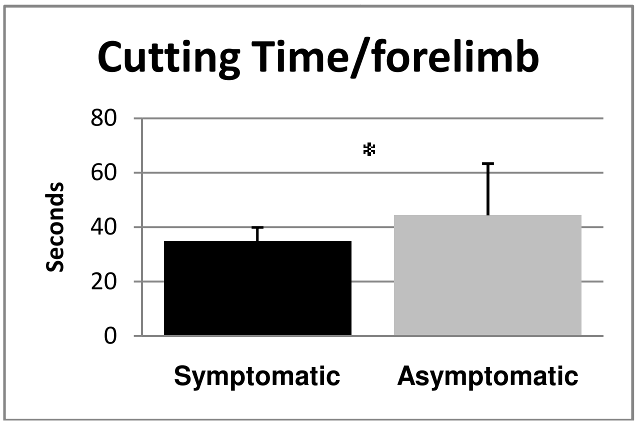


Figure 7: Mean cutting time per forelimb distributed on work experience.*: P<0.005

Figure 3: Mean cutting time per forelimb distributed on occurrence of discomfort in the shoulder-neck region. *: P<0.001

7.3 Work Experience

The dependent variables used in the statistics of kinematics were 10^{th}, 50^{th} and 90^{th} percentiles of the displacement in position (cm) as well as the mean (cm) and range of motion(ROM, cm). Also velocity (peak to peak, m/sec) and acceleration (peak to peak, m/sec^2) were extracted. Extracted variables used in the statistics of motor variability were, standard deviation (SD), coefficient of variation (CV), approximate entropy (ApEn), Sample Entropy (SaEn) and Correlation Dimension (CorDim) for each of the three displacement data. All variables are described in work sheet no. 6.

7.3.1Head-shoulder displacement

Work experience had a significant effect on the 10^{th} percentile and range of the displacement of the head-shoulder position (respectively, (*F*=4.46; *P*<0.05) and (*F*=5.72; *P*<0.05), figure 4).

The low experienced subjects had both the greatest 10th percentile displacement and range of the motion compared to high experienced subjects.

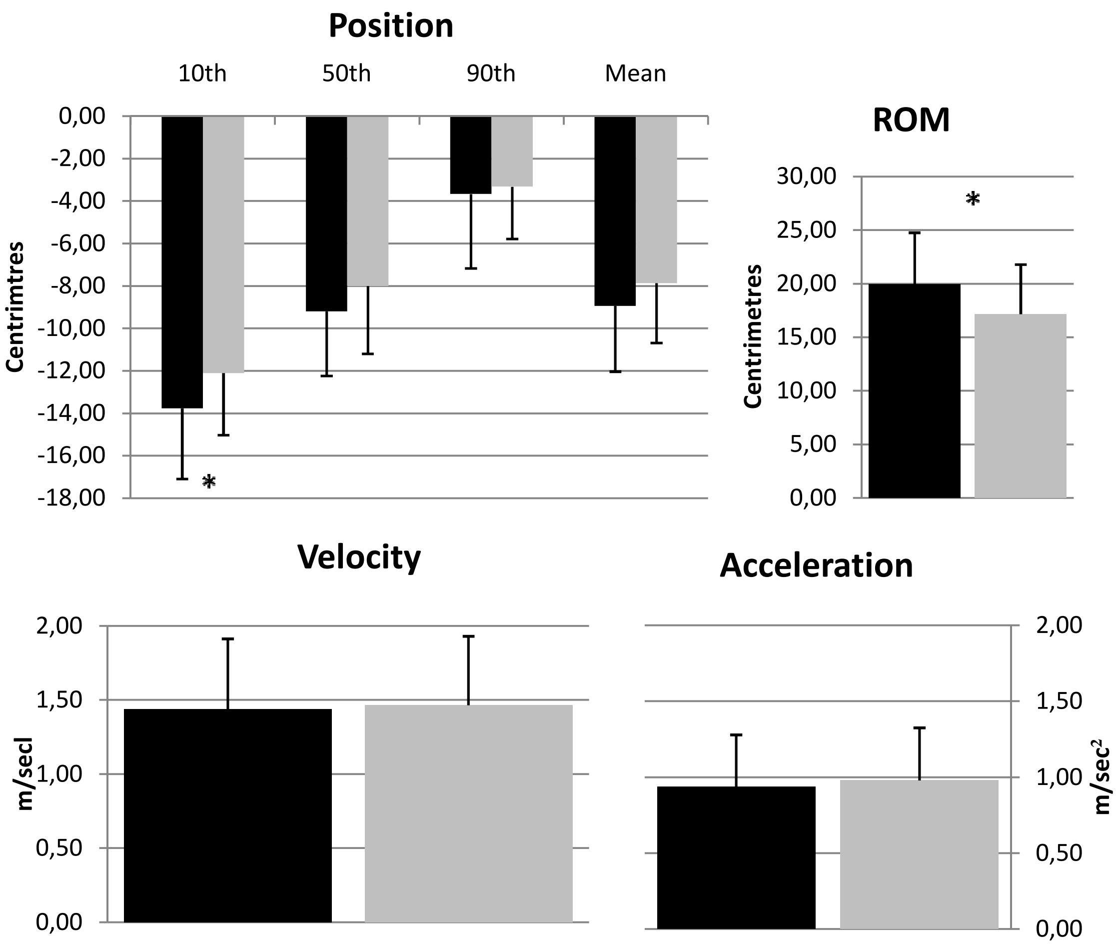


Figure 4: Effects of work experience on the 10th, 50th and 90th percentile, mean and range of the displacement between head and shoulder, velocity (peak to peak) and acceleration (peak to peak). Negative values in position denote a shortening in displacement from the upright position. ■ low experience ■ high experience ***: P<0.05**

The results of work experience in relation to variability of the head-shoulder displacement are presented in the extracted parameters in figure 5. Work experience had a significant effect on the standard deviation, approximate entropy and correlation dimension of the position of the head-shoulder (respectively, (F=7.59; P<0.05), (F=4.54; P<0.05) and (F=6.59; P<0.05)). The group of low experienced subjects had a larger mean SD value and mean CorDim value than the group of more experienced subjects. In contrast the mean ApEn of the displacement data were smallest for the low experienced subjects.

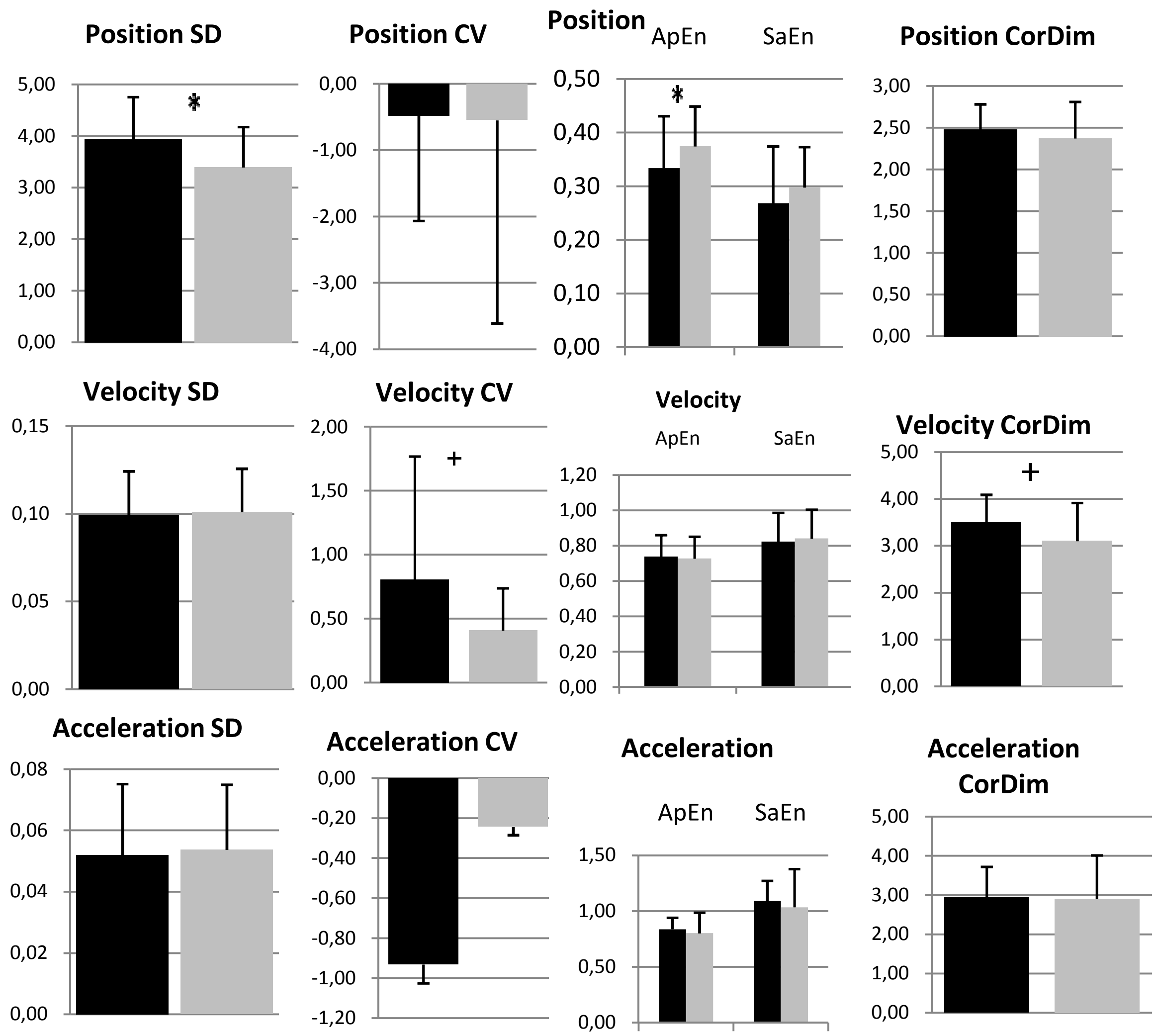


Figure 5: Statistical results for the study part on standard deviation (SD), coefficient of variation (CV), approximate entropy (ApEn), sample entropy (SaEn) and Correlation dimension (CorDim) of the head-shoulder displacement, velocity and acceleration. ■ low experience ■ high experience **(*: P<0.05) (+: P<0.1)**

In velocity, work experience tended to have an effect on the coefficient of variation (F=5.64; P<0.05) which tend towards lower value in respect to higher experience.

7.3.2 Shoulder- hip displacement

In general, none of the methods revealed significant differences between the levels of experience with respect to work posture (figure 6 and 7). However, in velocity and acceleration work experience had a significant effect the coefficient of variation (respectively, (F=8.96; P<0.05) and (F=6.08; P<0.05), figure 6). The group of low experienced subjects had lower mean values of the coefficient than the high experienced group in both velocity and acceleration.

In velocity, work experience also tended to have an effect on standard deviation (F=2.8; P<0.1) and the values of approximate and sample entropy (respectively, (F=3.48; P<0.1) and (F=3.6; P<0.1)).

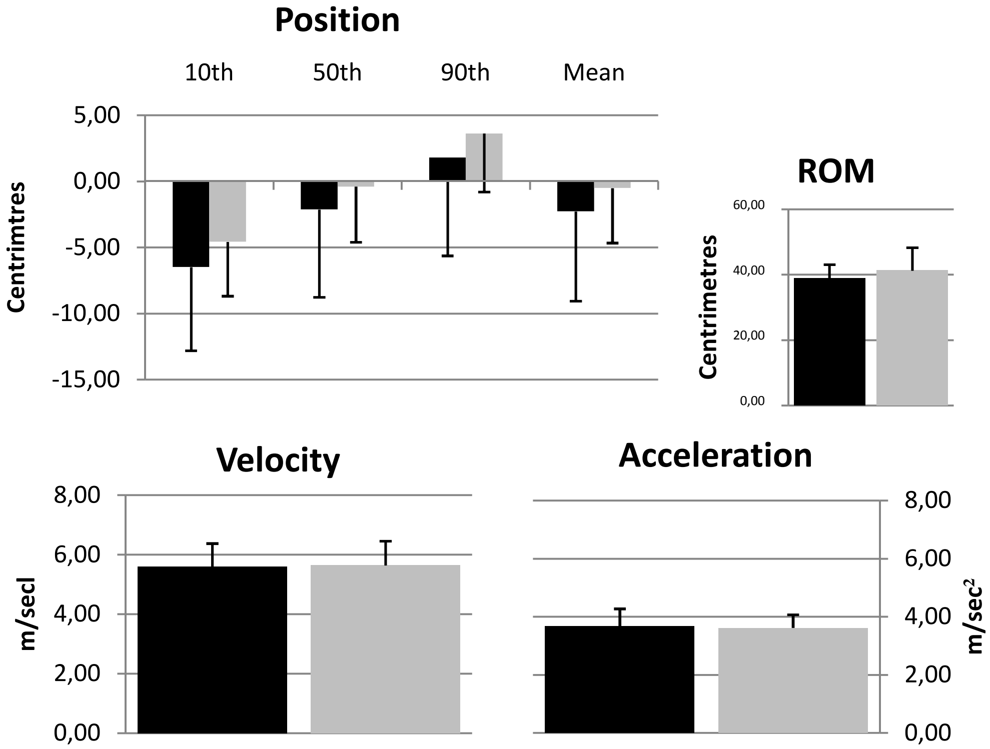


Figure 6: Effects of work experience on the 10th, 50th and 90th percentile, mean and range of the displacement between shoulder and hip, velocity (peak to peak) and acceleration (peak to peak). Negative values in posture denote a shortening in displacement from the upright position. ■ low experience ■ high experience

The standard deviation tended to have a higher value and the entropy values tended to be smaller for the low experienced subjects. In addition for the standard deviation of the velocities, there was a significant interaction between work experience and discomfort in the shoulder-neck region (F=6.28; P<0.05)).

In acceleration, work experience tended to have an effect on the value of sample entropy (F=2.82; P<0.1), shown as tend towards a lower mean value in respect to higher experience.

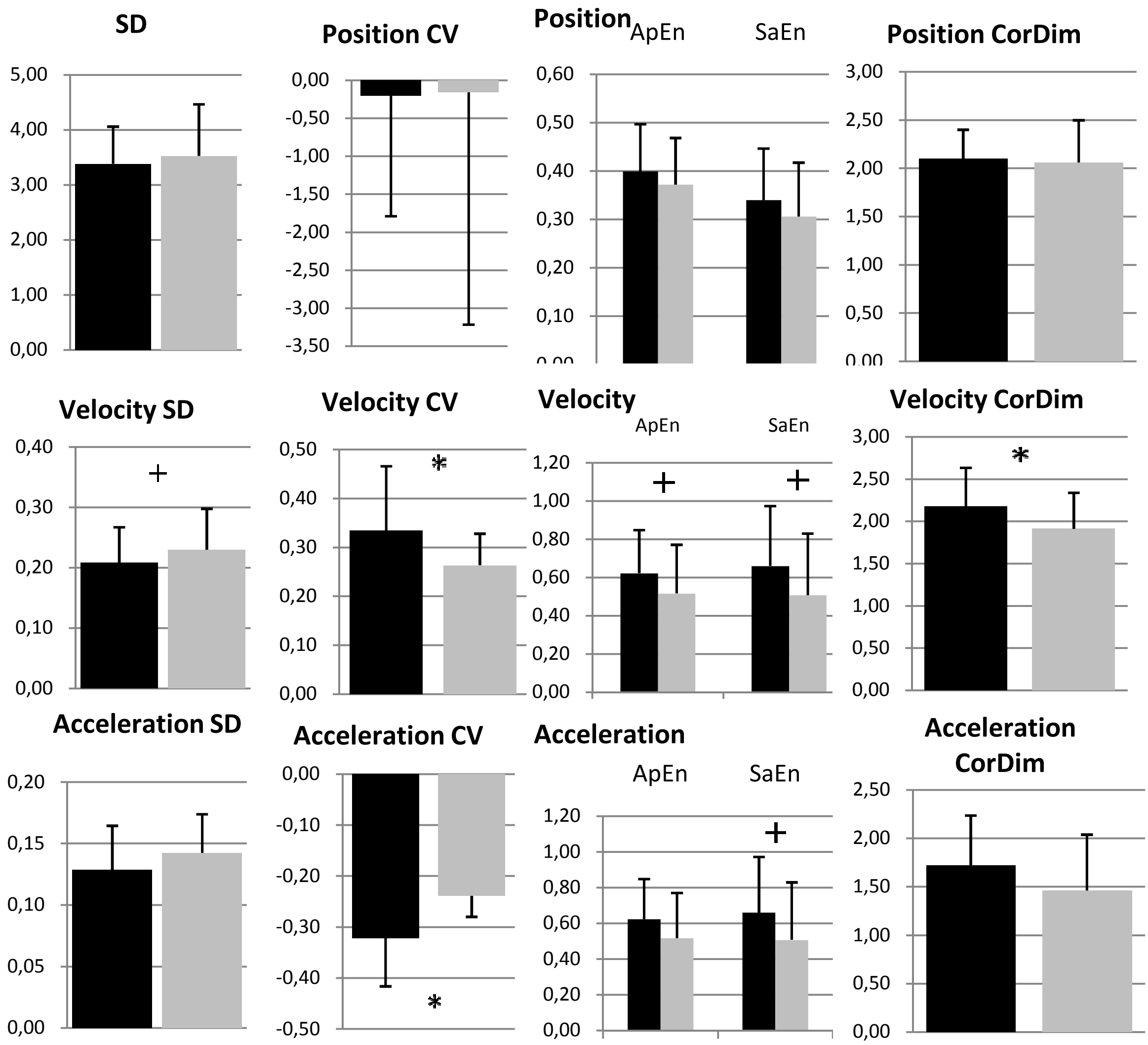


Figure 7: Statistical results for the study part on standard deviation (SD), coefficient of variation (CV), approximate entropy (ApEn), sample entropy (SaEn) and Correlation dimension (CorDim) of the head-shoulder displacement, velocity and acceleration ■ low experience ■ high experience **(*: P<0.05) (+: P<0.1)**

7.3.3 Elbow-Hip – displacement

In general, work experience revealed no differences with respect to work posture of the distance between elbow and hip (figure 8 and 9). However, in acceleration there was a significant effect on the peak to peak magnitude (figure 8) and on the value of the correlation dimension (figure 9) between the two experience levels (respectively, (F=4.11; P<0.05) and

(F=4.54; P<0.05), figure 6). The accelerations of the displacement of the elbow-hip positions were highest among the subjects with low experience. The value of the correlation dimension was also highest among the low experienced subjects.

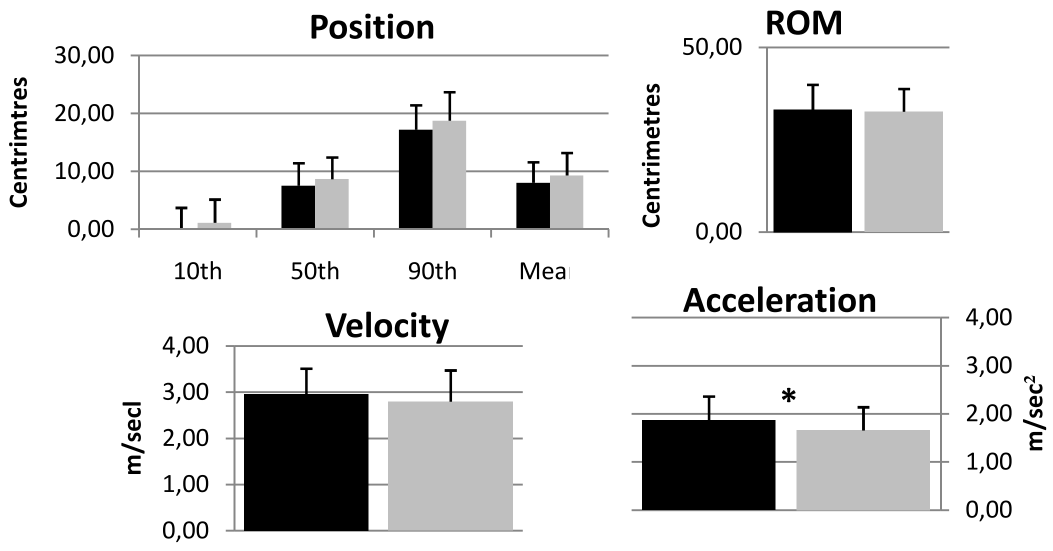


Figure 8: Effects of work experience on the 10th, 50th and 90th percentile, mean and range of the displacement between elbow and hip, velocity (peak to peak) and acceleration (peak to peak). ■ low experience ■ high experience (*: P<0.05)

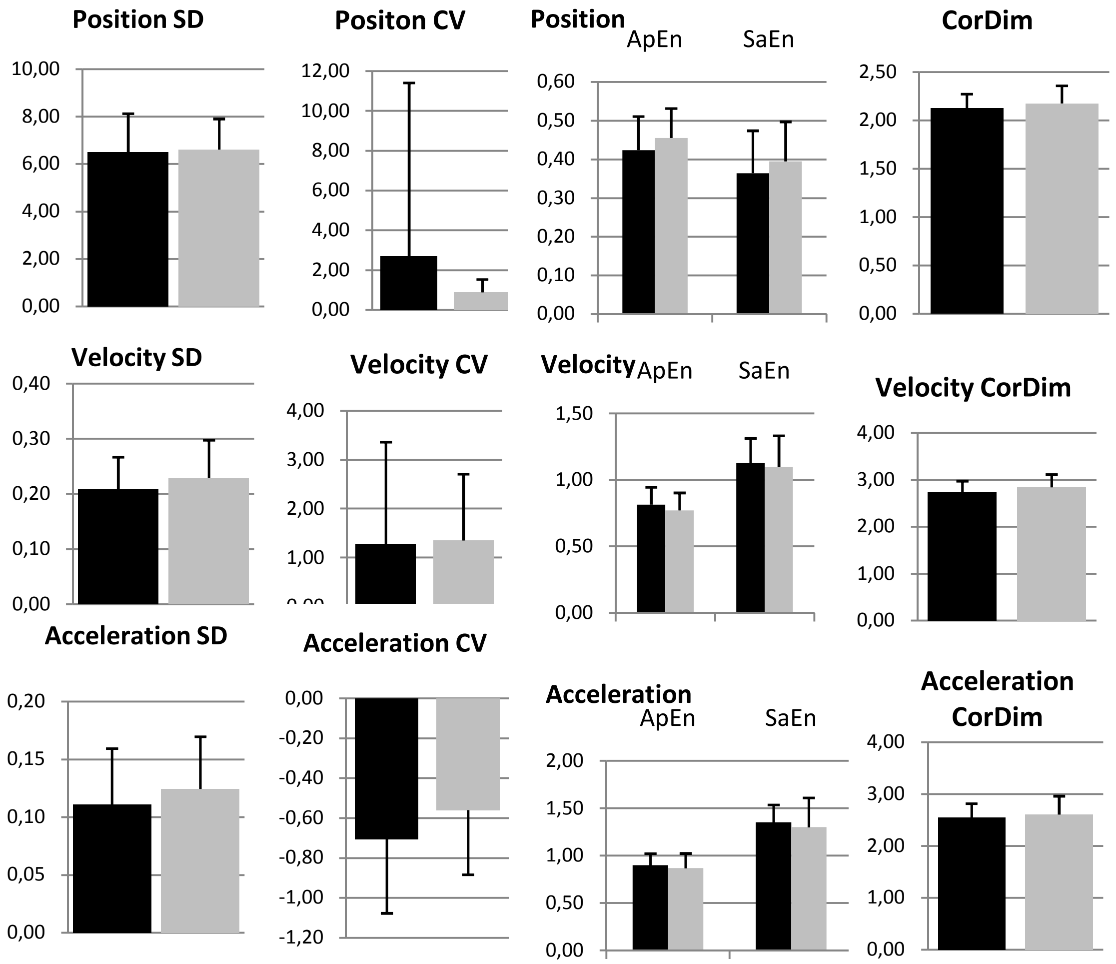


Figure 9: Statistical results for the study part on standard deviation (SD), coefficient of variation (CV), approximate entropy (ApEn), sample entropy (SaEn) and Correlation dimension (CorDim) of the shoulder-hip displacement, velocity and acceleration. ■ low experience ■ high experience (*: P<0.05)

7.4 Discomfort

7.4.1 Head-shoulder displacement

A main significant effect for discomfort in the displacement of the head-shoulder positions was found (figure 10); Mean (F= 5.93; P<0.05), 50th - (F= 7.05; P<0.05) and 90th percentile (F= 4.33; P<0.05). In addition there was also a significant trend of effect for discomfort in the 10th percentile (F= 3.03; P<0.1). The main effect revealed that the group of symptomatic workers had the greatest displacement away from the upright standing position compare to the asymptomatic workers.

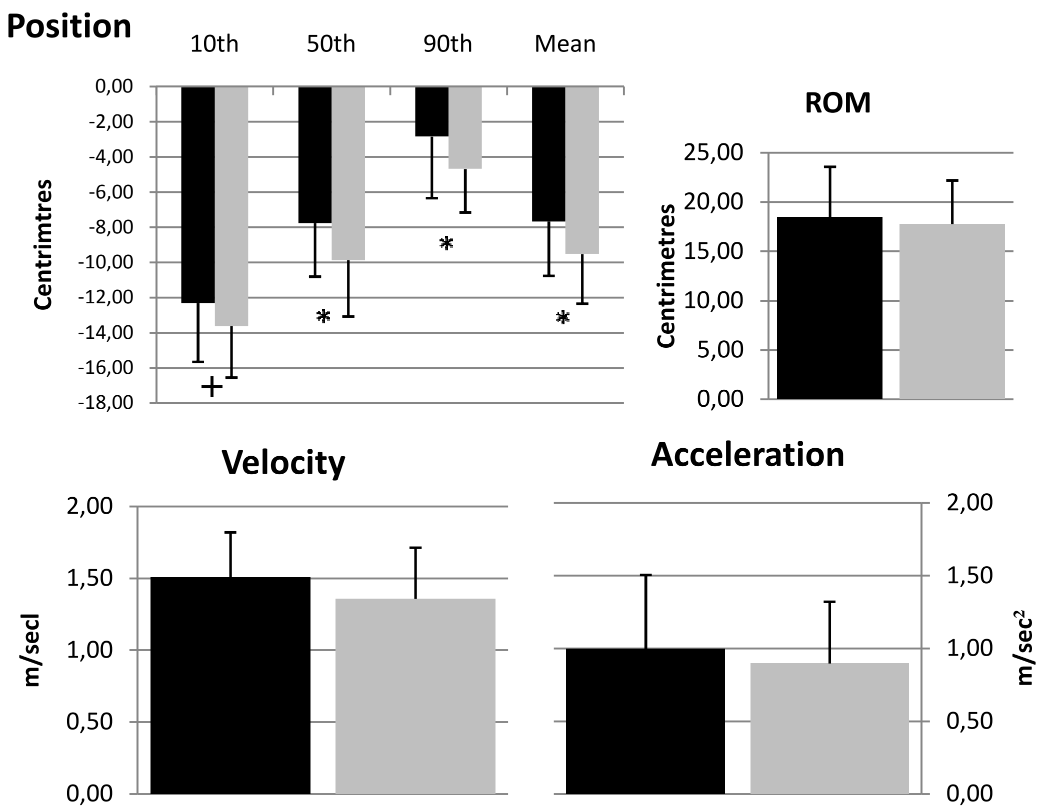


Figure 10: Effects of discomfort in the shoulder-neck region on the 10th, 50th and 90th percentile mean and range of the displacement between head and shoulder, velocity (peak to peak) and acceleration (peak to peak). Negative values in position denote a shortening in displacement from the upright position. ■ asymptomatic ■ symptomatic workers. (*: P<0.05) (+: P<0.1)

The results of discomfort in relation to variability of the head-shoulder displacement are presented in the extracted parameters in figure 11. In position, discomfort had a significant effect on values of the coefficient of variation and the correlation dimension (respectively, (F=4.94; P<0.05) and (F=12.15; P<0.05). The group of asymptomatic workers had the values of both the coefficient of variation and the correlation dimension.

In velocity, there was a trend towards an effect of discomfort on the values of the coefficient of variation (F=3.64; P<0.1), towards a higher mean value among the subjects with discomfort in the shoulder-neck region.

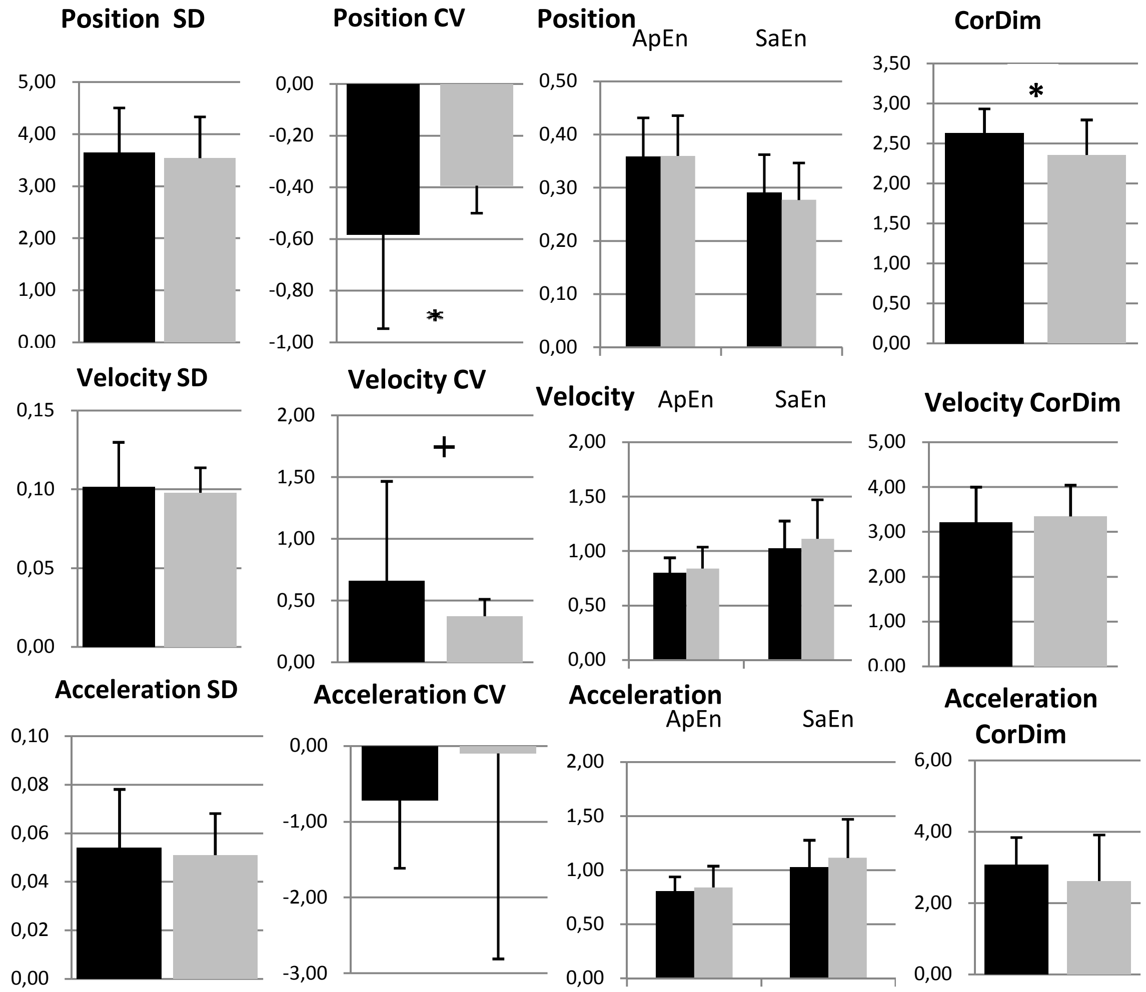


Figure 11: Statistical results for the study part of the effect of discomfort on standard deviation (SD), coefficient of variation (CV), approximate entropy (ApEn), sample entropy (SaEn) and Correlation dimension (CorDim) of the head-shoulder displacement, velocity and acceleration. ■ asymptomatic ■ symptomatic workers. (*: P<0.05) (+: P<0.1)

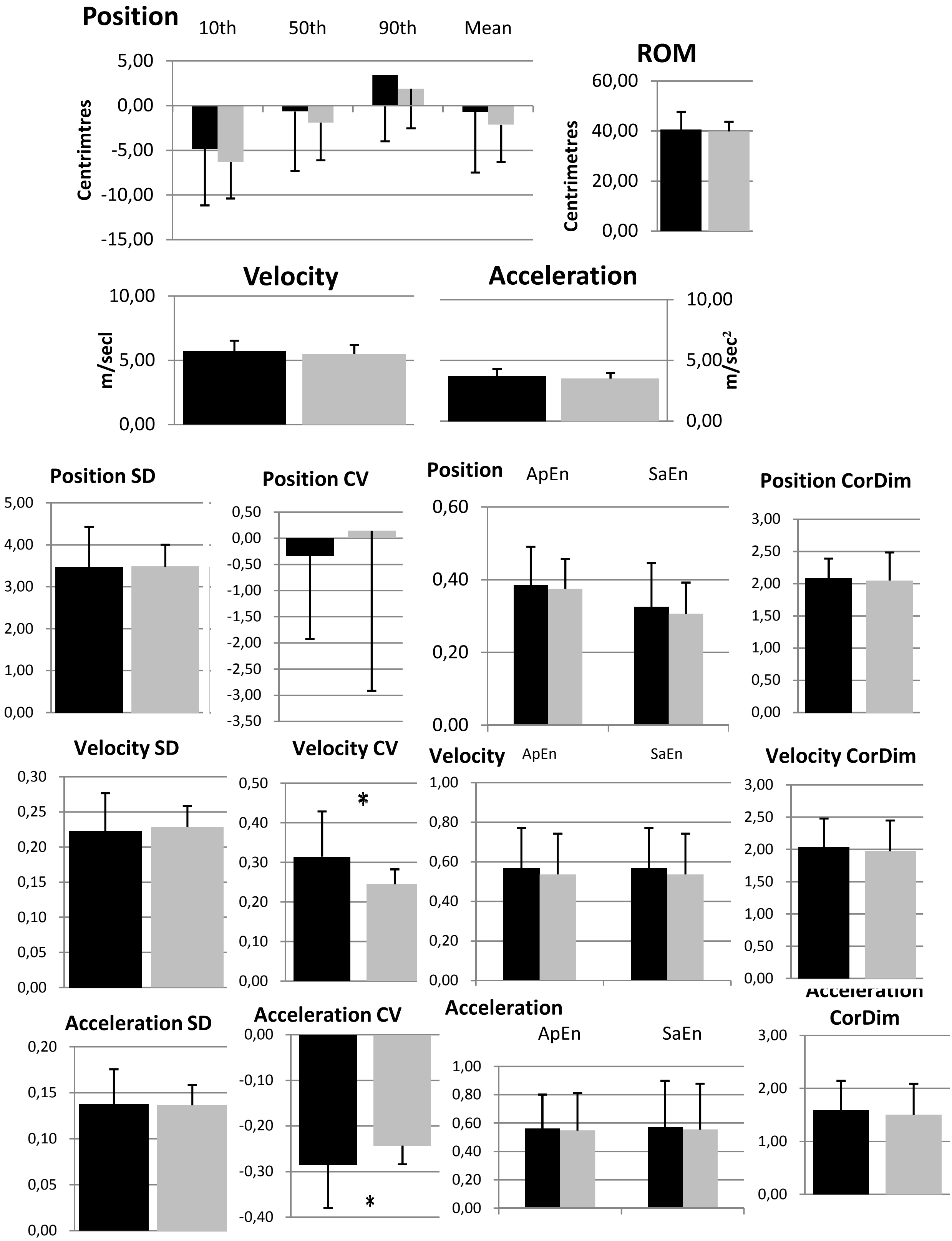
7.4.2 Shoulder- hip displacement

No differences were revealed of discomfort with respect to the displacement of the distance between shoulder and hip (figure 12 and 13).

In velocity and acceleration, a significant effect of discomfort on the values of the coefficient of variation was found (respectively, (F=8.96; P<0.05) and (F=6.08; P<0.05), figure 12).

The values of the coefficient were highest among the subjects with discomfort in the shoulder-neck region than in the asymptomatic group.

Figure 12: Effects of discomfort in the shoulder-neck region on the 10th, 50th and 90th percentile mean and range of the displacement between shoulder and hip, velocity (peak to peak) and acceleration (peak to peak). Negative values in position denote a shortening in displacement from the upright position. ■ asymptomatic ■ symptomatic workers (*: P<0.05) (+: P<0.1)


Position
10th
50th
90th
Mean
Centrimtres
5,00
0,00
-5,00
-10,00
-15,00
ROM
Centrimetres
60,00
40,00
20,00
0,00
Velocity
m/secl
10,00
5,00
0,00
Acceleration
m/sec2
10,00
5,00
0,00
Position SD
5,00
4,00
3,00
2,00
1,00
0,00
Position CV
0,50
0,00
-0,50
-1,00
-1,50
-2,00
-2,50
-3,00
-3,50
Position
ApEn
SaEn
0,60
0,40
0,20
0,00
Position CorDim
3,00
2,50
2,00
1,50
1,00
0,50
0,00
Velocity SD
0,30
0,25
0,20
0,15
0,10
0,05
0,00
Velocity CV
*
0,50
0,40
0,30
0,20
0,10
0,00
Velocity
ApEn
SaEn
1,00
0,80
0,60
0,40
0,20
0,00
Velocity CorDim
3,00
2,50
2,00
1,50
1,00
0,50
0,00
Acceleration SD
0,20
0,15
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0,00
Acceleration CV
0,00
-0,10
-0,20
-0,30
-0,40
*
Acceleration
ApEn
SaEn
1,00
0,80
0,60
0,40
0,20
0,00
Acceleration CorDim
3,00
2,00
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7.4.3 Elbow-hip displacement

No differences were revealed as an effect of discomfort on the extracted kinematic variables with respect to the displacement between elbow and hip (figure 14).

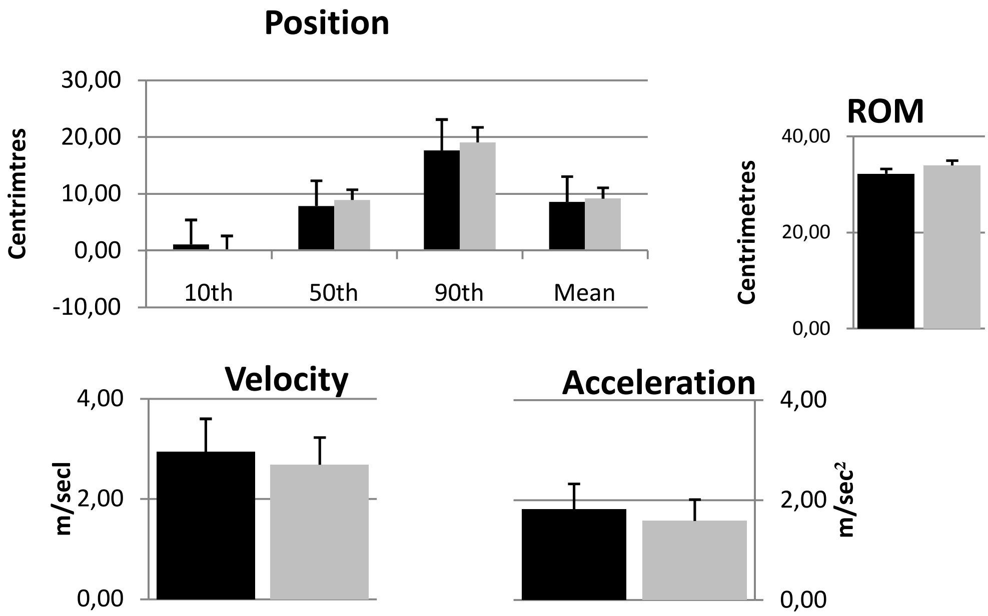


Figure 14: Effects of discomfort in the shoulder-neck region on the 10th, 50th and 90th percentile mean and range of the displacement between elbow and hip, velocity (peak to peak) and acceleration (peak to peak) ■ asymptomatic ■ symptomatic workers.

Motor variability in relation to the extracted parameters revealed a main significant effect of discomfort on the displacement between the shoulder and hip positions (figure 15); Standard deviation (F= 6.9; P<0.05), approximate entropy (F= 4.92; P<0.05) and sample entropy (F= 6.75; P<0.05). This main effect revealed that the group of symptomatic workers had the greatest values compare to the asymptomatic workers.

In velocity, a significant effect of discomfort was also found in the standard deviation ($F=10$; P<0.05). A trend towards higher values of sample entropy among the symptomatic subjects was also revealed ($F=3.86$; P<0.1).

In acceleration, a significant difference in the values of sample entropy was also found, revealing higher value for the group of symptomatic subjects. in ($F=6.75$; P<0.05).

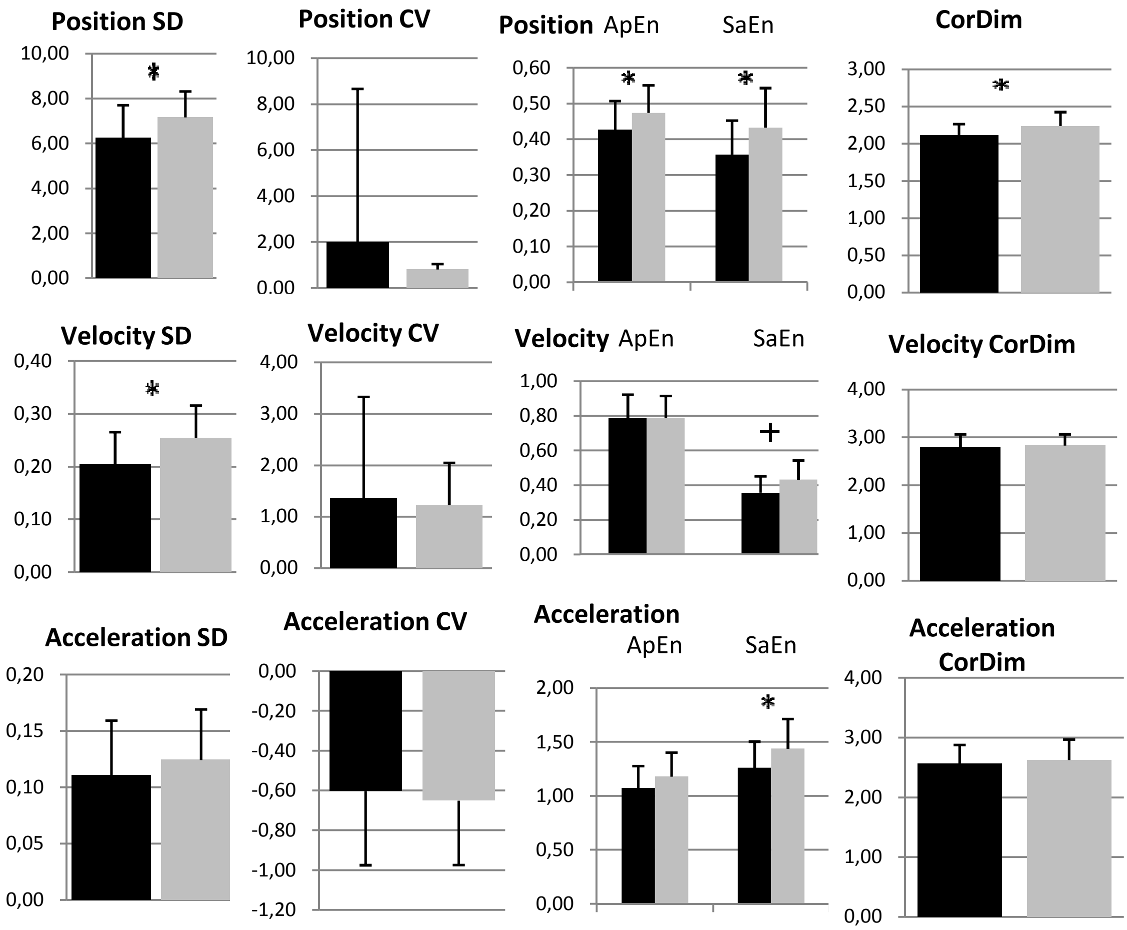


Figure 15: Statistical results for the study part of the effect of discomfort on standard deviation (SD), coefficient of variation (CV), approximate entropy (ApEn), sample entropy (SaEn) and Correlation dimension (CorDim) of the elbow-hip displacement, velocity and acceleration. ■ asymptomatic ■ symptomatic workers (*: P<0.05) (+: P<0.1)

Appendiks A: Forsøgsprotokol

Projektansvarlig: Tine Marie Toftgaard Madsen

Projektbeskrivelse

Projektet bygger på et feltstudie af arbejdsudførelsen blandt slagteriarbejdere der udbener forender i forenderaketten på Danish Crown i Sæby. Deltagerne udfylder desuden et spørgeskema og derigennem svarer på blandt andet på spørgsmål angående ømhed/ubehag i udvalgte kropsdele samt anciennitet.

Formålet med forsøget er at vurdere, om der kan ses en forskel i arbejdsudførelsen mellem deltagerne og om dette i så fald kan relateres til variabler som anciennitet og rapporterede lidelser

Baggrund

Der er mangel på praktisk industrispecifikke case studies, der tager udgangspunkt i konkrete arbejdssituationer samt risikofaktorer og som kan anvendes ved risikoforebyggelse indenfor slagteribranchen. Der er desuden få konkluderende videnskabelige studier, hvis undersøgelsesresultat kan overføres direkte til selve slagteribranchen. Gennemgangen af litteraturen omkring MSD i forbindelse med slagteriarbejde afslører, at langt de fleste undersøgelser af risikofaktorer ved slagteriarbejde er blevet foretaget i laboratorier, i stedet for ude på slagterierne og dermed uden indflydelse af andre arbejdsmæssige faktorer fra kontekst.

Ergonomiske rådgivere er vant til at stole på kvalitative estimater af eksponering baseret på validerede prøver og analytiske metoder der sammenlignes med retningslinier eller standardiserede regulativer. En evaluering af eksponeringen for MSD bliver således generelt kvalitativ og baseret på den enkelte observatørs skøn af tilstedeværelse af en eller flere generelle risikofaktorer. Kvantitative biomekaniske analyse af manuelt arbejde kan blandt andet føre til identifikation af de anvendte bevægemønstre under arbejde. Metoden vil kunne bruges til vurdere manuel udførelse af rutineopgaver og komme med konkrete kvantitative forslag til en mere sundhedsmæssig passende teknik.

Dette projekt er motiveret af den alvorlige effekt arbejdsbetingede lidelser har på slagteriarbejderes bevægeapparat og vil tage udgangspunkt i en kvantitativ kinematisk feltanalyse omkring udbeningsarbejde udført på et dansk svineslagteri.

Formål

Formål og problemstilling for det samlede projekt:

At beskrive udvalgte biomekaniske parametre under udbeningsarbejde med henblik på kvantitativt at kortlægge motorvariabiliteten i bevægelserne bag og relatere dem til anciennitet samt rapporterede lidelser omkring ubehag i knivførende overekstremitet.

Planlægning

Testdeltagerne skal udføre deres normale arbejde og derfor skal registreringen af kinematisk data foregå ved deres daglige arbejdsplads.

Før forsøget start vil mulige deltagere modtage information om forsøgets formål og omfang.

Testdeltagere skal melde sig frivilligt, men opfylde følgende inklusionskriterier:

- Arbejde i forenderaketten
- Højrehåndede personer

Der udføres pilotforsøg efter at de mulige deltagere er blevet informeret om forsøget og før den egentlige rekruttering og start på forsøget.

Deltagere

18 ud af de 58 slagteriarbejdere der udbener forender i forenderaketten på DC-Sæby indvilligede frivilligt i at deltage i studiet. Den normale arbejdstid for deltagerne er 40 timer pr. uge og alle har faste pauser hver 1½ time (tre pauser af 15 minutter og én pause af 30 minutter).

Metode

Forsøget foregår i selve forendeafdelingen, og deltagerne arbejder ved deres eget skærebord. Testdeltageren får påsat markører, som via videooptagelser skal anvendes til analyse af arbejdsbevægelser.

Det følgende er den punktvise procedure i forsøget:

1. Information til deltagerne om hvad der skal ske (først spørgeskema, så markørpåsætning og til sidst optagelse)
2. Spørgeskema udfyldes

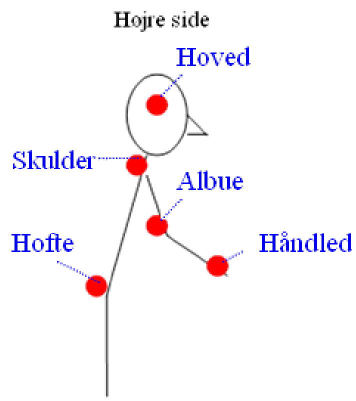
3. Markører placeres på forsøgsdeltageren (se markørplacering)
4. Deltageren genoptager sit arbejde
5. Tænd kamera og sikker at forsøgsdeltageren er i billedet samt at markørerne ikke bevæger sig uden for billedrammen under bearbejdningen af en forende.
6. Optagelse af arbejdet med minimum seks forender
7. Foretag referenceoptagelser (se referenceopstilling)
8. Check kvaliteten af optagelserne

Anvendt apparatur:

- Sony digitalt videokamera (Handycam DCR-DVD205E) med samplings rate på 25 Hz. Placeret på stativ.

Markørpåsætning

Placering af de anvendte markørerne var på udvalgte og relevante anatomiske punkter, der var palperbare på trods af deltagernes arbejdstøj. Markørerne fastgøres med elastik



Følgende fem punkter blev anvendt til markørplacering:

Hoved-højre (5cm over Art. temporomandibularis)

Acromion -højre

Lateral epicondyl - højre

Håndled -højre (distalt for processus styloideus radii)

Hofte-højre (SIAS – Spina Iliaca anterior superior)

Referenceposition

Deltagerne optages for hver vinkel (forfra og højre side) i en reference position, hvor de står og kigger lige frem og med afslappede arme (og håndled i neutralposition med tommelfingeren pegende anterior).