Motor strategies during meat cutting tasks in simulated and real environment

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Abstract. Butcher work often involves static and repetitive loads to the neck and shoulder that can lead to the development of work-related musculoskeletal disorders (WMSD). Motor strategies were assessed by recordings discomfort/pain intensity, work task timing, cutting forces, surface electromyographic and 3D kinematics in both laboratory and field settings. Novice butchers developing discomfort or shoulder pain are characterized by a motor strategy that can predispose them to develop WMSD. The motor strategies are changed in presence of discomfort and shoulder pain. These changes underlined the role of the known physical risk factors as well as the importance of motor variability.

Keywords. Musculoskeletal injuries, Motor control, Human performance.

1. Introduction

Work-related musculoskeletal disorders (WMSD) are caused by the complex interplay between physical, psychological and individual characteristics (Sjøgaard, G., Sejersted, O. M., Winkel, J., Smolander, J., Jørgensen, K., & Westgaard, R. H., 1995). Physical risk factors such as repetitive arm movements, vibrations, heavy work, work duration, insufficient rest and, static posture are known to play a role in the development of WMSD in the shoulder region (Madeleine, P., 2010; Sommerich, C. M., Mc Glothin, J., & Marras, W. S., 1993; da Costa, B. R. & Vieira, E. R., 2010). WMSD are generally accompanied by pain located in cartilage, tendons, ligaments and, muscles. Despite an increasing knowledge regarding the transduction, transmission and projection of deep pain; the patho-mechanisms governing the transition from pain free to pain stage are not well established (Madeleine, P., 2010). A way to gain knowledge about these disorders is to investigate motor control strategies among workers performing a certain motor task.

Butchers or slaughterhouse work is characterized by many physical risk factors potentially resulting in WMSD (Madeleine, P., Lundager, B., Voigt, M., & Arendt-Nielsen, L., 1999; Juul-Kristensen, B., Fallentin, N., Hansson, G.-Å., Madeleine, P., Andersen, JH, & Ekdal, C., 2002). Thus, the physiological and biomechanical responses recorded during butchers work can increase our understanding of why some workers develop WMSD while others do not. More specifically, motor variability has been suggested as an important determinant to the risk of developing WMSD (Madeleine, P., Lundager, B., Voigt, M., & Arendt-Nielsen, L., 2003a; Srinivasan, D. & Mathiassen, S. E., 2012; Cote, J. N., 2012).

The goal of this paper is to review the adopted motor strategies during butcher or deboning work in relation to le level of experience and the shoulder pain status. A special emphasis is given to motor variability.

2. Methods

2.1 Participants

Healthy unexperienced subjects, experienced butchers and butchers suffering from neck-shoulder pain participated in these studies. Twenty four butchers suffer from discomfort or chronic pain in the shoulder region and 12 healthy butchers constituted the control groups in the laboratory and field studies (Madeleine, P. & Madsen, T. M. T., 2009; Madeleine, P., Lundager, B., Voigt, M., & Arendt-Nielsen, L., 1999). Twenty inexperienced and six experienced butchers participated as well as 12 newly employed filetering butchers took part in the laboratory measurements (Madeleine, P., Voigt, M., & Mathiassen, S. E., 2008; Madeleine, P., Lundager, B., Voigt, M., & Arendt-Nielsen, L., 2003a). The level of experience ranged from no experience (novices) to approx. 13 years of experience. Acute shoulder pain (injection of hypertonic saline), sub-chronic (shoulder pain reported after 6 months work) and chronic (shoulder pain reported for a minimum 3 months within the last 2 months) shoulder pain status were investigated.

2.2 Work task

The observation of real work situations in fish and poultry industries led to the design of a work task simulating slaughterhouse processes in the laboratory (Madeleine, P., Lundager, B., Voigt, M., & Arendt-Nielsen, L., 1999). The work cycle was time-paced and consisted of five 1 s events in which the participant was asked to: (i) “take a filet - left hand”, (ii) “place it” on the workbench, (iii) “cut it - right hand”, (iv) “cut it - right hand” and, (v) “deliver the filet - left hand” for 3 or 5 min. Every second a tone generator was triggered to standardize the working rhythm. Furthermore, the level of cutting force was fed back to the experimenter. In the field study, the deboning task was performed in real conditions.

2.3 Recordings and analyses

In the laboratory studies (Madeleine, P., Lundager, B., Voigt, M., & Arendt-Nielsen, L., 1999; Madeleine, P., Lundager, B., Voigt, M., & Arendt-Nielsen, L., 2003b; Madeleine, P., Lundager, B., Voigt, M., & Arendt-Nielsen, L., 2003a; Madeleine, P., Voigt, M., & Mathiassen, S. E., 2008; Madeleine, P., Mathiassen, S. E., & Arendt-Nielsen, L., 2008), force sensing resistor devices (Toptronic, Echternach, Luxembourg) were used to record the onset/offset of the left hand movement (sampling frequency: 500 Hz). The duration of the events as well as the duration of the work cycle were computed for each cycle. A full bridge strain gauges knife was constructed and calibrated to estimate the force applied during the cutting phases (sampling frequency: 500 Hz). The applied force was approx. 30 N (visual feedback was provided). Bipolar EMG surface electrodes (Ambu A/S, Medicotest N-10-E, Ølstykke, Denmark) were aligned vertically (2 cm apart) on abraded ethanol-cleaned skin along the right deltoideus anterior and medius, infraspinatus and trapezius muscles. The surface electromyographic (EMG) signals were amplified 2000 times, band-pass filtered [10-400 Hz] and sampled at 1 kHz. The root mean square (RMS) values were computed for each muscle during active (events 3 and 4) and passive phases (event 2) of the work cycle. The EMG activation ratio was computed as the ratio between RMS values during active phases and passive phases. A motion analysis system (Mc Reflex, Qualysis A/S, Partille, Sweden) was used to record upper right arm and trunk movement in 3D (sampling frequency of 30 Hz). Three cameras acting as infrared illuminator and detector of passive markers were used to track triplets were attached on the upper back (torso) and the upper right arm. The 3D coordinates of each marker were low-pass filtered with a Butterworth filter (4^{th} order, $F_{cut\text{-}off}$: 3 Hz). The movements of the upper arm and the trunk were expressed in anatomical terms.

In the field study (Madeleine, P. & Madsen, T. M. T., 2009), video recordings were made using a digital video camera (sampling frequency: 25 Hz). Visible markers were placed on the right side of the head, the right shoulder, right elbow and the right hip. The relative motions of the markers in the vertical direction were calculated for head-shoulder, shoulder-hip and elbow-hip displacement.

The subject's starting position and the range of motion were computed in 3D for both the right arm and trunk movement for each work cycle (Madeleine, P., Lundager, B., Voigt, M., & Arendt-Nielsen, L., 1999). Linear parameters representing the size of variability (standard deviation) were computed (Madeleine, P., Voigt, M., & Mathiassen, S. E., 2008; Madeleine, P., Mathiassen, S. E., & Arendt-Nielsen, L., 2008). Nonlinear parameters (approximate and sample entropy as well as correlation dimension) were also computed to describe the structure of variability (Madeleine, P. & Madsen, T. M. T., 2009).

2.4 Statistics

Two-way, two-way repeated measures and three-way analysis of variance (ANOVA) with Student-Newman-Keuls (SNK) method for multiple comparisons were applied. $P<0.05$ was considered significant.

3. Results

3.1 *Effects of working experience*

In terms of work cycle timing, longer duration and smaller size of variability characterized the novice butchers compared with the experienced butchers ($P<0.05$). The novice butchers exhibited higher level of EMG activity, more static activation pattern and higher size of variability in EMG ratio compared with the experienced butchers ($P<0.05$). Further, smaller initial posture of the arm, smaller range of motion and size of variability of the arm and trunk movement characterized the novice butchers compared with the experienced butchers ($P<0.05$).

The duration and the size of variability of the work cycle were both larger and smaller with increasing level of experience ($P<0.05$). Butchers with moderate experience adopted more elevated and variable initial posture of the arm, smaller range of motion for arm and trunk as well as, smaller/larger size of variability and larger sample entropy values for the arm and trunk movement ($P<0.05$).

3.2 Effects of neck-shoulder pain

In acute shoulder pain conditions compared with pain free conditions, the work cycle was shorter in duration and more variable (size of variability, $P<0.05$). The cutting force tended to decrease. The level of EMG activity decreased in the painful muscles ($P<0.05$). Larger initial posture of the trunk, larger range of motion of the arm and trunk as well as larger size of variability for the arm and trunk movement were measured ($P<0.05$).

In presence of sub-chronic shoulder pain compared with no pain (control group), the work cycle was longer in duration ($P<0.05$) and tended to be less variable (size of variability). The cutting force decreased ($P<0.05$). The ratio of EMG activity (active vs. passive phases) decreased ($P<0.05$) and tended to have smaller size of variability. Larger initial posture of the trunk, smaller/larger range of motion of the arm/trunk as well as smaller size of variability and sample entropy for the arm and trunk movement were measured ($P<0.05$).

In presence of chronic shoulder pain compared with no pain (control group), the work cycle was shorter in duration and more variable (size of variability, $P<0.05$). The pattern of EMG activation was more static and the size of variability of the activation ratio smaller

($P<0.05$). Larger initial posture of the arm, larger range of motion of the arm and trunk as well as smaller size of variability for the arm and trunk movement were found ($P<0.05$).

4. Discussion and Conclusion

The series of experiments conducted in both laboratory and field environment is somehow unique. The recorded data based on cross-sectional and prospective studies has enabled to benchmark the effects of experience and pain status (i.e. acute, sub-chronic and, chronic pain) on motor strategies during butcher and deboning work. Further, both the size and structure of motor variability were assessed for the first time in relation to an occupational task.

An increased sensitivity to pressure pain is considered as a possible prognostic factor for WMSD development. Butchers with chronic shoulder pain and butchers that developed shoulder pain after six months work have lower pressure pain threshold than controls (Madeleine, P., Lundager, B., Voigt, M., & Arendt-Nielsen, L., 1998; Madeleine, P., Lundager, B., Voigt, M., & Arendt-Nielsen, L., 2003b). Butcher or deboning work can lead to generalized muscle hyperalgesia expanding to both sides of the upper body. The assessment of motor strategies offers the possibility to extract objective parameters susceptible to provide new information about the physical risk factors linking to WMSD. The novice butchers were characterized by longer work cycle and smaller of variability of the work cycle compared with experienced butchers. Moreover, higher level of EMG activity, more static EMG activation and, higher size of variability in EMG ratio were found in novice butchers compared with experienced butchers. These changes highlight that muscle synergies are changing as a function of work experience. Moreover, the increased EMG activity and the more static activation pattern are known physical risk factors that play a role in the development of WMSD (Veiersted, K. B., Westgaard, R. H., & Andersen, P., 1993). The initial position of the arm, the range of motion and the size of variability of the arm and trunk movement were smaller among the novice butchers compared with experienced butchers. This cannot be seen as a favorable trait as more dynamic and variable motor strategy, i.e. increased range of motion and larger variability are associated with lower risk of WMSD development (Kilbom, A. & Persson, J., 1987). At moderate level of experience, both increased and decreased are respectively found in the work cycle duration and the size of variability of the work cycle. Similarly, both larger and smaller size of variability and larger sample entropy values were found for arm and trunk movement. These different motor strategies have most likely functional implications since pain-free experienced butchers seem to have implemented a specific pattern of motor coordination protecting them from WMSD.

The work cycle duration is shorter in acute and chronic shoulder pain conditions compared with no pain underlining that spinal/suprasinal mechanisms may mediate the spreading of pain to the contralateral side through, e.g. reflex mediated pathways. The cutting force tended to decrease in presence of acute pain and was decreased for workers with sub-chronic shoulder pain. This decrease in force most likely represents a protective response towards the ongoing pain (Madeleine, P., Lundager, B., Voigt, M., & Arendt-Nielsen, L., 1999). The level of EMG activity decreased in presence of acute shoulder pain. This can also been seen as a protective adaptation. On the contrary, in butchers suffering from chronic pain, the EMG activation pattern was more static compared with pain-free butchers. Furthermore, the ratio of EMG activity, i.e., ratio between active and passive phases of the work cycle, was less variable confirming a lack of relative changes in EMG amplitude at sub-chronic and chronic stages. The results suggest a dynamic reorganization of the EMG activity as a function of the pain stages. In presence of experimental pain, the

initial posture and the movement of the arm and trunk decreased compared pain free conditions confirming the presence of protective mechanisms in acute pain conditions. Moreover, large size of variability for the arm and trunk movement are found suggesting that the central nervous system engages and tests different biomechanical solutions taking the nociceptive influx in consideration (Madeleine, P., 2010). On the contrary, in sub-chronic and chronic shoulder pain conditions, smaller size and structure of variability for the arm and trunk movement suggest that the adopted motor strategies do not take benefit from the abundance of degree of freedom (Latash, M. L. & Anson, J. G., 2006) suggesting a less flexible motor repertoire.

In conclusion, these series of studies underline the complex interactions between the level of experience, shoulder pain and motor control. The known physical risk factors, i.e. repetitiveness, force level, EMG activity pattern and amplitude, body posture and movement are good descriptors of butcher or deboning work. Moreover, novel genuine information on the importance of motor variability in relation to the development or not of WMSD is revealed. The present studies contribute further to the understanding of the motor adaptations and pain status transition from pain-free workers to workers with chronic shoulder pain.

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