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Biomechanical requirements of meat cutting tasks: an overview

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1. Introduction

Butchering (meat cutting, deboning) tasks are repetitive, strenuous, and quasi-static at wrist. Meat industry employees are particularly prone to work-related musculoskeletal disorders (WMSD) (Åkesson & Nordander 2012). Wrist and Hand WMSD represent about 50% of the WMSD declarations for these workers. Several attempts were made to assist the users in their tasks and reduce their physical exposure, particularly by developing assistive exoskeletons (Pontonnier et al. 2021) or cobots (Maithani et al. 2021), delivering an assistive force to the user during the task execution. However, such systems raise numerous issues to be efficient, such as their control or adaptability to the user. At first, it is fundamental to investigate the task in terms of biomechanical requirements to specify the assistance level of the system. The following abstract presents preliminary results of an in-depth biomechanical characterization of meat cutting tasks.

2. Methods

2.1 Data collection

Six professional (industry) butchers took part of the experiments, validated by the national INRIA ethics committee (COERLE, n° 2021-07). They were professional meat cutters or deboners with experience ranging from 5 to 32 years. The subjects performed meat cutting tasks for 3 different types of meat, depending on their expertise. Subjects 1 and 2 prepared pork belly parts, subjects 3 and 4 prepared pork ribs, and subjects 5 and 6 prepared pork shoulders. The task consisted in five replications of the regular task they were doing at work with a sharpened knife and a worktable. During the trial, motion of the subject was captured with an optoelectronic motion capture system (Qualisys, QTM software, 22 cameras, 200Hz), following the ISB recommendations. Ground reaction forces at 2000Hz were recorded using two force plates (AMTI Gen 5) synchronized with QTM. Knife force at 500 Hz was recorded using an instrumented knife with a 6dof force sensor (ATI Mini45-E Transducer). The system also recorded at 2000Hz the synchronization signal coming from Qualisys. The knife sensor was wired to a portable, battery-powered wireless transmitter. Table force at 1000Hz was recorded using an instrumented worktable with a 6dof force sensor (HBM MCS10-005-6C). The system (HBM

CatmanEasy AP 5.3.1.27) sampled at 1000 Hz the synchronization signal coming from Qualisys. Subjects additionally performed maximal isometric exertion in neutral position to assess their Flexion FL, Extension EX, Radial Deviation RD and Ulnar Deviation UD maximal strength (Con-Trex MJ® isokinetic dynamometer, CMV AG, Dübendorf, Switzerland).

2.2 Data analysis

Motion capture and force data were prepared to be applied to a whole-body biomechanical model in CusToM (Muller et al. 2019) as represented in Figure 1. Inverse kinematics and dynamics were performed on all trials to compute wrist FL, EX, RD and UD torques during the tasks.

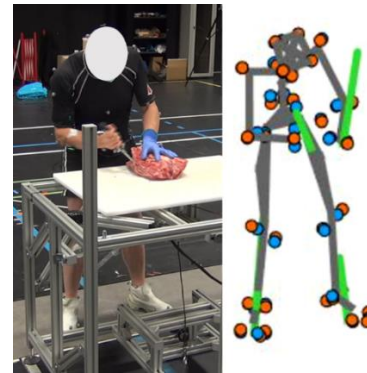


Figure 1 A subject performing the experiments and the corresponding biomechanical model in CusToM

For all trials, peak and mean torques per cutting task and motion type (FL, EX, RD and UD) were evaluated. Further, cutting events were isolated by considering part of the trials with cutting force greater than 5N. For these cutting events, wrist torques were extracted regarding the wrist position. The torques were normalized to the maximal strength per subject extrapolated using the Torque Angle Velocity envelope from Xia & Law 2015 and scaled according to the isometric maximal strength at 0 degree of each subject.

3. Results and discussion

Figure 2 shows the results of the cutting events isolation and torque normalization per event with regard to the wrist position in UD and the percentage of time passed in this posture during the trial for subject 4. Such a graph identified the highest solicitations to be associated with high RD/UD angles (about 13% at -35° of RD). This information is particularly relevant since it assessed the cutting mechanisms and its potential effect on the worker. In addition to that, we observed that most of the cutting tasks were performed with a static posture, maintaining the wrist in RD while applying a high force in the opposite direction (UD torque). However, a few cutting tasks were performed with the wrist in UD, which corresponded to a change in knife grip. Subjects

3-6 used both forward (hammer) and reverse (dagger) knife grips, resulting in different posture and torque requirements. An assistive device should be able to provide its maximal assistance at these angular values and allow the subject to change the grip of the knife. Table 1 shows the results gathered for all subjects. We can see that subject 1, 3 and 4 exhibited particularly high UD strength, which seems logical since their action is mostly done in this direction. More generally, the subjects exhibited high strength values with regard to Xia & Law 2015. This was expected since their work clearly asks to develop such a strength.

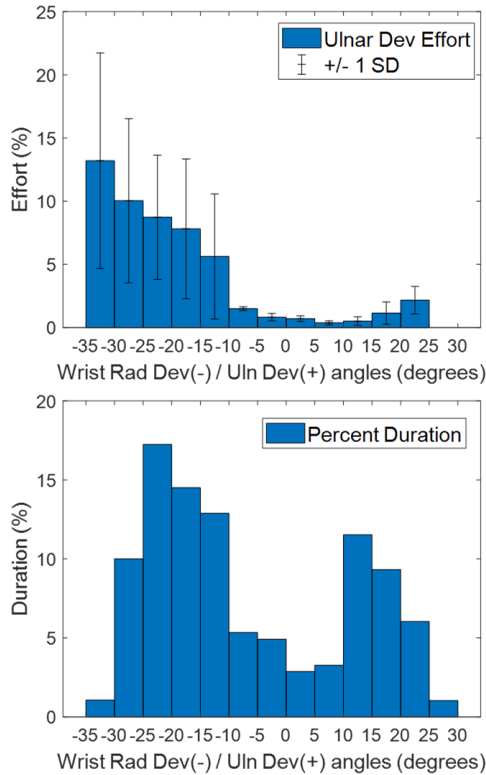


Figure 2 UD effort requirements regarding the wrist RD/UD position for subject 4.

We are currently developing more advanced approaches to generalize these results to the real working conditions, considering cadencies and other environmental factors to better represent the task and its biomechanical implication. Studying deeply the task to assist should be a key step in the design of assistive devices in the future, making it more efficient and faster than classical trial and error approaches.

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| Subject | Exp . | Task | Isometric Wrist Strength at 0° (Nm) | | | | Mean (SD) TT (Nm) | | | | Maximum (SD) TT (Nm) | | | |
|---------|-------|-------------------|-------------------------------------|------|------|------|-------------------|-----------|-----------|-----------|----------------------|-----------|-----------|-----------|
| | | | FL | EX | RD | UD | FL | EX | RD | UD | FL | EX | RD | UD |
| S1 | 27 | Pork Belly Side 1 | 21.6 | 10.2 | 16.0 | 23.4 | 2.4 (1.9) | 0.2 (0.2) | 1.2 (1.2) | 0.6 (0.7) | 8.4 (1.4) | 1.8 (0.5) | 6.8 (1.4) | 4.2 (2.5) |
| S2 | 21 | Pork Belly Side 2 | 20.6 | 19.8 | 18.4 | 15.8 | 2.1 (1.7) | 0.2 (0.2) | 1.2 (1.1) | 0.7 (0.8) | 9.9 (1.2) | 1.2 (0.4) | 6.5 (1.3) | 3.4 (1.1) |
| S3 | 27 | Pork Spare Rib | 28.4 | 13.9 | 18.0 | 25.4 | 2.1 (1.8) | 0.3 (0.3) | 2.1 (2.1) | 1.9 (1.8) | 8.0 (0.5) | 1.6 (0.1) | 8.3 (0.9) | 6.6 (0.6) |
| S4 | 11 | Pork Spare Rib | 31.6 | 16.0 | 26.1 | 21.6 | 1.0 (1.3) | 0.5 (0.5) | 0.8 (0.9) | 1.6 (1.3) | 5.7 (1.4) | 2.9 (0.5) | 4.1 (1.1) | 5.5 (0.4) |
| S5 | 32 | Pork Shoulder | 19.4 | 9.4 | 9.2 | 14.8 | 2.0 (2.1) | 0.2 (0.3) | 0.2 (0.3) | 2.3 (2.0) | 9.6 (1.3) | 1.6 (1.2) | 1.4 (1.0) | 9.7 (0.7) |
| S6 | 5 | Pork Shoulder | 18.7 | 11.3 | 11.7 | 13.1 | 1.7 (1.7) | 0.4 (0.7) | 0.3 (0.4) | 1.9 (1.8) | 8.3 (1.2) | 5.1 (0.6) | 4.0 (1.0) | 8.4 (0.7) |

Table 1 Subjects experience, trial type, maximal strength and required task torques (TT) during trial