Effect of mass addition on upper limb joint torques during meat cutting tasks: a parametric study

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1. Introduction

Musculoskeletal disorders (MSDs) are a major public health issue. In the meat processing industry, elbow and hand MSDs are over-represented, neck and shoulder MSDs prevalence still being high (Nordander et al. 2009). To mitigate the exposure to physical risk factors of MSDs, especially to forceful exertions, the use of a wrist exoskeleton delivering an assistive force to the user during the task performance can be considered (Chander et al. 2022). During the development process of wrist exoskeletons, the risk of increasing physical load by the addition of a given mass, depending on its position on the forearm, arose. To investigate this effect in biomechanical terms, the intensity of the user-generated torques associated with the exertion *versus* rest duration can be used (Potvin 2012). The goal of the study was to identify, based on these criteria, areas of maximum increase in joint torques of a mass added to the forearm, during a real meat cutting task.

2. Methods

2.1 Data collection

A previous dataset, described by Chander et al. (2022), was reused. A meat cutting task consisting in pork belly deboning was performed by a professional butcher (INRIA ethics committee COERLE, n° 2021-07). The butcher's motion was recorded with an optoelectronic motion capture system (Qualisys, 200Hz). Knife and table forces were recorded using 6 degree of freedom (dof) force sensors (ATI Mini45-E Transducer, 500 Hz, and HBM MCS10-005-6C, 1000Hz, respectively).

2.2 Joint torques computation

The cutting task was defined as the part of the trial with a cutting force intensity higher than 3N. A biomechanical model of the upper limb (3 segments, 7 dofs) was designed in CusToM (Muller et al. 2019), following the International society of biomechanics recommendations, and using body segment inertial parameters of Dumas et al. (2007) scaled to the participant. This baseline biomechanical model was modified to provide a range of models integrating a 0.5kg additional point mass at successive locations on the forearm, to simulate the mass of an exoskeleton and realistic positions of its center-of-mass. Three parameters were combined: distance along the forearm $\vec{Y}$ longitudinal axis (n=2), distance from this axis (n=3), angular position on the transversal plane (n=8), for a total of 34 locations (Figure 1). Inverse kinematics and dynamics were computed, under the assumption of unmodified task performance, in terms of upper limb kinematics and external forces.

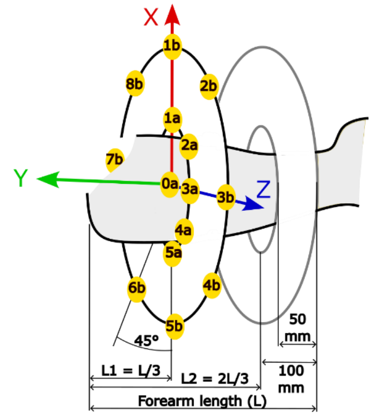

Figure 1. Positions of the additional mass on the forearm. Related model names (in yellow) on the proximal transversal plane (black circles).

2.3 Postprocessing

Peak torques were computed, for each dof, as the 97.5 and 2.5 percentile of torque distributions across time, to prevent measurement artifacts exceeding 2 standard deviations from the mean. The peak torque variations were computed as $(\tau_{i,a,j} - \tau_{i,b})/\tau_{i,b}$, *i* being the different dofs, *a,j* the different altered models, and *b* the baseline model. The duty cycle (DC) was computed as the percentage of frames exhibiting positive torques (e.g., elbow flexion) or negative torques (e.g., elbow extension). Differences between the baseline model ($DC_{i,b}$) and each altered model ($DC_{i,a,j}$) were computed as ($DC_{i,a,j}$ - $DC_{i,b}$). As internal/external rotation of the arm can hardly be interpreted clinically, this result is not reported.

3. Results and discussion

3.1 Effects of mass location

Areas of maximum increase in joint torques were identified. Firstly, peripherical positionings resulted in larger joint torques than positioning close to the longitudinal forearm axis, for shoulder elevation, elbow flexion and, in case of distal positioning, for shoulder elevation plane (-). Secondly, proximal ulnar positionings resulted in larger joint torques than proximal radial ones, for shoulder elevation plane (-), shoulder elevation and pronation (Figure 2). Maximum joint torques were increased at most by 38.3%, 38.0%, and 23.0% for supination, pronation, and shoulder elevation plane (-), respectively (Table 1). The associated DC were increased by 12.3%, 36.9%, 6.0%, respectively. This increase of torques, especially when combined with increased exposition durations (Potvin 2012), seems large enough to increase the risk of forearm and shoulder MSDs, which is already high among butchers (Nordander et al. 2009).

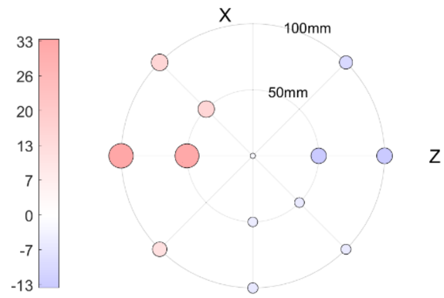

Figure 2. Pronation peak torque variations (%) for different proximal mass locations

3.2 Limitations

Firstly, kinematics was assumed to be unmodified; in real life, kinematics might be influenced by a mass addition (Latash et al., 2016). Secondly, the forearm diameter varies depending on people anthropometry and along the longitudinal forearm axis, which will influence the position of an exoskeleton; this should be accounted for accurate prediction of the effect of a specific exoskeleton. Finally, as high inter-personal and inter-task kinematics variability has been reported during meat cutting tasks (Chander et al. 2022), more kinematics records should be analyzed to conclude about the best mass positioning. Moreover, an active exoskeleton is expected to induce motion adaptations that were not considered in the current study.

4. Conclusions

The effect of diverse mass positions on upper limb joint torques was assessed, by virtually adding a 0.5kg mass at different locations on a butcher's forearm, during a real meat cutting task. Proximal ulnar, along with peripherical positionings, increased multiple joint torques. Pronation torques were particularly affected by the choice of the additional mass positioning, in terms of peak torques and exposure duration. Consequently, the efficiency of an exoskeleton can probably be compromised by poor center of mass location, even for relatively light exoskeletons. Inertial parameters must be considered when developing an exoskeleton.

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	Baseline model		Maximum effect of mass addition		
	Duty cycle (%)	Peak torque (N.m)	Peak torque variation (%)	Model name	Difference in duty cycle (%)
Shoulder plane of elevation +/-	61.8 / 38.2	18.4 / -4.2	1.0 / -23.0	5bL1 / 5bL2	0.2 / 6.0
Shoulder depression / elevation	44.5 / 55.5	15.1 / -9.5	5.6 / -13.1	7bL2 / 5bL2	-3.0 / 4.0
Elbow flexion / extension	85.0 / 15.0	16.7 / -7.4	6.1 / -0.0	7bL1 / 2aL1	1.7 / 0.0
Pronation / supination	32.3 / 67.7	1.5 / -1.4	38.0 / -38.3	1bL2 / 5aL1	36.9 / 12.3

Table 1. Maximum effect of mass addition, in terms of joint torque increase: magnitude, mass position, and associated effect on exposure duration