Evaluating the action detection of an active exoskeleton: a muscle-control synchronicity approach for meat cutting assistance

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1. Introduction

Butchering industry is a sector heavily impacted by work-related musculoskeletal disorders (WMSD), in particular meat cutting workers. Cutting and deboning meat pieces ask for precise, repetitive, and strenuous actions that cannot be automatized. These actions lead to particularly high demands in terms of wrist exertion, corroborated by the high prevalence of wrist WMSD for these workers (Arvidsson et al. 2012). Therefore, developing assistive devices (exoskeletons) able to reduce the biomechanical constraints suffered at the wrist is of primary importance. The evaluation of the benefits and drawbacks of this assistance asks to investigate the human-system interaction. The interaction of the exoskeleton with the worker raises many issues such as joint misalignment, force transfer, control design… To detect properly the action of the human is a keystone to assist the user efficiently. This pilot study aims at evaluating the action detection of a wrist exoskeleton prototype, by investigating the synchronicity of action of both the user and the device during controlled tasks. Additionally, the study explores the impact of the exoskeleton on range of motions and muscle activity during the execution of those tasks.

2. Methods

2.1 Wrist exoskeleton

The exoskeleton is a patented wrist exoskeleton prototype called Exoscarne (Alric & Peyron 2020), composed of two articulated shells fitting respectively the hand and the forearm of the subject. The system assists radio-ulnar deviation (RUD) and wrist flexion/extension (WFE) through two pairs of antagonistic artificial muscles (Festo E.U.R.L., Esslingen am Neckar, Germany) developing a maximal force of 150N under 6 bars pressure. Their rest diameter and length are 5mm and 210mm respectively. The action of the user is detected through two piezo-resistive pressure sensors placed on the dorsal side of the hand for WFE detection, and on the medial side of the second metacarpal bone for RUD detection The measured action between the user and the exoskeleton regulates the pressure inside the artificial muscles with an incremental control scheme implemented in a microcontroller (Arduino Mega). A calibration phase loads the sensors to a medium value and any shift from this value generates a pressure shift in the corresponding pair of muscles. A portable compressor provides 6 bar compressed air to the system. The study is focused on the second pair of muscles (M3 and M4), supposedly assisting RUD.

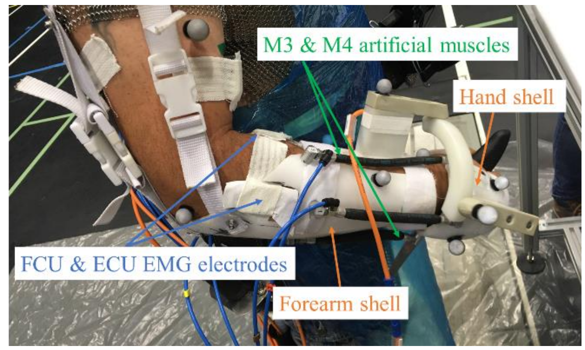

Figure 1 Exoskeleton equipped on the subject, and electromyography details.

2.2 Data collection & analysis

A subject (meat cutter expert, 1.72m, 80kg) was asked to perform standardized lifting tasks corresponding to wrist RUD under different loads (0-2-4kg in ulnar deviation, 0-4-8kg in radial deviation, 5 times per condition). The protocol was repeated with and without the exoskeleton for comparison. Motion of the subject was captured with an optoelectronic motion capture system (Qualisys, 22 cameras, 200Hz), following the ISB recommendations and a customized marker set for the exoskeleton. Electromyography (EMG) electrodes were placed on wrist muscles (Flexor and Extensor Carpi Ulnaris (FCU, ECU), Delsys Trigno, 2000 Hz). FCU and ECU are antagonists in WFE and synergistic in RUD (ulnar deviators). Finally, exoskeleton state data (pressure measured inside the artificial muscles) was synchronously recorded with the other quantities (National Instrument cDAQ 9185, 2000 Hz). WFE and RUD ranges of motion (RoM) were computed using the CusToM library (Muller et al. 2019) and compared with and without the exoskeleton for all trials. FCU and ECU mean activations, previously detrended and RMS-processed (200ms), were compared as well during all the trials. Muscle-control exoskeleton synchronicity was evaluated using cross-correlation between the pressure measured in M3 and M4, and FCU, ECU, and RUD signals.

3. Results and discussion

Figure 2 (a) shows that the RoM of the subject was drastically reduced with the exoskeleton, especially in radial deviation, meaning that the motion was disturbed by the device. It can be explained by the fact that WFE largely helped the subject to perform RUD without the exoskeleton, whereas this motion was hampered with the exoskeleton. This observation makes the comparison between both conditions subject to caution.

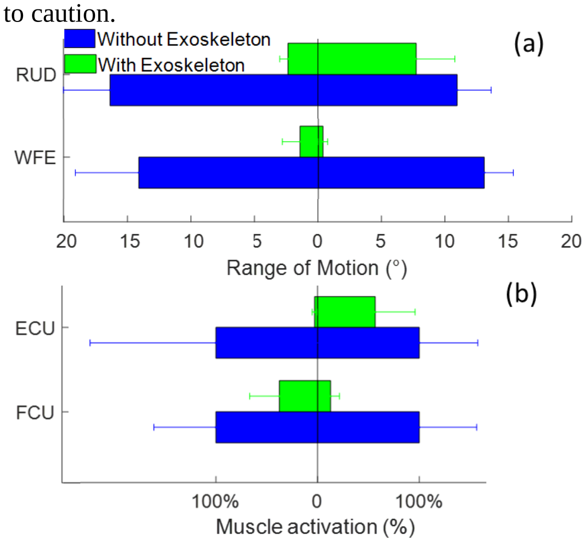

Figure 2 (a) Mean RUD and WFE RoMS during radial (left) and ulnar (right) deviation motions, with and without assistance. (b) Mean ECU and FCU activations during radial (left) and ulnar (right) deviation motions, with and without assistance. Results were normalized by means without assistance.

Figure 2 (b) demonstrates that the exoskeleton diminished the action of the ECU and FCU. Figure 3 illustrates part of a sample trial, showing the synchronization between muscle, joint angles, and control during a radial deviation trial. As illustrated, we can see a strong synchronicity between RUD and M4 (supposedly assisting radial deviation). FCU and ECU are out of phase with M3 and M4. Analyzing more in detail the synchronicity results (table 1), we can see that the motion was fairly synchronized with the control during both actions, whereas muscle actions were not efficiently assisted. These results indicate that the action detection was properly detected by the piezo-resistive sensor, but the assistance (2 pairs of artificial muscles acting respectively and independently on RUD and WFE) was not well adapted to the strong coupling in actuation between those joints. Such a result is of primary importance to design the assistance: even if muscles activation seemed less important with the assistance, the synchronicity highlighted the need of a coupled actuation and control (with an architecture close to the anatomical one to preserve RoMs) to assist both degrees of freedom efficiently.

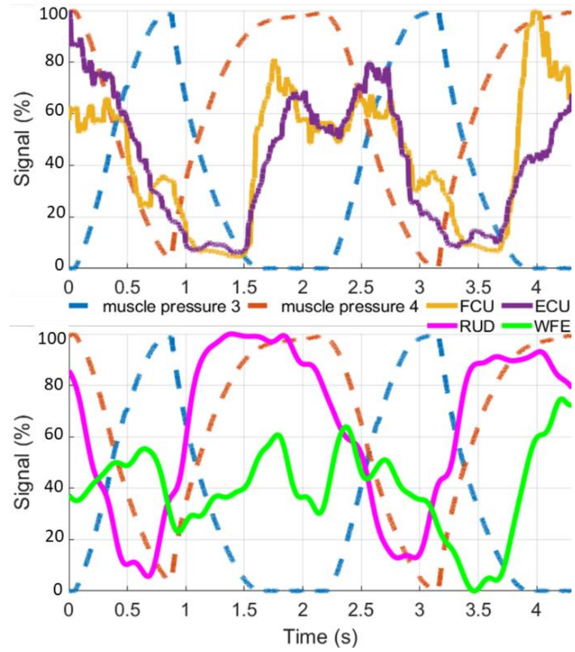

Figure 3 Sample radial deviation trial. Pressure in artificial muscles dedicated to radio-ulnar deviation are superposed on FCU, ECU and RUD, WFE respectively.

		FCU	ECU	RUD
Radial	M3	0.88 ± 0.05 $\mathbf{-515 \pm 63}$	0.89 ± 0.04 $\mathbf{-489 \pm 31}$	0.74 ± 0.05 $\mathbf{238 \pm 422}$
	M4	0.86 ± 0.04 $\mathbf{562 \pm 158}$	0.81 ± 0.07 $\mathbf{560 \pm 197}$	0.86 ± 0.04 $\mathbf{0 \pm 0}$
Ulnar	M3	0.78 ± 0.05 $\mathbf{-32 \pm 529}$	0.84 ± 0.02 $\mathbf{-15 \pm 448}$	0.77 ± 0.06 $\mathbf{0 \pm 0}$
	M4	0.89 ± 0.02 $\mathbf{-687 \pm 177}$	0.91 ± 0.02 $\mathbf{-264 \pm 697}$	0.80 ± 0.08 $\mathbf{-210 \pm 98}$

Table 1 correlation and **delay (in ms)** means and sd between muscle 3 (M3) and muscle 4 (M4) pressure and FCU, ECU, and RUD signals for Radial and Ulnar lifting motions.

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