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Motor variability in human-robot interaction during an assisted trajectory-tracking task: preliminary results from the MOVER experiment

SAVIN Jonathan
INRS

Vandœuvre-les-Nancy, France
jonathan.savin@inrs.fr

BOUSIGUES Raphaël
LORIA

Villers-les-Nancy, France
raphael.bousigues@loria.fr

MAURICE Pauline
LORIA

Villers-les-Nancy, France
pauline.maurice@loria.fr

PADOIS Vincent
Inria

Talence, France
vincent.padois@inria.fr

REZZOUG Nasser
Institut P'Prime

Poitiers, France
nasser.rezzoug@univ-poitiers.fr

DANEY David
Inria

Talence, France
david.daney@inria.fr

Abstract—In an occupational context, the use of a collaborative robot raises numerous questions relating to the health and safety of operators. In particular, the scientific and technical literature has virtually ignored the question of how to preserve operators' motor variability (MV). Yet, this MV is supposed to have a beneficial effect in terms of the prevention of biomechanical risk factors (reduction in the onset of fatigue, distribution of biomechanical stress on the locomotor system, etc.).

Inria and INRS have therefore set up the MOVER (MOTOR Variability Experiment with a Robot) experiment in order to gain knowledge of an operator's MV when performing a trajectory-tracking task with and without interaction with a collaborative robot.

The experimental results presented in this paper concern the nominal situation (no cobot used). They confirm that MV exists, related to some features of the task observed (movement direction, pace, position along the tracked trajectory). These results should eventually be used to develop control laws for collaborative robots likely to adapt to the operator's MV and preserve their health and safety at the workstation.

Index Terms—motor variability, motion analysis, human-robot interaction, ergonomics, workstation design

I. INTRODUCTION

Work-related musculoskeletal disorders (WMSDs) are a major issue among occupational diseases in many countries worldwide, and affect a large number of industrial workers, especially when they perform repetitive or physically demanding tasks [1]. In order to reduce operators' exposure to occupational risk factors, more and more workstation designers are considering the use of collaborative robots (cobots).

However, such an approach raises numerous questions relating to operators' motor variability (MV). MV stems from the large kinematic and actuation redundancy of the human body, as well as from possible redundancy at task level [2]. It is linked to numerous factors, both inter- and intra-individual (e.g. body morphology, expertise, fatigue, cognitive state...) and results in operators using different motor strategies (mus-

cle activations, postures and joints coordination) to execute a given task [3], [4].

Workstation designers are seldom aware of the pivotal role of MV. Yet, ignoring MV when designing a workstation could lead to underestimating occupational risk factors, especially if only a single way of executing the task is considered [5]. Moreover, MV is thought to be beneficial to help reduce WMSDs risks, by modifying the load distribution on the human body over time [6]. Hence, accounting for MV is crucial to efficiently improve the prevention of occupational risks, particularly in the case of cobotic workstations.

An experiment has been designed to analyze the upperlimb's MV during a trajectory-tracking task where subjects are assisted - or not - by a cobot. This paper presents preliminary results of this analysis for the "nominal" situation (without the cobot). It deals with one subject not assisted when performing the tracking task.

The first section of this paper describes the experimental setup and protocole. The second section highlights the 3 main findings : 1) the existence of MV is confirmed for the subject observed ; 2) MV depends on the direction and pace of the movement, as well as the position along the tracked trajectory ; 3) this MV is high enough to induce changes in the assessment of biomechanical risk factors.

II. THE "MOVER" EXPERIMENT

A. Physical setup

The MOVER experiment (MOTOR Variability Experiment with a Robot) is a laboratory experiment inspired by a trajectory-tracking task similar to an industrial "gasket sealing" task. The target path is a "wireloop" profile alternating curved and straight sections, within a rectangle measuring approximately 50x25 cm. The total length of the profile is 129 cm.

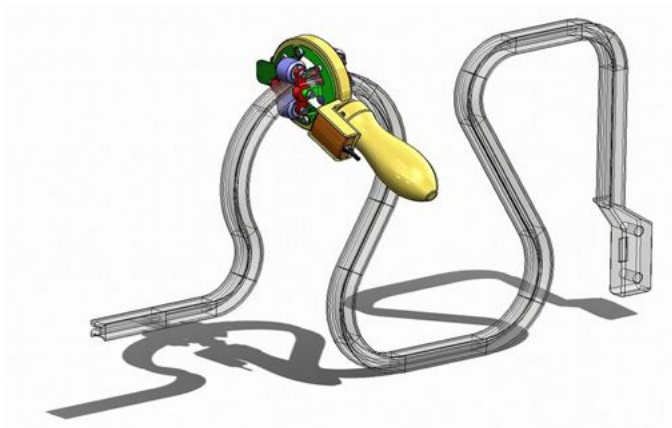


Fig. 1. the wireloop, the guided ring and the handle.

A passive mechanical system guides a ring along the profile (cf. Fig. 1). This ring is attached to a handle held by the subjects, who are asked to set the position of the ring along the profile according to a light signal included in the profile. The position of the ring is defined by its linear abscissa (cf. Fig. 2). The orientation of the handle is free in a plane normal to the wireloop at the current position of the ring.

B. Experimental protocol

18 subjects participated in the experiment, which was validated by an ethical committee. All were right-handed, with no history of pain or pathology in the right upper limb, and gave their informed consent.

The subjects were seated on a seat, their trunks held to the back of the seat by a harness to prevent unwanted movements. The height of the seat is set according to subjects' anthropometry, so that the height of their glenohumeral joint is the same as the distance between the top and the bottom of the wireloop (cf. Fig. 3).

Each subject performed $n_T = 20$ successive trials (one trial includes a forward and a backward run) for $n_P = 3$ different paces (slow: 5 cm/s, medium: 12 cm/s, fast: 20 cm/s) in a

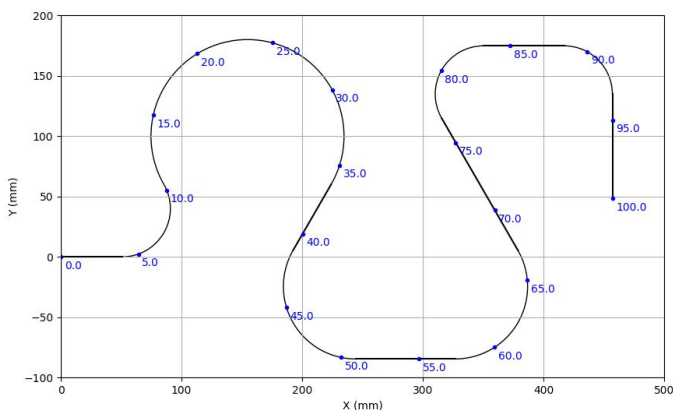


Fig. 2. Linear abscissa along the wireloop path. Abscissas read in ascending order indicate forward direction

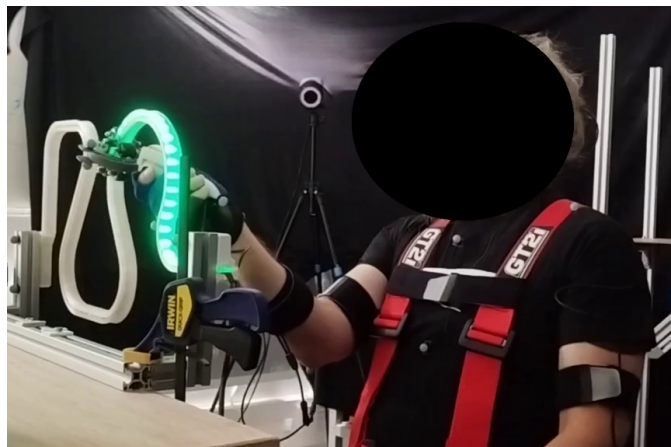


Fig. 3. experimental setup: the subject sets the position of the ring according to the light signal. The orientation of the handle is free in the plane normal to the wireloop.

random order with a 5 mn-rest period between two series. Their movements were recorded thanks to an optical system (Qualisys xxx, x cameras, recording frequency 100 Hz).

C. Data processing

The 3D-positions of optical markers placed on the subjects' body segments were processed to compute joint angles thanks to the inverse kinematics feature of the OpenSim software [8]. This processing was based on a $N = 7$ -Degrees of freedom (DoF) model of the right upper limb, which geometry (body segment lengths) was customized according to subjects' anthropometry.

Because of the different paces and recording durations, joint angles values have been tagged by the linear abscissa of the ring along the wireloop. Hence, ${}^p_d q_i^j(s)$ stands for the joint angle value of DoF $i \in [1, N]$ of trial $j \in [1, n_T]$ for pace $p \in \{\text{slow, medium, fast}\}$ and direction $d \in \{\text{forward, backward}\}$ when the ring is at position s . Finally, a linear interpolation has been performed to compute joint angle values at specific positions, namely $\{5\%, 15\%, 25\% \dots 85\%, 95\%\}$.

Moreover, joint angle values have been used to compute an index commonly used by ergonomists to assess occupational risks factors, namely the RULA (Rapid Upper Limb Assessment) [7].

All these quantities have been arranged in bundles of 20 values, each bundle \mathcal{B} being defined by a triplet $\{s, p, d\}$ with s the position of the ring along the wireloop, d the movement direction and p the pace.

III. RESULTS

The results presented below concern only one subject (age 19, height 162 cm, mass 62 kg) among the 18 participants, as a preliminary analysis.

A. Distribution of joint angles

MV can be highlighted in terms of range and mean value of joint angles. Boxplots are a convenient representation of

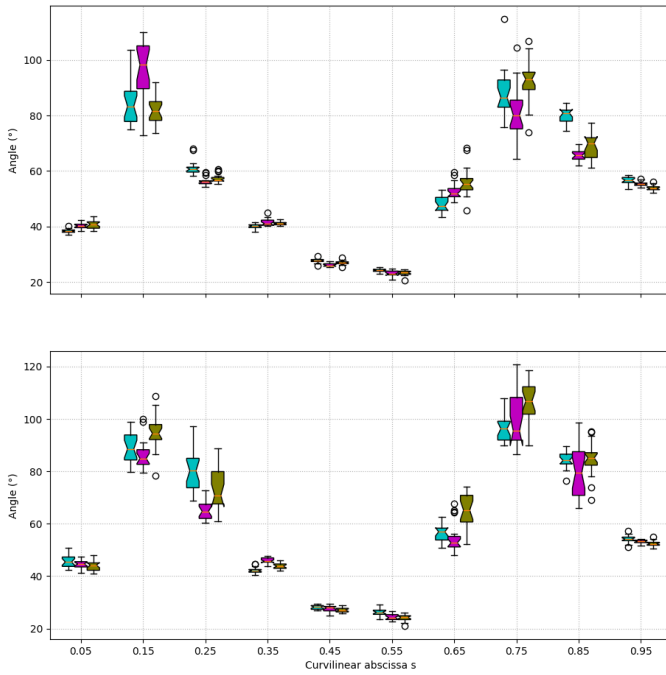


Fig. 4. Boxplots of the 20-values bundles of the right upper-arm flexion angles of common pace (cyan: slow, magenta: medium, fast: olive green), direction (top: forward, bottom: backward) and position (x-axis).

these features. For instance, Fig. 4 focuses on arm flexion joint angles. Each boxplot summarizes the distribution of one bundle as defined in the previous section. This figure shows that MV exists and that it depends on :

- the position of the ring along the path;
- the pace. For example, the medium pace is statistically different from the other paces in terms of range and mean value at positions $s = 15\%$ and $s = 75\%$;
- the direction of the movement. For example, the mean value and range in the forward (top) and backward (bottom) directions are statistically different at position $s = 15\%$.

Other DoFs show very similar characteristics.

B. Ergonomic assessment

MV can also be highlighted in terms of biomechanical risk factors. For each posture of the subject, the RULA score associated to the posture of right upper-limb has been computed and arranged in bundles of common position, pace and direction. The histograms of the distribution of these bundles are depicted in Fig. 5. It highlights that changes in postures associated to MV may also induce changes in risk assessment. For instance, for positions $s = 15\%$ and $s = 85\%$ in backward direction, neglecting MV may lead to underestimate biomechanical risk factors of up to 2 points of RULA score.

IV. CONCLUSION

Motor variability is an essential feature of human movement. It exists also in occupational contexts, for instance an

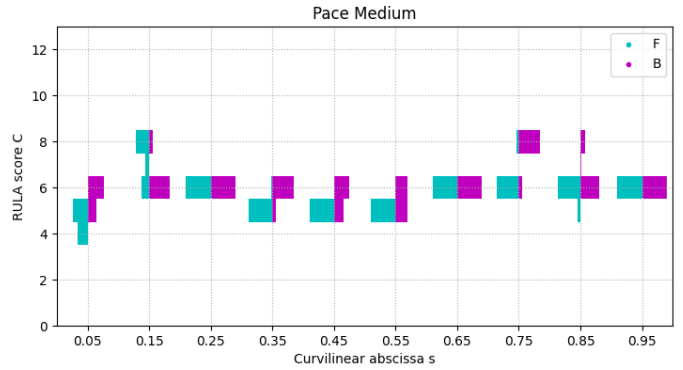


Fig. 5. Histograms of the 20-values bundles of RULA scores for the right upper-arm joint angles for the medium pace and a given direction (cyan: forward, magenta: backward) and position (x-axis).

operator interacting with a collaborative robot. The MOVER experiment has been designed to bring knowledge about occupational MV in such a work situation. In this paper, we focused on MOVER preliminary results for one participant. The main findings are that 1) the existence of MV is confirmed for the task and the subject observed, 2) MV depends on some features of the task, especially pace and direction of the movement, 3) this MV is high enough to induce changes in biomechanical risk factors as estimated through the RULA score. These results shall soon be extended by analysing the data from the 17 other subjects. The study will also be extended to a similar task using a collaborative robot to assist subjects in the trajectory-tracking task.

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