Assessment of human sensorimotor functions with robotic interfaces

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***Abstract*— Recent research on the use of robotic technologies specifically aimed at human subjects has been focused on developing accurate, quantitative assessment of sensorimotor functions. This work presents the framework and the results of a robot-aided assessment protocol of mechanical and sensorimotor components of the human wrist joint, tested on subjects. Proper knowledge of human wrist properties and functionality can be applied in different fields, from clinical evaluations to industrial ergonomics.**

Keywords—robotic assessment, human wrist, proprioception, joint stiffness

I. INTRODUCTION

Recently, the expansion of robotic technologies out of the industrial manufacturing sector, i.e. service robotics, has target an application area related to the assessment of human sensorimotor functions, on the basis of accurate measuring and monitoring protocols of parameters related to both the external environment and our way of interacting with it. Through artificial intelligence and sensors, robotic devices could assure controlled conditions and accurate measures. Moving from qualitative measurements towards quantitative ones could have benefits on countless fields of application, above all in industrial and clinical settings. The possibility to measure constantly and accurately some human parameters could help in the prevention of diseases related to repetitive work or in tailoring rehabilitative protocols on the performance of the single patient. Nowadays, a wide range of qualitative clinical scales and questionnaires are used to assess sensorimotor functionality. The main idea of this work is to evaluate functionality through robot-aided protocols: particularly, here we will focus on measuring mechanical and sensorimotor components related to the human wrist joint, such as range of motion, position sense and stiffness. Joint Position Sense (JPS) is a specific proprioceptive process related to the ability to reproduce a defined joint angle. Actually, proprioception is the sense responsible for the perception of body awareness, essential for coordination and motor planning during daily actions [1]. Nowadays, the most established clinical methods to assess proprioception manually evaluate different aspects of sensory perception, resulting in a long-to-administer qualitative test, not focused on a specific joint and its performance across the workspace [2]. On the other hand, the assessment of wrist joint stiffness is essential to understand the mechanisms of motor control and could become a useful clinic tool for the analysis of compensatory strategies adopted by patients with different neurological disorders. Indeed, neuromuscular disorders such as spasticity are related to an increased stiffness, with a consequent abnormal muscle tone and exaggerated stretch reflex responses proportional to the speed of movement [3]. However, despite being a widespread disorder, spasticity is still poorly defined and assessed only through manual tests of resistance to stretch, not enough accurate and reliable to clinically quantify its severity. Since a reliable and comprehensive evaluation of wrist position sense and stiffness is still missing, in this work, we propose and test a novel robot-based protocol of assessment. The final goal would be to replace currently used qualitative scales with quantitative and reliable measurements, performed under controlled and repeatable conditions.

II. METHODS

A. Experimental Setup

The robotic device used for testing is the WRISTBOT [4][5], a fully back-drivable manipulandum, which allows wrist movements along its three Degrees of Freedom (DoFs), flexion/extension (FE), radial/ulnar deviation (RUD) and pronation/supination (PS) planes, leading to a full human-like range of motion (ROM) along all planes. The device is equipped with four brushless motors, able to both deliver torques and set target positions, in order to manipulate the wrist joint. An integrated virtual reality environment provides visual feedback to the user. The handle of the robot is wrapped with a soft sensor able to measure the exerted grip force.

B. Experimental protocol

During the testing protocol, subjects sat on a chair in front of a screen, with their right forearm strapped to the robot through velcro bands (Figure 1).

Figure 1. WRISTBOT (Panel A) and experimental setup (Panel B)

Active ROM assessment

Subjects had to move actively in order to achieve their maximal angular rotation along a specific direction. These consisted in 12 equally-distributed directions in the whole space defined by flexion/extension and radial/ulnar deviation movements.

Wrist position sense assessment

Starting from the neutral position, the robot moved the hand of the blindfolded subject towards a target position. After being passively moved back to the neutral position, the subject had to actively replicate the previously assumed configuration and then push a button, in order to be brought back to the neutral position. Targets were located at the 80%

of the ROM assessed along each of the 12 directions. Each subject performed six target sets, with a 1-minute long break after the first three. Performance was evaluated along each direction of movement, computing the mean absolute error (matching error, ME) between target and matched position. Since matching movements were not constrained to the direction of the target, ME was computed considering errors in either the direction ([°]) or the length ([ROM%]) of the matching movement.

Wrist Stiffness assessment

The device delivered small and quick rotational disturbances in the FE DoF of the human wrist [6].The device passively moved the wrist from a starting position in extension to flexion and back to the start, with a random length pause after each movement. Three different perturbation velocities were evaluated, including: slow: 100 °/s, medium: 130 °/s, fast: 150 °/s. Three hand grip conditions were assessed at each perturbation velocity. Subjects were instructed to grasp the robot handle with no imposed grip force, at 40% and 60% of their maximum grip force. There were 3 mins of rest between conditions to avoid fatigue. To extract the parameters of stiffness, we computed the passive impedance of the wrist, relating the torque applied by the motors of the robot to the kinematics of the wrist (angular displacement, rotational velocity and acceleration) through a second order mass-spring-damper model. These parameters were computed for each movement (from extension to flexion and from flexion to extension), by means of a least-square estimation of the torque.

III. RESULTS

Here, we present results from nine right-handed subjects, with no history of neurological disorders, enrolled in this study. Figure 2 shows anisotropy of active ROM: particularly, movements along flexion (F) and its closest directions presented the largest ROM, while the RUD plane the lowest. Concerning wrist position sense, our results (Figure 3) show the presence of anisotropy in the perception of both the extent of movements and the direction. However, looking at perception of direction, we can clearly notice that movements along combined directions resulted in higher directional error respect to movements along the four orthogonal main directions. Finally, the average stiffness values varied slightly between different hand grip conditions (Figure 4). In particular, its values were higher in the greater hand grip condition and faster perturbation. Interestingly, there results were consistent among subjects with no statistical difference in stiffness values evaluated in extension and flexion movements.

IV. DISCUSSION

In this work, we proposed a novel method to quantitative assess both sensorimotor and mechanical components of human wrist functionality. Particularly, active ROM assessment was crucial for the evaluation of wrist position sense: given the unfeasibility of the “one-fits-all” approach, robotic devices permit to tailor the sensory assessment on single subjects, choosing the extent of the target movement based on the actual ROM. Wrist motion and sensory components have been previously assessed along its two main axes of rotation, flexion–extension (FE) and radial–ulnar deviation (RUD). However, rotations along oblique axes are commonly performed during many activities of daily living: along these directions, we identified difficulties in having an accurate perception. Since an accurate sense of position is crucial for fine control and manipulation, these results could be particularly relevant in both clinical and industrial settings. Furthermore, this study represented a promising starting point to validate the consistency and reliability of the robot-based method for evaluating passive impedance of the wrist. Specifically, it provided a collection of stiffness values of healthy subjects to allow comparison with patients. In addition, we altered grip conditions to effectively stiffen the joint and evaluate stiffness responses through various levels of muscle contraction. These results demonstrated the importance of having a tool able to assure repeatable and robust measures among non-homogenous samples and solve issues related to practicability, accuracy and safety in both clinical and industrial settings.

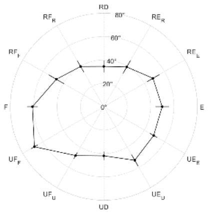

Figure 2 Active ROM mean and standard deviations for the 12 directions

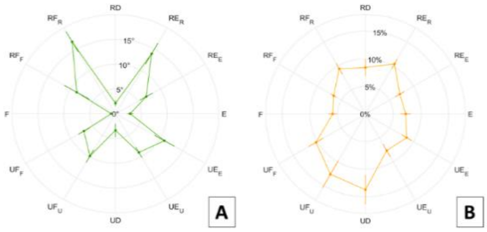

Figure 3 Mean ME and standard error. A) shows ME for perception of direction, B) for perception of movement length.

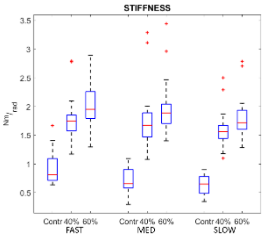

Figure 4. Average stiffness values vs grip and speed conditions.

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