Usability of a SEA-based upper-limb rehabilitation device

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Abstract—This contribution aims at presenting the first clinical evaluation trials of a Series-Elastic-Actuator based exoskeleton for post-stroke rehabilitation, NEUROExos, from the BioRobotics Institute of Scuola Superiore Sant’Anna.

I. INTRODUCTION

The robot-aided physical rehabilitation paradigm has been proposed for high-intensity rehabilitation treatments [1]-[2], in order to reduce the therapists' workload and to allow them to follow more than one patient at a time. Robotic systems lead to various advantages; it is possible to record quantitative measurements about the patients recovery [3], and to replicate a given protocol always in the same conditions. In this paper, we present the results from clinical trials exoskeleton with a series elastic actuator (SEA, [4]) for post-stroke rehabilitation [5].

II. NEUROEXOS SERIES-ELASTIC ACTUATOR

In SEA robotic systems, the presence of an elastic element between the power source and the actuated joint allows a compliant and safe interaction, as the user will be exposed to the spring stiffness, instead that to the whole reflected inertia of the actuation unit. Moreover, the spring deformation provides a reading of the transmitted force. These advantages come at the cost of a limited transmission bandwidth, due to the spring stiffness.

In [5] authors presented the NEUROExos elbow exoskeleton, Fig. 1(a), which employs a SEA transmission with a custom designed, patent-pending [6] torsional spring with100 N-m/rad stiffness (a trade-off between the safety and bandwidth requirements). Such spring can withstand torques higher than 30 N-m while remaining in the elastic behavior, allowing an almost indefinite working life ($10^5$ cycles under peak-to-peak loading of ±30 N-m).

III. EARLY EXPERIMENTATION AND DATA

NEUROExos was tested with three chronic post-stroke patients with Ashworth < 4, with rehabilitation session of 15 minutes, and the desired joint's mean angular velocity in the range 5-10 deg/s. For all the subjects, the spasticity of the elbow generated a hyper-flexed natural condition, and the final aim of the rehabilitation was to reduce the elbow stiffness, towards a more extended resting position. In the presented preliminary data analysis, first and last 5 torque-angle curves are compared, Fig.1(c-d-e). For all the subjects it is possible to see a reduction of the angle corresponding to the zero-torque value, but the three of them show different stiffness behaviors, respectively with a reduced, not altered and increased value between beginning and end of the trial.

In analogy with a very simplified system, the human elbow can be assimilated to a rotational joint driven by two elastic mono-directional actuators, the extensor and flexor muscles, Fig. 1(b): the result is a joint with modulation of stiffness and resting position. In this view, the effect of NEUROExos can be interpreted as a re-establishment of a symmetry in the two muscular groups contraction, trying to make the difference of their natural values smaller, but without addressing directly the muscular stiffness, as the more extended position did not necessarily reflect in a more relaxed position, Fig. 1(f-g-h).

IV. CONCLUSION

Series-elastic architecture offers many advantages in the human-robotic physical interface; it conjugates the position and force sensor functionalities, and introduces an inherent safe compliance. In this contribution, we showed through the NEUROExos system, the feasibility of a quantitative assessment of rehabilitation treatment variables. The SEA
transmission allowed to absorb spastic reactions, as well to implement torque/position thresholds in the protocol.

REFERENCES