PhD Thesis Title: Design of robotic hand-based intervention with brain stimulation applications for post stroke neurorehabilitation

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ABSTRACT:

Robots have the potential to help provide exercise therapy in a repeatable and reproducible manner for stroke survivors. To facilitate rehabilitation of the wrist and fingers, an electromechanical exoskeleton was developed that simultaneously moves the wrist and metacarpophalangeal joints. A Computer Aided Design model of the mechanical linkage was made, simulated for Factor of Safety and fatigue life, 3D printed and assembled. The device was designed for ease of manufacturing and maintenance, and crucial considerations for countries with limited resources. Active participation of the user is ensured by the implementation of electromyographic control and visual feedback of performance. Muscle activity requirements, movement parameters, range of motion, and speed can all be customized to meet the needs of the user. Twenty-three stroke survivors, ranging from the subacute to chronic phases of recovery (mean 10.6 months poststroke), successfully participated in a randomized controlled study with two groups: the Robotic therapy (n=12) and the Control group (n=11). In the robotic therapy group, participants completed 20 sessions, each lasting 45 minutes. Twenty sessions of 45 minutes of physiotherapy were given to patients in the control group. In robotic therapy group, patients exhibited statistically significant changes ($p < 0.05$) in the clinical outcome measures (Fugl-Meyer Stroke Assessment score for the upper arm, Barthel Index, active range of wrist motion and Modified Ashworth Scale) than the control group following the treatment. Cortical excitability, amplitude of Motor Evoked Potential and Resting Motor Threshold, was observed to be increased post-therapy in the robotic therapy group than the control group ($p < 0.05$). Thus, this device shows promise for improving rehabilitation outcomes, especially for patients in countries with limited resources. The device has been synchronized with brain stimulation for evoking activity-dependent stimulation. Hardware has been developed, protocol optimized with Transcranial Magnetic Stimulation, and tested on four patients completing 20 sessions with promising results.

References to author publications that relate specifically to the dissertation:

1. **N Singh,** M Saini, N Kumar, P Srivastava, and A Mehndiratta, "Evidence of Neuroplasticity with Robotic Hand Exoskeleton for Post-stroke Rehabilitation: A randomized control trial," 2021 May in **Journal of Neuroengineering and Rehabilitation,** Volume 18(76). https://doi.org/10.1186/s12984-021-00867-7
2. **N Singh**, M Saini, S Anand, N Kumar, P Srivastava, and A Mehndiratta, "Robotic Exoskeleton for Wrist and Fingers Joint in Post-Stroke Neuro-Rehabilitation for Low-Resource Settings," 2019 December in **IEEE Transactions on Neural Systems and Rehabilitation Engineering,** Volume 27(12), pages 2369-2377. DOI: 10.1109/TNSRE.2019.2943005
3. **N Singh,** M Saini, N Kumar, P Srivastava, S Kumran, and A Mehndiratta, "A case report: Effect of robotic exoskeleton based therapy on neurological and functional recovery of a patient with chronic stroke," 2021 May in **Frontiers in Neurology,** Volume 12(680733). DOI: https://doi.org/10.3389/fneur.2021.680733

4. **N Singh**, M Saini, S Anand, N Kumar, K Deepak, P Srivastava, and A Mehndiratta, "Time-Frequency Analysis of Motor-Evoked Potential in Patients with Stroke vs Healthy Subjects: A Transcranial Magnetic Stimulation Study," 2019 August **in SN Comprehensive Clinical Medicine,** Volume 1(10), page 764-780. DOI: https://doi.org/10.1007/s42399-019-00113-1

Patents Published:

1. **US patent 15/733,028, European phase EP 18871528.8, PCT filing PCT/IN2018/050649, Indian Patent:** 201711037641, entitled "Exoskeleton device for upper limb rehabilitation," Inventors**: N Singh**, A Mehndiratta, and S Anand
2. **PCT/IN2020/050600, Indian Patent:** 201911027688, entitled "System for rehabilitation of limb of patient," Inventors**: N Singh** and A Mehndiratta

Patents Filed:

1. **European Phase EP 20837783.8, US patent 17/625958** "System for rehabilitation of limb of patient," January 2022, Inventors: **N Singh** and A Mehndiratta

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1. **Copyright Diary No. 18440/2017-CO/L of 19/12/2017, "**An algorithm of controlling closed-loop rehabilitation devices," November 2017, **N Singh** and A Mehndiratta