Response to Reviewers
Journal of Rehabilitation and Assistive Technologies Engineering

Manuscript Title: Myoelectric Untethered Robotic Glove Enhances Hand Function and Performance on Daily Living Tasks after Stroke (RATE-20-0024.R1)

We would like to thank the reviewers for their time and efforts to provide positive comments and constructive criticisms. The reviews were very useful in helping us to improve this manuscript. In this letter, we provide our detailed responses to each of the reviewers’ comments and present how we have incorporated their suggestions. We have provided the clean and tracked changes versions of the manuscript separately.

The line numbers we reference in this response refer to the line numbers in the tracked changes version of the manuscript. For the responses to the comments in this letter, we have used the following color code:

• In black and bold are the comments from the reviewers.
• In purple, our response.
• In green, the relevant and unmodified text.
• In red, the additions to the text
• In blue, the deletions to the text.
Reviewer #1

The paper describes an EMG-controlled untethered robotic glove (My-HERO) to assist post-stroke subjects in performing activities of daily living. The effectiveness of the system has been tested in a pool of 9 patients, by comparing the scores of commonly used assessment scales for the hand function, with and without using the glove.

The paper is well written, but it can be improved in some aspects:

- **The Participants section, together with the inclusion criteria, should be moved to the paragraph describing the study design**

We have moved this information to Study Procedures, directly above study design (L.291). We also revised the “Organization of this Article” section.

(L.109) In the Materials and Methods section, we describe the participant inclusion criteria, the study protocol, and the novel untethered robotic glove and its myoelectric calibration and control algorithm that were designed specifically for people with severe hand impairment after stroke. We then describe the participant inclusion criteria and the study protocol.

- **In the description of My-Hero, some information about the hardware and control system of the glove and the EMG armband should be provided (e.g. power of the actuators, sampling frequency of the controller)**

We have added the actuator, microcontroller and PWM specifications. In addition, the article referenced (9) describes the HERO Grip Glove, a previous version, which is now published and open access (https://jneuroengrehab.biomedcentral.com/articles/10.1186/s12984-020-00659-5).

(L.147) My-HERO uses one dorsal and one palmar linear actuator (Actuonix, L12-R, 210:1, 80 N max force, 50 mm stroke length) to exert mechanical forces on all five fingers to assist hand extension (i.e. five-finger extension and thumb abduction) and grip strength (i.e. five-finger flexion and thumb opposition and adduction).

(L.183) The battery pack (9V Energizer Lithium battery) and Bluetooth-enabled microcontroller (tinyTILE Intel Curie) are relocated to the proximal end of the wrist brace for improved aesthetics and to reduce the arm torque required to lift the glove.

(L.192) The armband’s EMG, acceleration and orientation data are transmitted through Bluetooth to a laptop computer at 200Hz to create a dataset of stroke participants’ forearm muscle and motion signals during hand function assessments and daily living tasks. The computer detects the user’s intent from the EMG data. The computer uses Cloud and Bluetooth protocols to communicate with the on-board microcontroller, which commands the actuators to move to a fully extended or fully retracted position using a 50Hz pulse-width modulation signal, with a delay less than 0.5 seconds.

- **In the calibration procedure, how are the calibration movements segmented? I.e., is the procedure completely automatic (by switching to the following movement after 10 seconds) or an external input is required to identify the start of each movement?**

Clarifications have been added. The entire procedure was automated and used text instructions. These instructions were supplemented by researcher demonstration.
The user is seated at a table with their affected forearm and hand resting on the table. They are asked to follow an automated set of text instructions, which display consecutively on the computer screen for 10 seconds. The instructions were also read aloud and demonstrated by a researcher because the user interface was not optimized for visual, cognitive or other impairments. The first on-screen instruction is for the user to “relax your arm and hand” and the following instructions are “lift your arm and relax your hand” and “lift your arm and make a fist”.

- To measure the intention detection time, how were vocal commands synchronized with the glove for the calculation?

The audio-visual recordings were synchronized with the computer’s data recordings (e.g. IMU, EMG and motor command data).

- Accuracy alone is not completely informative to evaluate the performance of the detector. E.g., how many times an undesired assistive action was triggered? Consider the possibility to report additional measures, e.g. recall and precision.

We have added information regarding undesired assistive action (i.e. false positive) to the text and in Table 2.

False positives did not occur often, with grip assistance incorrectly triggered on 4.3% of the occasions where the participant was instructed to maintain their hand in extension and extension assistance incorrectly triggered on 2.8% of the occasions where the participant was instructed to maintain a grip.

Minor comments:

- The acronym "FMA-H" is introduced, but then it is always replaced by "FMA-Hand"

(L.311) Changed from FMA-H to FMA-Hand.

- Line 529-530: typo in the sentence.

(L.589) We removed the period and the “They” after “60%”

- In Table 2, std time for each participant should be reported as well.

We have added the per participant SD values for the grip and extension delay times in Table 2. We also identified and fixed an averaging miscalculation.

Reviewer #2
The manuscript presents the myoelectric control algorithm and experimental validation of the HERO Glove with stroke participants.

1) The discussion of using EMG for individuals with clenched fists was unclear (line 81-88). It seems counterintuitive for large force generation to result in only small muscle activation signals, and the use of flexible force sensors could seemingly use an offset to counter the flexed neutral pose.
The related sentences have been removed since grip intent detection methods using EMG and fingertip force sensing during robot-assisted finger extension have not been compared. We have added force and motion sensing possibilities to the discussion.

(L.77) These studies have found mixed results about the possibility of accurately detecting hand opening, extension, multiple grasp postures and individual finger flexion hand closing and multiple grasps accurately for people with severe hand impairment after stroke. However, their grip signal (i.e. mass hand flexion) is often detectable through forearm flexor EMG and thumb flexion force measurement (20), yet these studies suggest that the grip signal is often detectable. For people with clenched hands after stroke, EMG may be a more suitable control input than force sensors. EMG may be preferred because the large extension forces required to open their hands would not generate high electromyography signals unless a spastic response is provoked. However, tone and spasticity would generate high force readings on flexion force sensors that could falsely trigger grip assistance.

(L.721) However, combining dexterous robots, sensor fusion from IMU, force, bend and dense electromyography sensors on the forearm and hand, classification algorithms for controlling grasp type and force, and user training programs may enable people with hemiplegic hands to perform delicate tasks, in-hand manipulation and multiple tasks at once (34–37).

2) The description of the EMG algorithm should be expanded somewhat (line 216, figure 2). It is unclear if lifting their arm to trigger assistance is detected by muscle activations in the forearm, or if the IMU in the MYO is being used.

We have expanded the EMG algorithm description in the text.

(L.249) The last 5 seconds of data under each condition are averaged to automatically find the electrode most sensitive to hand gripping relative to arm motion (Hand Channel), the electrode most sensitive to arm motion (Arm Channel) and the corresponding thresholds for arm relaxation (Arm Rest Threshold), hand relaxation (Hand Rest Threshold) and hand grasping (Grip Threshold). To trigger hand extension assistance, the user relaxes their shoulder, elbow and hand muscles so that the EMG signals on the identified Arm Channel and Hand Channel are below the Arm Rest Threshold and Hand Rest Threshold. To trigger grip assistance, the user attempts to grasp an object so that the EMG signal on the identified Hand Channel increases above the Grip Threshold.

We have made an addition to explicitly state that the IMU is not used.

(L.234) Inertial measurement unit (IMU) data was not used.

What pose is the arm lift made in? Does this align with the simulated ADL or the tests used? Is it possible that other arm configurations (forearm pro/sup, elbow flex/ext) would change which channel would need to be the 'arm channel'?

We have made an addition to explain that users were able to lift their arm in the way they chose to.

(L.246) Users were free to choose how they lifted their forearm off of the table, regardless of if this included shoulder internal rotation or elbow flexion.
It is possible that there would be a more ideal ‘arm channel’ that is task specific or that it is only added once muscle fatigue is detected, most probably for participants with a CMSA-Arm of 4 or above.

(L.710) Further, our task set did not require movement throughout the entire shoulder, elbow, and wrist workspaces. A task-specific ‘arm channel’ selection algorithm could improve task performance for participants with arm control (e.g. CMSA- Stage of Arm of 4 and above) and it could be useful to disable the arm lift detection feature until muscle fatigue is detected.

And to clarify, the 'synchronization' of the armband is through the MYO provided software, and not something else?

We have made the following clarifying addition.

(L.284) Two additional participants (P10 and P11) with a CMSA - Stage 1 of Arm and CMSA - Stage 1 of Hand were recruited but excluded from this study because the Myo Connect software did not recognize their attempts to synchronize the armband.

3) The discussion concerning the implementation of myoelectric control could be expanded. Depending on the clarifications from the first comment, the use of the whole arm may or may not be ideal. Further, it may seem that this algorithm is limited when expanding to multiple poses.

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(L.710) Further, our task set did not require movement throughout the entire shoulder, elbow, and wrist workspaces. A task-specific ‘arm channel’ selection algorithm could improve task performance for participants with arm control (e.g. CMSA- Stage of Arm of 4 and above) and it could be useful to disable the arm lift detection feature until muscle fatigue is detected.

4) A similar device has proposed to use a Myo armband for control and could be cited (intro, or line 711): Rose, Chad G., and Marcia K. O’Malley. "Hybrid rigid-soft hand exoskeleton to assist functional dexterity." IEEE Robotics and Automation Letters 4.1 (2018): 73-80.

This citation has been added (L. 783)

5) Discussion of the limitations preventing independent donning (line 540, or in discussion).

Further explanation has been added.

(L. 774) The main challenge to independent donning was in inserting a toned ring or little finger. This is an open challenge in full-hand robotic orthosis design that may be improved by incorporating Velcro straps as well as by providing donning training to the user and caregiver.

Minor comments:
6) Some content could likely be summarized in a table or placed in an appendix, such as lines 440- 457, 464-477, 503-521.

We have moved the references to the FMA-Hand, CAHAI-13, QUEST and USE Tables above the associated qualitative information to make brief reading easier. Since the paper is within the page limits the authors’
A stylistic preference is for the patient-specific qualitative observations that support these scores to be present nearby in the main text.

(L. 491) The FMA-Hand results are shown in Table 3.
(L. 520) The CAHAI-13 results are shown in Table 3.

(L. 574) The results from the QUEST, USE and additional questions are shown in Tables 4 and 5.

**Associate Editor(s)**
The paper investigated the myoelectric untethered robotic glove on stroke subjects, reviewers have some major concerns and would like to have more details in the manuscript, please follow the reviewer's comments to make the changes.

The authors have made edits for each of the reviewer comments.