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Protocol for Robot-Assisted Progressive Muscle Strength Training

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ABSTRACT

This is a protocol for an progressive muscle strength training in a new domain of adaptive robot-assisted training interactions. The protocol was defined based on sports science literature, where the participants would be performing maximum voluntary contraction (MVC) trials at first, then taking a recovery break, then starting with a low-intensity task, and then gradually increasing the difficulty level. The protocol included a preparation stage, followed by initial measurements, a familiarisation session, and finally a performance session.

Thirty (17 males, 13 females) healthy participants of at least 18 years old with no history of injury to the upper limb and back were involved in this experiment. Participants were students or staff members of University of Hertfordshire or other volunteers from outside the university. The total duration of the experiment, including the set-up time for each participant, was normally 40-55 minutes. A questionnaire was given as part of the experiment. The participants were asked to fill in a part of the questionnaire at the beginning of the experiment. They were also requested to update the fatigue state in the questionnaire after finishing the experiment.

The electromyogram measurements were taken using an EMG acquisition device (g.USBamp amplifier) from g.tec medical engineering GmbH. The data acquisition parameters (sampling rate, channel selection and so on) of the device were configured using Simulink 2017b.Three EMG electrode channels were configured in bipolar mode with a sampling frequency of 1200Hz. Electromyogram (EMG) signals were collected from 3 upper limb muscles (Biceps Brachii, Anterior Deltoid, and Middle Deltoid) of the participants during a robotic interaction. EMG electrodes for Biceps Brachii muscles were connected to Ports 11-12 of g.USBamp amplifier, Frontal Deltoid muscles to Ports 13-14 and Middle Deltoid muscles to Ports 15-16.

The experiment set-up included the HapticMaster robotic interface configured for a rowing task.
The tasks involved upper limb exercises, which simulated rowing, using a robot arm (HapticMaster robot) as directed by visual instructions on screen and audio cues. In order to support an aesthetically pleasing interactive task for the participants, an animated rowing environment embedded with audio cues and haptic sensation of underwater viscosity were created using the HapticMaster robot. The background on a wide-screen 43 inch LCD monitor would display the front-end of a rowing boat with flowing water, which would potentially motivate the participants for an active involvement in the task. A suitable audio for water flow was played in the background. The HapticMaster robot was programmed to deliver different viscosities under water and above water while rowing. The starting time, the break period and the stopping time of the experiment were guided by audio cues. The task involved moving a robotic end-effector, while an animated boat rowing environment running in front of the participant on an LCD monitor. Kinematic measurements by the robot were logged into separate csv files for each participant.

There were be 3 groups of participants in this study. Control 1 Group (Group A) participants did not receive any adaptation from the robot during the interaction and were given break periods at regular intervals. Intervention Group (Group B) interacted with the adaptive robotic environment, which was designed to adjust the difficulty level of the training exercise based on EMG based fatigue indicators. Control 2 Group (Group C) participants had a similar environment as Group B, but the environment only adapted based on the subject-reported fatigue. The participants were asked to continue the exercise until they felt very tired or until they reported fatigue 3 times or until the maximum feasible robotic resistance was reached. Participants were allowed to stop the session in cases discomfort.

EXTERNAL LINK

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GUIDELINES

EMG sensor electrodes were connected to the skin on the upper limb locations. The skin area for the sensor application was prepared by cleaning with a wet wipe. The participants were asked to sit straight on a non-rotating chair during the experiment. The hand involved in the experiment was not externally supported. The opposite hand was allowed to rest on any external support like a table or chair to maintain an upright posture. Participants were advised to wear a loose garment for the ease of fixing the electrodes on the upper limb.
A non-invasive EMG acquisition device (CE marked g.USBamp) from g.tec medical engineering GmbH, was used to acquire the EMG signals from the upper limb muscles. The data acquisition parameters (sampling rate, channel selection and so on) for the g.USBamp amplifier were configured using a Simulink model. Three EMG electrode channels were configured in bipolar mode with a sampling frequency of 1200Hz. An electrode cable with a clip-lead was attached to sterile disposable non-invasive electrodes to measure EMG signals. A bipolar electrode configuration was used for the EMG acquisition and the electrode placement errors were minimised by following SENIAM guidelines. The measurement of physiological parameters such as body weight, Body Mass Index (BMI), visceral fat classification, skeletal muscle percentage and body fat percentage was conducted using OMRON digital weight scale.

MATERIALS TEXT

HapticMaster Robot, OMRON digital weight scale, EMG acquisition device (CE marked g.USBamp) from g.tec medical engineering GmbH.

Preparation Stage

1 Participants were assisted to fix the EMG electrodes on three specific upper limb muscles (Biceps Brachii (BB), Anterior Deltoid (DLTF), and Middle Deltoid (DLTM)). The ground electrode was connected to a bony area near the elbow.

Initial Measurements

2 The most feasible and highest robotic resistance for the rowing task was measured for each participant. The robotic resistance was gradually increased to a comfortable highest level by adjusting the damping coefficient of the robotic end-effector and verbal feedback about the task difficulty was collected from each subject. The value of damping coefficient corresponding to the highest feasible force was noted. This was termed MVC trials

3 Three such measurements were conducted. There was a break period of at least 30 seconds between each MVC trial. The average value of the three readings was calculated. This was termed as MVC-Equivalent (MVC-Eq) and was approximated as each subject's MVC force, which was used to set the initial task difficulty for each subject.

4 After the three MVC trials, there was a break period for 10 minutes or until a self-reported full recovery before starting the rowing task.

5 The body weight, Body Mass Index (BMI), visceral fat classification, skeletal muscle percentage and body fat percentage of participants were measured before the experiment. The gender, age, and height of the participants were also measured.

6 Different parameters like subject group name, MVC-Equivalent, number of rowing iterations, kinematic measurements such as the end-effector position, velocity and force were logged into a file at a rate of 10 samples per second approximately.

7 The different states of muscle fatigue were also logged during the experiment (reported fatigue, detected fatigue and relaxed state).

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Familiarisation and Performance Session

8 After the initial measurements were completed, all the participants familiarised themselves with the robot and the environment in a practice run, which was then followed by the performance session.

9 There were three experimental conditions and hence, three groups of participants in this study. They were randomly assigned to a group and each group was assigned 10 participants.
There were different strategies for the break period or reducing the difficulty level in the 3 subject groups.
The subjects were requested to report fatigue when they were in a state of pain or unable to continue, which helped to assess their psychological perception of fatigue. Participants of all groups were allowed to report fatigue orally during the interaction, which was then recorded as a subjective measure of fatigue. The experiment would continue until the participants reported fatigue 3 times or until the robotic resistance reached the 100% of MVC-Eq.

10 The intervention group (Group-B) was designed to involve the participants in a fatigue-adaptive robotic environment, where the subjects would receive varying resistance from the robot automatically based on their muscular state (fatigue) detected using EMG features. The protocol was designed to follow the sports science procedure for muscle training using robotic assistance when fatigued.

10.1 The participants interacted with an adaptive robotic environment which was designed to adjust the difficulty level of the exercise automatically based on EMG fatigue indicators from the upper limb muscles. In addition to automatic fatigue detection, the participants were also allowed to report fatigue when needed.

10.2 There were no break periods given; instead, there was a single continuous trial that incremented the difficulty level by 10% MVC-Eq every 1 minute.

10.3 When the algorithm detected fatigue, the difficulty level was automatically decreased to 50% of the current value.

10.4 When relaxed, the robotic resistance was again incremented by 10% MVC-Eq after 1-minute trial and then the trials were repeated until the resistance reached 100% MVC-Eq.

11 Control Group 1 (Group-A) was meant for studying the performance of the subjects in a similar environment as in the intervention group, but instead of receiving a robotic adaptation they were given break periods at regular intervals and then an increased resistance after the break.

11.1 The participants did not receive any adaptation from the robot and there were no reducing of difficulty levels during the robotic interaction. While the status of the muscle fatigue was recorded, there was no intervention based on the detection of fatigue, instead, the participants could only report fatigue.

11.2 The participants were asked to perform each trial for a duration of 1 minute or until they felt tired before they could take a break of 30 seconds .

11.3 After each break, the next trial lasted for 1 minute. After the break period, the robotic resistance was incremented by 10% MVC-Eq before the next trial.

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12 Control Group 2 (Group-C) was designed for exploring the task performance during the same adaptive robotic environment as in the intervention group, but instead of receiving an automatic adaptation, the subjective state of muscular fatigue was used for the robotic adaptation.

12.1 The subjective fatigue was reported by each participant and the robotic adaptation was performed based on this.

12.2 Similar to the Intervention group, there were no break periods between trials instead, there was a single continuous trial that incremented the difficulty level by 10% MVC-Eq after every 1-minute trial.

12.3 The robotic resistance was adapted only based on the subject-reported fatigue and did not use the status of automatically detected fatigue. When the fatigue was reported by the participant, the difficulty level was decreased to 50% of the current value.

12.4 After 1 minute, the robotic resistance started incrementing by 10% MVC-Eq and then the trials were repeated until the resistance reached 100% MVC-Eq.

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