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Instrumented Upper-Body Brace for Computerized Training of Muscle Control

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Abstract **-** Each year in the United States, over 2,000,000 individuals suffer from neuromuscular disorders that severely impair movement abilities. Physical therapy is the predominant option for rehabilitating motor function for these patients; however, traditional therapies often focus on physical training without greater cognitive engagement or leveraging of motor learning principles. As such, computerized interfaces for rehabilitation, such as virtual reality and robotics, are more promising given their natural approaches to motivate and provide enhanced feedback about performance while re-training motor skills. Our laboratory has prototyped an upper-extremity brace device integrated with a virtual reality environment for isometric training of improved muscle-level control of the upper-body for persons with motor disability. This research platform includes a position-adjustable restrictive upper-extremity brace instrumented with sensors for skin-surface electromyography (EMG, measure muscle activity) to control virtual avatars and vibration motors for haptic guidance cues during training. The core objective of this research is to adapt the current brace design to better include instrumentation elements (EMG sensors, vibration motors) onboard the brace towards an embodiment of this device that is self-contained and with greater commercial potential. Specifically, this project will focus on building the next version of this brace system that allows for custom-placement of affordable (not high-end research-grade) commercial EMG (Myoware) sensors at locations personally fitted to each participant. The Myoware sensors will be embedded onto the current upper-body restrictive brace through modular attachments based on designs developed in SolidWorks as presented in this paper. The SolidWorks design utilizes sliding mechanisms, screws, springs, and clamps to make the modular attachment more user-friendly and position adaptable in three dimensions. Embedding Myoware sensors onto the brace design replaces the need to tape research-grade (Delsys) sensors onto each participant to ensure flush and consistent contact with each participant arm for robust EMG measurements and reliable transfer of haptic feedback. Overall, these improved design implementations will result in a version of this device that is more affordable, easier to use, more customizable to each user, and facilitates greater portability. The potential customers and stakeholders would include not only patients, but also clinical support staff and telehealth companies. This versatile, advanced system for computerized rehabilitation will be valuable to any communities of neuromuscular disorders affecting upper-body function that benefit from motor rehabilitation.

***Keywords*:** neuromuscular disorders, motor rehabilitation, Myoware sensors, upper-body restrictive brace, computerized training

1. Introduction

Neuromuscular disorders are often incurable and result in lack of motor control over time [1]. Physical therapy is currently recognized as the primary movement rehabilitation option for regaining strength, treating symptoms, enhancing quality of life, delaying disease progression, and restoring independent function [2]. However, physical therapy is limited as such treatment neglects consideration for neurocognitive contributions of motor learning towards recovery. Integrating motor learning concepts into physical therapy practices, in the form of visual and haptic feedback, is proven to promote superior motor performance for individuals suffering neuromuscular disorders [3]. As such, this study investigates a method to advance a custom restrictive brace for training improved muscle-level control of the upper-body for persons with motor disability using multi-sensory feedback approaches (Fig. 1). The first iteration of this custom platform includes a position-adjustable restrictive upper-extremity brace instrumented with skin-surface Delsys electromyography (EMG) sensors and vibration motors (haptic guidance cues). A primary feature of the brace includes gravity compensation for clinical populations, who have functional limitations preventing them from being able to maintain arm positions, to strength-train at elevated arm positions. This instrumented brace is also real-time compatible with custom-developed virtual reality environments for training reach and grasp actions (Fig. 2). While wearing the custom restrictive upper-body brace, patients receive visual feedback through the virtual reality headset by controlling a virtual avatar to complete a reaching task in the shortest and most effective path. The purpose of the virtual reality headset is to effectively train the user to complete dynamic rehabilitation for more effective assist device control.

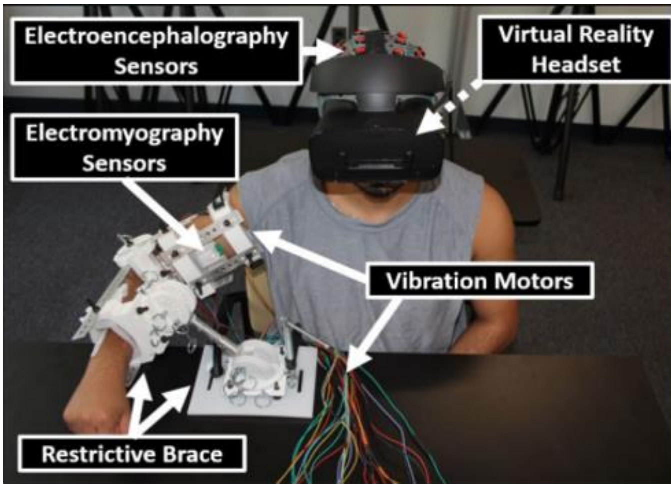

Fig. 1: Restrictive Upper-Extremity Brace

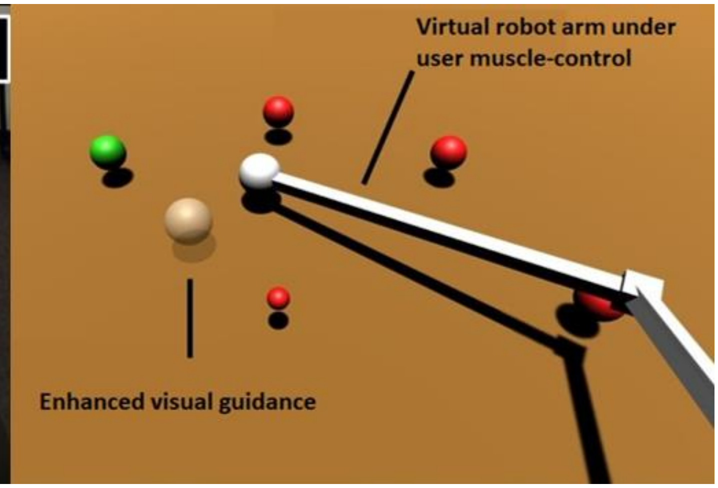

Fig. 2: Custom Virtual Reality Training Environment

The effectiveness of this novel restrictive upper-extremity device for training muscle control was evaluated through experimental testing conducted in our laboratory [4]. The study population included three able-bodied participants, who wore the novel upper-body restrictive brace for generating isometric contractions [4]. Participants were asked to apply orthogonal forces for 48 trials at different combinations of force levels and vibrations, while EMG muscle activity was measured from fourteen upper-body muscles: per trapezius, middle trapezius, lower trapezius, pectoralis major, anterior deltoid, posterior deltoid, serratus anterior, latissimus dorsi, biceps brachii, triceps brachii, brachioradialis, pronator teres, flexor digitorum, and extensor digitorum [4]. The findings of the study prove the novel restrictive upper-extremity device improved the able-bodied participant's control of a myoelectric assistive device and muscle control for greater independent function [4]. Despite positive findings during experimental testing of the novel restrictive brace on able-bodied participants, the device is largely a research platform (still in the early prototype development phases). This paper reviews the design process for creating an embodiment of the upper-extremity brace device that is more self-contained by embedding Myoware sensors onto the design through modular attachments (Fig. 3).

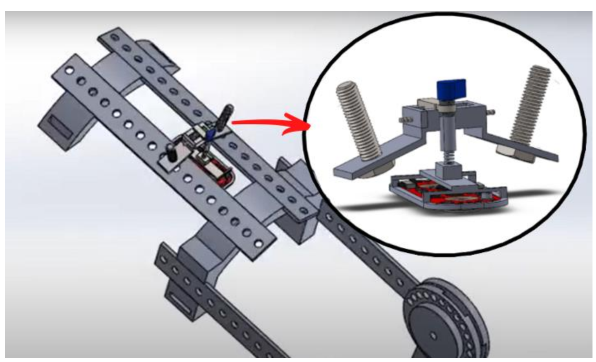

Fig. 3: Modular Attachment Attached to the Existing Restrictive Brace.

2. Methods

A more streamlined version of the novel upper-restrictive brace is created by utilizing lower cost EMG systems, such as Myoware Sensors. The widespread use of electromyography sensors for capturing muscle activation patters in real-time is limited due to high costs. As such, Myoware sensors are utilized in the next iteration of the upper-restrictive brace as a cheaper alternative to the expensive, research-grade (Delsys) EMG sensors previously used. The validity of Myoware sensors as an effective low-cost EMG system was determined through a study, which compared Myoware sensors with commercially available EMG systems during isometric contractions [5]. Two surface electrode sets were placed along the same Vastus Lateralis fiber line while the peak and mean contraction and contraction duration were analyzed between Myoware Muscle Sensors and a commercially available EMG system [5]. The results of the study verify that Myoware EMG sensors are reliable when compared to the more expensive, commercially available EMG systems [5].

A more self-contained version of this upper-restrictive brace device is created by embedding Myoware sensors directly onto the brace using modular attachments. Embedding Myoware sensors onto the brace design replaces the need to tape Delsys sensors onto each participant to ensure flush contact with each participant arm for robust EMG measurements and reliable transfer of haptic feedback. Enclosing Myoware sensors onto the device directly results in a more user-friendly rehabilitation system, which promotes at-home usage by eliminating the need for physical therapist supervision. The Myoware sensors are embedded onto the device through a modular attachment designed in Solidworks. The SolidWorks design utilizes bolts, sliding mechanisms, and springs to make the modular attachment position adaptable in three dimensions.

2.1. Customization of the Modular Attachment

The modular attachment is position adaptable along the y-axis using bolts (Fig. 4). The bolts of the modular attachment allow the design to utilize the perforations of the existing brace device. The bolts can easily be attached and detached from the brace and modified along the y-axis to suit each patient.

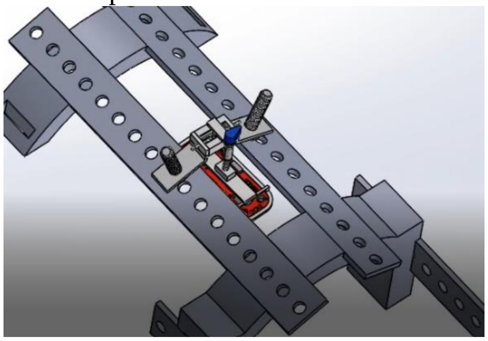

Fig. 4: The modular attachment attached to the existing restrictive brace through bolts.

The modular attachment is position adaptable along the x-axis using a sliding mechanism (Fig. 5). The sliding mechanism, comprised of a lead screw system, allows for the embedded Myoware sensor to move horizontally and lock in place to suit each patient's needs. The lead screw mechanism includes a threaded rod (not pictured) that translations rotation motion into linear motion. Lead screw actuators were selected in this design due to their cost-effectiveness and self-locking capabilities, which secures user configuration and maintains flush contact with the patient's skin for accurate sensor measurement. The slider also includes a placeholder for the spring-screw system, which ensures z-axis customization (further explained in Section 2.3).

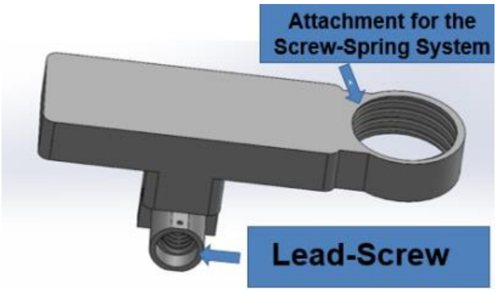

Fig. 5: The Lead Screw and Slider of the Modular Attachment.

The modular attachment is position adaptable along the z-axis using a flexible screw-spring system. The flexible screw-spring system allows for the embedded Myoware sensor to move vertically and adjust to each patient's user configurations (Fig. 6). The flexible spring system ensures that flush contact is made between a patient's skin and Myoware sensor as a patient contract and relaxes their muscles, guaranteeing accurate sensor measurements.

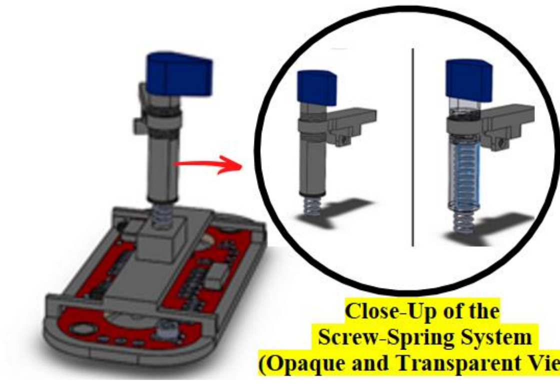

Fig. 6: The Screw-Spring Mechanism that Holds the Myoware Sensor.

3. Design Specifications

Future work involves manufacturing the modular attachment using Aluminium alloy 3003. Aluminium alloys are lightweight and durable, which enhances portability while maintaining mechanical integrity. This material selection results in a lightweight design weighing 0.219 kg. The substitution of Delsys research-grade EMG sensors with Myoware sensors result in a 72% price reduction, which allows the rehabilitation device to be more affordable and accessible to the public. The modular attachment of this neurorehabilitation device is customizable to patients of various ages, heights, and weights because it is position adaptable in three dimensions through the bolts that allow for y-axis customization, the slider with the lead-screw mechanism that allows for x-axis customization, and the flexible screw-spring system that allows for z-axis customization.

3.1. Potential Methods of Evaluation

Future work to validate the proposed designs effectiveness in clinical environments involves manufacturing the modular attachment. The device will undergo experimental testing with able-bodied participants to assure the functionality of this design in measuring EMG muscle activity. The usability, and acceptability of the modular attachment will be compared to the conventional research platform and evaluated by patients using the System Usability Scale (SUS) questionnaire.

4. Conclusion

Rehabilitation devices with continuous EMG sensor monitoring processes are critical for effectively conveying rehabilitation results to physical therapists for analysis. As such, a wearable rehabilitation device was designed and proposed to replace the existing models, which are expensive, complex, and often require the supervision of a physical therapist. The proposed design is more affordable, customizable, facilitates portability, user-friendly, and allows for at-home monitoring. Neuromuscular disorder patients, as well as clinical support staff and telehealth companies benefit from the increased clinician-patient interactions, which is geared to overall improve a patient's control of a myoelectric assistive device and muscle control for greater independent function.

References

[1] Jeppesen, T. "I.4physical Exercise Training in Patients with Neuromuscular Disorders." *Neuromuscular Disorders*, vol. 29, 2019.

[2] Demir, Yasemin Parlak. "Neuromuscular Diseases and Rehabilitation." *Neurological Physical Therapy*, 2017.

[3] Sigrist, R., Rauter, G., Riener, R., & Wolf, P. (2012). Augmented visual, auditory, haptic, and multimodal feedback in motor learning: A Review. *Psychonomic Bulletin & Review*, *20*(1), 21–53.
[4] Sanford, S. P., Collins, B. D., Liu, M., & Nataraj, R. (2021, August). *Vibrotactile Feedback for Improved Control of Myoelectric Devices*.
[5] Heywood, S., Pua, Y. H., McClelland, J., Geigle, P., Rahmann, A., Bower, K., & Clark, R. (2018). Low-cost electromyography – validation against a commercial system using both manual and Automated Activation Timing Thresholds. *Journal of Electromyography and Kinesiology*, *42*, 74–80.