AFFORDABLE EEG-BASED ELBOW EXOSKELETON

EXOSKELETONS AND NEUROMUSCULAR REHABILITATION

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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INTRODUCTION

Imagine the possibilities offered when neuromuscular abilities are amplified with the help of wearable robotics. The upper limb is involved in a number of daily life activities, so upper limb functionalities affect the quality of life (Keramiotou et al., 2020).

Individuals typically assume that neuromuscular diseases are only relevant to the elderly. However, experts across the world have provided arguments that younger generations are at risk as well and statistics that put the severity of the issue into perspective. In the United Kingdom, the increase in the prevalence of neuromuscular disease patients was observed in all age groups with an overall prevalence increase of 63% between 2000 and 2019 (Carey et al., 2021). In Ontario, Canada, between 2003 and 2014, the prevalence of neuromuscular disease patients increased by 8% per year on average. Although the neuromuscular disease prevalence increased in all age groups, younger adults aged 18-39 years were identified as the age group with the highest increase in neuromuscular disease prevalence with 11% per year (Rose et al., 2019). Additionally, a strong correlation exists between increasing upper limb neuromuscular disease prevalence in the younger generations and their exposure to electronic devices (Almomani et al., 2019). As electronic devices diversify and participate in larger portions of daily life activities, additional risk factors such as stress, sleep deprivation, and work environment contribute to even higher neuromuscular disease prevalence (Kazeminasab et al., 2022). In other words, neuromuscular diseases are beginning to influence a wider range of individuals regardless of age and residence.

Although no cure exists, numerous treatment methods exist. The current treatment methods for neuromuscular therapy can range anywhere from gene sequencing through therapeutic products to occupational therapy. Depending on the type of neuromuscular disease, certain methods are more effective than others (Dowling et al., 2017). However, neuromuscular treatments can seem unrealistic because of the financial cost. Amyotrophic Lateral Sclerosis (ALS), Duchenne Muscular Dystrophy (DMD), and Myotonic Dystrophy (DM) are major types of neuromuscular diseases. A 2014 research calculated the average total annual cost per person was $63,693 for ALS, $50,952 for DMD, and $32,236 for DM (Larkindale et al., 2014).

One treatment method of increasing popularity is the use of wearable robots, or exoskeletons. When a neuromuscular patient attaches the exoskeleton on the body, the exoskeleton will recognize and support the patient's intended actions. Exoskeletons are continuously diverging into multiple branches as researchers invent additional versions to meet specific needs (Lee et al., 2017).

While the exoskeleton industry is still at its early stages, our research will examine the effectiveness of exoskeletons as a neuromuscular disease treatment method. The technical section will describe ways the various features of the exoskeleton design proposed by my technical team serve as the solution to neuromuscular disease patients. The following section will analyze the sociotechnical impacts of exoskeletons by examining the change of relationships and roles between neuromuscular patients and physical therapists.

INTERNAL MECHANISM OF EXOSKELETON

Explaining the proposed exoskeleton design my technical team plans to build and analyzing the reasons why the proposed design is beneficial to neuromuscular disease patients is the goal of this section. Although exoskeletons are continuously evolving, most are designed by defining exoskeleton as a mechanical system consisting of sensors, actuators, and feedback control. An example that best explains the current state of the exoskeleton industry is the mechatronic design that has three components. The sensors measure the parameters of the user. The control system processes and activates the actuation system. The actuation system moves the exoskeleton. The team ends with a list of future improvements, implying that the exoskeleton industry is an evolving field (Vélez-Guerrero et al., 2021).

A major task in the technical portion of the research is building an exoskeleton with the technical team members. The exoskeleton design proposed by my technical team includes four components: sensors, actuators, feedback control, and mechanical design. Although inertial measurement unit (IMU) and electromyogram (EMG) sensors that measure muscle signals are popular (Ganesan et al., 2015), crucial disadvantages, such as inconsistent signal quality and unknown muscle excitation magnitude, exist. For this reason, the exoskeleton design will utilize electroencephalogram (EEG) sensors to directly, accurately, and efficiently extract brain signals indicating the magnitude of muscle excitement (Lee et al., 2022). Once brain signals are collected by locating sensors on the scalp, machine learning (ML) techniques are utilized to recognize the intended action. The ML technique for EEG processing is undecided, but the team must recognize that various ML techniques have respective advantages and disadvantages. If implemented successfully, ML offers exact and fast interpretations of the EEG with constantly improving performance over time (Hosseini et al., 2021). Since finding an appropriate ML technique is the priority, the current scope of the exoskeleton design is one degree of freedom: 135° rotation around the elbow.

The interpretation of EEG signals is delivered to an actuator that moves the exoskeleton. When selecting an actuator, two factors are prioritized: the masses of the exoskeleton parts and the actuator strength (Kavalieros et al., 2022). Based on experiments, pneumatic artificial muscles (PAM) can generate about 5-10 times greater force and 4-9 times greater energy-to-mass ratio than single-acting cylinders (Deaconescu & Deaconescu, 2022). For this reason, PAMs, which imitate flexion and extension of human muscles by varying the internal pressure, are chosen as actuators. Figure 1 below visually represents the internal mechanism of the proposed exoskeleton design described above. The cycle indicates feedback control where the output of a step is taken as the input of another step.

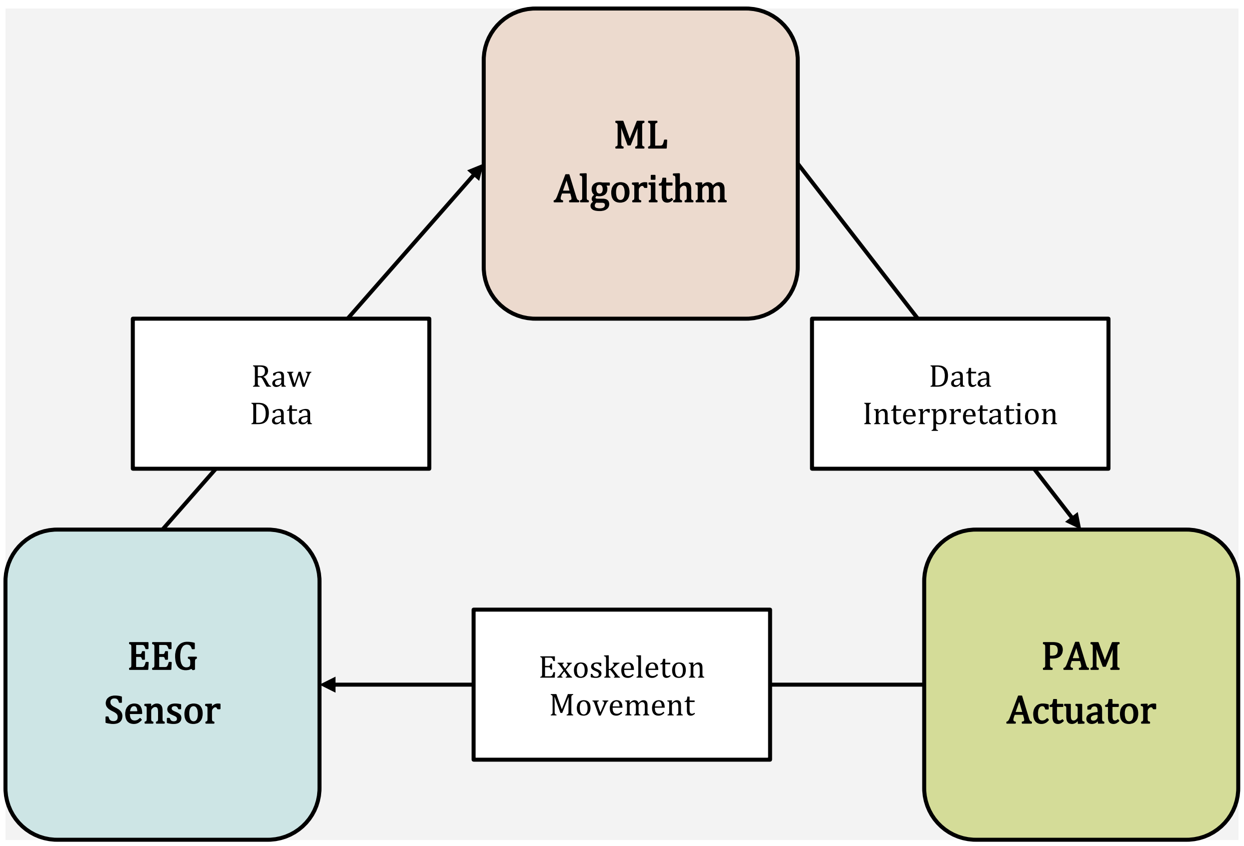

Figure 1. The internal mechanism of the exoskeleton design proposed by the technical team members (Created by Lee, 2022).

The mechanical design aspect of the proposed design refers to 3D-printed parts. Constructing a 3D-printed exoskeleton enhances user experience. Some explicit advantages include affordability, reproducibility, and portability. In other words, lightweight parts allow the users and actuators to easily move the exoskeleton while minor adjustments are required for users of various sizes to acquire an exoskeleton they can use at home (Esposito et al., 2022).

The proposed exoskeleton design is an effective solution to neuromuscular disease patients. The technical advisor, Professor Sarah Sun, believes that an exoskeleton composed of EEG, ML, PAM, and 3D-printed parts is a rare combination that may contribute significantly to the evolving exoskeleton industry. While the combination of EEG, ML, and PAM provides functional advantages such as quick and detailed detection of and response to user intention, 3D-printed parts offer additional characteristic advantages such as cost, weight, production, portability, and independence.

When implemented correctly, exoskeleton is a powerful technology that offers an independent and affordable treatment method to neuromuscular patients. However, the effects of exoskeleton on the current standards of neuromuscular rehabilitation must be considered as well. In other words, exoskeleton is a powerful technology that exerts influence beyond neuromuscular patients.

EXOSKELETON IN NEUROMUSCULAR REHABILITATION

The purpose of this section is to evaluate the sociotechnical effects created by the introduction of exoskeletons, specifically the change of relationships and roles between physical therapists and patients. The neuromuscular rehabilitation process is a set of arduous, lengthy steps for physical therapists. According to the American Physical Therapy Association (APTA), a person spends more than three years completing a Doctor of Physical Therapy program and passing the National Physical Therapy Examination after earning a bachelor's degree (APTA, 2022). A physical therapist typically spends 30-45 minutes per day, 4-5 times per week, and 8 weeks per patient (Louie et al., 2021). Another issue is physical therapist shortage where the aging population and increased public medical interest cause increased demand (Zhang et al., 2020). In contrast, physical therapist supply is declining due to the fear of COVID and poor working conditions. As a result, exoskeletons are gaining popularity. Exoskeleton increases the independence of a patient by allowing freedom of long duration exercise. Accordingly, the role of physical therapist shifts from guiding exercise activities to monitoring patient progress, which minimizes the spread of COVID by preventing physical contact. As exoskeletons improve, the marginalized social group may change from neuromuscular patients experiencing disability to physical therapists losing necessity (González-Mendoza et al., 2022).

However, no technology is perfect, and an unpromising technology is rejected by individuals. Research on utilizing exoskeletons to prevent injuries of construction workers observed that some construction workers rejected exoskeletons due to reasons like lengthy training process and injuries due to exoskeleton failures (Choi et al., 2022). Another long-term challenge for successful implementation of exoskeletons is the additional cost, such as time and research effort, necessary to persuade the individuals by ensuring the credibility of exoskeletons.

In order to further analyze the sociotechnical aspects of exoskeleton, Bruno Latour’s arguments are noteworthy. Latour’s major argument is the Actor-Network Theory, which perceives the world as an enormous network of intertwined influential relationships amongst numerous actors of the network. In other words, Latour’s argument serves as the midpoint between technological determinism and social construction of technology where even the most miniscule actor is able to affect other actors. Parts of Latour’s arguments especially valuable when considering the sociotechnical effects of exoskeleton are *delegation* and *program of action*. Delegation, in general, means transfer of work. Delegation to nonhuman is when an artifact takes over the manual work of humans. To better explain delegation, Latour identifies a groom that closes a door instead of humans as an example. Program of action is when a technology reflects human value. As an example, Latour mentions a seatbelt that must be on when a car is moving (Latour, 1992). The use of exoskeletons in neuromuscular rehabilitation aligns with Latour's arguments because the manual procedures conducted by physical therapists may be assigned to exoskeletons. Hence, arguments by Latour represent the foundation of the research strategy.

RESEARCH STRATEGY

To explore aspects of exoskeleton, I will pursue the research question, in what ways does exoskeleton alter the conventions of neuromuscular rehabilitation? The scope of the research question only refers to neuromuscular diseases related to the elbow to stay consistent with the proposed exoskeleton design. The research topic is valuable for analyzing the long-term technical and sociotechnical effects of exoskeleton implementation while the exoskeleton industry is at its infancy.

In terms of the evidence collection, participant observation of rehabilitation procedure will be conducted. The technical advisor, Professor Sarah Sun, recommends completing the exoskeleton prototypes by the end of the Fall 2022 semester. Then, the plan is to bring the prototypes to the University of Virginia hospital, test the prototypes on the intended users, and receive comments on improvements. Keeping the ANT framework in mind, participant observation will gather evidence on the impact of exoskeleton by conducting separate observations of rehabilitation procedures with and without exoskeleton.

In terms of data analysis method, thematic analysis of agency reports is the most appropriate. Thematic analysis is when patterns in a set of qualitative data are identified (Kiger

& Varpio, 2020). Given the combination of participant observation and thematic analysis, a significant number of hours must be devoted to gathering data from a diverse set of individuals. If successful, a valuable set of insights on the effects of exoskeleton on neuromuscular rehabilitation should be gathered.

CONCLUSION

This research evaluates the effectiveness of exoskeleton as a neuromuscular rehabilitation technology by discussing its technical and sociotechnical aspects. The proposed elbow exoskeleton design is a realistic solution that offers advantages such as low cost and weight and high production and responsiveness to neuromuscular patients. However, successful implementation may also bring sociotechnical effects like marginalization of physical therapists. While the exoskeleton industry is infant, proper research on the ways exoskeletons may alter the neuromuscular rehabilitation industry must be conducted. The more exoskeletons evolve, the more influence exoskeletons exercise on the standards of neuromuscular rehabilitation.

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