LIMITATIONS AND BARRIERS OF EXOSKELETON REHABILTIATION ADOPTION

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By

Abigail Kong

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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.

ADVISOR
Catherine D. Baritaud, Department of Engineering and Society

INTRODUCTION TO EXOSKELETON USE FOR STROKE REHABILITATION

According to the CDC, stroke is the leading cause of long-term neurological disability and a leading cause of death in the United States. Strokes occur when a blockage or vessel rupture disrupts blood flow, which carries oxygen and nutrients, from reaching the brain (About stroke, n.d.). The severity of post-stroke conditions varies depending on the obstruction's location and the extent of brain tissue affected. Physical complications include spasticity and decrease in muscle strength, which can lead to long term pain or discomfort for patients. Progressive decrease in muscle movement due to loss of muscle fiber cross-sectional area is also experienced by patients. As a result, basic tasks can be difficult to accomplish.

Stroke rehabilitation can substantially improve a patient's function. While it does not reverse their brain damage, it can help them regain independence. One method of receiving rehabilitation is through visiting physical therapists who work through exercises and stretches with patients. Occupational therapists can also be visited to receive help practicing daily tasks like eating and bathing. Other rehabilitation techniques include mirror therapy, bilateral movement training, and mental imagery training. However, this common stroke rehabilitation treatment method of seeking out therapists who provide guidance through exercises will not be able to support the number of patients projected in the future. Additionally, Chet et al. (2020) pointed out that "therapist-led rehabilitation treatments require intensive labor, and typically are time-consuming" (p. 1).

The STS thesis seeks to identify the challenges of exoskeleton use for stroke rehabilitation. Greenbaum (2015) explained that exoskeletons are a type of wearable technology that "replace diminished or lost limb functionality, helping people regain some ambulatory freedom" (p. 1). Exoskeleton based therapy has been sought after in the stroke rehabilitation world due to its claims for shortening hospitalization time and minimum need of human intervention. Yet, while exoskeletons have been designed and developed since 2000, many of them have never been used by target population (Heide et al., 2014). By examining case studies on various exoskeleton and similar devices through the lens of Actor-Network Theory, which was developed by STS scholar Michel Callon (1986), the relationships and conflicts between actors will reveal what limitations and barriers are hindering the potential of exoskeletons. This theory will aid in this paper's goal to investigate controversies surrounding rehabilitation exoskeletons. It will also draw focus on how the power to drive change is not dependent upon individual actors but rather dependent upon the relations between them.

In efforts to provide post-stroke patients an improved quality of life and means to regain muscular function, the technical work aims to design and prototype a 3D printed low-cost exoskeleton. It will assist patients during upper limb rehabilitation, specifically the shoulder and elbow, using stepper motors, gearboxes to increase torque (Gandolla et al., 2020), pneumatic artificial muscles, and sensors. The development of this model will offer unique qualities such as being more accessible to patients and having an open-source design for future developers, while also providing patients with reliable and controlled rehabilitation exercise.

Joining the STS research with the technical research will allow for the identification and implementation of factors that make an exoskeleton design successful. While the use of exoskeletons in stroke rehabilitation is promising, a design is only valuable if stroke patients are able and willing to employ it. Therefore, the perspectives of a variety of actors must be considered when producing a working exoskeleton.

ACTORS VERSUS EXOSKELETON POTENTIAL

Actor-Network Theory allows for the visualization of power dynamic relationships that are formed and changed through the construction and maintenance of networks (Rodger et al., 2009). It identifies relevant social groups, objects, beliefs, and interactions between them. To fully understand the controversies regarding exoskeletons, both non-human and human actors should be analyzed with equal attention and contribution. Figure 1 illustrates the Actor-Network Model in relation to the introduction of exoskeletons used for stroke rehabilitation.

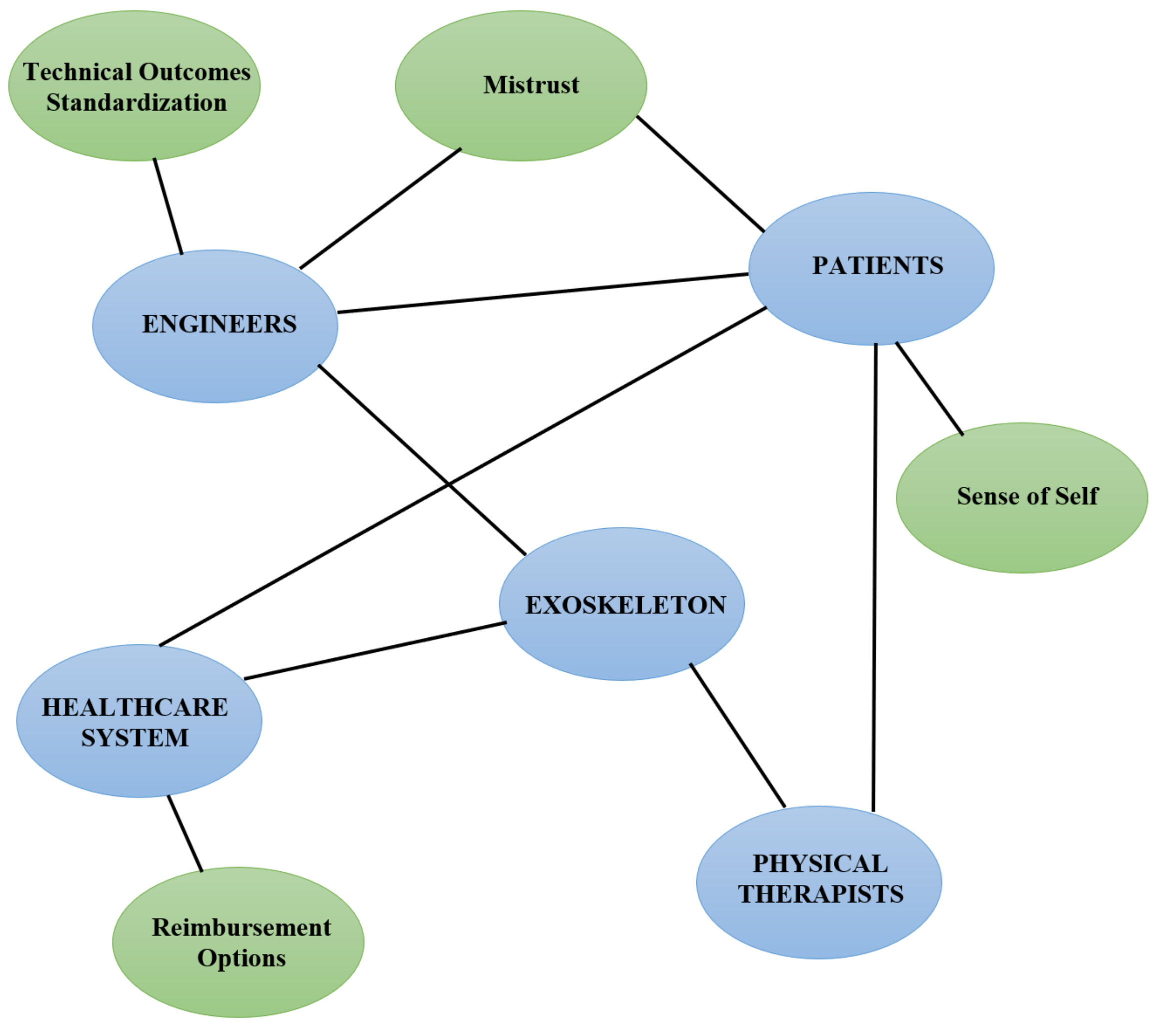

Figure 1: Actor Network Model: The construction of this network describes controversies between actors, which will explored to understand how they influence the potential of rehabilitation exoskeletons for stroke patients (Rodger et al., 2009).

Translation is a concept of Actor-Network Theory that describes the process by which a network is built and established. In the words of Michael Callon (1986), "[Translation] attaches characteristics to [entities] and establishes more or less stable relationships between them. Translation is a definition and the delineation of a scenario" (p. 26). Each actor mentioned in Figure 1 has their own interests and interpretation regarding the potential of rehabilitation exoskeletons. As actors shift their interpretation about the problem by drawing on those of other actors, new adaptations arise and translation has taken place. Figure 2 depicts the stages of translation.

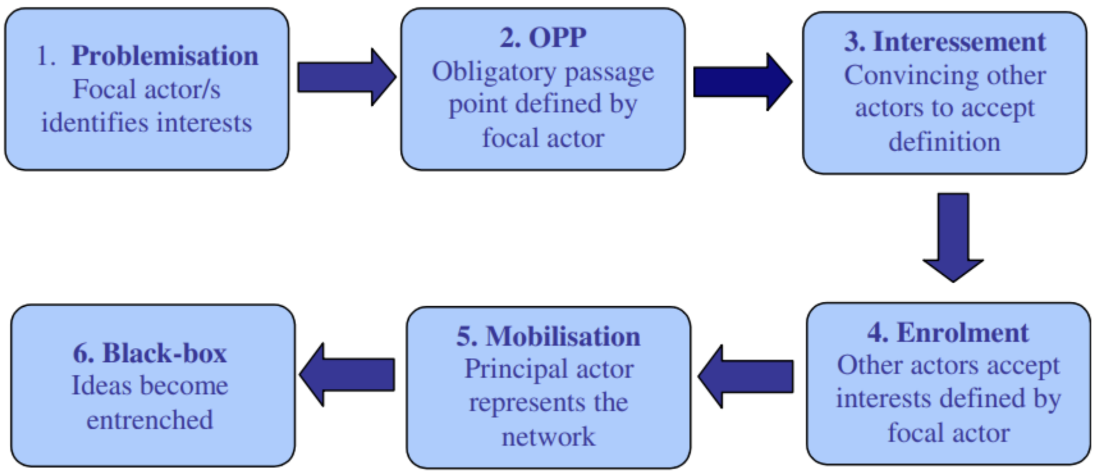

Figure 2: The Process of Translation, as adapted from Rodger et al. (2009, p. 648): Translation is a continuously changing process that forms the network and drives communication between actors. Cooperation of actors to give attention and understand the interest of other actors leads to a successful network where solutions to controversies may form (Cai & Guo, 2020).

Translation emphasizes the standpoint that the advancement of change will occur when actors take the time to understand each other's perspective. Therefore, analyzation of exoskeleton adoption must include the establishment of the identities and conditions of interaction between actors.

LACK OF DESIGN IMPROVEMENT

An increasing rate of emerging exoskeleton technologies signals a clear indication of high interest in developing devices for individuals with weak muscular function. However, this path of enthusiasm has encountered a low acceptance rate from stroke patients (Bergsma et al., 2015). Advancement in exoskeleton design and adoption are suffering due to the current condition of a poor balance between the functional benefit of exoskeletons and individual's burden of using the devices. One explanation can be accredited to the conflict of engineers not understanding what makes a design suitable for stroke patients. There is limited research conducted to determine the variables behind adoption rate and how to integrate them into the development process. Additionally, engineers are exhibiting difficulty in targeting design efficacy and usability because there is a lack of standard outcome measures that evaluate rehabilitation exoskeletons (Janssen et al., 2019). As a result, the progress of significant exoskeleton development has been restricted. Further aggravation to this conflict is due to the tendency of engineers to place more weight on technical outcome than the patient's experience. Context of stroke patients should be included because exoskeleton technology success should be based on availability, comfortability, and cost decisions in addition to muscular function improvement (Janssen et al, 2019).

Another explanation for unchanging levels of user adoption and minimal exoskeleton design development is engineers are not encouraging advancements in their field of work. Analysis of a database of dynamic arm supports by experts in assistive technology revealed that there is limited diversity of technical designs and functionalities in current and developing products. Additionally, interfaces are too complex and inputs for exoskeleton operation are not intuitive for stroke patients (Heide et al., 2014). Engineers have unknowingly cornered themselves into a position of constant reinvention rather than properly addressing the issues of past designs through innovation. As Heide et al. (2014) noted, “although many devices have been developed, those that disappeared were succeeded by similar devices in functionality and technical design” (p. 299). It is important for engineers to evolve exoskeleton technology with the stroke patients’ needs and desires in mind rather than only creating a technology that impresses and meets their technical goal. Ultimately, lack of design improvement leads to a small number of exoskeletons being commercially available and an even smaller number of exoskeletons offering unique characteristics to stroke patients.

DISPELLING THE GLAMOR OF NOVEL TECHNOLOGY

A predicted shortage of therapists and developing technology has contributed to the proposal of employing exoskeletons to help facilitate the rehabilitation process. The perspectives of therapists can help forecast the conflicts exoskeleton-based therapy may encounter when aiding stroke patients, as therapists have the expertise to identify what makes rehabilitation successful or not. While an alleviation of labor is desired by therapists, they stand firm in the fact that their role is critical for stroke patients to receive optimal rehabilitation results. Thus, their reservations regarding the potential adoption of exoskeletons originate from high skepticism of the new technology’s capabilities and unfamiliarity with new rehabilitation methods (Dijkers et al., 1991). The problem of a communication gap between clinical knowledge and technical knowledge presented itself clearly to therapists during their interaction with exoskeleton models (Vaughan-Graham et al., 2020). For example, it was noted in a study on patient and staff acceptance of robotic technology in occupational therapy that “many therapists may stop using devices if set-up takes more than 5 minutes” (Maciejasz et al., 2014, p.12). Therefore, a concern emerges with the adoption of exoskeletons in that if physical therapists, a figure that patients look towards for help, find the device bothersome to set-up then patients will mirror the same opinion and have less desire to pursue exoskeleton-based therapy.

Therapists present the argument that the adoption of exoskeleton should not be taken quickly simply because it is a new high technology method towards rehabilitation. New equipment must be able to withstand the tolerance of patients and not be too complicated, provide satisfactory feedback, and be able to be in use for long periods of time in their judgement before reaching full acceptance (Dijkers et al., 1991).

DOUBTS ABOUT PROMISES OF EXOSKELETON TECHNOLOGY

There has been a voiced opinion of rehabilitation exoskeletons being a prime medical device by individuals with mobility impairments. For example, after evaluating several designs and learning about the potential health and social benefits of using exoskeletons, a survey found that wheelchair users were eager to use and recommend an exoskeleton (Wolff et al., 2014). This level of reception has been mirrored by stroke patients who have hope for exoskeletons augmenting muscular function. However, other case studies have reported that exoskeletons in rehabilitation programs will be met with conflicted thoughts because doubts and fears of technology will inevitably have weight over enthusiasm for possible improvements in functional abilities (Kinnett-Hopkins et al., 2020). The relationship between mistrust in the hope of exoskeletons potential and stroke patients has resulted in a negative impact on the adoption of the technology. One case study indicated that patients receiving robot-assisted therapy demonstrated similar motor function improvement as the patients that received usual care or intensive therapy after 12 weeks. Frustration about the restrictive nature of exoskeletons or disappointment that the technology did not meet their expectations, formed from advertisement of promising solution, explains why patients are distant to the option of exoskeleton as a rehabilitation treatment. Exoskeleton designs and promotions of their abilities by engineers and the healthcare system must be adjusted to maintain interest of the target population.

PSYCHOLOIGCAL IMPACTS OF EXOSKELETON USE

A stroke patient’s use of exoskeleton to rehabilitate their functional abilities inevitability will stimulate the conflict of an altering sense of self. Positive experiences with exoskeletons may result in the restoration of independence and feeling of control to recover from stroke effects. For instance, individuals with spinal cord injury who participated in a study on the use of robotic locomotor exoskeletons expressed that their experience of being able to walk with the aid of the device led to hope for the prospect of regaining their ability to walk routinely (Kinnett-Hopkins et al., 2020). Yet, while the study reported on the positive implications of exoskeletons, it failed to address the psychological impacts exoskeletons have on patients. A study on assistive devices for decreased arm function claimed that “no device will be as efficient as the healthy human arm” (Heide et al., 2014, p.12).

This bothering experience of assistive devices never fully having the capacity to replace weak muscles use can be generalized to explain why stroke patients are weary of the results exoskeleton will deliver to them during rehabilitation. In a study that provides end-users’ perspectives on exoskeleton use in post-stroke gait rehabilitation, stroke patients noted that the device dominated them and directed their exercises rather than themselves training their muscle motor control with the assistance of the device. As a result of the disconnect between the patient and the device, the patients did not feel that their walk was natural at the end of the study

(Vaughan-Graham et al., 2020). Patients being forced to depend on exoskeletons during their rehabilitation exercises will eventually foster a negative sense of identity. The fickle interaction between a sense of self and stroke patients may dissuade patients from beginning or continuing exoskeleton use as a rehabilitation method. Despite these difficulties and negative remarks, McDonald et al. (2022) reported that participants in their study "considered RAGT [robotic-assisted gait training devices] as useful and beneficial and would choose to add RAGT to their rehabilitation programme, if given the choice" (p. 7). This contrasting finding indicates that the presence of exoskeletons still has an encouraging future in the medical sphere if promotions of their impact by engineers and the healthcare system are adjusted to maintain the well-being of patients.

THE FIGHT FOR ACCESSIBILITY

Accessibility has proven to be a main element that contributes to the barriers of exoskeleton potential for rehabilitation adoption. The power dynamics between stroke patients and engineers reveals the problem of insufficient effort being put to commercializing exoskeleton models. The slow technical development of engineers working towards refining their models and technology has resulted in a small number of exoskeletons being brought into the market (Heide et al., 2014). The power dynamic between stroke patients and healthcare brings to attention further explanation as to why accessibility to exoskeletons has proven a challenge. Financial burden of purchasing access to rehabilitation exoskeletons has turned patients away from the possibility of using the technology. However, for the stroke patients that still have a desire to experience exoskeletons despite the high cost, limited reimbursement options and device availability (Janssen et al., 2019) will still restrict their selection of exoskeletons.

Patients that require less intensive rehabilitation exercises and programs prefer home-based therapy rather than visiting a hospital or rehabilitation center. Yet, many exoskeleton models cannot be used in home situations due to safety issues or their size (Heide et al., 2014). As a result, stroke patients are left with accessing exoskeletons only at therapeutic institutes to be supervised and assisted by therapists (Maciejasz et al., 2014). The conflicts of an unfavorable cost-benefit ratios, limited commercialized exoskeleton models, and restricted access to the technology participate in the explanation of low user adoption rate for exoskeleton-based therapy.

FUTURE IMPLICATIONS FOR EXOSKELTON REHABILITION ADOPTION

New and developing exoskeletons do not properly address the common frustrations of previous exoskeleton designs. Despite so, the potential of exoskeletons for rehabilitation survives through the positive hope of improved function demonstrated by patients suffering with muscular issues. Engineers need to reflect on and integrate the target population's response to their exoskeleton technology before moving onto another design. Therapists should shift their disproving attitude towards new rehabilitative technology to accommodate their patients' eagerness to explore exoskeleton-based therapy. Patients should also shift their interpretation of exoskeleton capabilities and be prepared for their high expectations not to be met, despite questionable promises being advertised to them. Engineers and the healthcare system should prioritize the psychological impacts of the technology they are promoting to sustain prospective patient interest. Lastly, the healthcare system needs to address and take action to supporting patients' high interest demand of exoskeleton use by making the technology more accessible.

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