Dual Use of Medical Exoskeletons in the Military

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Olivia Mabe

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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

Rider W. Foley, Department of Engineering and Society

Introduction

Neuromuscular disorders affect hundreds of thousands of people around the world (Deenen et al., 2015), yet there is currently no cure. This wide variety of conditions disrupts the nervous system and results in progressive loss of muscle control. Treatments include improving the quality of life for the patients and aiding them in their day-to-day lives (Cedars-Sinai, 2021). One such method of helping patients cope with muscle loss is the use of robotic exoskeletons. Robotic exoskeletons are wearable robotic systems that assist the wearer with their motion, with studies showing promising results of their use in rehabilitation (Gorgey, 2018). There are, however, many technical and sociological factors to consider when designing this technology. Ultimately, this paper will be answering the question: How do robotic exoskeletons and humans interact?

I am part of a project designing and fabricating a robotic exoskeleton arm for patients with neuromuscular disorders to help the patients regain arm function and mobility. Successful implementation will improve the standard of living for patients and allow them to move more freely and independently. However, such technology has the power to be expanded to uses beyond healthcare. Militaries have already taken steps to apply this technology, including full-body exoskeletons, in combat settings, bringing up numerous ethical and social concerns. This paper explores how this medical technology could be used to harm instead of heal and how this technology could interact with and affect social systems related to the military.

Case Context

Exoskeletons are mechatronic systems with electronic sensors, actuators, analog and digital circuits, a mechanical structure system, and feedback control. Sensors placed on the wearer's arm measure electromyographic (EMG) signals from the contraction of the arm muscles and respond with soft pneumatic actuator motion to help the wearer achieve their desired motion. This can improve mobility, stamina, and accuracy for the wearer. In military applications, exoskeletons can allow soldiers to carry heavier loads, decrease fatigue (Yeem, Heo, Kim, & Kwon, 2019), and improve weapons aiming. Though the technology for full deployment of exoskeleton-wearing soldiers has not yet been fully developed, certain features of military exoskeletons already exist. For example, the U.S. Army has developed a robotic exoskeleton arm that increases weapons aiming accuracy significantly using tremor-canceling technology originally developed for people with Parkinson's disease (New Army Exoskeleton, 2015).

ISTA and Dual Use Frameworks

This paper explores how medical exoskeleton technology could be used in the military and how this technology could interact with and affect social systems involving the military. To do this, the Interactive Sociotechnical Analysis (ISTA) framework was applied to dual use of exoskeleton technology. ISTA is a model for sociotechnical systems that includes workflows, culture, social interaction, and technologies. It analyzes recursive technological feedback loops and unintended consequences of technology, based on the idea that sociotechnical organizations are dynamic and interconnected. ISTA is built upon several research areas and underlying theories. Sociotechnical systems (STS) research contributes the concept of dynamic interactions between social subsystems, technical subsystems, and environments. Ergonomics and social construction of technology studies examine the interconnection of technologies, individuals, and physical environments, with the former analyzing the effect of technologies and environments on individuals and the latter analyzing how technology users help change or create technologies.

Technology-in-practice shows how technologies mediate use within a society, demonstrating the recursive nature of STS systems. Social informatics, the final research field from which ISTA draws its basis, acknowledges the embeddedness of technologies both within specific organizations and in broader social contexts (Harrison, Koppel, & Bar-Lev, 2007).

This model is used in conjunction with dual use studies, which analyzes technologies that have both intended and unintended uses, both often dissimilar or contradictory. It informs debates for engineers and administrators about morals and responsibilities when developing a technology (Forge, 2010). Dual use studies can be broken into four groups: political, security, intelligence, and military (Mahfoud, Aicardi, Datta, & Rose, 2018). Since most exoskeleton uses are and are projected to be in military, this is the subsection I focus on in this paper. Also, because exoskeleton technology has not yet been developed to the point at which it can be used widely in militaries, this paper largely analyzes anticipated rather than observed social interactions of the technology.

The ISTA model involves looking at several types of interactions between social systems, the technology-in-use, the new technology, and technical and physical infrastructure. These interactions are depicted in the figure below, labeled one through five.

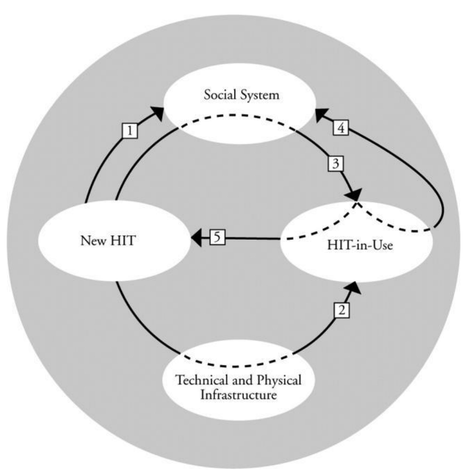

Figure 1. Interactions within sociotechnical systems (Harrison, 2007).

The first type of interaction is new technology changing the existing social system. For medical exoskeletons, this could mean more social inclusion of persons with neuromuscular disabilities due to greater autonomy and mobility (Ambrosini et al., 2014), but it could also mean a shift toward ableism and stigmatization of exoskeleton-wearing groups (Kapeller et al., 2020). For military exoskeletons, this could mean dehumanization of exoskeleton-wearing soldiers (Greenbaum, 2015). The second type of interaction is technical and physical infrastructures mediating technology use. Insurance infrastructures could dictate who receives rehabilitory exoskeletons and who does not (Greenbaum, 2015). Advances in direct-fire weaponry infrastructure could prompt further development and use of military exoskeletons (Kott, 2019). The third ISTA interaction is social systems mediating technology use. This is difficult to anticipate before full implementation of the technology, and thus is not analyzed in this report. The fourth is technology-in-use changing social systems, which for medical applications could involve a change in societal opinion or use of data tracking due to monitoring devices in the exoskeleton. Military exoskeletons could result in changes in legislation and regulation regarding wearable robots and weaponry definition (Harrison and Kleffner, 2016). The final interaction is technosocial system interactions resulting in technology redesign. I will be discussing these interactions with regards to both medical and military uses of exoskeleton technology and comparing the results.

Research Methods

The question that this paper intends to answer is how the medical technology of rehabilitation exoskeletons used in military settings could interact with and affect social systems using the frameworks described in the previous section. This is a particularly significant topic when considering the unintended physical and sociological consequences of technology development, which could have serious and unchecked impacts in the world. The research method used to answer this question is case study research. Case study research is an observational study that investigates a concept within real-life context using empirical data to help develop theories. Multiple case design, as compared to single case studies, contributes to forming a theoretical framework for a wide variety of variables (Ridder, 2012). The sources for data collection include prior literature, historical data, expert interview reports, agency reports, and legal cases, examples of which are shown in the previous section. All data collected is analyzed through the ISTA and dual use frameworks. Examples of each of the applicable ISTA interaction types are analyzed for both medical and military exoskeletons and used to come to a conclusion on the effects of the technology in both settings.

Results

Medical exoskeletons result in improved social inclusion and quality of life for individuals with mobility disorders while also creating significant issues such as insurance companies dictating who can receive a rehabilitory exoskeleton and a possible societal shift toward ableism. Military exoskeletons, on the other hand, have the possibility of altering modern warfare by introducing enhanced, dehumanized soldiers and influencing legislation regarding and further development of robotic weaponry.

Type 1: New technology changing the existing social system

The creation and implementation of new technologies often greatly impacts existing social systems. For medical exoskeletons, one expected change is more social inclusion of persons with neuromuscular disabilities due to greater autonomy and mobility. Usability studies show that exoskeleton use allows more locations and activities to become available to people with mobility impairments (Ambrosini et al, 2014). However, one caveat to this is that it could result in a societal shift toward ableism and stigmatization of exoskeleton-wearing groups. There is a concern that wearable robotic technology could promote having a "standard body" and "fix" certain body functions, as if the issue were a technical problem in need of a straightforward technical solution. This is far from the truth, ignoring the human factors involved and implying that disabilities are inherently bad, which is a harmful ableist assumption (Kapeller et al, 2020).

An anticipated effect of exoskeletons on the military is the dehumanization of warfare. Turning soldiers into "quasi-machines" has significant implications on both how battles are fought and how soldiers are treated. Soldiers equipped with exoskeletons can carry far heavier loads, cross more difficult terrain, perform for longer periods, and have greater aim. An excellent example of this is Lockheed Martin's Human Universal Load Carrier (HULC), allowing soldiers to carry loads up to 91 kg (*Human universal load carrier,* 2020). This could mean intensified fighting in previously inaccessible locations, changing the nature of ground warfare. This could also mean that the soldiers would be treated more as machines than humans. Soldiers may be overworked, mistreated, or put in more dangerous positions than they would be otherwise. Human augmentation for performance is a very ethically concerning topic, and use of military exoskeletons could be a tipping point in the conversation (Greenbaum, 2015).

Type 2: Technical and physical infrastructures mediating technology use

Existing infrastructures often govern how a new technology is used. In medical settings, this includes insurance infrastructures dictating who receives rehabilitory exoskeletons. The technology is currently very expensive, necessitating that patients pay for it with insurance, but this means that the power is with the insurance companies. Many insurance plans would likely not cover exoskeletons, meaning that only certain insured people would benefit from them and limiting their use, similarly to the limitations on insulin in the United States (Wintergerst et al., 2010). This contributes to the social dilemma of healthcare and opportunities being limited to those wealthy enough to afford them and the question of whether disabled persons have a right to such technology (Greenbaum, 2015).

Advances in the military infrastructure of mobile direct-fire weaponry could prompt further development and use of military exoskeletons. Technological growth of mobile weapons has occured as long as warfare has existed and can be modeled and predicted. Following historical trends, it has been predicted that the power of soldier-carried weapons will match that of current machine guns within 30 years. Wielding this technology, either a weapon derived from machine guns or an entirely new technology, would likely require the soldier to wear an exoskeleton. This could spur new developments in military exoskeletons and solidify the technology in combat applications (Kott, 2019).

Type 4: Technology-in-use changing the social system

Technology-in-use refers to the technology in its actual use rather than intended use. This unintended use can lead to changes within the social system. In both medical and military applications there is a threat of exoskeletons being hacked, creating two potential problems for the wearer: being tracked and losing control of the robot. Monitoring could violate the wearer's privacy, particularly in medical settings, and lead to a shift in societal opinion on and frequency of data tracking. Losing control of the robot would pose a safety risk for any wearer, but could become a serious ethical problem if a weaponized soldier is no longer in control of their movements (Kapeller et al, 2020).

Another example of this interaction in the military is changes in legislation and regulation regarding wearable robots and the definition of weaponry. Weapons developed by a particular state must follow the guidelines of approval by that state, with a number of states following Additional Protocol I of the Geneva Conventions, which requires reviews of and prohibits some new weaponry. An issue that arises from military human enhancement is the point at which the technologies require this approval, since there is a question of whether the technology is a weapon or a method of warfare. Superfluous injury and unnecessary suffering are major points in international law, but there is some ambiguity in whether this only includes weapons intended to cause unnecessary suffering or if weapons that can but are not designed to cause suffering should be included as well. As an example, in the case of human enhancement, if countermeasures against enhanced soldiers are developed that would cause greater suffering for unenhanced soldiers, they would remain legal even if unwittingly used against unenhanced soldiers. These complications that arise from military exoskeletons have the potential to change social and legal standards that could impact other aspects of militaries and warfare (Dinniss and Kleffner, 2016).

Type 5: Technology-social system interactions result in technology redesign

Interactions between new technology and social systems can result in redesigning of the technology. Because of this technological feedback loop, soft exoskeletons are becoming more common in medical settings. Exoskeletons are more commonly being used by patients with delicate physiology, and thus the technology must be very safe and functional. Most traditional exoskeletons are rigid and use motors, which is far from the true biology of the wearer and can be too heavy and discontinuous for safe rehabilitative use. Soft exoskeletons match the wearer's biology much better by using soft actuators such as McKibben artificial muscles, which are air-powered tubes that mimic actual muscles. Soft technology such as this allows the robot to be lightweight, compliant, and gentle, which has become clear to be essential for medical applications (Daerden and Lefeber, 2002).

In the military, exoskeletons are valued for increasing soldiers' ability to carry heavy loads. As the technology has developed, more emphasis has been placed on utilizing them in intense situations and on rugged terrain. This has led to the technology becoming more versatile, personalized, and intelligent (Zhou et al, 2020). An example of this is Lockheed Martin's Onyx Exoskeleton, designed specifically to assist wearer with intense leg motion, using AI to predict the intended motion and conforming to the wearer's body, greatly improving their strength and endurance (Watson, 2019).

Discussion

Rehabilitory exoskeletons reflect a societal shift toward equality and respect for disabled persons. They have the potential to benefit many lives and progress society further toward equality, though with some risks that could defeat the purpose, as with any well-intended technology. Military exoskeletons have the capability of changing social systems within militaries and reshaping balances of power between nations as a result of military capabilities. This is particularly applicable in the environment of the early 2020's, especially with the Russia's invasion of Ukraine. Though no reports are currently available about exoskeleton use during the conflict, it is entirely possible that Russia has deployed its exoskeleton technology in Ukraine.

The main limitation to this study is that there has been limited implementation of medical exoskeletons and no widespread implementation of military exoskeletons given the newly-developing nature of the technology. Most analysis presented is based on small-scale examples and predictions. More accurate and thorough analyses can be made once the technology reaches a benchmark of common use. This paper, however, is intended to be an anticipatory rather than a retrospective analysis in order to have knowledge of possible societal impacts and unintended consequences of this technology prior to its implementation.

For a more accurate and thorough analysis of this technology than this paper provides, one would have to wait for full implementation. At this point, the third ISTA interaction could also be analyzed, allowing for a broader understanding of the sociotechnical interactions of the technology. Comparing the anticipated impacts with the true impacts would be worthwhile, and once implementation has happened, more comprehensive case studies can be used to draw conclusions. Also, while the military exoskeleton technology I included in this paper is from a range of countries, the medical exoskeletons I focused primarily on are U.S.-based. To provide a more extensive view of the societal implications of the technology, examples from other countries should be analyzed as well.

My technical project focuses on the development of a new type of medical exoskeleton aimed at providing arm mobility for patients with neuromuscular disorders. In-depth analysis of possible societal impacts and unintended consequences of the technology I create is crucial to consider during the development process. Applying this technology to the military is common, such as with the tremor-canceling technology designed for patients with Parkison’s disease that improves weapon aiming, and must be considered regardless of whether it is intended for military use.

Conclusion

The analysis in this paper reveals how wearable robotic exoskeletons could interact with and affect social systems and how rehabilitation exoskeletons used in military settings could be used to harm instead of heal. This information, which includes sociotechnical feedback loops and unintended consequences, can and should be taken into consideration when developing such technologies. Without this foresight, the technology could have dire consequences, such as reshaping warfare to be all the more deadly. More in-depth exploration of these topics can be done and compared to this analysis once the technologies are fully implemented. With this knowledge, disaster can be prevented and better, safer, and more effective technologies can be developed to affect and interact with society in positive ways.

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