Potential Applications of Exoskeleton Suits in the Armed Forces

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Colton Applegate
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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

Signature ______________________ Date 05 May 2022
Colton Applegate

______________________ Date 05 May 2022
STS Advisor: Richard D. Jacques, Ph.D., Department of Engineering & Society

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Introduction

We live in a world where technology grows more advanced with every passing day. From self-driving cars that take people wherever they want to go, to autonomous hydroponic farming that lets us grow a plethora of foods with ease, technology has improved nearly every aspect of human life. Notably, the one thing humans really have yet to try to improve with technology, are humans themselves. While creating a perfect human body may be possible through pure genetic manipulation sometime in the future, for now technology will have to focus on improving the body that is already there. This is most commonly done by means of an exoskeleton suit. Broadly, an exoskeleton is an electromechanical structure worn by a person that matches the shape and function of the human body (Anam, 2012). The specifics of the various types and functions of different exoskeletons will be explored in detail later in this paper, so for now it is sufficient to understand that an exoskeleton is a wearable robotic system that helps a user complete a task or motion.

There are numerous different applications for exoskeletons across several different industries, but the primary implementation of exoskeletons so far has been in medical research context. Whether it be patients with muscular dystrophy in their arms, nerve damage in their hands, or partial paralysis in their legs, exoskeletons have been developed that serve all these groups. But even though exoskeletons provide a potentially tremendous breakthrough in medical research communities, as with most technologies in our modern world, where there is potential for great benefit also comes the possibility for great harm. Much like the weaponization of chemical gases in World War 1, or even the atom in the 1940s, any technology that has the potential to be used for war is likely going to be. Already, the United States Military has pursued several contracts with exoskeleton developers to create models for deployment by the armed forces.

As with any emerging technology, it is necessary to look at both sides of the coin, the positive and negative effects the technology might have. Unfortunately, up until this point, there has been very little investigation into the potential negative consequences widespread exoskeleton use might cause, especially in the hands of military powers. Therefore, the question this paper will explore is 2-fold. First, based on the current state of exoskeleton technology, will we ever see the United States Army deploy exoskeleton suits that enhance the combat ability of their soldiers, and second, should we support a widespread deployment of exoskeleton suits in the army, whether it be for our own ethical reasons or otherwise?

Methodology and a Caveat

This topic was pursued by taking a deep look into the current state of exoskeleton technology, especially the prototypes being developed in conjunction with the United States Military. Several research papers written by experts in the exoskeleton field were reviewed, to get a summary of where these experts think the technology is going in both the immediate and long-term futures. Additionally, military spending documents and development plans were also considered to determine the likelihood that we will see the actual deployment of exoskeleton suits in combat scenarios. However, there is one caveat to the overall scope of this research. Unfortunately, the research conducted will not be completely indicative of the current state of military exoskeletons, as much of the research and product developments are kept internal to the government for national security reasons. I do believe that there is enough publicly known information that accurately portrays the current state of military exoskeletons, which is enough to extrapolate from to form predictions about the future. Additionally, due to the ever-changing nature of an up-and-coming technology, there may be new developments after this paper's publication that are not incorporated into the conclusions reached.

A Brief Review of Exoskeleton Technology

While most novel developments in exoskeleton technology have occurred in only the last decade, the roots of this technology can be traced back to the 1960s. One of the first constructed prototypes for an exoskeleton suit was the HARDIMAN I, which was developed in 1969 by the General Electric Company (Croshaw, 1969). Although to call this prototype a success would certainly be a stretch, as most attempts to use the suit resulted in violent, uncontrolled motions. This model, although primitive by today's standards, was a crucial first step into opening the door to a future where an individual's strength could be directly improved with technology.

Because of the high cost and general failure of initial prototypes like the Hardiman, most design attempts were put on the backburner for decades. But with the advent of lighter, more mobile, more energy efficient systems, the world is seeing a boom in the number of commercially available exoskeleton designs. Additionally, the capabilities of exoskeletons have broadened immensely in recent years, ranging from motion amplification to medical rehabilitation. As shown in Figure 1, there are now a dozen upper-limb exoskeletons on the current market, each of which specializes in a specific motion or function (Gull, 2020). However, at the core of every exoskeleton design, there is one key principle: help a user achieve a desired motion.

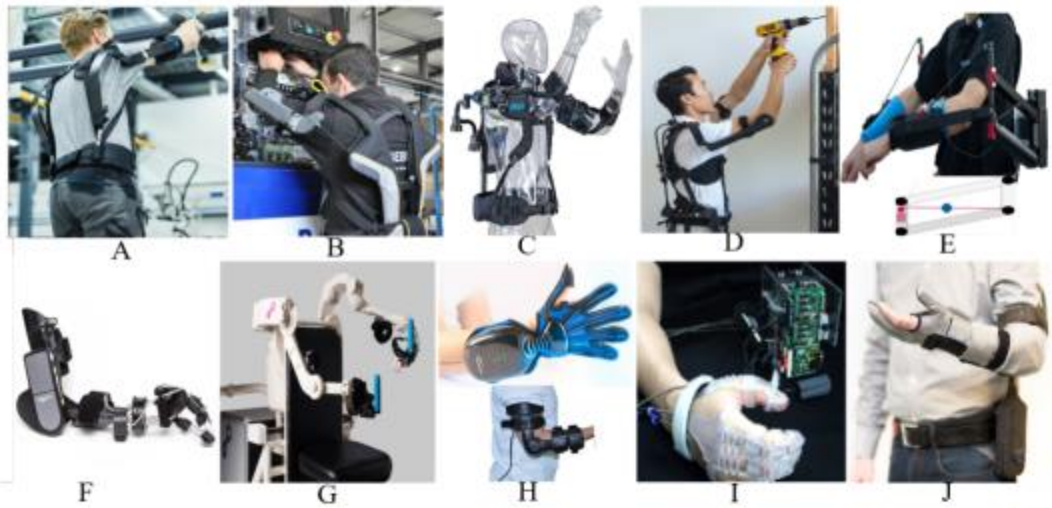

Figure 1: Commercially available upper-limb exoskeletons: (A) Skelex; (B) Egrosquelettes by GOBIO-robot (Gobio is the brand of Europe Technologies that promotes exoskeletons); (C) EksoVest by Ekso Bionics; (D) Modular Agile eXoskeleton (MAX) by SuitX; (E) Robo-Mate; (F) MyoPro Orthosis by Myomo, Inc.; (G) Alex exoskeleton by Kinetek Wearable Robotics; (H) Hand and Arm tutor by MediTouch; (I) Exo glove poly; and (J) Soft extra muscle glove by BioServo.
(Gull, 2020)

Exoskeleton technology has made considerable progress in the past few years, especially when it comes to models produced for the medical research industry. There is a particular interest in using exoskeleton limbs to help rehabilitate patients who have nerve damage as the result of a stroke (Pineda-Rico, 2016). There have been several factors specifically related to medical rehabilitation exoskeletons that have really pushed innovation in the exoskeleton industry. When dealing with an at-home or in-hospital use of exoskeletons, comfort and ease of use becomes a lot more important. The average person is not going to be willing to adopt the use of an exoskeleton if it is painful to wear. This has caused a significant shift in the production of exoskeletons from typically hard and rigid models to softer and more flexible models (Proietti, 2021). The traditional exoskeleton composed of a rigid metal brace actuated by DC motors is being slowly replaced by pneumatic or hydraulic artificial muscles, which can expand and contract more naturally with the human body. This promising new technology could be that which paves the way for the next major wave of exoskeleton advancements.

But the medical industry is not the only industry that has seen significant improvement in recent years. The manufacturing sector has also been experimenting with deploying exoskeletons to their workforce, especially in places with demanding manual labor requirements. Exoskeletons in this context help to reduce the fatigue of workers lifting repeated heavy loads, as well as prevent chronic injuries from manifesting (Zhao, 2021). Additionally, exoskeletons can be used to increase the productivity and efficiency of a single human worker, by allowing them to carry more at once. With companies always bent on cutting costs, it would not be surprising to see a surge in industrial-use exoskeletons in factories and warehouses, as companies can use fewer workers but still meet their production quotas thanks to the increased production rates exoskeletons allow (Bogue, 2018). Additionally, since these exoskeletons will be able to prevent significantly more workplace injuries, companies are further incentivized to invest in this technology. When a worker gets a workplace injury, it usually requires a several week medical leave, where the company then must both pay worker's compensation for the injured party, as well as train and pay a new worker to pick up the slack in the meantime. This represents a potential benefit for all parties involved, as the implementation of exoskeletons can both protect worker health and save the company money. This idea is precisely what has driven further research and development of exoskeletons in the commercial industry.

Applications of Exoskeletons in the Armed Forces

With so many novel discoveries happening with exoskeleton technology in the private sector, it is only natural that the public sector, in this case, the military, is not far behind. As far back as 2009, the United States Military had already begun to look for commercial partners to develop a line of exoskeletons for army use. Lockheed Martin was one of the first companies to accept this challenge, with testing of their first prototype, the HULC (Human Universal Load

Carrier), beginning in 2011 (Keller, 2011). The goal of this prototype was simply to be able to help an infantry soldier increase the weight they can carry and the distance they can travel before requiring rest. This design was met with moderate success, with it being able to help soldiers carry loads of up to 200 lbs. across all terrains for extended periods of time without causing the soldier any additional fatigue.

In fact, most exoskeletons contracted by the military so far have had the same goal: reduce fatigue and injury chances of soldiers. They are generally not intended for direct combat purposes, but for soldiers traveling on long distance excursions, where a lot of ground needs to be covered in a short amount of time. The ACE-Ankle is a 2019 prototype developed specifically for the purpose of assisting the movement of soldiers in rough terrain environments to reduce fatigue and prevent ankle or leg injuries (Hong, 2019). It is no surprise at all to see the focus on reducing soldier fatigue when considering some of the tasks a soldier must be able to complete. Equipment for each soldier alone ranges from 100–150 pounds, and this often must be carried for miles at a time, often through steep or uneven terrain. Additionally, soldiers must be prepared to jump from high places, land after parachuting, or carry a several hundred-pound wounded comrade out of harm’s way (Keller, 2022). This causes immense strain and fatigue on the legs and joints, which not only reduces the time a soldier can be active per day, but also gives them a higher chance of developing chronic injuries. This is another issue that could be resolved through exoskeleton implementation, as there have already been studies that have proven that using an exoskeleton suit to assist with daily tasks can reduce the likelihood that a soldier will suffer from chronic injuries later in life (Gibson, 2017).

But the potential use for exoskeletons in not just limited to soldiers deployed in the field. For example, when stationed at a base, a soldier may be required to move pallets, fill sandbags, or carry heavy machinery. A study of these tasks conducted by Proud et al. suggested that most exoskeletons that were evaluated were able to help soldiers complete more tasks than they were able to otherwise (Proud, 2020). This study does however mention that further development is required to get exoskeletons to the point where they would be practical on a mass scale. So, while the technology may not be at the point where it is ready for widespread use, the potential benefits that military exoskeletons can have are starting to be realized more and more. The United States Government is actively looking into ways to further their research on exoskeleton technology, including posting a RFI (Request for Information) in March 2022 to the government contracting website SAM.gov, specifically citing inquiries into exoskeletons that would help soldiers achieve all the tasks listed above (SAM.gov, 2022).

The main takeaway from the military development of exoskeletons so far, is that most are not designed for an explicitly combative role. While it can be argued that a less-fatigued soldier will have more energy and as a result be able to perform better in combat, this has not been the primary goal. However, this may not be the case for much longer, as the United States Military has been interested in a new generation of exoskeletons suits designed to help soldiers fight better in close quarters (Keller, 2018). A few prototypes already exist with this specific goal in mind, such as the B-Temia/Revision Prowler Exoskeleton, which started development in 2014 (Young, 2017). This suit was explicitly designed to be used by personnel in combat, with the goal of improving combat performance. Another example is the army's Third-Arm prototype, which is designed to help stabilize a soldier's weapon and reduce its recoil when being fired (Cox, 2018). Unfortunately, little information about these potentially combat enhancing prototypes is known to the public, so it is currently unclear whether exoskeletons will be further developed down the direct warfighting path.

Figure 2: Army Sgt. Michael Zamora uses a prototype Third Arm exoskeleton to easily aim an 18-pound M249 light machine gun during testing at Aberdeen Proving Ground, Maryland, on March 14, 2018. (U.S. Army photo by Conrad Johnson) **(Cox 2018)**

Regardless of if exoskeletons will be used in combat scenarios or will just exist to reduce fatigue and improve soldier health, it does seem like there is a role for them in the army's arsenal. The North Atlantic Treaty Organization (NATO) cites five key capabilities that are essential for the close-quarters combatant (Mudie, 2018). Three of these capabilities are mobility, lethality, and survivability, all of which can be improved using exoskeletons. The technology is nearly there, but the question remains as to whether it will ever be widely implemented. Despite having several potential working prototypes that effectively reduce fatigue and strain on their soldiers, the United States Army has been hesitant to deploy these exoskeletons for widespread use. One source cites a major drawback as the lack of adaptability of the average exoskeleton, as many exoskeleton prototypes are designed specifically to assist with only one task (Mudie, 2021). While this is halting the deployment of exoskeletons in the present day, this is something that can be overcome in the next few years of exoskeleton research. If the technology can reach the point where it needs to be, what else might be the cause for the limited implementation of exoskeletons by the United States Military?

One of the first things to consider would be the cost of the exoskeletons, and if the United States Army could ever afford to deploy them. According to the SIPRI Military Expenditure Database, the United States spent $778 billion in 2020 on its military (SIPRI, 2021). While this exact number is disputed by various sources, in any case it is one of the highest military budgets in the world. Additionally, this number has been increasing steadily since 2017 and will continue to follow this same trend. Of this massive spending budget, the Department of Defense reported that 14% of its budget is dedicated to the research and development of new technologies, a percentage that is only expected to increase in the next few years (Department of Defense, 2022). While the Department of Defense’s spending report does not list all their ongoing projects receiving funding, there is no explicit mention of any exoskeleton-specific projects in their budget highlights.

Because most exoskeletons are still in the research and development phase, the per-unit cost is still extremely high. While no public information is known about how much a current army exoskeleton costs to build, it can be assumed that it will remain high until a mass-producible model is complete, which could take years of more development. There are only a few dozen currently working exoskeleton suits that are being used for research and testing, and so to get the technology to the point where it would be ready to deploy to tens of thousands of troops would take billions of dollars in manufacturing alone. The question then needs to be asked if it is even worth it to spend all this time and effort on exoskeleton development to improve combat ability and reduce fatigue in soldiers only marginally. Especially when the role of standard army foot soldiers over the years has been steadily declining.

While the total size of the United States Armed Forces has remained relatively constant in the past decade, this does not necessarily equate to the fact that the number of soldiers has stayed the same. As a military modernizes, it has less of a need for people to fight directly, and more of a need for specialized forces. This can include jobs like drone operators, nuclear submarine engineers, and counter cyber-attack specialists. In recent years, all out ground conflicts between nations have become less frequent, as things like precision missile strikes can achieve much more than a platoon of soldiers ever could. Furthermore, with all the world's superpowers possessing some form of a nuclear arsenal, the idea of soldiers themselves are almost obsolete, as a single nuclear strike can neutralize an entire army.

The extremely high cost it would take to bring an effective, mass-producible, military-grade exoskeleton to the market, as well as the time it would take to achieve this, does not bode well for the immediate future of exoskeletons. Coupled with the fact that there are so many other ongoing projects that the Department of Defense is currently funding with potentially more benefits, it starts to become clear why exoskeletons have taken a spot on the backburner. Barring the advent of a major international conflict in the next decade that could potentially reinvigorate the need for exoskeletons, it is my opinion that it is unlikely that we will see exoskeleton deployment in any large capacity anytime soon.

A Discussion of Ethical Concerns

While it is true that the world may never see a mass adoption of military exoskeletons, it is a future that is still certainly within the realm of possibility. And since there is a chance there may be exoskeletons used directly in combat someday, the question now needs to be asked: should they? Whenever there is a discussion of subjecting the human body to an unnatural change, there will always be controversy. Especially when those augmentations can be used to do harm. This is exactly the controversy that exoskeletons have become a part of.

Since the stone age, war is something that has only evolved and grown deadlier. The line between ethical and unethical when talking about war has always been blurred, as there is no real "right way" to conduct a war at all. When compared to chemical gases or atomic strikes, it seems like exoskeletons fall well within ethical standards, at least for how most of the world defines what is acceptable. In a future where robots and drones complete all the fighting autonomously, an exoskeleton still controlled by a human may be massively preferable to face in combat, as the human user still has a moral compass, and can ultimately make a more ethical decision (Kott, 2015). Given that in their current state exoskeletons only seek to reduce fatigue and injury in non-combative scenarios, I would deem them considerably more ethical than many other technologies currently used by the United States Military.

However, with any piece of complex, modern technology, exists the potential of malfunction. Consider the following scenario: a soldier deployed into combat with an exoskeleton has a suit malfunction, and accidentally kills a civilian (Herr, 2015). In this case, who is to blame for the death of the innocent person? Is it the person in the suit for agreeing to use it? The programmer who wrote the code? The manufacturer that was not thorough enough? Or the commander who approved the mission? It easily becomes a web where it is easy to pass the blame to another party, which makes it hard to judge whether it is really the fault of the exoskeleton, or if this accident could have happened just as easily with some other technology.

But those are just the ethical concerns in combat, and there are even more potential ethical dilemmas that are revealed when you dig even deeper, like will they even be safe enough to use? It is true that exoskeletons have successfully improved the physical performance of soldiers in test environments, but there have been few investigations on the potential mental effects the use of an exoskeleton may have on a person. A 2020 study suggested that exoskeleton use can cause additional cognitive stress and can affect the ability of a subject to perform visual and audio tasks (Bequette, 2020). While this study is far from conclusive, it does highlight the need to conduct additional testing to evaluate the potential mental stress wearing exoskeletons can cause.

Another potential negative consequence of exoskeletons is the dehumanizing aspect of them. Forcing exoskeletons on people may make them feel less than human, as if they are giving up their control for increased efficiency (Kapellar, 2020). This idea of turning workers or soldiers into machines paves the way for the potential to exploit them as well. By using an exoskeleton to reduce fatigue felt, a person can be forced to complete more tasks or take fewer breaks because they have been given a suit to wear. So, while in theory the army or whatever companies try to employ these suits can say they are doing it for their workers' health, they could just be trying to stretch the human body's potential further toward its limits in the name of efficiency. Furthermore, soldiers or workers who refuse to wear exoskeletons for their own personal reasons, may be discriminated against or provided fewer opportunities because employers may not want them. A worker could be fired or a soldier relieved from duty simply because they refuse to let their body be augmented past its natural limits.

There are two potential paths that exoskeleton technology could go down, and it all depends on what we value more as a society. Do we focus on continuing to use exoskeletons to improve the lives of patients around the globe, or do we use them to achieve absolute dominance on the battlefield? It is my opinion that exoskeletons, even when considered in a military context, can still provide benefits that outweigh the potential costs, but it is up to the engineers who design them to make sure they adhere to the standards we set out as a society.

Conclusion

Already in the short 50 or so year history of its development, the exoskeleton has gone from an uncontrollable, unusable piece of technology to something that could one day revolutionize the armies of the world. While it is easy to let our imagination run with this idea and think that one day we may see the world's first *Iron Man* suit, this technology is still nowhere close to where it needs to be to achieve a feat such as that. The simple fact remains that it is vanity to attempt to predict exactly where this technology will be in 20 or 30 years, especially given the recent surge in development. But if this paper attempted to highlight anything, it is that the ethical and moral considerations involved with further developing this technology need to catch up. There has been little talk of the potential negative consequences that exoskeletons may bring to the world, which is something that needs to change before this technology gets to the point of no return. Some specific areas to consider would be mental and cognitive effects exoskeleton use can have on a user, the dehumanization of our army or workforce, and the potential destruction an exoskeleton-equipped army could cause in the wrong hands. In an era where everything can be turned into a weapon, let us make sure to take the time to consider what, if anything, should be.

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