A Virtue Ethics Approach to Exoskeleton Research and Development

A Research Paper submitted to the Department of Engineering and Society

Presented to the Faculty of the School of Engineering and Applied Science
University of Virginia • Charlottesville, Virginia

In Partial Fulfillment of the Requirements for the Degree
Bachelor of Science, School of Engineering

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Spring 2025

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

The fields of biomechanics and biomedical engineering have driven some of the most groundbreaking research and innovations of the 20th and 21st centuries. As healthcare costs increase at unprecedented rates and significant global health challenges persist, these industries are at the forefront of a modern healthcare revolution. In parallel, the modern military-industrial complex is in a perpetual state of innovation with regards to advantages on the battlefield. Utilizing the prowess of engineers and scientists in biomedical engineering to accomplish this, there will always be a desire to gain a step in militaristic superiority. Now, building on decades of research and billions of dollars of funding, exoskeletons are poised to be the next great engineering breakthrough in the industry.

An exoskeleton is a wearable robotic device (often in the form of a suit or frame) that works in tandem with the user to augment their physical capabilities. Regardless of its potential, exoskeleton technology is extremely complex, blending the nuances of anatomy, robotics, artificial intelligence, and software engineering. These technologies are advancing rapidly in both the healthcare and military domains. In rehabilitation medicine, exoskeletons can play a crucial role for patients in regaining mobility, rebuilding strength, and improving neuromuscular function after traumatic injuries or progression of neurological disorders (Erden & Rainey, 2024a). In the military, similar technologies promise to enhance combat performance and soldier endurance (“Human Universal Load Carrier (HULC),” n.d.). These contrasting applications raise an ethical dichotomy: one use aims to heal and uphold human dignity, while the other is tied to warfare, destruction, and human suffering.

Ethical considerations regarding the development and design of this technology are paramount, especially when considering the polarized use cases of healthcare and defense.

Addressing race, gender, class, and disability in exoskeleton research involves ensuring equitable access, diverse clinical trials, and inclusive design. These systems should consider different body types and affordability to avoid exacerbating inequalities. Emphasizing user diversity and accessibility helps prevent marginalization and promotes the technology's broad societal benefit. From a business perspective, ethical sources of funding, corporate strategy, and measures of profitability are also important to take into consideration.

For the purpose of this paper, a holistic view of exoskeleton development will be examined and how ethical principles can guide the design and use of technology. To conduct this ethical analysis, the framework of virtue ethics will be applied in order to investigate the connection between human virtues and moral tensions between medical and military uses of exoskeletons. Drawing on Aristotle’s conventional approach and contemporary interpretations, virtue ethics is particularly equipped to handle the complexities of this analysis. Unlike utilitarian or deontological approaches, virtue ethics provides a nuanced lens by focusing on the moral character and intentions of exoskeleton developers, rather than just consequences or rules (Hursthouse & Pettigrove, 2023). A case study of Ekso Bionics, a pioneer company in exoskeleton development, will ground this analysis in real-world practice. This will be used to answer the research question: how do the virtue ethics of exoskeleton developers affect innovation and go-to-market strategy? This paper will argue that virtue ethics significantly shapes the innovation and commercialization of exoskeletons, influencing corporate decision-making, and the ethical tensions between medical and military applications.

Virtue Ethics: Classical and Modern Perspectives

Virtue ethics originated in ancient philosophical traditions, primarily in the works of the Greek philosophers Plato and Aristotle. Despite some differences of implementation and practice between modern and classical interpretations, the framework has consensus in its roots originating in three Greek concepts: *arête* (excellence or virtue), *phronesis* (practical or moral wisdom) and *eudaimonia* (happiness or flourishing). Virtue Ethics is effective in that it is not a superficial lens on morality. It's not a simple determination of right versus wrong. It's an analysis of the intentions, motivations, and emotions of acting in good character.

Its basic methodology is grounded in the societal mindset of choosing to help those in need for the purpose of being charitable or benevolent. (Hursthouse & Pettigrove, 2023). However, this does not mean that simply moral action is indicative of virtuous behavior. The "good" in virtue ethics isn't just simply acting with integrity—it's the connection between doing the right thing *and* having the right desires and emotions. Since the ethical framework is agent-centered—meaning that the morality of an action is a reflection of an individual's own actions, as opposed to adherence to rules or acknowledgement of consequences—virtue ethics introduces intrinsic dialogue such as: "How should I live?", "What makes me a good person?", and "Who do I want to be?" (*Virtue Ethics | Internet Encyclopedia of Philosophy*, n.d.). These ideas are foundational to becoming a virtuous person and are heavily emphasized in both neo-Aristotelian and modern virtue ethics.

Aristotle's classical virtue ethics rests heavily on the idea of *eudaimonia*, ensuring human flourishing through cultivating virtuous behavior. He believed that these virtues are nurtured over a lifetime and evolve into subconscious tendencies with enough reinforcement. This makes virtue ethics a compelling framework for didactic presentations of ethics in business, engineering, medicine, and other sectors of academia. Aristotle also believed in an intermediate topography that applies to all virtues. This idea of a "golden mean" between excess and deficiency is foundational to formulating reasonable virtues. For example, a courageous person lies between he who flees every danger and cowers and he who recklessly approaches risk and feels no fear (Kraut, 2022). This delicate balance is foundational to identifying virtue and will be advantageous in upcoming ethical analysis.

After some centuries of irrelevance, virtue ethics made a strong resurgence into the philosophical world of ethics in the 20th century. Spurred by G.E.M. Anscombe's 1958 essay, *Modern Moral Philosophy,* her ideas marked a revival in the West (Vallor, 2016). Anscombe argued strongly against the popular moral theories of utilitarianism and deontology and emphasizes the importance of virtue in relation to combating injustice (Anscombe, 1958). Today, virtue ethics is considered a rich framework for applied ethics, especially with emerging technologies. It does not address just what we do, but who we are as we engage with engineering and science. As outlined in the *Engineering Code of Ethics*, the virtues of integrity, honesty, fairness, and respect are all critical to professional success (*NSPE Code of Ethics for Engineers | National Society of Professional Engineers*, n.d.). Unlike strict rule-based (deontological) or outcome-based (utilitarian) approaches, virtue ethics provides a flexible, context-aware perspective—acknowledging that moral judgment requires sensitivity to particular situations and a balance of competing values. This flexibility makes virtue ethics attractive for emerging fields like technology ethics, where fixed rules may fall short and character-driven leadership is needed to ensure technology is effective in its intention (Conwill et al., 2025). Shannon Valor, author of *Technology and the Virtues: A Philosophical Guide to a Future Worth Wanting,* argues that this framework of analysis is "ideally suited for managing complex, novel, and unpredictable moral landscapes, just the kind of landscape that today's emerging technologies present", making it a strong candidate for modern ethical analysis (Vallor, 2016).

Developments in Exoskeleton Technology

At once a figment of the imagination of science fiction, rapid advances in robotics and wearable technology in recent decades have turned exoskeletons into practical tools. Pioneered by General Electric in the 1960s, original designs were engineered to aid humans in lifting heavy objects and were funded by the U.S. Defense Department. Over time, these technologies were adopted by innovators in the healthcare sector for support of the human skeletal system in rehabilitation facilities. Defense funding has persisted over the last 50 years and cultivated an extensive arm of military investment and research that is dedicated to creating the next-generation of foot soldiers. Original designs used a network of springs and dampers that stored energy that could be deployed to support the user. Modern powered exoskeletons use advanced sensors, motors, computational control, and elaborate algorithms to enhance or assist human movement (*Exoskeletons in Nursing and Healthcare*, n.d.). Innovative progress has culminated in the creation of two major sectors in the exoskeleton market: medical exoskeletons designed as assistive or rehabilitative devices, and military exoskeletons designed to enhance strength and endurance for able-bodied users. While both share similar engineering principles, their goals and contexts differ drastically.

In the context of healthcare, rehabilitation exoskeletons are most often used for patients with spinal cord injuries, stroke survivors, or patients with neurological disorders that limit the ability to walk. Modern suits typically require the user to wear a frame strapped to the legs and back; motorized joints at the hips and knees move the legs in a walking gait, often with crutches or a walker for additional balance (*Revolutionize Mobility*, n.d.). Exoskeleton design has also benefited from advanced research in predictive models and the development of artificial intelligence in the last few years. Modern algorithms enable support structures and motorized features to instantly react to user's movements and ensure the most optimized functionality and comfort of these devices. The overarching goal of these technologies is to enhance patient autonomy, rehab efficiency, and overall quality of life. As exoskeletons grow in complexity, more consideration must be concentrated on the implications of the technology. To combat the systemic limitations of biased data and improve exoskeleton functionality, future development must focus on diversifying datasets and incorporating real-world feedback from a wide array of users. This might involve creating open-source data sets where researchers and companies share diverse measurements from various demographics, making it easier to develop adaptable algorithms and hardware that meet a broader range of needs. Another promising approach is incorporating more adaptive, user-specific customization capabilities into exoskeleton software. By bringing together data scientists, engineers, medical professionals, and social scientists, exoskeleton developers can better understand the social, physical, and psychological impacts of their technology. This holistic approach could reduce exclusionary design practices, contribute to standards that promote inclusivity and safety in exoskeleton use, and bridge gaps in representation. Despite progress, medical exoskeletons face significant challenges: high costs, the need for insurance coverage or reimbursement, bulky hardware, and the requirement of extensive training. Nevertheless, their development reflects a humanitarian motive to use robotics for healing and inclusion, aligning with virtues of compassion and benevolence in medicine.

Contrasting with medical exoskeletons, military specialized exoskeletons are still a very crude technology. Despite billions of dollars in funding directed toward defense contractors like Lockheed Martin, none of the military branches have widely adopted the technology yet. Although limited success thus far, the military exoskeleton market is expected to grow to 3.5

billion by 2030 (Erden & Rainey, 2024b). Exoskeletons have been proven to be effective in reducing the energy cost during pedestrian missions, however a combat advantage has yet to be asserted as a result of the vulnerability associated with decreased agility and lethality (Mudie et al., 2022). That being said, in order for realistic implementation, exoskeletons must be able to interact with the environment and optimize a diverse range of movement types. For a soldier who can be expected to run, crawl, crouch, and jump, a useful exoskeleton must be able to support all of these movements. This is identified as the single greatest challenge in development and will serve as the hurdle rate for success. In order to accomplish this, these devices must not only be highly dynamic, they must also be smart and capable of learning from users, as well as predicting their movement. Contemporary advances in artificial intelligence and algorithmic research are promising in supporting this requirement for deployment (Erden & Rainey, 2024b). The military's hunger to develop a combat advantage in the form of augmented soldiers is no different than nuclear research during World War II or the arms race during the Cold War. As long as there is potential for combat advantage, the government will continue to fund its development.

Ethical Analysis

Due to the contrasting objectives of medical and military exoskeletons, the ethical considerations in their development also differ significantly. A thorough analysis requires identifying the key virtues essential to ethical integrity and evaluating their impact on technological advancement. Virtue ethics emphasizes adherence to these principles to ensure that a technology is built upon a morally sound foundation. Ethical discussion will be grounded in the assessment of application specific virtues for both use cases of the technology. Pursuit and achievement of human flourishing must be evaluated in order to determine ethical standing.

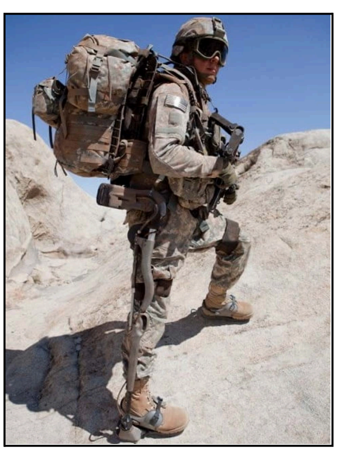
From a virtue ethics perspective, the development and provision of medical exoskeletons exemplify virtues of compassion, respect, and inclusion. Aristotle's classical application of *eudaimonia* aligns well with developers aspiring for increased human flourishing by aiding patients in living a better life . However, this is a narrow perspective in the modern age of technology. There is so much nuance of societal effects in the potential implications imposed by a new technology that a purely classical perspective is insufficient. Virtues must be utilized in a greater societal context than simply idealizing *eudaimonia* (Svensson, 2011). Compassion is a powerful virtue in a corporate domain because it blends business development goals with social responsibility. In the case of exoskeletons, this is a notably strong virtue in an industry that has been dedicated to aiding those in need live a "better" life. That being said, questions arise regarding what constitutes a better life? As a byproduct of a cultural majority, the paradigm of this "better" life has corroborated sentiments that the ability to walk is better than the inability to do so. While exoskeleton companies have good intentions rooted in compassion for individuals impacted by immobilizing conditions, they risk alienating those who they wish to serve. Ironically, their design is inherently ableistic in that the primary function is to "fix" a disability, as opposed to curating an environment that is more inclusive and supportive for those with disabilities. There is a delicate line between providing care to those in need and patronizing those who don't necessarily want the aid. This balance needs to be something that exoskeleton developers are conscious of in the development and marketing of their products. Respect as a virtue is complementary in this context. The goal should be to offer additional opportunities and capabilities, not to imply that one must walk (with a robot's help) to have a worthy life. Thus, the virtuous path navigates a mean between apathy and overzealous "techno-savior" attitudes. Developers, as well as a society as a whole, should neither ignore the needs of disabled individuals nor assume technology alone can solve all personal and social challenges of disability. As the final pillar, inclusion as a virtue encapsulates the importance of both compassion and respect. Insurance that a technology is comprehensive in its applications is paramount. The exoskeleton industry faces serious hurdles in achieving a just landscape of implementation of their medical technology. The capital intensive nature of the innovation process has a tendency to trickle down to the consumer level and influence costs. As a result, class differences may impact the demographics that receive potentially life-altering healthcare. As exoskeletons continue to develop and approach commercial availability, corporations must consider how their technology will be able to reach lower-income individuals, who often disproportionately require the assistance and rehabilitation that these technologies provide (Leibman & Choi, 2023). Companies must also be aware of the target gender demographics for their products. Many of the products are "one-size-fits-all", potentially reinforcing gender bias. Women's bodies are often underrepresented in healthcare products and medical research, further emphasizing the responsibility of exoskeleton designers to create inclusive technologies that do not perpetuate demographic discrepancies (*Exoskeletons and Occupational Health Equity | Blogs | CDC*, 2020). Addressing race, gender, class, and disability in exoskeleton research involves ensuring equitable access, diverse clinical trials, and inclusive design. These systems should consider different body types and affordability to avoid exacerbating inequalities. Emphasizing user diversity and accessibility helps prevent marginalization and promotes the technology's broad societal benefit. By demonstrating virtuous character and using technology to serve the common good and enhance human flourishing companies can align their intrinsic virtues with long-term growth (Machura, 2024).

While identifying virtues of medicinal applications is relatively straightforward and intuitive, the same cannot be said for these technologies deployed in the military. The idea of *eudaimonia* is contradicted when the technology is used for the act of ending a human life. This perspective stands in direct opposition to the enhancement of human-flourishing, so a more nuanced position of virtues must be taken into consideration. Ethics of war and conflict are always complex, often blurring the lines of humanity and subjecting ethicists to moral dilemmas beyond objectivity. Similarly, a purely utilitarian approach might celebrate any innovation that gives “our side” an edge, but a virtue ethics approach inspires deeper reflection on what kind of military and society evolves through these enhancements. Although not all-encompassing, the key virtues to uphold in this domain are temperance, justice, and integrity. When developing technology for military applications, it’s critical to adhere to a certain level of temperance. Avoidance of a relentless pursuit of military advantage without moral restraint is a necessity in navigating the tortuous landscape of military ethics. Virtue ethics demands that agents–trickling down from political leaders to individual engineers–make decisions without emotional influence, mitigating misuse of technology and immoral over-correction (Fisher, 2011). While complete annihilation of the “enemy” may be compelling, the virtuous man, assuming war is a necessity, shall do only enough to protect against aggression. As these technologies advance, manufacturers must be mindful of how they market their products. While it is appropriate to highlight the technological advantages of exoskeletons, care must be taken to avoid framing them primarily in terms of their destructive potential. To do so would not only distort their intended purpose but could also contribute to an arms race mentality that prioritizes lethality over responsible use. This concern ties directly into the virtue of justice. Justice as a virtue demands that these technologies serve a purpose aligned with the common good rather than being wielded as instruments of unchecked power. However, determining what the “common good” looks like is an inherently subjective and arbitrary process. Due to its difficulty, reliance on virtues to serve as a compass for moral decision making is a beneficial tool. Building on this idea, and as outlined in *Just War Theory*, technology should not contribute to force exceeding what is deemed necessary to neutralize a threat (*Just War Theory | Internet Encyclopedia of Philosophy*, n.d.). Justice in war does not only concern the immediate conduct of battle but also its long-term effects. If exoskeleton technology leads to an unjustified extension of conflicts or shifts the balance of power in ways that promote aggression rather than peace, then their development would be morally questionable. These all must be accounted for by developers, financers, and marketers of exoskeleton technology in order to ensure ethical practices. Integrity as a virtue is paramount as adherence to ethical principles that align with just warfare and preservation of human dignity grow in importance. Military exoskeletons present immense potential to protect soldiers, enhance operational capabilities, and reduce casualties, but without integrity, they risk being used in ways that escalate conflicts, promote unchecked aggression, or compromise ethical warfare standards. The core purpose of military exoskeletons should be clearly and honestly articulated. Their development should focus on protection, mobility, endurance, and mission effectiveness, not on increasing lethality beyond what is necessary for defense. Technological advancements should be pursued in a way that upholds moral and operational integrity. This means designing military exoskeletons to enhance soldier safety and mission success while minimizing the risk of excessive destruction or human rights violations. This is not easy to do when innovation stems from the funding and fulfillment of government contracts, but engineers and corporations are obligated to account for these implications.

Case Study: Ekso Bionics

Ekso Bionics, founded in 2005 and formerly known as Berkeley Bionics, is a robotics and exoskeleton manufacturing company that specializes in both medical rehabilitation and military products. As one of the leaders in the industry, they offer a compelling real-world example for how virtue ethical principles can manifest and be challenged in practice.

The company's first projects reflected this theme of medical/military polarization. On one hand, Ekso developed a device called eLEGS (Exoskeleton Lower Extremity Gait System) – a rehabilitation exoskeleton to enable paraplegics to stand and walk. On the other hand, they worked on the HULC (Human Universal Load Carrier) – a load-bearing exoskeleton for soldiers, which was licensed exclusively to defense contractor Lockheed Martin for further development. By roughly 2010, these two prototypes exemplified the dichotomy of exoskeleton use: one aimed at healing disability, the other at enhancing combat capability (*Past Products - Eksobionics*, n.d.). This dual focus was not unusual for early exoskeleton research (which often relied on military funding), but Ekso's approach to both domains offers insight into corporate ethics and strategy.



Ekso Bionics HULC (Human Universal Load Carrier)

Ekso Bionics eLEGS (Exoskeleton Lower Extremity Gait System)

Adapted from Ekso Bionics Past Products (https://eksobionics.com/past-products/)

Beginning with Ekso's public image, their mission statements and branding emphasize human empowerment and health. Ekso's mission statement reads: "Improving health and quality of life with advanced robotics designed to enhance, amplify, and restore human function," invoking the virtues of compassion, respect, and benevolence. This framing reflects an ethical commitment to human flourishing, aligning closely with virtue ethics principles. By centering their purpose around restoration and empowerment rather than profit or dominance, Ekso positions itself as a company that integrates moral intention with technological innovation. Even when acknowledging their work with the military, they frame it as "providing research for the advancement of R&D projects intended to benefit U.S. Defense capabilities" (*About Us - Eksobionics*, n.d.). This implies that virtues of temperance and integrity are at work. They're conscious of the implications of their technology and are focused on benefitting soldiers rather than simply increasing lethality. The inclusion of defense research in their mission suggests they see supporting soldiers' well-being as part of their purpose (for instance, by preventing the well-known problem of musculoskeletal injuries from heavy gear). Notably, Ekso does not market any offensive weaponry; their contributions to defense are protective/assistive in nature. This indicates an ethical stance geared towards helping those who face danger, rather than enabling harm to others.

Today, Ekso Bionics' product development and inventory reflect a substantive commitment to virtuous corporate practices. The rehabilitation line of the EksoGT and EksoNR are their flagship products and are used in clinics worldwide. Thousands of patients have regained the ability to stand and walk, logging millions of steps collectively. Such outcomes demonstrate real contributions to patient flourishing with patients regaining abilities and confidence. Ekso often shares patient stories (e.g., a veteran with paralysis walking on Ekso, regaining hope), which serves to humanize the technology and underline the virtuous impact of their innovations (*Veterans - Eksobionics*, n.d.). By contrast, Ekso's commitment to military applications has wavered since their initial innovation of the Human Universal Load Carrier. After this product was transferred to Lockheed Martin for further development, Ekso's focus seemed to shift towards one more aligned with medicinal technology. This trajectory suggests that Ekso Bionics gravitated toward applications with direct positive social impact (healthcare) over purely military enhancement. That said, Ekso Bionics has maintained a level of defense collaboration, including grants and R&D partnerships with the U.S. government to improve exoskeleton technologies. However, as outlined previously, this research is targeted at improving the quality of life of soldiers, not perpetuating violence. Their coordination with the U.S. Veterans Administration also embodies Ekso's commitment to the armed forces beyond the battlefield. This continued engagement reflects the virtue of integrity, as the company appears cognizant of the dual-use nature of its innovations and makes deliberate efforts to steer their application toward ethically responsible and less morally ambiguous ends.

Despite surface-level strength in virtue, the case of Ekso Bionics isn't without ethical challenges. Cost and access remain two of the most significant hurdles to implementing this technology in the medical field. Advanced exoskeleton systems are expensive to produce and purchase, often placing them out of reach for lower-income patients and underfunded clinics. Without comprehensive insurance coverage, these life-changing devices risk becoming accessible only to a privileged few. Cutting costs to combat this may limit the adjustability and functionality of these products, further increasing divides between body types, race, and gender. This would undermine the very virtues Ekso promotes, particularly compassion and inclusion, by limiting the benefits of their technology to those who can afford and fit the device. However, Ekso seems to have an answer for almost all of these concerns. First of all, their partnerships with the U.S. Veterans Administration, Medicare, and other insurance providers allow their products to reach not only those who can pay out-of-pocket. By integrating their devices into systems that support injured veterans and individuals with long-term disabilities, Ekso Bionics is proactively broadening access and bridging socioeconomic gaps. These efforts suggest a deliberate alignment with the virtues of justice and compassion, aiming to homogenize advanced rehabilitation tools. Furthermore, the company's collaboration with major hospitals and rehabilitation centers across the world indicates a commitment to embedding their technology within standard clinical practice, not just high-end care facilities. Harmoniously, Ekso Bionics' commitment to inclusion is best exemplified by their Ekso Indego Therapy model. This product is easily adjustable to fit a patient in less than five minutes, features a comprehensive software suite that enhances individualized rehab, and light enough for a range of body types to benefit from its functionality. These design choices reflect a deliberate effort to meet the diverse needs of real-world patients rather than designing for a narrow ideal. By prioritizing adaptability, accessibility, and user-centered design, Ekso demonstrates how the virtues of respect and inclusion can be embedded directly into engineering decisions. While cost and equity challenges still exist, Ekso's strategic approach reflects a recognition of those gaps and a willingness to address them through systemic solutions that are independent of profit dependability.

Conclusion

Exoskeletons are a unique technology that stands at the forefront of technical innovation and ethical complexity. They hold the power to uplift lives through revolutionary medical treatments, yet also the potential to amplify force in conflict in ways that test moral thinking. Through the lens of virtue ethics, this balance and nuance has been carefully examined and demonstrated how Aritstotelian insights and modern renditions can guide the ethical evaluation of technology. Illuminating the dichotomy between medical and military applications, virtues like compassion, respect, and integrity are paramount in the ethical design of both devices. The case study of Ekso Bionics grounded this analysis in reality, exemplifying that these ethical choices are not merely theoretical. Real companies must navigate them, and can indeed strive to do so virtuously by prioritizing benevolent goals over purely tactical advantages or profitability. By consciously embedding ethical values into design, development, and deployment, companies can ensure that exoskeletons remain tools of human empowerment rather than instruments of destruction or perpetrators of inequality. These steps will help align the exoskeleton field with the overarching aim of virtue ethics: to promote a good life and a good society.

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