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EXOSKELETONS: ENHANCING THE FUTURE OF PHYSICAL WORK

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YOUNG REVIEWERS:

NIKHIL

AGE: 12

VIHAAN

AGE: 9

What if you could wear a suit that instantly boosted your strength or endurance—one that made lifting objects easier or allowed you to hold heavy tools without getting tired? It turns out you can. They are called exoskeletons (exos for short). This new class of wearable technology is already used by tens of thousands of workers around the world to do their jobs more safely and efficiently. But these exos are not like the robotic superhero suits in the movies. In this article, we dive into the science, engineering, and impact of real-life exos in the workplace. We explore how exos work—from simple spring-based devices to more complex motorized ones—and the challenges faced by designers. You will learn how exos are changing the way people do physical work in industries like manufacturing, logistics, agriculture, construction, and healthcare, and why exos may be commonplace by the time kids today start working.

HUMAN AUGMENTATION TECHNOLOGIES ARE EVERYWHERE

HUMAN AUGMENTATION TECHNOLOGIES

Technologies that improve human capabilities, such as mental or physical capabilities.

Human augmentation technologies are all around you. They are wearable and portable. And they are so much a part of your daily life that you may not even notice them.

Do you, or any of your family and friends, wear eyeglasses? We all have limited vision, and it gets worse as we age. Glasses allow us to see further, in finer detail, and to see things that we might have otherwise missed. Next, think about the phone in your pocket (or the one you wish your parents would get you). Phones enable us to quickly connect with people far away and to access a vast amount of information on the internet. Glasses and phones each enhance our human capabilities to an extraordinary degree. And yet, they are completely ordinary nowadays.

But, what about physical augmentation? Imagine something you could wear to instantly enhance your physical capabilities; for instance, something that made you 25% stronger, doubled your endurance, or enabled you to do a strenuous task more safely and with less effort.

EXOSKELETONS

Called exos for short, these are wearable devices that assist, support, or augment movement or performance through physical interactions (forces) with the user's body.

What you are imagining is called an **exoskeleton**, or exo for short. Exos are wearable devices that assist, support, or augment (increase) movement through physical interactions (forces) with the user's body. The coolest part: exos are real and already being used by tens of thousands of workers around the world.

While exos are still a relatively new innovation, many experts predict that they will become common. But these exos are not like the robotic superhero suits you may have seen on TV or in the movies. In this article, we dive into the world of real-life exos. We will discuss what exos are, where they are used, how they function, and some of the challenges in designing exos.

WHAT IS A WORK EXO?

Work exos (also called occupational exos) are wearable devices that make physical jobs easier, or that help improve a worker's physical performance or safety (Figure 1). This is a big deal because workplace injuries due to physical overexertion impact hundreds of thousands of people and cost over $12 billion (USD) each year in the U.S. alone. Exos can help people lift heavy items with less risk of injury [1], maintain a difficult posture with less muscle strain, or perform a repetitive task with higher quality and less fatigue. Exos can be made of metals, plastics, elastics, or fabrics. Traditionally, exos are rigid (thus the term exoskeleton), but modern exos can also be soft, for instance, textile-based exos (called **exosuits**).

EXOSUITS

Also called soft exos, these are exos made largely of soft materials like fabrics textiles, and flexible rubbers.

Figure 1

Examples of exos used at work. **(A)** Active hand exo used by a manufacturing worker to relieve strain when gripping tools. **(B)** Elastic back exo used by a warehouse worker to reduce back injury risks, increase endurance, and make lifting boxes easier. **(C)** Elastic arm exo used by a construction worker to reduce shoulder strain and fatigue during overhead work. **(D)** Active trunk exo used by a healthcare worker to support their body posture and reduce strain on the low back when moving patients [photo sources: **(A)** Bioservo, **(B)** HeroWear, **(C)** Iowa State University and Lean Steps Consulting, **(D)** Japet Medical].

WHERE AND WHY ARE WORK EXOS USED?

Workers who do overhead tasks, like painting ceilings or fixing electrical wires high up, can use arm exos (also called shoulder exos) to make these jobs less tiring and reduce their risk of shoulder injuries. These exos make holding up tools (and their arms) feel much lighter, almost like floating or having an invisible assistant supporting your arms. This means workers can do their jobs without getting as tired or sore, which can improve work quality and wellbeing both at work and after work.

There are also exos to support many other tasks and body parts. Exos exist for the back, hands, and legs. For instance, warehouse and delivery workers who load and unload boxes can use back exos to make lifting easier and less tiring. People in industries like agriculture, carpentry, and maintenance who work in bent-over or awkward postures for long periods can use back exos for stability and relief. Workers in manufacturing or construction jobs who grip heavy-duty

tools can use hand exos to reduce strain and fatigue on their finger muscles. Doctors, nurses, and assembly line workers who need to stand or squat for long periods of time can use leg exos to help support their body weight. Leg exos are also being developed for soldiers, firefighters, and mountaineers who may have to carry heavy equipment over long distances.

While each of these exos targets a different task or body part, they each serve a similar purpose: they help people who do physical work to do their jobs more safely and effectively. As a result, people can go home after work with less pain and more energy, so they can enjoy their families, friends, and other aspects of their lives.

HOW EXACTLY DO EXOS HELP?

Exos work like an extra set of muscles during movement (Figure 2). Instead of all the force coming from your own biological muscles, part of the force—for instance, force needed to walk, bend, lift, or stand—comes from the wearable exo. Usually, the person is still doing most of the work with their own muscles, but wearing an exo can make certain tasks 10%–50% easier [2]. That relief adds up for people who do hours of physical work every day.

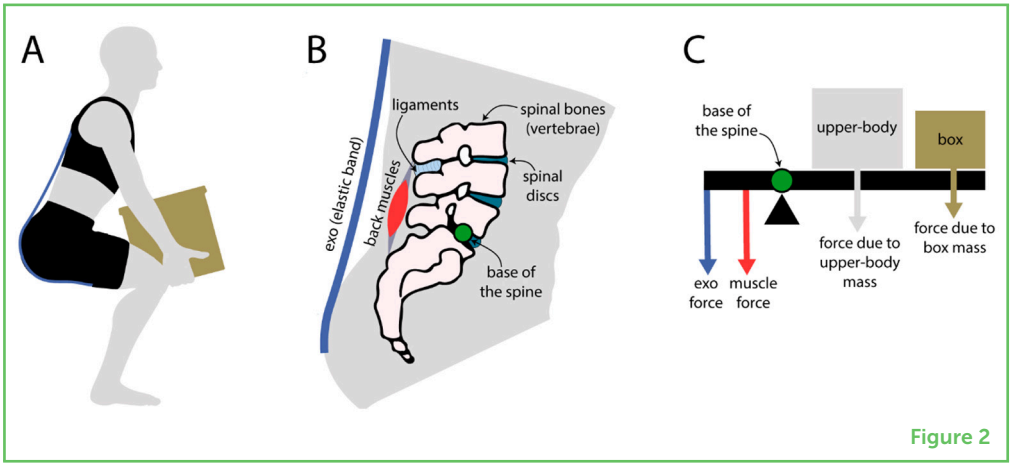

Figure 2

(A) A schematic of a person with an elastic back exo lifting a box. **(B)** A zoomed-in view of the low back, showing key biological structures involved in lifting. **(C)** A lever system showing how an exo assists a user's back muscles. Think of the base of the spine (green dot) as the pivot point of a seesaw. When bending down to lift a box, the upper body and the box exert forces that cause a forward rotation, and the back muscles contract forcefully to keep the body upright. When not wearing an exo, the back muscles and ligaments must generate all the force. When wearing an exo, it provides some of the force, reducing force on the back muscles and spine, and making lifting easier.

There are two main types of exos: **elastic exos** (also called passive) and **active exos** (also called powered). Elastic exos do not have motors or electronic parts. Instead, they use mechanical elements like springs and levers to support the body, assist movement, or enhance physical performance. For instance, when a person wearing an exo bends down to pick up an item, elastic potential energy is stored in a spring (e.g., due to an elastic band stretching, Figure 2), which reduces the amount of force on the back muscles and ligaments. When the person begins to lift, the spring returns its elastic energy, which provides a boost and makes the item easier to lift. Because of the physics principle of leverage, the exo also reduces the total compressive force on spinal bones (called vertebrae) and discs. Elastic exos are generally

ELASTIC EXOS

Also called unpowered or passive exos, these are exos that do not contain motors, but instead use springs, levers, or other mechanical mechanisms to provide assistance.

lighter, less expensive, and simpler than active exos. They do not require batteries or charging, which makes them very reliable and often easier to use. However, elastic exos can only provide certain types of assistance profiles and generally do not have the additional sensing capabilities offered by active exos.

ACTIVE EXOS

Also called powered or motorized exos, these are types of wearable robots that use motors or other powered devices to provide assistance.

Active exos are a type of wearable robot. They are equipped with motors that generate assistive forces, batteries that power the motors, and computer systems that control how much and when the motors exert forces. One of the benefits of active devices is that they can collect data from onboard **sensors**. Sensor data are used by active exos to interpret or anticipate the wearer's movements, and to coordinate the motors to assist [3]. It is actually very difficult to move a wearable robotic device in unison with the wearer in a way that is safe, does not interfere with movement, does not make many mistakes, and responds quickly and fluidly enough not to annoy (or endanger) the person wearing it. This problem remains a grand challenge in the exo field.

SENSORS

Devices that device that detect or measure a physical property or stimulus.

WHAT TYPE OF EXO IS THE BEST?

There is no simple or universal answer to the question of which type of exo is the best. Both elastic and active exos can enhance physical performance, relieve muscle strain, and reduce injury risks, often to similar degrees [4]. When it comes to assistance, the limiting factor is usually the wearer's comfort—how hard an exo can push or pull before the person feels uncomfortable [5]. Both springs and motors can generate forces higher than people can tolerate. So, it is generally not about whether the exo forces come from a spring or a motor—the best exo solution depends on the specific job and user. The same is true for rigid and soft exos—there are pros and cons to each. Exos are wearable tools, and different tools have different cases where they excel. With work exos, it is about trying to design and match the right tools to the right jobs.

HOW ARE EXOS DESIGNED?

Designing exos requires many skills and perspectives, including engineering (for mechanical parts and control), apparel design (for soft goods and comfort), and psychology (for aesthetics and user acceptance). This is because exos not only have to assist effectively and reliably, but they must also fit comfortably on people of all sizes and shapes, and they must look like something that people actually want to wear. Exos are an emerging technology, so there is still a ton of room for creativity, improvements, and design innovations. But you do not have to wait until you are an adult or work for an exo company to start building your own. There are exo kits for kids that you can purchase and build, such as a cyborg hand. Or you can build

your own unique exo from items and materials around your home. If you need ideas, go to this site and search for exoskeletons. You will find a treasure trove of do-it-yourself exo designs, from simple to complex.

ARE EXOS WIDELY USED AT WORK?

Exos are such a new technology that they are not yet widely used at work. But many experts expect that exos will become widely used in certain industries in the future. Work exos only started being used in workplaces over the last few years. Industries are gradually becoming aware of exos and learning where best to use them. Just like any new technology, exos have technical and practical challenges. For example, scientists, engineers, designers, and innovators are trying to reduce exos' cost and weight, improve physical and thermal comfort for men and women of varying sizes and shapes, minimize interference with other movements and tasks, make exos that are easier to use and optimized for specifics jobs, improve battery life, and overcome limitations in how exos are controlled.

THE FUTURE OF EXOS

The outlook for work exos is promising. This article focused on the growth of exos in the workplace, but there are also medical exos designed to help people with disabilities to perform daily activities, and recreational exos intended to help people do sports and other fun activities like hiking and skiing. There is still more to learn scientifically about the longer-term and larger-scale impacts of exos, but over the next decade, the prevalence of these wearable technologies is projected to grow exponentially. Exos might even become standard tools or safety equipment in certain jobs in the not-too-distant future. It is possible that kids born in the 2010s or later might be handed an exo on their first day of work—for instance, as bus boys, landscapers, or delivery drivers. This future of physical work is closer than most people realize!

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CONFLICT OF INTEREST: KZ is a co-inventor on intellectual property related to work exos. He co-founded and has a financial interest in HeroWear, LLC, which produces and sells back exos. HeroWear had no role in this manuscript preparation or the decision to submit this manuscript.

The remaining author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS

NIKHIL, AGE: 12

My name is Nikhil, and I am 12 at the time of this review. I enjoy science and am especially intrigued by things that are not in plain sight; either part of the micro-cosmos or the larger cosmos! I like watching sci-fi movies and writing realistic fiction. I also love sketching creatures that are similar to those from speculative biology.

VIHAAN, AGE: 9

Vihaan is an awesome 9 year old who likes to play with brother, read books, and sculpt with clay. He likes creating funny jokes, rock climbing, and is very active. He likes to learn facts he may never need to use.

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Žiga Kozinc is an assistant professor and research fellow at Faculty of Health Sciences (University of Primorska, Slovenia). His current research interests include sports biomechanics, assessment of mechanical tissue properties and musculoskeletal injury mechanisms. His Ph.D. work focused on user experience with exoskeletons, and he was involved in an international project called SPEXOR: spinal exoskeletal robot for low back pain prevention and vocational reintegration.
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Karl Zelik is an engineering professor at Vanderbilt University, where he co-directs the Center for Rehabilitation Engineering and Assistive Technology. His overarching mission is to improve health, mobility, and independence for individuals with physical disabilities and to enhance human performance and wellbeing through advances in movement science and wearable technology. Zelik is co-founder and chief scientific officer of HeroWear, which makes back exos that support workers in physical jobs. Zelik also serves on the board of a non-profit called the American Bionics Project, which seeks to accelerate the development and adoption of new wearable technologies for people with lower-limb disabilities.