BIONIC EXOSKELETONS

WHITEPAPER 2022

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THE RISE OF BIONIC EXOSKELETONS

Humans have been expanding their physical and biological capabilities since our ancestors first began utilizing simple tools to enhance their own welfare and improve survival prospects in an unforgiving environment.

These skills have progressed over millennia to include advances in science, technology, medicine, society, transportation, and even entertainment. However, despite our endeavor as a species, humans remain limited as organisms – in terms of aging, disease, cognitive impairment, and sustained injuries.

Modern human augmentation developments seek to solve some of the most profound challenges ever faced – such as personal mobility and high-level demographic shifts.

AGING SOCIETY

1 in 6 people in the world will be aged 60 years or over by 2030.

The share of the population aged 60 years and over will increase from **1 billion in 2020** to **1.4 billion in 2030**. By 2050, the world's population of people aged 60 years and older will double to **2.1 billion**.[1]

Some of the earliest exoskeleton devices were designed to support lower limb rehabilitation gait training in a medical setting to restore mobility for patients in recovery from suffering a stroke or other spinal / leg disability.

Bionic exoskeletons are being rapidly developed and deployed to help overcome injuries or to enhance the biological capacities to extend the period of active life into old age.

NUMBER OF EXOSKELETONS

The number of exoskeletons being used globally is expected to grow sevenfold from 2022 to 2030.

Exoskeleton deployments are forecast to increase from **93,000 units in 2022 to 719,000 in 2030.**[2]

Rehabilitation exoskeletons have assisted patients to take over 200 million steps.[3]

1 World Health Organization (WHO)
2 ABI Research
3 Ekso Bionics

TYPES OF BIONIC EXOSKELETONS

There are many different types of exoskeletons currently in use, assisting primarily the lower back, shoulders, and more. The main distinction is that of passive and powered exoskeletons. In simple terms, passive devices are purely mechanical structures, which may be cheaper and lighter in weight. Powered exoskeletons on the other hand, are robotics devices, which can provide a much higher level of assistance, and even enhancement.

Exoskeleton providers are an eclectic mix, arriving at the production of assistive devices from different backgrounds, and with very different problems to solve. Some of these manufacturers are well-established companies, with decades of experience in human augmentation, whereas others were founded with the specific purpose of researching and developing exoskeleton technology.

Figure 1: Ottobock started out in 1919 producing prosthetics

Each manufacturer – whatever their route to providing exoskeletons – has done so to solve very specific problems regarding the limitations of the human body, whether providing rehabilitation after injury, enhancements in strength, or the prevention of workplace injuries.

Figure 2: Sarcos' Guardian XO exoskeleton provides enhanced strength

For this reason, each type of exoskeleton will have different characteristics, as the companies producing them have made technology and mechanical choices and trade-offs which best solve the specific problem they seek to address.

In fact, even devices which appear to solve the same problem may actually have very different capabilities and functionality.

1 PASSIVE EXOSKELETONS

Passive exoskeletons are purely mechanical structures which support the user with lifting motions by utilizing the restorative force of springs and dampers.

Passive systems have relatively low complexity compared to powered devices, without any electrical components or software control, or additional assistance functions.

However, this allows them to remain lighter and cheaper to buy due to a lack of batteries, motors, and drive systems.

In Japan, manufacturers like Innophys have discontinued their industrial offerings to focus on releasing consumer-based devices designed with much cheaper pneumatic components, which use compressed air to provide lift compensation.[4]

Figure 3: B2C pneumatic / compressed air exoskeleton

Similarly, some providers like HeroWear in the U.S. have started releasing textile-based “softexos” which are worn like clothing and simply use elastic qualities to provide lift support.[5]

Figure 4: Softexo

The trade-offs in technology choices which affect complexity and cost determine the level of support and lift compensation provided, and therefore the specific use case.

LIFTING SUPPORT VIA:

SPRING

DAMPER

4 Innophys
5 HeroWear

2 POWERED EXOSKELETONS

Powered exoskeletons (sometimes also called 'active') combine mechanical structures with robotic technology and are especially designed for high intensity and high repetition lifting tasks that place a significant strain on the lower back, specifically in large-scale distribution and logistics.

In contrast to passive devices, these more complex and sophisticated structures come equipped with batteries, sensor-based controls, and actuators to provide lift compensation as and when required – allowing free movement and flexibility when not needed.

Figure 5: Cray X in deployment at one of Europe's largest logistics centers - Fiege Mega Center Ibbenbüren

Powered devices share the work by creating positive force for reducing the overall load of repetitive lifting tasks while allowing the user to focus energy on completing the task at hand.

Some manufacturers are taking powered devices to the next level by making them adaptable to all body types and handling environments with connectivity for real-time analysis and variable configuration over time, ensuring safety and supporting the user in a dynamic workplace.

With connectivity, the device can adapt to the user, not the other way around. It also accelerates R&D with access to ready data by opening a communications channel between user, owner, and provider.

Figure 6: Nurse utilizing active exoskeleton to lift patient - Charité - Universitätsmedizin in Berlin

The Cray X battery and motor-based powered exoskeleton provides 30kg lift compensation and can collect data on important real-time health insights to ensure safe and ergonomic operations.[6]

LIFTING SUPPORT VIA:

BATTERY **MOTOR**

6 German Bionic

3 CONNECTED EXOSKELETONS

Connectivity and the ability to capture, transmit, and analyze data has been an essential component of exoskeleton research, especially in the rehabilitation setting for understanding how patients respond to gait training.

More recently, exoskeleton manufacturers have been using connectivity in an industrial setting to provide their customers with important information about the human element of their operations, such as in logistics environments.

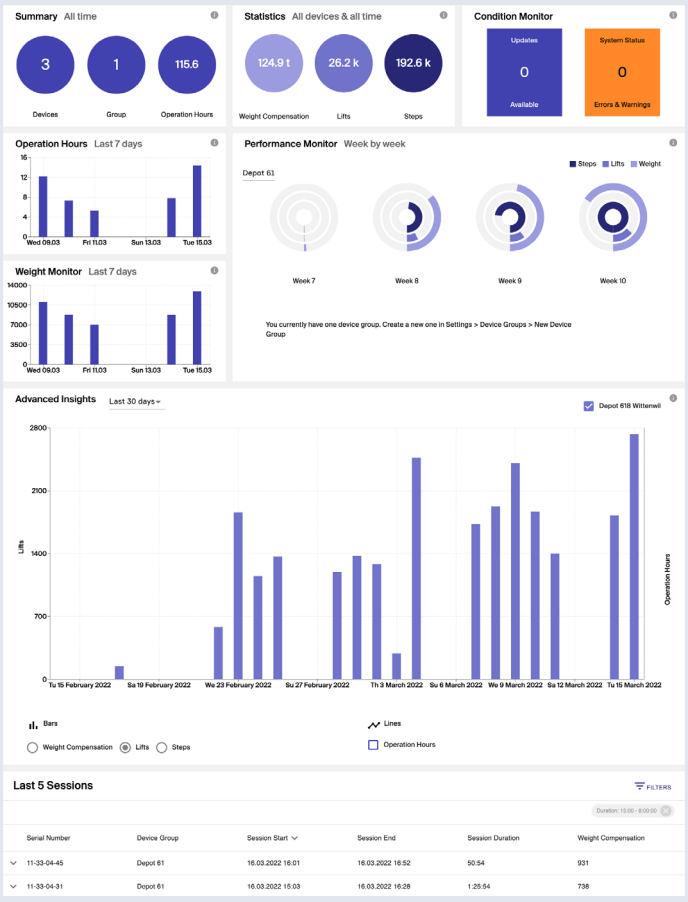


Figure 7: German Bionic IO platform for big data analysis

Where occupational safety & health officers have previously collected data manually, connected exoskeletons enable companies to gain instant access to notifications and improvements at various levels within the organization.

The sensory data obtained offers the benefit of thousands of hours of movement detection to recommend improvements for workplace safety, efficiency, and productivity.

Another benefit of connectivity is the ability to monitor system health for predictive maintenance, making it easier to plan for and reduce downtime.

Software and firmware can also be remotely updated ‘over-the-air’ via a cloud platform.

As demand increases and the margin for error in warehouse processes decreases, AI-enabled supply chain solutions are becoming imperative for warehouses that rely on speed, efficiency, and intelligence to remain competitive.

Valuable and actionable safety, efficiency, and productivity insights generated from various consolidated data sources for contextual and holistic analyses improve operations and ultimately create higher quality product flow and processes.

Therefore, amongst logistics and industry experts, connected exoskeleton devices are – after extensive testing – taking preference over non-connected systems.

EXOSKELETON EXAMPLES

As with any new innovation, researchers and manufacturers are constantly finding new and exciting uses for exoskeletons.

Clinicians have been using rehabilitation exoskeletons as a core component of their physiotherapy programs, helping disabled patients find their feet and walk again.

EKSO BIONICS [7]

Ekso NR

- 300 devices in use
- 2,000 patients
- 30+ countries
- Only FDA-cleared

Some devices are intended to be used exclusively on site, whereas others are designed to be used outside of a clinical setting to provide personal mobility in everyday life.

WANDERCRAFT [8]

Atalante X

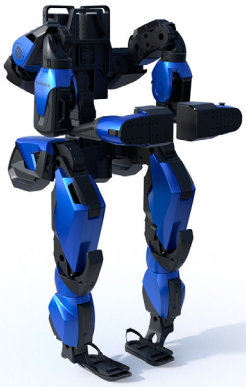
- Self-balancing
- Hands-free
- Dynamic standing
- Multi-directional

In industry, manual workers have been feeling the benefit of exoskeletons to reduce workplace injuries and prevent muscular pain.

SARCOS ROBOTICS [9]

Guardian XO

- Full body
- Heavy duty tasks
- 90kg lift support
- Enhances strength 20x



For heavy duty industrial jobs, Sarcos Robotics has developed an exoskeleton which enhances the user's strength and can enable the worker to lift up to a factor of 20x, with a maximum lift capacity of 90kg.

Currently, the full body Guardian XO exoskeleton from Sarcos is being used in aviation, construction, and assembly & manufacturing to enhance engineers and mechanics with their everyday tasks.

GERMAN BIONIC [10]

Apogee

- Lower back
- Logistics tasks
- 30kg lift support
- Connectivity

The 5th Generation Cray X from German Bionic is being successfully used in logistics to protect workers and improve their processes with real-time data analytics and connected services.

7 Ekso Bionics
8 Wandercraft
9 Sarcos Robotics
10 German Bionic

REHABILITATION EXOSKELETONS

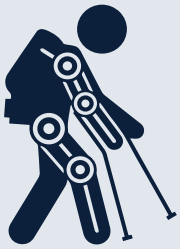
Robotic assistants have been a familiar sight in healthcare for years, but wearable assistive rehabilitation exoskeletons are still a relatively recent innovation in clinical settings.

Figure 8: Rehabilitation Exoskeletons helping patients find their feet

Rehabilitation exoskeletons are used in medical facilities to treat patients who suffer from motor dysfunction. The device connects directly to the body and supports the legs, spine, and trunk to correct movement patterns and allow patients to undergo intense and repetitive gait training.

Throughout the course of treatment, patients restore mobility to reshape motor function and eventually be able to regain physiological autonomy.

REHABILITATION EXOSKELETONS



Rehabilitation exoskeletons are being successfully used to treat spinal cord injuries (SCI), strokes, acquired brain injuries (ABI), and multiple sclerosis (MS).

Assistive physical rehabilitation is proving effective at helping those with paraplegia return to leading a more active life and ultimately get back into their communities.

SPINAL CORD INJURY

500,000

people suffer a spinal cord injury (SCI) every year globally.

Rehabilitation services are essential to manage these conditions – which cause significant barriers to economic participation, with global unemployment of more than 60%. [11]

Researchers are also beginning to understand how exoskeletons can help to improve the brain and nervous system with motor learning and movement coordination.

It has been discovered that the nervous system adapts specific aspects of movement and simultaneously decreases variability along these aspects. The researchers also found that these adaptive changes improved movement overall, reducing the energy cost of walking by about 25 percent.[12]

11 World Health Organization (WHO)
12 Abram, et al.

INDUSTRIAL EXOSKELETONS

Industrial Exoskeletons are wearable safety devices designed to be used in the workplace to augment the worker's metabolic performance.

Unlike rehabilitation devices, they are designed for preventative health – to reduce muscular strain and energy expenditure for manual jobs which require strenuous effort.

Industrial exoskeletons generally perform two main functions, relieving the localized muscle groups of the:

1. **shoulder when performing overhead work**

Figure 9: Passive Exoskeleton

2. **lower back with lifting and carrying tasks**

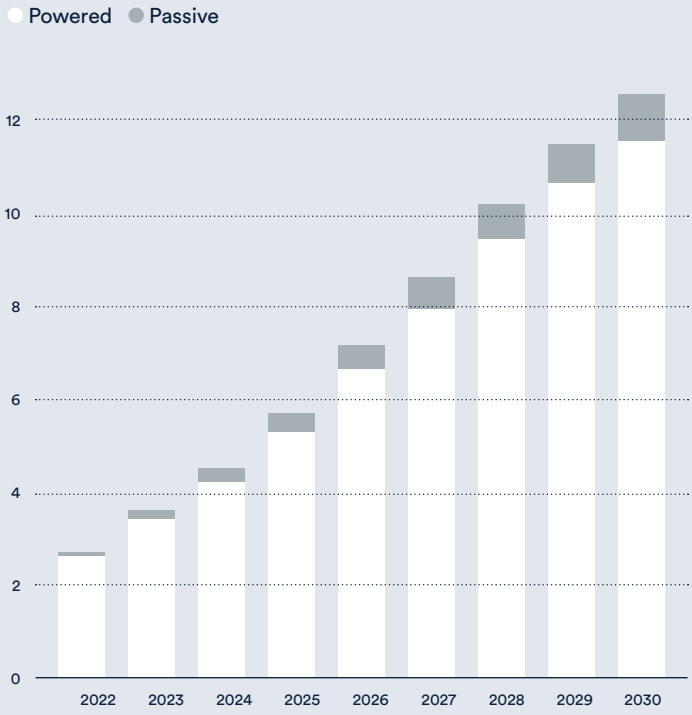
Figure 10: Powered Exoskeleton

Industrial applications focus on supporting workers with everyday tasks to prevent the onset of work-related musculoskeletal injuries and protect against workplace accidents. They are categorized by the technology components designed to support users with specific tasks.

Passive exoskeletons use the restoring forces of springs, dampers, or other materials to support human movement. With these devices the lift compensation is generated exclusively by the energy of the user themselves.[13]

Powered exoskeletons, on the other hand, are robotic and utilize external energy sources, such as electrical motors to power the actuators to support the user with lifting activities.[14]

MARKET SIZE (U.S. $, BILLIONS) [15]



Powered exoskeletons are expected to constitute the strongest demand for exoskeleton devices.

13 de Looze, et al.
14 Gopura, et al.
15 ABI Research

INDUSTRIAL EXOSKELETONS

1 OVERHEAD SHOULDER SUPPORT

Comfort is critical with industrial exoskeletons – meaning that the biomechanical units require the ability to make adjustments to suit the needs of the wearer based on factors such as height, as well as critical dimensions like spine and – in the case of overhead shoulder exoskeletons – forearm length.

Overhead shoulder support exoskeletons relieve stresses on the entire back and neck by supporting the arms and shoulders with overhead tasks such as in automotive manufacturing when working on the undercarriage of vehicles.

Most shoulder support exoskeletons on the market currently are passive systems which use regenerative force to redistribute the load and transfer muscular strain to more robust areas of the body, like the hips.

These devices utilize pulleys, cables, and springs to provide lifting power, with arm rests that capture and support the user's arms for extended periods of time.

However, this comes with trade-offs in terms of limited movement when compared to powered devices, as users may feel underarm strain when bringing their arms down against the force of the spring.

In terms of operation, manufacturers therefore prioritize the attributes of lightweight devices which offer a high degree of freedom of movement.

Overhead shoulder support devices have been some of the first exoskeletons to be broadly accepted in manufacturing plants globally.

For example, in 2020, Toyota Motor North America became the first company to introduce an exoskeleton device as mandatory personal protective equipment (PPE).[16]

Figure 11: Overhead Exoskeleton Airframe made mandatory PPE by Toyota Motor NA

16 Levitate Technologies

INDUSTRIAL EXOSKELETONS

2 LOWER BACK SUPPORT

Lower back exoskeletons are designed to relieve localized muscle groups in the lumbar region to protect manual workers who perform repetitive lifting and carrying tasks. The aim is to prevent lower back pain and injury, and to rehabilitate those already suffering from musculoskeletal injuries.

In 2021 the National Health Service (NHS) in the United Kingdom purchased 127 units of lower back exoskeletons to help nurses with patient care.[17]

They are used mainly in logistics and manufacturing; however, despite being known as industrial exoskeletons, the application of lower back exoskeletons is wide ranging, with successful deployments being reported in the health profession – helping nurses provide medical care with lifting and turning patients.

MUSCULOSKELETAL DISORDER

3 in 5 people report one or more musculoskeletal disorder (MSD)

The most common MSD reported was back pain with 45% of male and 42% of female respondents reporting injury.[18]

Back pain is almost an inevitability which becomes more prevalent with advanced age. As the world gets older it is expected that consumer exoskeletons will become increasingly popular to rehabilitate elderly individuals who wish to lead active lifestyles. For this reason, lower back exoskeletons come in several distinct categories in terms of design and technology to cater to different use cases, complexities, and cost points.

AGRICULTURAL WORKER IN JAPAN

67 YEARS

The average age of an agricultural worker in Japan.

Japan scores highest on the Old Age Dependency Ratio of countries worldwide – with persons aged 65+ counting as 28% of the total population.[19]

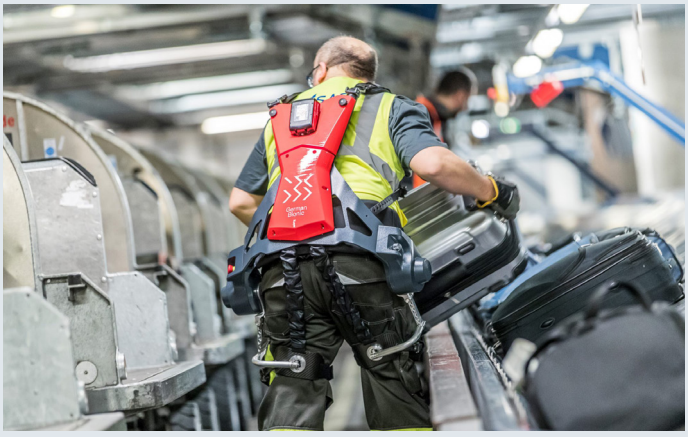


Figure 12: Baggage handling at Stuttgart Airport

17 Cyberdyne (2022)
18 EU OSHA (2019)
19 Japan Ministry of Agriculture, Forestry & Fisheries

INDUSTRIAL EXOSKELETONS

3 LOWER BACK SUPPORT IN LOGISTICS

Many logistics operations are still dependent on a large human workforce. Human workers can be invaluable as adaptable, cognitive assets with flexibility and problem-solving abilities as well as being able to lift and shift packages.

However, the increased demand for online shopping and fast delivery times means that much of the pressure created will often land on the backs of manual workers.

Repetitive and high intensity lifting and shifting motions causes physical strain which can in turn lead to debilitating chronic conditions, such as musculoskeletal disorders (MSDs), which render the worker a great deal of distress, as well as limiting their movement and mobility in everyday life.

There are a broad range of costs – both direct and indirect – associated with work-related musculoskeletal disorders. It has been estimated that the price of MSDs in terms of lost productivity accounts for around 2% of gross domestic product (GDP) of the European Union. [20]

Negative consequences on worker health are multifaceted:

Physical

- Range from discomfort, minor aches & pains, to serious conditions and permanent disability.
- Most well-known MSDs are lower back pain and work-related upper limb disorders.
- Main risk factors for the latter are associated with task repetition and awkward work postures. [21]

Psychological

- Carry emotional value and potential for causing physical or psychological damage to health. [22]
- Linked to design, organisation, management, as well as economic and social context of work.
- Cause increased level of stress and serious deterioration of mental and physical health. [23]

For this reason exoskeletons are now being used in large-scale distribution centers to protect logistics workers and prevent illness.

> “Technical and organisational measures to design workplaces can be impractical or infeasible, and therefore it becomes necessary to consider the use of exoskeletons.” [24]

20 Bevan (2015)
21 EU-OSHA (2019)
22 Devereux, J., et al. (2004)
23 EU-OSHA (2007)
24 EU OSHA (2020)

INDUSTRIAL EXOSKELETONS

3 LOWER BACK SUPPORT IN LOGISTICS

With the use of exoskeletons, logistics companies are reducing sick days, savings costs, and boosting productivity.

SICK DAYS

-25%

reduction in sick days

Logistics companies are also reporting increased picking rates, reduced error rates, and lower exhaustion.

The international parcel delivery service DPD uses the Cray X powered and connected exoskeleton to relieve workers with unloading activities.

Figure 13: Cray X powered exoskeleton onsite at DPD

The results so far have been very positive, with Senior Innovation Project & Sustainability Manager, Ville Heimgartner, explaining:

> **"Exoskeletons reduce physical work and thus help to improve the day-to-day lives of our depot employees. This is not an efficiency measure. First and foremost, the exoskeletons serve to protect the health of our employees by preventing back pain or slipped discs. As less physical strength is required when wearing the exoskeleton, older or less 'athletic' employees can also carry out this work. During our test phase to date, each employee is relieved of an average of one tonne in weight per hour. This equates to roughly the weight of one car per hour and per employee."** [25]

By protecting their workforce and preventing injury, logistics companies will also see the long-term benefit of cost savings from reduced claims.

Employers can assess the impact of occupational injuries and illnesses on their profitability. [26]

INJURY	DIRECT	INDIRECT	TOTAL
STRAIN	$32K	$35K	$67K
SPRAIN	$30K	$34K	$64K
MENTAL	$59K	$65K	$124K

The estimated costs provided by the Occupational Safety & Health Agency (OSHA) may also be combined, as physical injuries are often associated directly with psychological damage.

With exoskeletons, workers can remain physically and emotionally healthy into retirement – long enough to trade lifting packages with lifting their grandchildren.

25 DPD
26 OSHA.gov

INDUSTRIAL EXOSKELETONS

4 OTHER USES

The largest use case for industrial exoskeletons currently is in the logistics sector, but companies operating in many different fields are also benefitting.

Automakers are using exoskeletons to help workers with **manufacturing** and servicing vehicles, especially lifting and fitting tires.

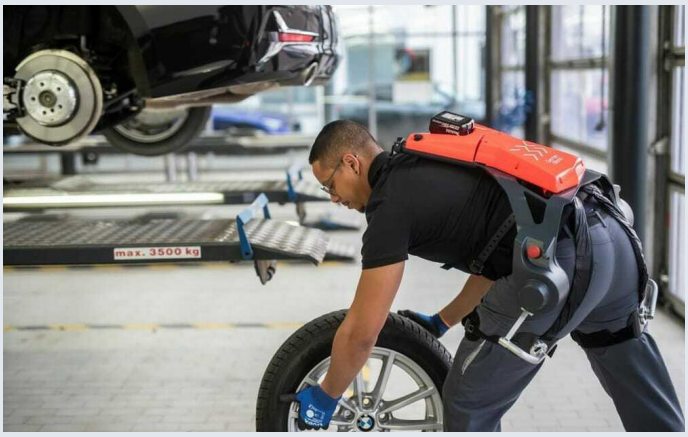


Figure 14: Cray X powered exoskeleton onsite at BMW

Nurses are using exoskeletons in **healthcare** when lifting patients into more comfortable positions, or in preparation for procedures.

Figure 15: Cyberdyne HAL Lumbar onsite in healthcare setting

Construction workers are supported with heavy lifting activities.

Figure 16: The Paexo Shoulder from Ottobock for working in construction

Train companies are using water and dustproof exoskeletons for **outdoor maintenance** on the track infrastructure.

Figure 17: The Cray + from German Bionic has been specially optimized for use in disaster areas

Exoskeletons may also be used to help people in **disaster relief** scenarios.

MARKET OVERVIEW

Company HQ locations

USA

ekso BIONICS

HEROWEAR

LEVITATE TECHNOLOGIES, INC.

SARCOS

SUITX

VERVE MOTION

EUROPE

AGADE

EXOATLET

German Bionic

Japet.

laevo

ottobock.

JAPAN

CYBERDYNE

INNOPHYS

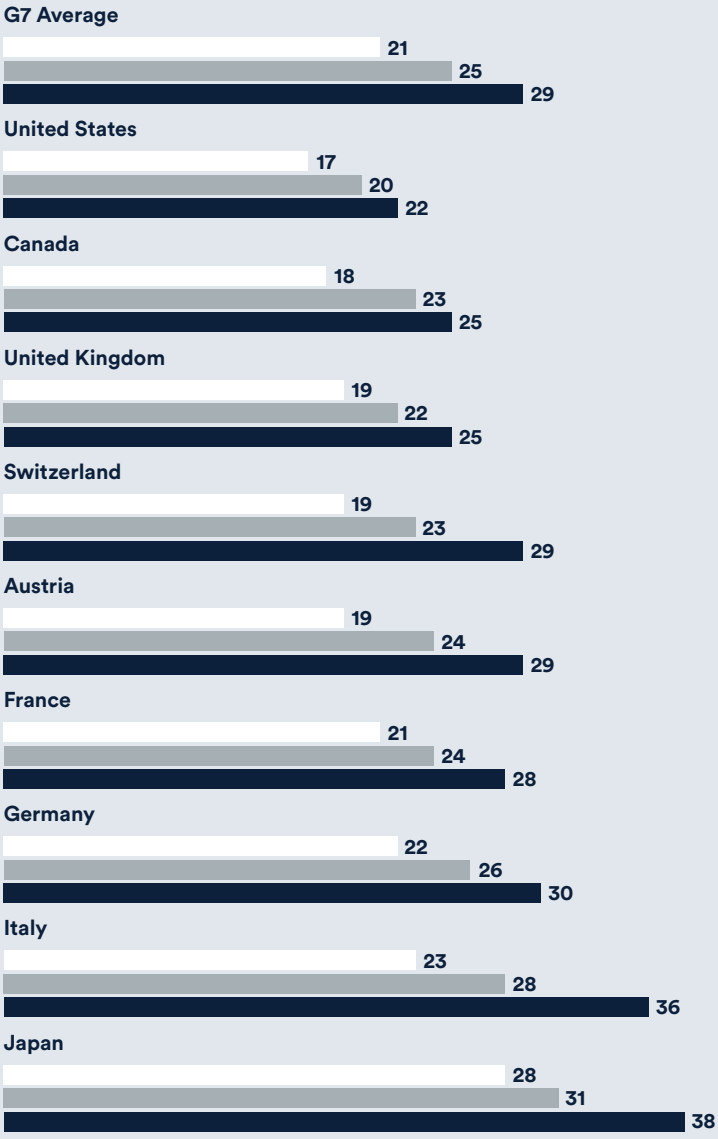
JTEKT

MUSCULOSKELETAL DISORDERS: A GROWING PROBLEM

Musculoskeletal disorders (MSD) are injuries or disorders of the muscles, nerves, tendons, joints, cartilage, and spinal discs. They become more prevalent with advanced age.

OLD AGE DEPENDENCY RATIO %

No. of persons aged 65+ as % of working population (15-64)



Primary ergonomic risk factors include:

- High intensity task repetition. The repetitive nature of tasks is often dictated by time-sensitive daily quotas that put workers under immense pressure. This pressure can often lead to workers adopting poor postures to keep up with the demand, as a proper lifting technique becomes an afterthought to fulfilling quotas and fatigue.
- High force loads. Muscular exertion increases with higher force requirements. This also can lead to higher general fatigue which can lead to poor postures and ultimately MSDs.
- Awkward posture. Compressive forces and prolonged loading put strain on the tendons around the joint. When joints are worked outside of their optimal 'mid-range' motion over a prolonged period in repetition, the risk of musculoskeletal disorder increases. [28]

To avoid these risk factors, exoskeletons have been proven to mechanically ensure correct postures, alleviate the muscles groups and tendons around joints, and reduce the rate of general fatigue.

27 International Labor Organization (ILO) (2020)
28 Ergo Plus

PROF. DR. MED. HERBERT SCHUSTER

Private Practice Genetics & Preventative Medicine, Berlin, Germany

Scientific Committee,
VDEI Association of the Exoskeleton Industry e.V

"Muscular and skeletal disorders are responsible for almost a quarter of all sick days in Germany and cause economic damage of more than 30 billion euros per year due to the loss of gross value-added product. This was calculated by the Federal Institute for Occupational Safety and Health,"
says Prof. Dr. Herbert Schuster.

The renowned preventive physician is a member of the scientific advisory board of the VDEI Association of the Exoskeleton Industry e.V based in Berlin. He goes on to say:

"This health risk arises because a third of all employees have to lift too heavy materials at work in high intensity repetition.

The Cray X revolutionizes manual handling and provides a remedy by actively preventing harmful overloads and work accidents."

BERTALAN MESKÓ, MD, PHD

Director of The Medical Futurist Institute
(Keynote Speaker, Author & Futurist)

"Beyond rehabilitation, a trend seems to be forming to equip workers with exoskeletons. A small-scale pilot experience of about 40 exosuit-assisted workers found promising results.

Those workers reported that the exoskeletons provided a reduction of 73% in lower back discomfort, and lowered work effort by 30%. Moreover, 80% felt that these mechanical add-ons could prevent injuries of the lower back. With some $100 billion in medical bills attributed to worker injuries in the U. S., it makes sense for employers to explore new methods to assist workers and limit healthcare hazards.

With this in mind, companies are developing exoskeleton solutions to assist workers and prevent injury. For example, the Cray X from German Bionic allows a worker to easily carry around weights of up to 30kg. Its embedded Smart Safety Companion system also helps prevent common lifting injuries."

CONCLUSION

Exoskeletons are still a very recent innovation; however, many people and enterprises are already experiencing the benefits worldwide.

In the medical space, clinicians are seeing breakthroughs in gait rehabilitation for patients with motor dysfunction disabilities, returning to mobility, and access to a fulfilling life.

Industrial workers are protecting their futures against debilitating shoulder and lower back musculoskeletal disorders with the mechanical support and lift compensation provided by industrial exoskeletons.

In terms of price parity, cheaper components and technologies have allowed smaller businesses and consumers to access passive devices for lightweight tasks.

On the other hand, powered exoskeletons utilize more advanced battery and motor-based systems to support high intensity and high repetition tasks, such as in largescale distribution and logistics.

Companies themselves are benefitting in terms of the costs associated with having a safer and more energetic workforce.

Some innovative companies are also adding the connectivity element to improve communications within large organizations by adding manual workers as nodes in the industrial IoT network.

Connected devices are also highly variable with automated configuration to ensure that the device adapts to the idiosyncratic movements and body types of the users themselves.

High adaptability ensures that the exoskeleton is comfortable and functional, supporting the user when needed, but not causing unintended and unnecessary strain when not.

Where exoskeletons were once confined to the paradigm of science fiction, they are now proving an invaluable asset in healthcare and protecting workers.

As they become more commonplace, science fiction is fast turning into reality.

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