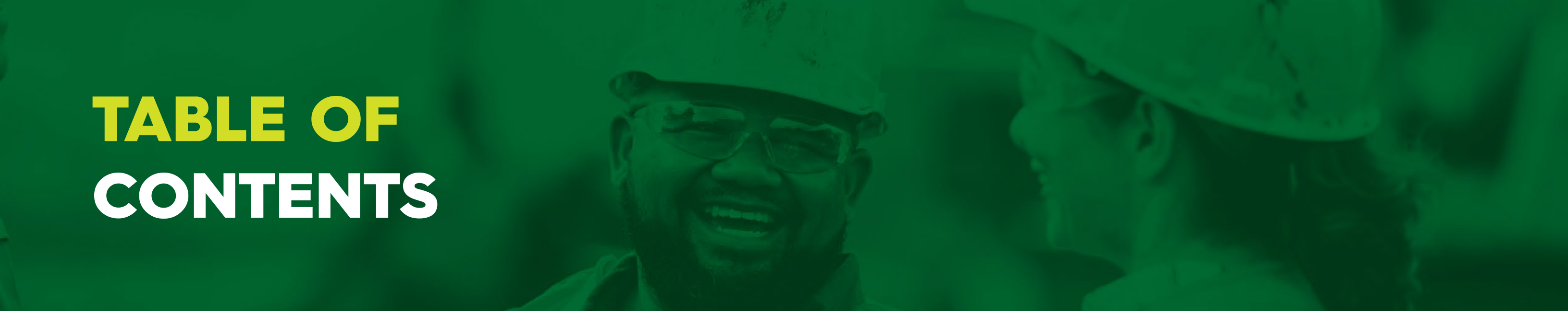
Emerging Technologies for the Prevention of Musculoskeletal Disorders



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Executive Summary

Over the past three decades, extensive research, development and implementation efforts have been made to redesign workplaces to accommodate or modify the work and work environment according to the capabilities of workers. However, work-related musculoskeletal disorders (MSDs) persist and continue to account for the majority of workplace injuries, offering a significant opening for emerging technologies to revolutionize solutions for reducing risk and preventing MSDs.

As workplaces undergo a transformation driven by digitization, automation and computer intelligence, the intricate interactions between workers and their workplaces can be simplified by automating work processes or integrating emerging technologies to eliminate or minimize worker exposure to ergonomic hazards. This allows employers to redesign operations and systems by leveraging emerging technologies, leading to rapid and significant improvements in preventing MSDs.

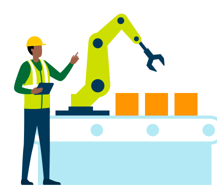
Emerging technologies offer potential solutions to workplace hazards including reducing physical strain on workers, enhancing ergonomics, improving productivity, and providing better training and guidance. This report reviews a range of these technologies that were unthinkable just a few years ago, including:

Computer Vision

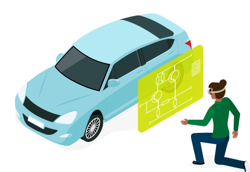
Wearable Sensors

Exoskeletons

Cobots



Extended Reality (XR)



However, the emerging technologies market is fragmented and complex due to the vast array of tools and systems available and their constant evolution. Consequently, potential buyers (e.g., employers) are uncertain about which technologies and suppliers meet their needs. In contrast, potential vendors struggle to validate their systems and instill confidence in potential buyers.

To address the uncertainties surrounding emerging technologies, the MSD Solutions Lab, in partnership with Safetytech Accelerator, organized a workshop with corporate executives. In the workshop, the executives shared their concerns regarding MSDs and engaged in discussions about their ongoing trials and efforts to mitigate these issues. Information was gathered on their perspectives regarding the most significant MSD risks in their respective industries, as well as the emerging technologies or solutions they had recently tested to address these risks. The lessons learned from these trials were documented as case studies throughout the report.

The MSD Solutions Lab demonstrates a commitment to advancing research and education on specific emerging technologies with the goal of enhancing current solutions, programs and processes. **The Lab also focuses on generating innovative and sustainable strategies to drive workplace transformation. Its primary objective is to equip employers and workers with the necessary information and tools to identify and mitigate risks associated with MSDs in data-driven workplaces. The Lab is committed to bridging the gap between industry adopters and innovators through collaborative efforts. The first steps in preparing transparent marketplaces for different tools and solutions are well underway, and our plans are ambitious to do much more, creating safe and healthy work environments for all individuals involved.**

Introduction and Approach

In June 2021, the National Safety Council (NSC), America's leading nonprofit safety advocate, established the MSD Solutions Lab to address musculoskeletal disorders, which are among the most common workplace injuries. This innovative initiative involves engaging key stakeholders, conducting research, identifying new technology-based solutions and scaling the results for the benefit of all workplaces.

As part of this multi-faceted initiative, the MSD Solutions Lab partnered with **Safetytech Accelerator,** which focuses on safety and risk in industrial sectors and critical infrastructure. Collectively, this report has been prepared to offer insights into the existing status of MSD technology solutions, the outcomes of their implementation, and prospects for advancing and testing emerging technologies for broader adoption in workplaces.

This report comes from extensive research, the most important of which was listening to the evidence and experience of a large number of executives from all sides of the community: those running operations that may have MSD risks and those developing MSD mitigation tools and solutions. To initiate the research process, a workshop was conducted with corporate executives where they shared their MSD concerns and discussed their trials to mitigate them, including successful and unsuccessful attempts. Following this, a questionnaire was distributed to a broad range of executives to determine if the experiences shared in the workshop were representative of other U.S. industries.

Executives from various industries, such as meatpacking, vehicle engine manufacturing, agricultural machinery, aviation, and logistics and supply chain, were interviewed in-depth. Questions with a predetermined set of inquiries were initially asked, which included:

- What tasks posed the most significant MSD risks?
- What technologies or solutions did they recently test to mitigate these risks?
- What lessons did they learn from these tests?

The executives were also interviewed using open-ended questions to gather in-depth information about their experiences with emerging technologies. The interviews were conducted virtually by a strategic consultant from Safetytech Accelerator, a subject matter expert and a research manager from the MSD Solutions Lab to explore the challenges of executives responsible for MSD risk reduction. After the interviews, Safetytech Accelerator followed up to develop a library of case studies and to analyze the executives' unmet needs. Additionally, Safetytech Accelerator experts interviewed various solution providers to understand the challenges in developing, validating and marketing MSD risk mitigation tools.

Industry 4.0 and Beyond

Digital and communications technologies are rapidly changing almost every sector of industry. Having started with music, e-commerce and financial services, these changes are now transforming manufacturing, logistics, health care, construction and mining, just to name a few. It is almost impossible to find an industry sector not changing work practices due to the digital and communications revolutions described as the fourth industrial revolution, also called Industry 4.0 (Schwab, 2016). This revolution refers to integrating advanced technologies, such as automation, robotics, artificial intelligence and the Industrial Internet of Things (IIoT), into industrial processes. As a result, Industry 4.0 offers numerous benefits and opportunities for increased efficiency and productivity.

Industrial Internet of Things (IIoT)

The IIoT is a merger of several technologies allowing almost every machine on a factory floor to be coordinated and every component (or batch of components) being processed to be uniquely identified and monitored in real time (Cisco, n.d.; Boyes et al., 2018). Machines can be given unique IP addresses along with devices that track and monitor the movement of components as they move through the supply chain and factory floor. New and improving communications technologies (e.g., 5G and mesh networks) allow new types of sensors to gather and share previously unknown or lost data. IIoT makes it possible for large amounts of valuable data to be collected, stored, analyzed and exchanged.

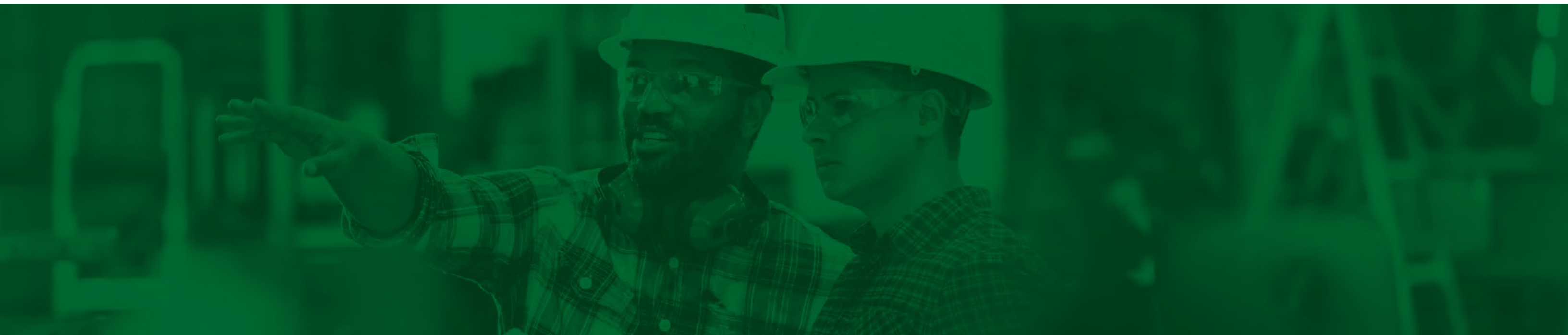
How does this relate to MSD risk?

As an example, new types of data can be collected by sensors that monitor a worker's:

- Physiological and biomechanical responses in real time (e.g., heart rate, temperature and motion) ensuring they are working safely within defined parameters (e.g., wearable sensors and cameras)
- Environment to alert them to external risks (e.g., machines, vehicles and environmental conditions)
- Other safety events or exposures in real time and communicate with their safety or ergonomics managers (as well as collect and monitor data from other workers/locations)

Digital Twins

A digital twin is created by combining data from workplace design, planned operations and IIoT technologies with artificial intelligence (AI) or machine learning (ML). Digital twins can then be used to increase productivity, improve workflows and design new products. The definition of a digital twin varies between industry and academia, with both groups placing different levels of emphasis on various aspects (Parrott & Warsha, 2018). Some consider a digital twin to be a comprehensive model of a product as it was built, designed to capture all manufacturing flaws and constantly updated to incorporate the effects of wear and tear during usage. Alternatively, some describe a digital twin as a sensor-equipped digital representation of a physical object that simulates the object in a real time environment. For example, by simulating a new factory layout, a manufacturer can test changes to production efficiency, work safety and find ways to improve capacity.



How does this relate to MSD risk?

Digital twins can enable the use of technologies, including AI/ML, and:

- Allow researchers, ergonomists and engineers to test workplace layouts, devices or tools without imparting risk to the worker and with a minimal material expense
- Enable any changes in a digital twin to automatically mirror and affect the status of its physical twin as the data flow bi-directionally – by connecting sensors on the worker, collected data can be mapped onto the digital twin to predict how the work could be performed (Barresi et al., 2022)
- Data analyses from connected sensors, combined with other sources of information in real time, allow for predictions and insights for informed decision-making on injury risk
- Predict MSD risk for each worker's role across entire operations
- Assess MSD risk as workloads vary so operations and controls can be adjusted to maintain the optimal conditions for the workforce

Industry 5.0

Although Industry 4.0 is still in its infancy, Industry 5.0 has already begun. It uses the same core technologies as Industry 4.0 but brings a renewed focus on the human and customization, and helps deliver broader organizational objectives than profit and productivity.

As described by the European Union (Dixson-Decleve et al., 2022), Industry 5.0:

- Provides a vision of an industry that pushes beyond efficiency and productivity as its primary goals, and reinforces the role and contribution of industry to society
- Places the wellbeing of the worker at the center of the process and uses new technologies to provide prosperity beyond jobs and growth while respecting the production limits of the planet

The key to Industry 5.0, therefore, is not about the enabling technologies but how people use them and are central in their operations, specifically putting the user at the center of the system. Benefits of a human-centered design include:

- Skills can be developed and retained if workers remain fit to work until older (Levesque, 2019; Wong & Tetrick, 2017)
- Greater workforce diversity can be supported
- Improved worker safety can be assured
- Operations can be made more resilient to a wide variety of internal and external shocks
- Environment, social and governance corporate responsibility can be defined, measured, delivered, audited and reported

Placing the person at the center of operational design means considering human-machine interfaces and human behavior as part of workplace (re)design and risk reduction. While this report reviews many technologies, some specific to Industry 5.0 include:

- **Gamification** where workers learn skills and change their behavior through enjoyable and incentivizing models of engagement (Gamify, n.d.); For instance, wearable sensors can track workers' movements to assess their MSD risks while their movements are rated for safety in a "game mode," where good performance is rewarded like in computer games

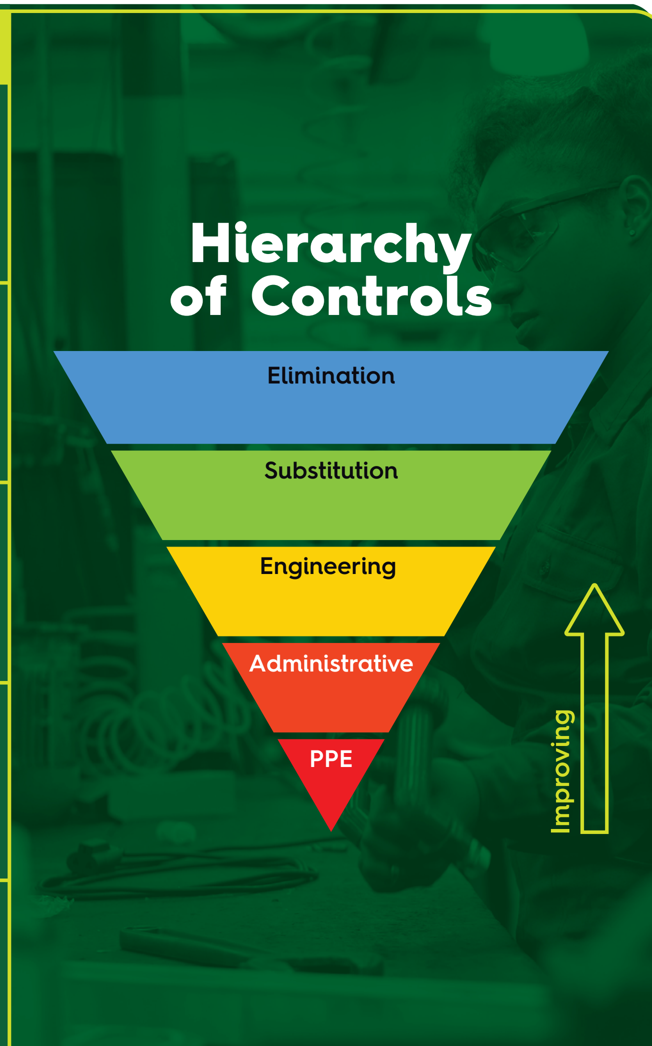
- **Worker-friendly workstations** where workstations can be readily adjusted so people of different ages, sizes, genders and health states can work safely and easily
- **Data confidentiality** systems and protocols are essential to ensure workers are happy that technologies are deployed to make their tasks easier and safer – not to micromanage their behavior and work performance

By leveraging these emerging technologies, organizations can proactively identify, assess and address ergonomic risks in real time or during the design phase. This proactive approach can help prevent MSDs, improve worker wellbeing and enhance workplace safety.

Major MSD Innovation Trends

Categorizing MSD-related technologies systematically through the Hierarchy of Controls (National Institute for Occupational Safety and Health, 2015) makes understanding their respective focuses and functionalities easier. These controls are created to identify and prioritize safeguards that eliminate or minimize exposure to hazards. This classification also helps identify suitable technologies for specific needs, such as measuring and analyzing hazards, providing biofeedback, or actively mitigating risks in the workplace.

Control Type	Risk is Reduced by:
Elimination	**Eliminating conditions or processes that contribute to worker injury/illness.** *e.g., instead of manually handling raw materials, the material is now received by tanker with direct input into the process*
Substitution	**Opting for a safer alternative to a working condition or process that would otherwise contribute to worker injury/illness.** *e.g., replacing manual spanners (requiring high force) with pneumatic ones*
Engineering	**Reorganizing or redesigning work to minimize exposure to hazards.** *e.g., a work bench is redesigned around worker movements in such a way that limits muscle strain and allows for more fluid range of motion*
Administrative	**Changing the procedure or providing suitable training.** *e.g., training staff on how to implement safe stretching or lifting techniques so they are safer when performing work*
Personal Protective Equipment (PPE)	**Providing protective clothing that offers a degree of safety.** *e.g., giving workers gloves to reduce exposure to a hazard*



Measure and Analyze

This category encompasses technologies primarily focusing on measuring and analyzing various MSD hazards in the workplace. These technologies gather data and employ analytical tools to monitor hazard levels over time. For example, some systems utilize known checklists or tools to calculate MSD risk levels automatically. The users of these technologies analyze the collected data to help with prioritization and making informed decisions regarding prevention and intervention strategies. An example of this type of intervention is a computer vision system that quickly assesses the postural scores of many tasks.

Data Analytics: Artificial Intelligence/Machine Learning

Data analytics in relation to MSDs is the detailed interrogation of data generated from a wide range of sources to identify when, where and why specific roles or tasks trigger risk factors for MSDs.

In a simple way, the software powered by AI/ML technology gathers and examines a vast volume of data in real time from diverse sources, including wearables, sensors, work schedules, injury reports and workers' compensation claims. The collected data is processed through an "AI/ML engine" that identifies patterns of MSD trends and specific risks. As the software works, the AI/ML engine learns and improves its risk assessment, becoming more customized to each company's unique context.

These systems can predict the risk of specific tasks given design data, such as working height for the worker, horizontal reaches, weights of components to be moved and forces exerted to predict the task's likely risk. Combining this with employee feedback and injury tracking reporting improves the accuracy of its predictions, which means a safer work environment can be designed and operated.

How does this relate to MSD risk?

AI/ML tools assess MSD risks in the workplace. Examples include:

- Identifying factors for injury risk assessment and performance prediction
- Monitoring data from wearable sensors to model the injury risk using an artificial neural network
- Predictively reviewing workstation layouts to identify specific MSD risks to improve workstation design
- Interpreting real time camera images to alert workers if their postures and movements are potentially hazardous

For more information on AI and data analytics, check out Using Data and AI to Gain Insights into Your Safety Program.

Be Mindful

When using AI/ML-derived algorithms for workplace injury data collection and tracking, big data are generated. Therefore, ensuring data quality, proper storage and security are paramount. Part of safeguarding the data at the workplace is defining policies for data collection and storage, checking and having oversight for continued data accuracy, classifying who has access to the data and for what purpose, investing in stringent data security software, encrypting data files with user authentication, masking personal identifying information and continuously monitoring and upgrading AI/ML models to deter any cybersecurity issues.

For example, AI/ML can automate certain aspects of data collection, but without knowledgeable staff oversight, the accuracy and relevance of the collected data can be questioned or misused. Remember, *garbage in, garbage out*, i.e., getting meaningful data in results in getting meaningful data out. In addition, the leadership of any organization should assist in mitigating biases, if any, and make ethical decisions while protecting the privacy and security of the workers' data. Organizations such as the U.S. National Institute of Standards and Technology are studying how to make people feel more confident in how AI is created, used and controlled (National Institute of Standards and Technology, 2023). They are researching to solve the problems that come with AI and make it trustworthy.

Innovation Opportunities

AI and ML are becoming increasingly powerful tools capable of generating actionable insights from a wide range of data sources. As IIoT continues to roll out (i.e., ever more data are collected from ever more sources), workplaces will become more digitized with digital twins, allowing them to be more confidently assured as being safe by design and assessed as being safe in operation.

As the industry moves towards this position, AI/ML will be applied to data sets as soon as they are detailed and accurate enough to allow actionable recommendations to be made, which is not typically the case now. At present, AI/ML is being used to assess images and videos of people at work. This is reviewed below in the Computer Vision section.

Computer Vision

Computer vision is a field of AI that enables computers and systems to derive meaningful information from digital images, videos and other visual inputs and take actions or make recommendations based on that information (IBM, n.d.). Computer vision trains machines to perform these functions in less time with cameras, data and algorithms as opposed to human vision.

In a simple way, human motion capture systems range from specialized fixed units to mobile phone applications, to take videos of workers performing their tasks. Then, computer vision systems process the images through smart software to identify ergonomic risk factors that may need further investigation, highlight the greatest MSD risk and suggest modifications to make the tasks safer.

The value of these systems is that they can be quickly and cheaply deployed without requiring input from skilled ergonomists. Roles and tasks can be prioritized for closer attention and redesign.

DID YOU KNOW?

Computer Vision systems utilize 3D models to analyze:

Employees' postures such as bending, twisting, and reaching

The frequency of particular movements

Posture duration during task performance

CASE STUDY

An excerpt from an industry trial at a large operation

Computer Vision
Solution used to understand and identify risks

Goal:

To enhance the accuracy and efficiency of ergonomic risk assessments across various industrial and logistics operations.

Safety Target:

At present, our assessment methods require input from ergonomists and industrial engineers. However, given our organization's size, it's challenging to establish a sound understanding of MSD risks that consistently delivers accurate assessments. To enhance our comprehension of these risks in our work, we aimed to adopt a technology-based tool that could leverage advancements in this field. By minimizing biases and enhancing assessment precision, we plan to effectively prioritize improvements and gauge progress.

Proposed Solution:

We evaluated multiple technology categories to compare their ergonomic risk analysis capabilities to our current methodology. Our assessment criteria included the following:

- Ability to integrate forces for risk analysis
- Ease of interpreting results, such as identifying high-risk jobs, understanding direct causes and suggesting improvements, user interface and more
- Hardware requirements, such as specialized sensors and cameras
- Capability for global implementation, such as standardized metrics and targets, user setup, hierarchy, cybersecurity and other related factors

We opted for a non-invasive computer vision technology that can analyze standard videos captured through a smartphone to perform postural risk analysis. The technology utilizes artificial intelligence to generate analysis results within minutes. We conducted a pilot program in multiple sites where employees were trained to use the tool. In total, 20 assessments were completed during the pilot program, and comprehensive feedback was provided on the process.

Pilot Outcome:

The new assessment method proved highly effective, with sites surpassing their assessment goals in record time. User feedback was overwhelmingly positive.

We conducted a verification of the automated assessment tool and found it accurately identified MSD risks and allowed for the prioritization of improvements within low, medium and high-risk bands. With the higher MSD risks identified, we could focus on investigating and reducing their risk levels. Moreover, the time required to complete assessments was reduced, which allowed more time dedicated to reducing risks through improvements.

Next Steps:

We are currently in the process of deploying and training employees across all sites on the new assessment tool. As the tool gains wider usage, the accuracy of assessments will increase, reducing potential biases. This will result in better prioritization of risk reduction actions within each site as well as an improved understanding of the differences in risks between sites. Additionally, employees will save time conducting assessments, allowing them to focus on designing and implementing improvements.

Special Considerations:

We have discovered the technology is incapable of accurately assessing risk in certain operational environments. For example, in situations where many staff work in close proximity, it's difficult to capture only one person in the video, thereby hindering accurate analysis. Similarly, personal protective equipment, such as welding helmets, might obscure the position of limbs or the head, while some parts of machinery or infrastructure may make it challenging to capture body segments during tasks, thus impeding accurate assessments.

How does this relate to MSD risk?

Computer vision is being increasingly used to assess MSD risks in the workplace:

- Vision algorithms can detect and track worker tasks, specific body movements, behaviors and postures in real time, through image processing, pattern recognition and machine learning
- They can extract features related to the shape, size and location of body parts from images or videos of the worker's tasks, without intruding on the worker (Li et al., 2020). Then by leveraging ML algorithms, computer vision extracts insights and patterns related to human behaviors so that pre- and post-job MSD risk assessments can be performed
- This prevention through the digitization approach of camera, data and ML algorithms facilitates subsequent (re)design of the tasks or worker education and training, with a final goal of risk reduction of MSDs
- Vision-based approach can also identify when and where PPE is or is not being used, in addition to identifying safety hazards, thus covering both ergonomics and safety aspects of the workers

For more information on computer vision, check out Using Computer Vision as a Risk Mitigation Tool.

Be Mindful

Given the relative newness of computer vision-based tools and their continuous evolution, a review of current literature has limited evidence regarding their ability to accurately estimate the risk for MSDs. Posture estimation (e.g., joint angles) using computer vision may be much easier than manually collecting other ergonomic risk factors, such as force or load handled. However, further work is needed in this domain to evaluate the reliability of computer vision and the capabilities of integrating multiple emerging technologies to validate risk for MSDs (Lim & D'Souza, 2020).

For example, the data may be accurately compared to the static Rapid Upper Limb Assessment (RULA)/Rapid Entire Body Assessment (REBA) scores, but the MSD risk has not been validated. More importantly, these tools do not address the risk of dynamic movements, such as joint velocity, acceleration or jerk experienced during work performance. It is essential to know that computer vision systems' accuracy and reliability depend on various factors, such as video quality, the tracking algorithms' sophistication and the calibration process.

Since computer vision models translate visual data for workplace injury data tracking, ensuring data quality, proper storage and security are paramount.

Innovation Opportunities for Computer Vision

Computer vision systems can assess the inherent risks of tasks performed in many situations. These systems become far more valuable in the workplace if:

- Workers can be observed for relatively long periods so all tasks can be assessed (many tasks generate high MSD risk only if they are repeated frequently and not performed in single instances)
- They can generate models of a body with its joints and body parts correctly positioned in three dimensions so the effects of all movements can be correctly analyzed
- They can reliably assess the forces being exerted by the body (e.g., weights moved, pull/push force exerted) inherently stated in the ability to assess forces

The opportunities for improvement are then to integrate data from other sources, such as:

- Wearable sensors and environmental sensors
- Details of the equipment being used (e.g., types of hand tools) and forces exerted (e.g., weights)

Overall, the goal is to increase the validity and reliability of computer vision systems so:

- Their recommendations are increasingly valid and reliable
- They can be used in varied and complex environments

Measure with Biofeedback

Technologies in this category provide feedback to individuals, utilizing both immediate (i.e., haptic) feedback and cumulative latent feedback through dashboards, gamification and other methods. These technologies help identify workplace trends and individuals who may require training or intervention. By incorporating real time haptic feedback (e.g., vibrate and buzz) or visual representations on dashboards, these technologies enable individuals to actively monitor their behaviors and make adjustments to mitigate the risk of developing MSDs.

An example is a wearable sensor that assesses the wearer's movements and provides haptic feedback if potentially harmful over-extension movements are detected. An additional example involves employing an inertial measurement unit that utilizes sensors such as accelerometers, gyroscopes and magnetometers, to provide an objective measurement and report of a worker's posture, force and movement. The data from an inertial sensor can be transmitted in real time through a wireless connection to a smartphone or computer, or stored directly on the sensor.

Wearable Sensors

A growing demand exists for a variety of sensors that can be worn to collect data on the health of the wearer, their movements and bodily stresses. Taken together, their data can identify MSD risks and alert the wearer and their employer so risks can be assessed and mitigated.

These systems typically hold sensors:

- In harnesses, so sensors are held on the upper back and upper arm or lower back and hips
- Belt-mounted to recognize positions and movements at the lower back
- In hard hats or headbands where they can assess vital signs and movements of the neck and head
- On wrists or fingers where they can assess lower arm movements and vibrations

Some sensors give real time feedback to the wearer if they perform any movements likely to be hazardous while most generate data and either download those data at the end of the shift (i.e., requiring no communications) or transmit it in real time to a data platform.

These systems can:

- Identify postural movement risks unique to each worker and alert them to change their behavior
- Measure simultaneously joint angles of more than one body part using multiple sensors in real time
- Identify tasks posing MSD risks so they can be assessed and mitigated

The main goal of single wearable sensors is to enable workers to proactively manage their health and wellbeing by receiving immediate feedback on various activities or environmental factors. By continuously monitoring key physiological indicators, these sensors can help users identify potential risks, such as awkward posture, which could lead to the development of MSDs over time. This real time risk identification allows users to make informed decisions and take necessary preventive measures to mitigate potential injuries or health issues.

While single wearable sensors focus on biofeedback and risk identification, multi-sensor systems emphasize comprehensive measurement, analysis and tracking of various parameters related to MSDs. These systems typically incorporate multiple sensors placed at different locations on the body to capture a wide range of data simultaneously. The collected data is then processed and analyzed using sophisticated algorithms to gain deeper insights into an individual's movement patterns, biomechanics and ergonomic conditions.

Both types of sensors contribute to the overall goal of leveraging technology to improve workplace prevention and management of MSDs. However, one should ensure the system's reliability and the quality of the collected data from these sensors (Schall et al. 2022).

How does this relate to MSD risk?

Wearable sensors are used to assess MSD risks in the workplace. They can:

- Track the position and alignment of worker(s) body parts to detect improper postures that can lead to musculoskeletal discomfort or injury
- Provide real-time alerts or vibration for correcting posture and arm movements. By analyzing the range of motion, speed or duration of force exerted during repetitive work, the sensor can provide feedback on posture or technique associated with overexertion
- Analyze collected data to identify injury trends or risk factors and offer personalized recommendations to the wearer, such as postural and other ergonomics-related adjustments, rest breaks, etc.

Be Mindful

Ensuring the accuracy and reliability of wearable sensors is crucial to generate meaningful insights. Precise measurements and consistent capture of relevant information are necessary. Still, factors like sensor placement, calibration and signal interference can affect data quality and introduce errors or inaccuracies (Schall et al., 2022).

Integrating wearable sensors seamlessly into the work environment comes with technical and logistical challenges. Compatibility with the existing systems is important; at the same time, these sensors' connectivity and battery life have to be considered. For example, if data collection is in a remote area, the lack of connectivity or interruptions can result in inaccurate data. The usability of these sensors by various user populations and the physical comfort of wearing them can also be challenging.

Effectively managing and interpreting the vast amount of collected data from wearable sensors is challenging. Sophisticated data analysis techniques, algorithms and software tools are needed to extract actionable insights and understand valuable risk reduction patterns. Expertise in data analytics is required to transform raw data into meaningful decision-making and improves workplace conditions. Like other emerging technologies, workers' buy-in regarding the type of data collected, how it can be used and data privacy is essential.

CASE STUDY

An excerpt from an industry trial at a large operation

Wearable Sensors
Solution used to understand and identify risks

Goal:

To investigate whether posture monitoring with real time haptic feedback can mitigate ergonomic risks and reduce incident rates. The focus is on postures involved in manual material handling in logistics settings.

Safety Target:

We aimed to minimize the risk to employees by enhancing their posture during manual material handling tasks. We achieved this by providing employees with real time haptic feedback, coupled with personalized feedback from supervisors. This approach aimed to reduce the incidence of ergonomic-related incidents.

Identified Risks:

We tried to reduce the risk of incidents related to the back region based on the history of incidents and assessed risks. We targeted poor postures, such as bending, lifting, over-reaching and twisting that contribute to such incidents.

Proposed Solution:

For piloting, we selected two different types of wearable technologies, a sensor worn between the shoulder blades on the back, and a sensor attached to the operator's belt on the hip. Both systems recorded operator behavior and provided haptic feedback when potentially risky movements and postures were detected.

Pilot Outcome:

The pilot yielded mixed outcomes, as the duration of the pilots, which ranged from one to three months, was too short to determine the actual impact of wearable technology on MSDs. This could be why there was no measurable difference in ergonomic-related incidents during the pilot. While a limited number of employees appreciated the haptic feedback, some employees were not receptive to wearing the devices, which made it challenging to gain buy-in from them. Although the devices provided valuable haptic feedback, our ergonomic experts had to offer specific support to employees, which was more time-consuming than anticipated, despite the software providing risk analysis.

Next Steps:

The decision has been made to allocate budget and personnel resources towards injury controls such as engineering and elimination, instead of using wearable technology with haptic feedback.

Special Considerations:

- When engineering controls are not feasible, implementing this type of technology may be a viable option for improving operator postural and working behaviors
- Short-term investigations using these systems may be useful in identifying tasks with a higher risk for MSDs, but the challenge lies in having the necessary resources to analyze and act on the data
- Haptic feedback may be distracting for someone who is performing a task requiring high cognitive demand

DID YOU KNOW?

Sensors can be comfortably and discreetly worn in a number of ways.

Hats | Sunglasses | Earbuds | Watches/Bracelets | Clothing | Chest Straps | Belts | Anklets | Shoes | Smart Phones

Innovation Opportunities for Wearable Sensors

Sensors are becoming more common in general consumer applications (e.g., smart watches measuring vital signs) and sports, where data on athletic performance and bodily shocks, vibrations and stresses are routinely gathered.

The challenges in general adoption as MSD mitigation tools include the following:

- Generating evidence that sensor data are genuinely predictive of MSD harm for individuals and cohorts
- The accuracy of the sensors is dependent on the joint and movement being measured (especially in the upper limb)
- Integrating sensors economically into standard wearable work equipment and clothing
- Addressing reasonable concerns over data privacy and confidentiality for each use case

Determining the responsible party for analyzing data and involving potential stakeholders who could be responsible for data analysis necessitates addressing this issue before implementation.

Risk Mitigation

This category comprises technologies specifically designed to actively reduce or eliminate exposure to MSD hazards, thereby mitigating the associated risks. Examples of such technologies include exoskeletons and collaborative robots (also known as cobots). Exoskeletons provide physical support to the wearer, reducing strain on muscles and joints during physically demanding tasks. Cobots, on the other hand, work alongside human workers, assisting with repetitive or strenuous tasks to reduce the risk of MSDs.

Exoskeletons

An exoskeleton is a wearable device that augments, enables, assists or enhances motion, posture or physical activity (Lowe et al., 2019). This definition also includes exosuits that are similar in function but are differentiated by predominantly soft and/or elastic structures. Two types of exoskeletons are currently used in industrial environments: passive and powered exoskeletons. They are suitable for different operations and address different types of risk.

Passive Exoskeletons

Passive exoskeletons are non-motorized equipment designed to tightly attach above and below the joints requiring protection (Lowe et al., 2019). These exoskeletons commonly use a combination of joints and elastic materials to accomplish two objectives. The first is to store the body's energy, for example, when squatting, so that rising to a standing position becomes easier. The second is to maintain the joints in the safest positions, thereby limiting over-stretching and twisting movements.

Passive exoskeletons can significantly reduce the forces on major joints (e.g., shoulders, back and hips) along with muscular load and fatigue. They are unpowered, so they do not increase the forces the worker can generate, but can significantly reduce fatigue and mitigate MSD risks at the joints.

Powered Exoskeletons

Powered exoskeletons are mobile machines worn over parts of the body to synchronize with the user's intended movements and trigger powered systems that increase the user's strength or endurance (Lowe et al., 2019). They can carry batteries for power, but many require connection to external power sources.

Powered exoskeletons can support each of the major joints along with their associated muscles. They are typically designed to allow workers to exert much greater forces than when unassisted, while increasing their endurance. This can make it safe for a wearer to:

- Perform tasks demanding very high forces (e.g., lifting heavier weights)
- Work in hazardous positions (e.g., with hands above their shoulders/heads for long periods)
- Work for longer periods avoiding physical fatigue

How does this relate to MSD risk?

Exoskeleteons are increasingly used to assess MSD risks in the workplace.

- When eliminating the hazardous task or workplace redesign is not feasible, exoskeletons reduce the risk by supporting and relieving the workers' localized or whole-body regions during material handling activities such as lifting, carrying or holding boxes or tools (Schwerha et al., 2021; Zelik et al., 2022)
- External support on the exoskeleton protects the worker by reducing internal biomechanical loads across the user's joints, muscles and soft tissue, or decreasing their whole-body metabolic exertion (Lowe et al., 2019)
- Per ABI Research, integration of exoskeletons with the IIoT to capture big data is the potential future and could be integrated with cobots, robotic arms and other emerging technologies

NOTE:
It is important to acknowledge that the categorization of passive exoskeletons as PPE is a subject of ongoing debate and remains inconclusive (Lowe et al., 2019).

Be Mindful

Before providing an exoskeleton to the worker, conduct risk assessments to identify potential benefits as well as risks associated with its utility at the workplace (Institut für Arbeitsschutz, 2019). Have a process in place to select exoskeletons designed for specific tasks or body parts. For example, a back exoskeleton should not be used for work that is upper extremity intense. Similarly, ensure a proper fit for the worker so they are comfortable using it throughout the job performance.

Provide adequate training and education to the workers to ensure they understand proper use, donning and doffing methods, and associated risks (e.g., in case of product failure). Perform periodic assessments of their comfort level in a typical shift. More importantly, integrate the exoskeleton into the workflow without impacting the worker's productivity. Last but not least, assess the usability of the exoskeleton periodically by asking workers for feedback and monitoring their productivity (Riccò et al., 2021).

CASE STUDY

An excerpt from an industry trial at a large operation

Passive Exoskeletons

Goal:

To alleviate shoulder fatigue among employees who perform overhead tasks, such as picking small to moderate-sized parts from a conveyor system and placing them into an auto-bagging line.

Identified Risks:

- Frequent picking and placing of small to moderate-sized parts at or above chest height result in shoulder and upper back fatigue
- The task involves upper arm flexion of 75-90 degrees, with a frequency of four times per minute, and a total duration of 35% of the time

Proposed Solution:

The implementation of automation and robots was not financially feasible, and administrative controls like job rotation were not practical. As a result, a shoulder exoskeleton device was adopted to decrease muscle activity and associated fatigue.

Risk Reduction:

Passive shoulder exoskeleton devices have been shown to reduce muscle activity by up to 40% using surface electromyography studies. Exoskeletons have been found to significantly decrease perceived fatigue and discomfort among employees, which has been verified through testing and evaluation. Employees were surveyed after the first day, first week, and then again at two, four and six weeks.

Employee Opinions:

After wearing the exoskeleton at the end of their shift, four employees reported a significant decrease in muscle fatigue and perceived pain. These employees work for 8-12 hours per day depending on production needs, up to six days per week. Surveys assessing opinions and discomfort levels indicated a reduction of 45% in perceived fatigue within the survey population.

Other Benefits:

The exoskeleton's ability to reduce fatigue and muscle activity enabled employees to enhance productivity and throughput by 8% as they require less time for micro-breaks and can concentrate better on their tasks.

Special Considerations:

Passive exoskeletons are categorized as personal protective equipment and should be treated accordingly. It is essential to consider cleaning, care, storage and hygiene when implementing these devices.

BENEFITS OF EXOSKELETONS:

Innovation Opportunities for Passive Exoskeletons

Based on the resources of small organizations, passive exoskeletons need to be available at more affordable prices. There are opportunities for researchers and solution providers to focus on creating passive exoskeletons accessible to all employers.

It is likely passive exoskeletons will increasingly embed sensors that monitor their wearer's movements. These sensors could provide feedback to the wearer if their movements start creating MSD risks while feeding data back into the company's systems so unsafe work practices can be identified and made safer.

There is currently inadequate evidence from reproducible trials that demonstrate the risk reduction of MSDs from each type of exoskeleton, making it difficult for potential users to create robust business cases for adoption. This creates an opportunity for vendors that can validate the MSD mitigation impact of their exoskeleton systems through sophisticated research and testing. Additional research is also required to examine the overall effect of exoskeletons and their impact on the stress and strain beyond the intended area. For instance, the utilization of an upper-body exoskeleton device alleviated stress on the arms but led to a significant increase of over 50% in low-back stress, highlighting the tradeoffs associated with current exoskeletons available in the market (Weston et al., 2018).

Innovation Opportunities for Powered Exoskeletons

Numerous companies and universities are making significant investments in the innovation of exoskeletons, focusing on:

- Enhancing the mechanical functions of these suits, such as improved actuators, joints and structural materials
- Increasing the suits' flexibility, adaptability and fit to different user demographics and tasks
- Providing evidence of enhanced safety by understanding the biomechanical improvements and risk reduction

While powered exoskeletons could be advantageous in specific work settings or tasks, their suitability may vary due to costs and usability concerns. In some cases, the user may need to be certified for using the solution which requires added resources and time.

(Semi)Autonomous Materials Handling Equipment

It is hard to think of a sector where material handling is not a major MSD risk area. Overexertion due to manual material handling is the largest MSD risk in the workplace, and costs U.S. businesses more than any other nonfatal workplace injury (Liberty Mutual Safety Index, 2023). The range of solutions is vast given the huge variety of use cases, from health care settings to logistics to manufacturing and construction.

Materials handling equipment, such as traditional lift tables, platforms, dollies and hoists are installed to make work safer and easier. These systems are becoming increasingly intelligent so systems can become (semi)autonomous or interactively work with people to support them in their tasks. As a result, they have varying degrees of autonomy in performing material handling tasks. This equipment is designed to assist or partially automate the movement, transportation and manipulation of materials or goods within a workplace.

Fully autonomous equipment is typically used in highly controlled and predictable environments and can operate entirely on its own without any human input. However, (semi)autonomous equipment works independently but still requires human input for specific tasks, such as loading and unloading materials. Therefore, (semi)autonomous equipment is typically used in more complex and unpredictable environments.

Cobots are (semi)autonomous machines working alongside workers performing the hazardous parts of their role. This includes "follow me" robots called autonomous mobile robots (AMRs) that can move loads around a facility following their operator, thus avoiding the manual handling activity of pushing, pulling or carrying a load. Other AMRs are designed with the capability to deviate from a predefined path to navigate around obstacles, requiring no specific supervision. For example, AMRs utilize advanced sensors, AI, ML and computing to interpret their surroundings and navigate autonomously. They are wireless and equipped with cameras and sensors to detect obstacles and make intelligent predictions. When faced with unexpected obstacles, such as fallen boxes, forklifts or workers, AMRs employ collision avoidance techniques to adjust their path, slow down, stop or reroute, ensuring the completion of their tasks.

How does this relate to MSD risk?

(Semi)autonomous and autonomous materials handling equipment are used to:

- Reduce overexertion due to materials handling activities such as lifting, lowering, pushing, pulling or carrying loads
- Eliminate repetitive activities such as performing the same hand motion repeatedly (e.g., pick and place and high precision or monotonous activities), which are implicated in MSD risk
- Reduce repeated exposure to workers in an environment with varied temperatures or hazards that are uncomfortable and unsafe for materials handling

For more information on (semi)autonomous robots, check out Improving Workplace Safety with Robotics.

Be Mindful

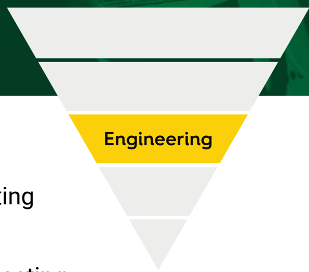
(Semi)autonomous materials handling equipment should only be operated by trained and qualified personnel (Campbell, 2020). To this effect, it is important to educate workers on how to work with cobots safely (e.g., identifying and avoiding potential hazards). Having a safety zone around the cobot is mandatory so that anyone other than a trained operator should not be in the safety zone during work (Jansen et al., 2019). Like any other material handling device, operating the cobot within its weight and speed limits should be a priority.

In terms of challenges, this equipment might not detect all obstacles accurately and may not operate in all environments. Since they are all part of IIoT, they collect big data, including operational information and/or worker interactions, implying that the privacy and security of the collected data are vital. With big data comes cybersecurity risks associated with collaborative robots (Yaacoub et al., 2022). Any potential attack targeting these devices can compromise sensitive information about the work, worker and workplace interactions, resulting in a huge financial loss. Finally, like any other emerging technology, workers' buy-in is important for smooth deployment at the workplace.

CASE STUDY

An excerpt from an industry trial at a large operation

Material Handling Device



Goal:

To minimize strain during the lifting process. Specifically, during the assembly process, a 39-pound casting must be lifted from a container and carefully positioned to be bolted into place. This task has typically required two people to perform.

Identified Risks:

Based on the NIOSH Lifting Equation, the lifting index for this task is 2.1, which indicates it as a high-risk task. The extended reaches in this task were a significant contributor to the increased risk for injury.

Proposed Solution:

To address the issue, an engineering control was deemed necessary. After evaluating numerous lift-support systems, we selected an articulating assist device that could be mounted overhead in a horizontal position and easily integrated into the current workstation. The implementation of this solution incurred a cost of $30,000.

Risk Reduction:

This intervention replaced a high-risk MSD task previously performed by two operators, rated as “Red/Black,” with a machine-operated process. The operator’s role became simpler and safer as a result.

Other Benefits:

Now one operator can perform the lifting, placing and bolting of the casting safely and quickly. Moreover, the positioning of the casting for bolting has become much easier.

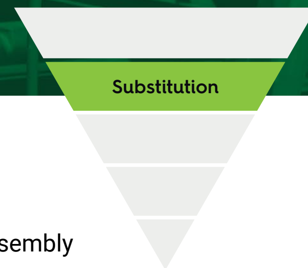
Special Considerations:

The implementation of this solution may face challenges in certain cases due to limited space and height restrictions. Additionally, some training is necessary to ensure the assist device is used safely at all times.

CASE STUDY

An excerpt from an industry trial at a large operation

Material Handling Device



Goal:

To minimize the risks associated with using hammers. Specifically, during assembly operations, our employees frequently use five-pound hammers to fix pins in place throughout their entire shift.

Identified Risks:

- The use of five-pound hammers for fixing pins into place during assembly operations can result in repetitive motion disorders in the hand, wrist, elbow and shoulders
- The impact vibration from using the hammer adds to the risk of MSDs from this task

Proposed Solution:

Redesigning the product to use different assembly and fixing methods was considered, but proved unsuccessful. As a result, we investigated mechanized alternatives using various types of tooling and automation levels. We developed a custom air-over-hydraulic press with the appropriate force and mounted it on an air-balanced arm, allowing for easy positioning. This solution had a cost of $24,000.

Risk Reduction:

This intervention replaced a high-risk MSD task that had been assessed as “Red/Black” for an operator with a simpler and safer role of positioning the press.

Employee Opinions:

The new assembly method was considered an improvement requiring minimal training or changes in other work practices.

Other Benefits:

Removing the hammering operation has resulted in noise reduction, which has contributed to enhancing the work environment for both the operators and those working in their proximity.

Special Considerations:

We are currently developing a program to eliminate the use of hammers in our assembly operations. However, this approach may not be viable in cases where hammers are required frequently or where there is limited space for installing presses and their positioning systems.

Innovation Opportunities for (Semi)Autonomous Materials Handling Equipment

The rapid digitization of the workplace makes it increasingly common to have “smart machines” that can work alongside staff to take away much of the physical strain from their tasks. Building sufficient intelligence into systems so they have intuitive interfaces with workers, and can work safely among and with people, will transform many workplaces. This transformation to “semi-smart” is already happening with many types of machines (AMRs in “follow-me” mode moving large loads around relatively unstructured workplaces). Still, building the capacity of co-working with people is predicted to transform many workplaces by reducing MSD risks.

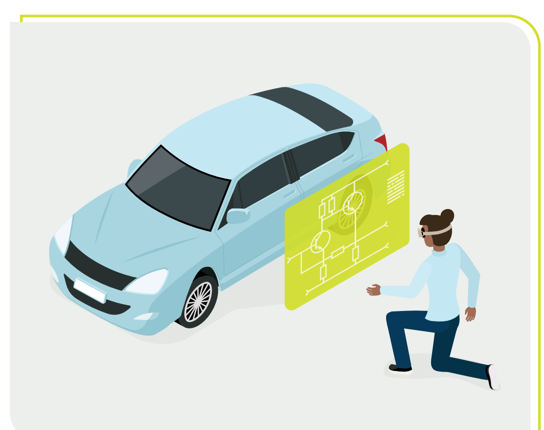
Furthermore, by integrating IIoT and connectivity with (semi)autonomous equipment, data can be exchanged between (semi)autonomous equipment and other systems and devices. These data can be used to improve coordination and operational efficiency. For example, data from (semi)autonomous equipment can be used to optimize the work flow in a warehouse or factory, resulting in reduced costs and improved productivity.

Extended Reality

Extended reality (XR) is a growing inclusive concept encompassing various immersive technologies (Marr, 2019). These include virtual reality, augmented reality, mixed reality and future innovations. These expand human perception of reality by either blending virtual elements with the real world or providing entirely immersive experiences. XR can provide immersive training simulations allowing workers to practice hazardous tasks or emergency scenarios in a controlled virtual environment (Raghavan & Rao, 2018). This helps familiarize workers with potential risks and proper safety procedures without exposing them to real-world dangers. XR can simulate work environments and identify potential safety hazards or ergonomic issues. By analyzing virtual representations of workplaces, organizations can proactively address and mitigate risks before they occur.

Virtual reality (VR) is a computer-generated digital environment, and can be experienced and interacted with as if that environment were real (Jerold, 2016). VR systems place the wearer in a completely computer-generated world. VR headsets project computer-generated images into the wearer’s eyes, while smart clothing can assess the positions of their body parts (e.g., arms, hands and head) that appear in computer-generated images. VR provides immersive experiences allowing workers to prepare for hazardous situations in a controlled and safe environment.

VR technology can be integrated with digital human modeling to provide a more immersive and interactive user experience, promoting safer and healthier workplaces. This integration enhances the ergonomic analysis of computer-aided design models by enabling users to visualize and interact with the models realistically. For instance, users can virtually explore a factory and interact with machinery. It also allows for a precise evaluation of risk factors like reach, clearance and visibility through the simulation of human movements and interactions. This helps identify potential ergonomic hazards, such as confined spaces or awkward postures. Moreover, VR supports practical training, improving employee safety, reducing injuries and boosting productivity.



Augmented Reality (AR) is a technology that integrates or merges digital information, such as images, videos or 3D models, onto real-world objects or places to enhance the user experience (Berryman, 2012). This interaction is achieved through holographic technology, resulting in an immersive and engaging encounter. AR systems project images overlaid onto the real world using headsets, visors or other “head-up displays” to inform and advise the user.

AR displays connected to expert systems will see a growing prevalence in the workplace for multiple purposes, such as:

- Training workers in an interactive and engaging format
- Offering guidance during the execution of complex and hazardous tasks, providing the safest and most efficient approach to proceed
- Providing easy access to instructions, drawings and other needed information
- Allowing third-party or offsite individuals to observe and assist with the performance of work
- Enhancing a worker's perspective of their environment, bolstering safety measures by delivering real time information and alerts regarding potential hazards

Be Mindful

When using XR technologies, big data comes into play. Therefore, privacy and data security matter the most. User comfort is of utmost importance because motion sickness or discomfort are potential adverse effects, especially during extended usage of this technology. When discussing VR technologies, there is frequent mention of the challenges associated with accessibility for users across a spectrum of physical disabilities and sensory impairments, such as the inability to customize the experience and the requirement to move specific body parts (Phillips, 2020).

Innovation Opportunities for Extended Reality

Only a very limited library of extended reality material exists as this technology is still relatively new within industrial settings, but this is likely to expand as:

- Original equipment manufacturers compete to reduce the costs of operating their equipment by making in-field maintenance safer
- XR can deliver interactive ergonomics and safety training programs that engage workers and promote behavioral change by simulating hazardous situations and measuring performance (Kaplan et al., 2020)
- XR allows users to better understand the challenges faced by workers and use that information to improve work design, and when needed, help reinforce safety protocols and encourage adopting safe practices
- There is increasing evidence of the growing importance of the interrelationships between AI and XR technology developments in various industries, thus exploiting the advantages of both powerful emergent technologies. Reiners et al. (2021) cited a study that utilized both XR and AI to develop virtual (simulated) patients for medical training. Although none of the studies were in the MSDs domain, one can only imagine the potential of the powerful combination of XR and AI in training workers on various issues that they experience during their day-to-day work
- Users can visualize and interact with virtual representations of physical assets or environments by combining XR and digital twin technologies – this allows for a deeper understanding of complex systems and enables better decision-making based on real time data (Dougherty & Michl, 2021)

For more information on AR and VR technologies, check out Virtual Reality and Augmented Reality For Hazardous Work Training.

By leveraging XR technologies thoughtfully, organizations can enhance safety and situational awareness, improve training effectiveness and ultimately reduce the risk of workplace injuries.

Conclusions and Recommendations

The changing workplace is being transformed by new and emerging technologies to improve productivity and profitability. As a result, the ability to help employers identify, evaluate and reduce MSD risks is rapidly expanding, resulting in both commercial and socially-responsible benefits. The market for MSD risk reduction and management tools is enormous, as improved safety and wellbeing positively impact individuals, businesses and communities. This report examined some of the challenges, benefits and innovation possibilities associated with emerging technologies as part of MSD prevention efforts.

Upon review, some technologies are in the early stages of development with limited applications but are rapidly expanding in usefulness. Other technologies have recently arrived on the market with many applications and are still advancing technologically. Lastly, some technologies are ready for adoption in many situations while still advancing technologically.

The following diagram shows the salient points for each scenario of technological inclusiveness.

Emerging	• Powered active exoskeletons that have some valid applications and are becoming accepted as worker augmented devices • Extended reality systems that are exploring their initial applications in trials • Digital twins that are being developed to assess the (re)design and safe operation of work areas
Recently Arrived	• Cobots that can work with people (e.g., AMRs) may become autonomous later
Ready for Adoption	• Data analytics that can take data from incident reports and workers' compensation claims to identify risk areas • Wearable sensors and computer vision that can identify and assess MSD risks in many situations • Smart work handling equipment that can remove the MSD risks from many tasks • Passive exoskeletons that can reduce worker fatigue

It is important to note that, regardless of the type of technology used for workplace MSD risk assessments, employers must:	
Obtain Informed Consent	Seek informed consent from employees before using these technologies to collect job-related ergonomics risk factors.
Collaborate with Your Workforce	Get employee buy-in for risk assessment by: 1. Communicating the purpose of the assessment; 2. Explaining the benefits associated with assistance from technology in their job performance; 3. Addressing employee concerns about the technology.
Use Data Intentionally	Collect and use the risk assessment data only for its intended purpose. Be sure to educate whoever is collecting the data on the parameters of use.
Validate Data for Accuracy and Reliability	Use ergonomists or EHS professionals who are trained in the technology so the right data are collected, measured and translated into meaningful insights for ergonomic interventions.
Secure Privacy	Implement robust data privacy and security measures by establishing clear policies for data storage and retention.
By considering these points, organizations can responsibly use emerging technologies, promoting workplace safety in a collaborative manner while respecting privacy and fairness.	

Recommendations for Implementation and Future Research

Due to the rapid pace of change and the lack of clear performance standards for MSD-focused innovations in industry, uncertainty among industry adopters exists regarding which technologies actually deliver promised improvements for each potential MSD risk area. Furthermore, according to an NSC study (Washburn, 2020), one of the barriers is a limited number of use cases and examples of successes with technology.

Innovators, or those producing technology solutions, also encounter uncertainty in determining which solutions to create and how to validate their effectiveness. This is a common challenge due to the lack of clarity surrounding MSD-focused innovations within the workplace.

This apparent market gap can be best addressed by organizations that can bring together adopters implementing MSD solutions to share experiences and innovators that have the potential to develop MSD-related tools and systems.

Adopters can:	Innovators can:
• Develop good practices in defining MSD improvement opportunities and testing potential solutions • Share their lessons learned on trials of potential and actual solutions • Demonstrate to innovators that a major market is open to new work practices	• Work with potential clients to define their needs and trial innovative solutions • Understand how to position their innovations in a growing marketplace for MSD-risk solutions • Validate their innovations so customers have confidence to invest in them

In order to bridge the gap between the potential benefits of new technologies and their integration into businesses, the support of both employers and workers is essential. It is important to consider the costs of widespread implementation of emerging technologies as this can be a large barrier for many workplaces. As such, developing, deploying and maintaining these technologies can involve a significant financial investment. Therefore, organizations need to weigh the costs against the potential benefits and ensure the value gained from the data justifies the expenses incurred.

Addressing these challenges requires collaboration between stakeholders, technology developers, employers, employees and regulatory bodies. By addressing accuracy, privacy, integration, data management and cost concerns, emerging technologies can effectively collect workplace data and improve occupational health and safety by reducing MSDs. To this effect, the Council's recent publication of a **roadmap for piloting and implementing** technologies can be a valuable resource for employers and could be applied in the MSDs domain (Guasta et al., 2022). It is crucial to evaluate and plan the adoption of new technologies carefully, ensuring they align with the organization's goals and values, minimizing any potential negative impacts, and most importantly, solving for workplace risks.

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