Exoskeleton Technology
Making Workers Safer and More Productive

By Terry Butler

IN BRIEF
- **This article discusses the use of exoskeleton technology to ergonomically reduce shoulder overexertion in employees who extend and raise their arms.**
- **It presents some potential benefits and safety challenges of using such technology to simultaneously protect workers and increase productivity.**
- **The benefits presented are quantified from real-life field testing conducted at a large manufacturing facility and should help the reader understand the level of testing and research necessary to properly evaluate an exoskeleton technology before introducing it into a workplace.**

Exoskeleton technology comes in many forms, some of which can be powered by batteries and some with the use of stored energy within mechanical components. This article focuses on the latter, as its application is more universal and affordable for a broader range of industries. The exoskeleton technology discussed in this article is a lightweight, strictly mechanical device that will ergonomically reduce shoulder overexertion in persons who extend and raise their arms.

This exoskeleton consists of a frame, armrests and a system of mechanical components that transfer the weight of the arms from the shoulders to the core body. The body-worn exoskeleton moves with the user while not intruding into the user's workspace and while giving the user full range of motion, akin to wearing a backpack around the upper body. The exoskeleton uses mechanical arm-support technology that is inactive until the arms raise. It progressively activates as the arms lift and gradually releases as the arms return to a resting state.

The device can be configured to a specified range of motion over which the support mechanism is active, as well as a specified level of support for the arm. For example, assembly workers often use tools that weigh as much as 15 lb. These workers may require the device to support 70% of arm weight. Alternatively, welders and painters who typically work with lighter-weight equipment, such as a weld gun or paint gun, may require the device to support 50% of arm weight.

In a 2015 article, Panasonic spokesperson Mio Yamanaka is quoted as saying, "We expect that exoskeletons, or power-assist suits, will be widely used in people's lives in 15 years" (Knight, 2015). Fifteen years is not long for OSH professionals to prepare for the deployment of these devices in the workplace. The physical and psychological effects of wearing an exoskeleton device are but a few of the considerations, depending on the device and its intended application.

Due to exoskeleton technology's perceived benefits to productivity and quality, pressure may be placed on safety professionals to allow workers to wear such devices. As with all forms of PPE, safety professionals must assess the care, use and limitations of each device introduced to the workplace. Exoskeletons will vary greatly in complexity as each will have a specific purpose, so assessing their limitations will be key to protecting workers who choose to wear one.

This article presents some potential benefits and safety challenges of using such technology to simultaneously protect workers and increase productivity. The benefits presented are quantified from real-life field testing conducted at a large manufacturing facility and should help the reader understand the level of testing and research necessary to properly evaluate an exoskeleton technology before introducing it into a workplace.

According to *Encyclopedia Britannica for Kids*:

Terry R. Butler, CSP, is president of Lean Steps Consulting Inc. He has previously worked in global manufacturing for Archer Daniel Midlands and Sheaffer Pen Co., and most recently vice president of facilities and EH&S for Vermeer Corp. in Pella, IA. Butler holds B.S. degrees in Occupational Safety Engineering and Industrial Technology from Illinois State University. He is a past member of the Iowa Emergency Response Commission and Safeguard Partnership, and currently serves on the Governor's Iowa Occupational Safety and Health Advisory Council board and Safe Water International Ministries board. He is a professional member of ASSE's Hawkeye Chapter.

> An exoskeleton is a hard covering that supports and protects the bodies of some types of animals. The word exoskeleton means "outside skeleton." Many invertebrates, or animals without backbones, have exoskeletons. Insects are the largest group of animals that have an exoskeleton. (Exoskeleton, 2016)

When researching exoskeleton technology, it appears inventors are focusing their efforts in three areas of use: rehabilitation, military applications, and maneuvering heavy loads or performing repetitive motion tasks in various industries.

In the movie *Iron Man*, the title character invents and wears an exoskeleton that enables him to fly, fight villains and ultimately save the world. People are fascinated with the concept of a suit that can be worn on the outside of our body to make us superhuman, or if nothing else help us do our jobs and live life without so much pain from inflamed or worn out joints.

This article presents the results obtained from testing an exoskeleton device known as a personal ergonomic device (PED) with welders and electrostatic painters at Vermeer Corp. in Pella, IA, Aug. 24-28, 2015. Dave Landon, 2015 American Welding Society president, believes that "exoskeleton devices can and will be part of our everyday options for PPE in the coming years as this technology is further refined."

According to Bureau of Labor Statistics (BLS, 2014), the U.S. is seeing an increase of older workers in the active job market. People are not retiring in their 50s as they did 20 years ago; from 2000 to 2012, the number of people age 45 and older in the workforce swelled from 34% to 44%. In fact, the 65 and older age group has more than doubled in the same 12-year period (BLS, 2014).

Aging employees bring to work physical changes that are not always immediately recognized or accommodated for in the work environment. In fact as they enter the mid-40s and 50s, workers start to experience physical and mental changes with vision, hearing, cognitive ability, mental health, stress levels and movement control. With age, these changes often continue to accelerate. Because of the increase in aging workers, it is no surprise that sprains and strains continue to lead the trends of reportable injuries in almost every job sector.

The field test design team intended to prove or disprove the following hypothesis regarding the use of an exoskeleton device: "The use of an exoskeleton PED increases productivity and quality of dynamitic (electrostatic painting) and static (MIG welding) tasks because operator fatigue and associated soreness are reduced."

Field Test Research

In preparation for the field testing, the Herberts and Kadefors (1976) study of painful shoulders in welders was evaluated. This study was collaborative between the departments of otrhopaedic surgery and clinical nurophysiology at Sahlgren Hospital in Gothenburg, Sweden. The study is worth reading in its entirety, as it clearly shows and explains the physical impact of moderate and severe ergonomic work positions on the shoulder and its surrounding tissue over time.

PHOTOS BY TERRY BUTLER

Interesting and applicable to the field test design team, Herberts and Kadefors' (1976) study revealed that one of the four rotator cuff muscles (the supraspinatus muscle) of the upper back that runs over the shoulder was shown to be consistently fatigued during moderate and severe ergonomic stress (overhead) welding. Herberts and Kadefors (1976) referenced studies that showed "interference with the blood supply to the muscle results in 'localized muscle fatigue.'"

This study was important to the assessment of exoskeleton device use by welders and painters because it clearly demonstrates that localized muscle fatigue occurs with both inexperienced and experienced welders. Because the study used both surface electromyography (EMG) electrodes (Medelec Ltd.) that were applied to pick up EMG

Photos 1 and 2: Vermeer welders during testing with the exoskeleton.

Photo 3 (bottom): Vermeer painter during testing with the exoskeleton.

PHOTOS BY TERRY BUTLER

signals from the trapezius and deltoid muscles, and monopolar fine wire (Karma) electrodes were inserted by means of a tube (cannula) into the supraspinatus muscle, the exoskeleton field test team could gain a complete understanding of fatigue in welders' muscles while doing moderate and severe ergonomic stress type work.

This is particularly important because, should the use of an exoskeleton device be proven to minimize welder fatigue, one must understand why and how. Even with an exoskeleton device, it is important to prevent fatigue from setting in and restricting blood flow. In general terms, fatigue is the decline in the ability of a muscle to generate force. If an exoskeleton device permits a welder to work longer but the worker reaches the same level of fatigue, what has been gained by protecting the worker? Knowing how fatigue occurs and how long it takes is important in establishing the use and limitations of such a device in the workplace.

The team also examined a study by MacDermid, Ghobrial, Quirion, et al. (2007), that describes the development of a new test for measuring functional performance of the upper extremity and neck, and assesses reliability and concurrent validity in patients with shoulder pathology. The relevant factors of this study to the testing of subjects, with and without an exoskeleton device, were the test design and the stopping criteria used to determine when a patient was fatigued. These details are important because neither surface EMG monitors nor monopolar fine wire electrodes were permitted for use at the test site.

The protocol test criteria from the MacDermid, et al. (2007), study—the functional impairment test-head and neck/shoulder/arm (FIT-HaNSA) protocol—formed the basis for the exoskeleton test protocol this article's design team used to select the severe and moderate ergonomic stress positions to be used in the exoskeleton test to accelerate fatigue. This test further helped the team specify the sequencing of tasks so they varied from moderate to severe and back to moderate tasks while welding and painting. The goal was to replicate moving pegs or bottles up and down on shelves, as well as manipulating nuts and bolts overhead, as done in the MacDermid, et al., study. The ergonomic stress positions used to accelerate fatigue and the stopping criteria of the MacDermid, et al., study were identified as the most important elements to use in the field test of the exoskeleton device.

Field Test Design Overview: Quality & Productivity Measurements

It was the goal of the field test protocol to ensure that the test subjects performed their work in similar ergonomic stress positions as those found in the studies cited previously. They were asked to perform moderate to severe ergonomic tasks repeatedly until the test subject was fatigued and there was a decline in the ability of his/her muscles to generate enough force or control to maintain an acceptable quality level.

Quality and productivity were measured using state-of-the-art weld and paint simulators that recorded test performance in real time. The weld simulator captures quantitative quality and productivity data throughout the weld by recording position, contact tip work distance, work angle, travel angle and travel speed, and total weld time, all of which are critical to weld quality.

The weld simulator scored the performance for each category and provided a total score as well. Anything less than a cumulative score of 80 produces an unacceptable weld. The paint simulator captures quantitative quality and productivity performance data throughout the painting test by recording visual defects such as light pain and runs, real-time film thickness, transfer efficiency, average/minimum/maximum film thickness, average/minimum/maximum dry thickness, and time to paint each part. Anything below a cumulative score of 83 produces a part that does not meet finish and performance quality standards.

Vermeer uses paint and weld simulators daily when training all welders and painters. For painting, the team used a 2-D paint simulator designed by University of Northern Iowa. For welding, the team used a Lincoln Electric VRTEX 360 3-D weld simulator. Both simulators allowed the collection of quantitative quality and productivity data, both in real time and downloaded to a memory stick for inclusion in the test analysis. In addition, both simulators allow the instructor to vary the degree of difficulty and ergonomic stress by selecting from a menu of various parts, sizes, shapes and heights.

For the 2-D paint simulator, the painter sequenced between five flat parts of varying levels of height, width, length and difficulty to paint (rectangle, key, circle, duck, hood). Each part received a primer coat and a topcoat. For the 3-D welding simulator, a 1G V-groove four-pass weld was selected to add duration of the weld time and vary the angle the welder had to hold the weld gun and position the body, arm and shoulder while operating. This weld was performed at two different height positions. This is an advanced weld that only experienced welders can perform consistently.

Mark Doyle, founder of Levitate Technologies, invented the exoskeleton PED used in this study. According to Doyle, "It was designed to minimize fatigue and soreness associated with surgeons performing surgical procedures." He continues, "It was designed to help prevent inflammation of the muscle, thereby improving blood flow, reducing fatigue and improving productivity and quality." The ultimate goal, he says, is "to help prevent injury and discomfort to the shoulder, neck and back."

Field Testing

The exoskeleton field test kicked off Monday, Aug. 24, 2015. The 5-day field test of the exoskeleton device was specifically designed to prove or disprove whether such a device has a place in a real-world work environment. The field-test design team started by reviewing the final test protocol with test subjects. The two most experienced welders and the two most experienced painters were selected and fitted with the device. The field-test team requested the most experienced personnel to minimize test variables from those less experienced at welding and painting.

On Monday, each welder and painter was permitted to try out the exoskeleton unit while practicing on welds and parts to be painted during the test. On Tuesday, the two welders repeatedly performed the moderate to severe ergonomic stress weld positions on the weld simulator without the aid of the exoskeleton device. This established a baseline for quality and duration prior to reaching fatigue or their inability to maintain an acceptable quality level. On Wednesday, the two painters performed moderate to severe ergonomic stress painting positions repeatedly until they were fatigued or unable to maintain an acceptable quality level. This gave the welders a day to recover between testing with and without the exoskeleton device.

On Thursday, the welders performed the same test as was conducted on Tuesday, but this time with the aid of an exoskeleton device. On Friday, the painters repeated the same test conducted on Wednesday, but this time with the aid of the exoskeleton device.

To measure when fatigue set in and when there was a noticeable decline in the ability of a muscle to generate enough force or control to maintain an acceptable quality level, the team used the following criteria to stop the test. Each welding task was continued until the quality reached an unacceptable level as noted by the simulator results, cumulative score of less than 85, but the test could also be terminated mid-test based on the following stopping rules:

1) The subject stops or reports that it is too painful to continue (subjective pain 8 out of 10).

2) The subject is severely off pace and the quality drops below an 80 overall score as shown by the computer simulator to the extent that subject is unable to complete or correct the pace after a brief pause of less than 10 seconds.

3) The subject substitutes using trunk/whole body movement and cannot correct with feedback within 10 seconds while performing the task.

4) The examiner believes the subject is at risk of injury or other adverse complication if tests were to continue.

The four stopping rules noted for the welder were the same for the painter. The only difference was the simulator used a cumulative score of less than 83 for more than one test out of each set of 25 painting task repetitions for when to stop the test. If the painter was unable to complete or correct the pace after a brief pause of less than 10 seconds, the test was stopped.

Test Results

The results of the testing performed without, then with an exoskeleton device confirm the original hypothesis. The painter test subject's productivity was improved with the use of the exoskel-

An added hypothesized but unforeseen benefit revealed by the testing was relief of existing shoulder discomfort with the use of the exoskeleton device.

eton PED. One painter's productivity improved by 26.79% and the other by 53.13% while performing a dynamitic, moderate to severe ergonomic, repetitive job.

The welder performance without, then with an exoskeleton device showed that productivity improved 86%. Both welders' and painters' quantitative computer data showed quality was maintained at a higher level for the duration of the painting and weld tests while wearing an exoskeleton device. It is believed by the consistency of the quality scores in both welders and painters that this is due to improved hand steadiness. Both welders and painters were able to maintain an acceptable quality level for a longer period with the aid of the exoskeleton PED.

An added hypothesized but unforeseen benefit revealed by the testing was relief of existing shoulder discomfort with the use of the exoskeleton device. This was confirmed with the comments made by one weld test subject who was still experiencing shoulder pain after 1 day of rest. At the start of the second test, the subject reported that his shoulder felt better after donning the exoskeleton device.

In August 2015, just prior to starting the testing at the Vermeer site, the same exoskeleton device was evaluated in a laboratory setting at the University of San Diego. That test aimed to determine exoskeletons' objective and subjective impact on a group of volunteers. EMG data were collected by Bradley Chase (of Chase Consulting) and the university's ergonomics lab director. The results were presented in an unpublished white paper. The results of the study are illustrated as a percent maximal voluntary contraction (%MVC). Chase's test protocol followed the Vermeer test protocol, which mirrored the Purdue Peg Board Task, Minnesota Manual Dexterity Task, and the MacDermid, et al. (2007), FIT-HaNSA task protocols.

Chase's EMG results show the percentage ratio of the applied force to the MVC, for the same muscle group, in the same posture and expressed in the same units, to be lower when wearing an exoskeleton device. The significance of this study is that it explains why the welders and painters in this article's field test were able to weld and paint longer, and maintain a higher degree of accuracy. According to Chase, "the EMG data show participants exhibited a significantly lower %MVC while wearing the exoskeleton device during physical tasks compared to the %MVC while not wearing the device." Chase continues, "A lower %MVC implies lower risk for injury due to task demands." Further, Chase's test confirms Herberts and Kadefors' (1976) finding that "the constant traction in the tendon probably accelerates the degeneration by circulatory impairment."

Conclusion

Although the exoskeleton testing proves welders and painters can perform at a higher quality level for longer periods (improved productivity) with the aid of an exoskeleton device, eventually humans will reach a level of fatigue at which they need to stop and rest. The perceived benefit is that with regularly scheduled breaks and lunch, welders and painters may not reach a level of fatigue that could be considered dangerous to their safety and health with the use of an exoskeleton device.

As shown in results of Chase's EMG study, the use of an exoskeleton PED helps to prevent fatigue by slowing muscle contractions that lead to the decline in a muscle's ability to generate force. In addition, the improved productivity and quality as found in this field test is a potential game-changer for many businesses whose workforce continues to age.

Add to this the positive effect on the bottom line by using exoskeleton technology to help newer, inexperienced workers perform at an acceptable quality level, faster and more consistently, and Yamanaka's (Knight, 2015) prediction that exoskeletons will be widely used in people's lives in 15 years, may be the latest we can expect to see exoskeletons in the workplace. Safety professionals should get ready as "the exoskeletons are coming." **PS**

References

Bureau of Labor Statistics (BLS). (2014, Jan. 6). Labor force participation projected to fall for people under age 55 and rise for older age groups. The Economics Daily. Retrieved from www.bls.gov/opub/ted/2014/ted_20140106.htm

Chase, B. The Levitate difference: Analysis of the Levitate personal ergonomic device (PED) during various physical work-related tasks (Unpublished white paper). San Diego, CA: Levitate Technologies.

Exoskeleton. (2016). In Encyclopedia Britannica Kids. Retrieved from http://kids.britannica.com/elementary/article-399448/exoskeleton

Herberts, P. & Kadefors, R. (1976). A study of painful shoulder in welders. *Acta Orthopaedica Scandinavica*, *47*(4), 381-387. doi:10.3109/17453677608988705

Knight, W. (2015, July 16). The exoskeletons are coming. *MIT Technology Review*. Retrieved from www.technologyreview.com/news/539251/the-exoskeletons-are-coming

MacDermid, J.C., Ghobrial, M., Quirion, K.B., et al. (2007). Validation of a new test that assesses functional performance of the upper extremity and neck (FIT-HaNSA) in patients with shoulder pathology. *BMC Musculoskeletal Disorders*, *8*(42). doi:10.1186/1471-2474-8-42

Acknowledgments

The Vermeer Corp. test site in Pella, IA, is a 2,500-employee facility that manufactures industrial and agricultural equipment. The company employs more than 500 welders, and operates 16 paint facilities with more than 50 painters. Special thanks to the company's management for giving the field-test team access to employees, their expertise and equipment.

For More Information

To learn more about the exoskeleton device tested in this article, contact Levitate's Joseph Zawaideh at josephz@levitatetech.com.