



ASTM International Exo Technology Center of Excellence Exoskeletons: Considerations when deciding to use them as Personal Protective Equipment (PPE)

Q&A Follow-up
December 29, 2020

Questions: For any questions or concerns regarding the event, please contact the ASTM ExoTechnology Center of Excellence at: ETCoE@astm.org

Summary: On Thursday, November 19th, **ASTM International Exo Technology Center of Excellence** hosted the Exoskeletons: Considerations when deciding to use them as PPE Panel Discussion. The Program agenda included a welcome and overview of the ET CoE by Bill Billotte (ET CoE Director), along with an overview of ASTM International by Pat Picariello (Director, Developmental Operations).

The Program panellists included:

- **Donald R. Peterson**, Ph.D., M.S., FAIMBE, Dean, College of Engineering and Engineering Technology Professor at Northern Illinois University, Mechanical Engineering, ASTM F48 Member and F48 Committee Chair
- **Christopher R. Reid**, Ph.D., Associate Technical Fellow - Human Factors & Ergonomics, Boeing Environment, Health & Safety (EHS), ASTM F42 & F48 Member
- **Marisol Barrero**, M.S., CPE, Manager, Safety Innovations; Toyota Motor North America, ASTM F42 & F48 Member
- **Gary B. Orr**, PE, CPE, Health Scientist – Ergonomist, US Department of Labor, Occupational Safety and Health Administration (OSHA), Office of Health Enforcement
- **Delia E. Treaster**, Ph.D, CPE, Ergonomic Technical Advisor, Division of Safety and Hygiene., Ohio Bureau of Workers' Compensation, ASTM F48 Member
- **Sascha Wischniewski**, Ph.D, Federal Institute for Occupational Safety and Health (BAuA)

During the Program, questions from the attendees were submitted and have been answered to the best of our knowledge.

{Please note, the answers provided do not reflect the position of any corporation or company. The answers provided are of the opinion of the panellists.}

QUESTIONS

1. **QUESTION:** Considering the so called ergonomic pitfall (ergonomics improvements eaten by increase productivity), do you see it as likely that exoskeleton within the next 5 years will be used as a tool not only to sustained productivity but rather to increase the productivity?

ANSWER: Broadly, productivity is about the efficiency of converting the input to outputs. There are many factors that impact productivity. Some of the key ones are people, technology, and the work environment. Exoskeletons have the potential to impact all three of these factors by increasing the efficiency of each. In respect to the workers, exoskeletons may reduce fatigue resulting in higher quality performance with fewer errors, reduce loss of work hours from injury

prevention, and provide faster return to work times. In the technology area, exoskeletons may provide new interfaces to processes and materials that allow greater leverage and interaction by the worker. In the work environment area, an exoskeleton may improve the conditions, such as changing the interface to the work pieces or reducing the strain of awkward postures for workers, thus enabling higher quality, better morale, and thus few errors.

2. **QUESTION:** Do you have experience in industry with active exoskeletons or do you mainly focus on passive exoskeletons? Do anyone see realistic evidence that active exoskeleton will be used within the coming 10 years?

ANSWER: Active or powered exoskeletons are being used extensively in the medical and rehabilitation area where they are used for patients who have had spinal cord injuries or strokes. There are also active exoskeletons available for industrial workers.

3. **QUESTION:** Exoskeleton use and incentive thoughts - control of costs and litigation will in large part determine who and what entity or country or industry will lead. As Musk said - we are merging with our devices (like it or not).

ANSWER: This raises an interesting question of where wearable technology ends and a cyborg begin. As exoskeletons and other forms of wearable technology become more and more integrated with the human user this line blurs. From a standards perspective, Committee F48 on Exoskeletons and Exosuits job is to develop standards that enable trust in the safety, performance, and the reliability of the technology in order to spur innovation. As humanity stretches into ever daring technology enabled endeavours, standards provide the confidence for humankind to take the next giant leap.

4. **QUESTION:** Question for Sascha: could you please give the name or the number of this European machine directive for manufacturers you mentioned?

ANSWER: Machinery Directive 2006/42/EC

5. **QUESTION:** What problems do the companies face upon introduction of exoskeletons in their workflow?

ANSWER: The introduction of any new tool or device into the workflow may cause new challenges and opportunities to arise. Committee F48 is working on standards from a life cycle approach in order to help companies with the challenges that may arise and to also take advantage of the new opportunities the technology may provide. There are several common factors to consider when introducing anything new into the workflow such as:

- Initial capital cost
- Training for workers
- Performance of the workers with the new device and after acclimatization
- Changes to the workplace and processes to fully utilize the new device
- Maintenance and consumable supplies
- Inspection and Cleaning
- Storage
- Retirement and Disposal

For exoskeletons, one of the things that stands out about them is that the workers will wear the

device. The fit, look, function, performance, and comfort all have dependency on the individual worker. Thus, ROI metrics may be more similar to professional development, training, or a safety program verses adding a new production line. Committee F48 is developing metrics for many areas such as this.

6. **QUESTION:** Can we find a list of companies using Exos as PPE?

ANSWER: Toyota North America is using exoskeletons as PPE. Dow Chemical is using exoskeletons as engineering controls.

7. **QUESTION:** Compatibility with other PPE, e.g. in the case of firefighters?

ANSWER: To my knowledge, the compatibility of exoskeletons with other PPE is still unanswered especially as to the impact of an exoskeleton on the thermal performance of bunker gear. NATO has investigated using exoskeletons with bomb suits. Some exoskeleton companies may be demonstrating and testing exoskeletons for firefighters. Successful deployment of exoskeletons in the fire community will depend on the interface and compatibility with NFPA standards.

8. **QUESTION:** What input do union's have regarding exoskeletons?

ANSWER: It is believed that unions are okay with exos as long as their objective is to improve safety and NOT to increase productivity (ie, a worker being required to produce more than they are currently due to wearing an exoskeleton). Productivity increases due to fatigue reduction or other benefits are acceptable.

9. **QUESTION:** What happens to a user cognitively when symbioses happens?

ANSWER: This is a challenging human factors question whenever people and automated systems share control of the environment. At this time exoskeletons do not share decision making tasks with the person, but that is likely to change with intelligent exos. As we know people are relatively poor at performing a task with high vigilance or where a large number of sequential steps are required. In those situations, like driving on an uncrowded straight highway or a launch sequence the automated system can perform more reliably, but when a quick decision is needed the person needs to make the decision or at least review the course of action. The quick transfer of control from automation to a person is very difficult as we have seen with auto pilot systems. Another challenge with a shared environment is humanizing the automation (anthropomorphism). People attribute human characteristics and personality (good or bad) to the automation, then people react to the automation as they would a person with those characteristics. These are areas that have been studied but continue to evolve as the function allocation tends to assign more tasks to automation.

Another consideration with symbiosis is that if the system is accepted as an extension of the person, then it is deemed as a natural part of the work. This is similar to use of types of PPE or tools such as surgeon's scalpels or artist's paintbrush. Machine or automation trust is a major research focus in human factors.

10. **QUESTION:** PPE is not fool-proof protection. Eye injuries can still happen with goggles. Head

injuries can still happen with helmets. Hand injuries can still happen with gloves. PPE protects from things outside the body. It reduces risk, but it doesn't eliminate it. Why do companies think PPE eliminates risk? Do PPE companies promise total protection?

ANSWER: Companies do not think that PPE eliminates risk. PPE is considered the last means of protection in the hierarchy of hazard controls. The weakness of PPE, like administrative and work practice controls, is the hazard is not eliminated. PPE must maintain a barrier between the hazard and person. For exoskeletons this means a barrier between the person and forceful exertions, repetitions, awkward posture, contact stress or vibration (and combinations of the risk factors).

Injuries can still happen if workers don't use their PPE or use them incorrectly. There needs to be a system for deploying PPE that incorporates proper training on PPE use including donning & doffing, inspection and replacement of damaged PPE, sanitizing or sterilizing re-usable PPE, safe disposal of contaminated PPE, etc. PPE manufacturers do not promise total protection.

11. **QUESTION:** What is required to determine if PPE is "protective"? A helmet might need to pass a test to show it will prevent a skull fracture, BUT it adds mass to the head which could change COM, strain neck muscles, obscure certain senses, etc. How would this question apply to exoskeletons? What is required to determine if an exoskeleton is protective, and what are the acceptable trade-offs?

ANSWER: Protection may be determined by conducting a risk assessment and evaluating a technology to determine the impact on that risk. Standards give you the means and confidence to know what risks a PPE or other technology reduces and to what measurable extent. When PPE is not mandated by OSHA (such as hearing protection when noise levels are above 85dBA), companies have discretion in using PPE – what type, when, for whom, for how long, etc. They do this based on the perceived benefits (reduced injuries, reduced worker fatigue), and the expected costs (exoskeleton price, cost to support exoskeletons such as additional training time, reconfigured work area, etc.). The cost-benefit trade-off is company-specific; each company independently weighs the costs and benefits based on their own values, priorities and workforce.

12. **QUESTION:** If other forms of PPE have known trade-offs, they reduce risk in some ways, but increase risk in others, such as gloves protecting against lacerations but increasing the grip force required to perform a task, but we still use them and accept them, why would we treat exoskeletons differently? If a worker who wears gloves starts getting Carpal Tunnel symptoms, we need to address that, but we don't pull the gloves off the shelves and stop selling them. Wouldn't we just do the same if a shoulder exoskeleton user starts having back pain?

ANSWER: All technology has trade-offs. Technology has applications where the benefits outweigh the negatives. Exoskeletons have applications where their benefits will outweigh the negatives. Having a standardized process, such as a risk assessment or job analysis, helps companies and individuals make those type of decisions.

Additionally, having standards for holistic ergonomic/safety exoskeleton design and validation will help reduce the chances that you will see a transfer of risk from one body area to another, such as the shoulder to back example.

13. **QUESTION:** If a shoulder exoskeleton has been found to increase loading on the spine, such as in the study by Weston et al 2018 from the OSUSRI, and a user experiences back pain 2 years

after beginning to use it, how can we prove it was the fault of the exoskeleton, and not other life factors?

ANSWER: It depends on what is meant by fault and what is the objective of this proof. If the objective is to allow the worker a change in the work environment or some form of accommodation, that would be completely different than the burden of proof in a court of law for a liability case. From a scientific perspective, longitudinal studies, such as the one NIOSH is beginning, to look at the rate of injury with and without an exoskeleton for the same job tasks starts to get at this question.

From a liability perspective – Back pain has many potential causes and it would be extremely difficult, if not impossible, to “prove” the exoskeleton caused the back pain. The back pain could have come from doing the job BEFORE the exoskeleton was used. Or it might have come from non-work factors such as hobbies or sports, or be due to normal aging changes, previous injuries or pre-existing conditions.

14. **QUESTION:** "voluntary" PPE: Does that mean the wearer is more protected than the worker nearby not wearing this voluntary equipment? How do you assess this situation from OSH point of view as employer?

ANSWER: Voluntary PPE has a precedence in several forms of PPE. An example of the requirements for voluntary use of a respiratory is in 1910.134 mandatory Appendix D:

You should do the following:

1. Read and heed all instructions provided by the manufacturer on use, maintenance, cleaning and care, and warnings regarding the respirator's limitations.

2. Choose respirators certified for use to protect against the contaminant of concern. NIOSH, the National Institute for Occupational Safety and Health of the U.S. Department of Health and Human Services, certifies respirators. A label or statement of certification should appear on the respirator or respirator packaging. It will tell you what the respirator is designed for and how much it will protect you.

3. Do not wear your respirator into atmospheres containing contaminants for which your respirator is not designed to protect against. For example, a respirator designed to filter dust particles will not protect you against gases, vapors, or very small solid particles of fumes or smoke.

4. Keep track of your respirator so that you do not mistakenly use someone else's respirator.

In addition, the degree of risk of a job is partially dependent on the worker who performs the job, due to natural differences in individual size, strength, skill, etc. So it isn't necessarily true that a worker wearing an exoskeleton is more protected than another worker without an exoskeleton – the exoskeleton may simply allow the exoskeleton wearer to do work that couldn't otherwise be done, or do it with less effort or less fatigue.

15. **QUESTION:** When using exoskeletons as PPE or engineering controls or tools would the training methods for the workers change?

ANSWER: It is possible that training could emphasize different aspects of the exoskeleton depending on how it is used. Training for exoskeleton-as-PPE should include explaining the

hazard that the worker is being protected from, how the exoskeleton protects from that hazard, and the limits of protection (i.e. conditions in which the exoskeleton does not protect). Training for exoskeleton used as an engineering control or as a wearable tool would cover these topics too but perhaps to a lesser degree, with more emphasis on how to use the exoskeleton most effectively to do the job.

16. **QUESTION:** Bill - interesting comment around certification on proper use of exoskeletons similar to forklift training. I believe we are skipping past the important aspect of humans certifying their movement habits. Why would we certify the use of exoskeletons on a foundation of not having expectations/certification for how employees use their body unassisted?

ANSWER: If I understand this correctly you are asking, is it possible to certify a person knows how to move ergonomically correct for certain job tasks?

There isn't consensus on what movements are "ergonomically correct". For example, the oft-repeated lifting recommendation to "lift with your legs, not with your back" assumes the load is compact enough to fit between the lifter's knees and allow bending of knees. However, many loads do not meet this requirement, so what is the "ergonomically correct" in these cases? Also, bending knees is not easy nor recommended for someone with knee damage or pain. For this person, bending the back may be easier than bending the knees.

Certifying human movements is exceedingly difficult if not impossible, since there may be significant differences in movement patterns when different people perform an identical task or activity. These differences may all be "ergonomically correct" (whatever that means), and may be due to anthropometry (size, strength) differences, as well as experience and skill level, or personal preference.

Further compounding the issue of ergonomically correct movements is the environment in which the task occurs. Example: Some distribution centers have pick quotas for workers. The time pressures from these quotas can outweigh any ergonomically correct slowdown of movements (we know that acceleration is a significant risk factor). So even though twisting while lifting is bad for the intervertebral discs (due to increased torque and shear pressures), the workers will do it anyways because it is faster.

Finally, movement patterns may necessarily differ when using and not using an exoskeleton to perform a task.

17. **QUESTION:** Do you also think to further investigate physical human robot interactions and maybe to assess them in order to better categorize and define safety from a more scientific point of view? How much this aspect is included and considered?

ANSWER: Interactions and interfaces are a critical element of safety for exoskeleton users. The Exo Technology Center of Excellence (ET CoE) would like to see further investigations in this area especially as research starts to blur the human-machine interface from a wearable technology to a more integrated technology. In developing standards in F48 and accelerating high priority areas in the ET CoE, we are purposely pursuing safety in all our efforts. Awareness of insights and information on the nature and dynamics of human-exoskeleton interactions will be key to our efforts.

In addition to these, many customers in industrial and military domains are working with universities and exoskeleton manufacturers to perform cognitive and physical evaluations of exoskeletons in relation to their work forces and work environments. These types of human

factors, ergonomic and safety evaluations are essentially predecessors of exoskeleton standards and certifications that are currently in development by F48 and the ET CoE.

18. **QUESTION:** Can Bill define what he means by a "standard"?

ANSWER: standard, n— as used in ASTM International, a document that has been developed and established within the consensus principles of the Society and that meets the approval requirements of ASTM procedures and regulations.

DISCUSSION—The term “standard” serves in ASTM International as a nominative adjective in the title of documents, such as test methods or specifications, to connote specified consensus and approval. The various types of standard documents are based on the needs and usages as prescribed by the technical committees of the Society.

Reference: https://www.astm.org/FormStyle_for_ASTM_STDS.html

19. **QUESTION:** Using gloves as an example different gloves provide different levels of protection and the same goes for a shoulder exoskeleton. Using the ACGIH TLV as the performance standard enables manufacturers to certify a set level of protection. Do you agree?

ANSWER: The protection afforded by an exoskeleton may differ for different users. A fundamental difference between traditional PPE and exoskeleton is that the traditional PPE usually protects from external hazards, such as noise. These external hazards can be objectively quantified and the degree of reduced hazard from the PPE can also be objectively quantified. However, exoskeletons may protect from internal hazards (biomechanical reaction forces within the body in response to an externally imposed load), so at the present, it is not possible to quantify the degree of protection of the exoskeleton, since it depends so much on the combined uniquenesses of the physical makeup of the user, the nature of the work they are doing, and the accommodations afforded by the make or model of the exoskeleton they are using.

20. **QUESTION:** If you consider different levels of protection that different kinds of PPE offer, they all have limits to their level of protection. That protection is established using performance standards to know how well the PPE in question protects the user from the hazard in question. That said if we use know standards like the ACGIH TLV to measure performance of a shoulder exoskeleton, why is this not sufficient to classify shoulder exoskeletons that meet that standard, as PPE?

ANSWER: The protection afforded by an exoskeleton may differ for different users. A fundamental difference between traditional PPE and exoskeleton is that the traditional PPE usually protects from external hazards, such as noise. These external hazards can be objectively quantified and the degree of reduced hazard from the PPE can also be objectively quantified. However, exoskeletons may protect from internal hazards (biomechanical reaction forces within the body in response to an externally imposed load), so at the present, it is not possible to quantify the degree of protection of the exoskeleton, since it depends so much on the combined uniquenesses of the physical makeup of the user, the nature of the work they are doing, and the accommodations afforded by the make or model of the exoskeleton they are using.

21. **QUESTION:** I think unions also care about how the exoskeleton affects life safety, specifically access and egress. Would it be easy to get out of in an emergency?

ANSWER: The ability to Don and Doff an exoskeleton is important for safety and performance.

The ability to self-evacuate in an exoskeleton in a timely manner or doff an exoskeleton quickly to self-evacuate are both topics that are important. ASTM F3444 Standard Practice for Training Exoskeleton Users specifically calls this out in several sections, such as:

“5.1 An exoskeleton user should be trained to perform the following basic skills:

5.1.1. Donning and doffing the exoskeleton in a normal situation and in emergency situations;”

This standard also considers the situation where a user may need assistance doffing an exoskeleton.