Discussion Panel
Examining the Perpetual Issue of Musculoskeletal Disorders (MSDs) – Challenges, Gaps, and Opportunities

Panel Co-Chairs:
Lisa Brooks, *National Safety Council, Itasca, IL, USA*
Rammohan V. Maikala, *National Safety Council, Itasca, IL, USA*

Panelists:
Christopher R. Reid, *The Boeing Company, Charleston, SC, USA*
Sean Gallagher, *Auburn University, Auburn, AL, USA*
Gary Allread, *The Ohio State University, Columbus, OH, USA*
Blake McGowan, *VelocityEHS, Ann Arbor, MI, USA*
Robert R. Fox, *Chair, US TAG to ISO TC159/SC3, USA*
Maury A. Nussbaum, *Virginia Tech, Blacksburg, VT, USA*

According to Injury Facts® data reported annually by the National Safety Council (NSC), overexertion (e.g., lifting, pushing, pulling, holding, or carrying objects) and bodily reactions have consistently been the leading cause of nonfatal injury or illness events involving days away from work. Likewise, overexertion topped the list of injury causes in the 2021 Liberty Mutual Workplace Safety Index, costing $13.3 billion in direct costs for businesses. Data from NSC, the Bureau of Labor Statistics, Liberty Mutual sources, and peer-reviewed research clearly emphasize the gravity of risk factors related to the worker, work, and workplace on MSD development. The NSC began a major initiative last year with a goal to examine the factors influence MSDs systematically. With the support of a major industry partner, it formed an international advisory council consisting of stakeholders from industry, academic, and research communities. The invited panel of experts, all members of this advisory council, will exchange their views on challenges, gaps, and opportunities to mitigate MSDs. These panelists will discuss various issues regarding research, translation, and work practice related to MSDs. Also emphasized will be knowledge gaps (e.g., causal mechanisms, pathophysiology, and MSD theories), opportunities for enhancing risk reduction through new assessment tools (e.g., mathematical models to predict the risk of injury), emerging technologies (e.g., wearable sensors and exoskeletons), and perspectives on future research/practice priorities.

Challenges

Beyond Ergonomics Solution Development and Feasibility: Barriers to Integration and Sustainment

Christopher R. Reid, The Boeing Company, Charleston, SC, USA

Much of the world of ergonomics to this point has been focused on the sides of scientific assessment of hazards and risks as well as feasibility studies for types of solutions that can be put in place for mitigation or removal of risk. However, there are a number of other factors that remain as major barriers (challenges) for practicing members of ergonomics in the field. An upfront integration-based example of a challenge might include how to create business cases to aid in organizational funding for ergonomics personnel, processes, policies, and solutions. Many in the field have been finding that this important initial piece needs to speak beyond the cost of injury avoidance alone and should be more holistic to include the impact on worker productivity and quality of work (McGowan, Reid, Bao, and Kapellusch 2019). Without this holistic approach with investors, solutions may never make it beyond a "potential solution" to reach the people they are being designed to help. Another integration barrier might include how to support standardized massive ergonomics technology integration deployments affecting hundreds to thousands of employees across multiple geographical locations nationally or internationally within a single organization. Examples include, such as for emerging technologies that utilize wearables (e.g., sensors, extended reality, exoskeletons, etc.), cloud computing infrastructure for the Internet of Things (IoT), artificial intelligence (AI), or robotics. These technical challenges

are complex for traditional ergonomists who may not always be versed in hard or soft skills for business, project management, operations, information technology (IT), medical, or engineering disciplines that are typically custom-tailored to organizations.

Beyond integration considerations, many practitioners in the industry face sustainability considerations of hurdles. For example, it is common for practitioners to talk about multiple solutions deployed to the same locations over time and "re-create the wheel" for locations experiencing ergonomics-based risks. One example includes cultural challenges to solution acceptance and utilization. Culture might be seen on multiple levels, from workers that might use the solutions themselves to management and support organizations for those solutions to regional and geographical differences. Beyond culture, another area that should be considered is the sustainability of solutions past the integration phase. These sustainment hurdles include continuous training development with solution updates, employee training, maintenance and repair, organizational support roles and responsibilities, disinfection/sanitization (if needed), storage, job process integration, and command media (policy) creation.

Overall, beyond just individual organization concerns are industry or market sector concerns at regional, national, and international levels, such as consensus standards, government regulation, health insurance or workers compensation, supply chains, and general advocacy funding for the human factors and ergonomics ecosystem. Sustainment and growth of this ecosystem or "circle of life" are important for perpetual resource recruitment and retention. Examples of this type of intentional market shaping can be seen with the emerging exoskeleton technology sector (Crea et al. 2021).

Knowledge Gap
MSDs: Status of Knowledge and Unanswered Questions
Sean Gallagher, Auburn University, Auburn, AL, USA

Over the past few decades, research on fatigue failure in musculoskeletal tissues has clearly shown that all musculoskeletal tissues experience fatigue failure when subjected to repeated stress. This has been exhibited both in ex vivo and in vivo studies (e.g., Barbe et al, 2013, Andarawis-Puri, Flatow and Soslowski 2015, Brinckmann, Biggemann and Hilweg 1988, Gallagher et al. 2007, Schechtman and Bader 1997, Sun et al. 2010, Weightman 1976). However, unlike inert materials the fatigue failure process in the biological setting is modified by various biological processes, most notably tissue remodelling and healing. If we are to effectively intervene to prevent cumulative trauma development in our tissues, we need to better understand the material characteristics of musculoskeletal tissues and acquire more in-depth knowledge about the dynamic processes at work in musculoskeletal tissues in the biological setting. The following and related matters will be discussed in this presentation:

1. Improved characterization of musculoskeletal tissue properties - In the world of engineering materials, a great deal of effort has been put into characterizing material characteristics critical to the development of fatigue failure. Factors such as tensile properties, monotonic, cyclic, and strain-life properties, and fatigue crack thresholds are well tabled for a wide range of engineering alloys (Stephens, Fatemi, Stephens, and Fuchs 2001). Conversely, data on fatigue life properties of musculoskeletal tissues remain rather sparse and disorganized. Thus, a more comprehensive exploration of the responses of musculoskeletal tissues to repeated stress would seem warranted (ex vivo, in vitro, and in vivo).

2. Musculoskeletal tissue responses to stress – musculoskeletal tissues are sensitive to stress and adapt (to a degree) in accordance with the stress experienced. Both anabolic and catabolic events can occur in tissues, depending on the magnitude and repetition of the stress encountered. There are clearly stress thresholds present that determine the response of the tissues, and we need to better understand the factors that result in various responses to stress, and how and why these thresholds are breached.

3. Understanding the impact of tissue remodelling, healing, and rest – The service life of musculoskeletal tissues is undoubtedly greatly extended by the remodelling and healing processes present in biological systems. However, the healing process can be negatively impacted depending on several factors, including psychological stress, age, sex, and obesity. Our understanding of the tug-of-war between damage development and healing is unacceptably deficient at present. Understanding the interaction between these processes is critical to our ability to maintain musculoskeletal health. Furthermore, the role of rest in prevention of musculoskeletal disorders needs additional study.

Knowledge Gap
Tackling the Impact of MSD Exposure Interactions
Gary Allread, The Ohio State University, Columbus, OH, USA

Causal pathways to musculoskeletal disorders (MSDs) are multi-factorial and complex, a finding known for more than two decades (National Research Council and Institute of Medicine 2001). That is, MSD causes have been linked to both physical workplace exposures and the environment in which the work is performed (i.e., psychosocial factors), and their impact can be influenced by individual characteristics. Unfortunately, little MSD research has focused on how these factors interact, particularly between types of exposures.

For example, investigators have studied the impact of combinations of physical loads (e.g., load weight and trunk posture) much more so than, say, interactions between physical exposures and psychosocial influences (e.g., load weight and job control) or individual factors (e.g., load weight and Body Mass Index). Although more MSD exposure interaction-based research is being conducted, results are slow to be integrated into a usable format. In fact, most of the ergonomics assessment tools commonly used by practitioners include little or no input of psychosocial or individual influences (Lowe et al. 2019). These findings highlight numerous opportunities for both the research and workplace safety communities, including: the development of validated models that integrate combinations of exposure types; the education of industry regarding holistic approaches to assess workplace injury risk; and the creation or modification of assessment tools that collectively assess known MSD exposures.

Opportunity
Practical Application of Validated MSD Risk Assessment Tools in Industry
Blake McGowan, VelocityEHS, Ann Arbor, MI, USA

From a practitioner's perspective, there are some knowledge *gaps* related to MSD (physical) risk factors and risk assessment tools, however, there are bigger *challenges* and *opportunities*. A primary challenge for practitioners is the lack of awareness of available risk assessment tools and the understanding on how best to apply these tools in the industry (David 2005, Oakman et al. 2022, Takala et al. 2010). Secondarily, these tools typically require manual/visual observation-based assessments, leading to significant inconsistencies in inter- and intra-observer reliability and repeatability (Eliasson et al. 2017). Thirdly, usability is a major concern. In practice, safety professionals and engineers in the industry struggle to conduct common risk assessment tools (e.g., Strain Index, ACGIH Activity Levels, NIOSH Lifting Equation, Psychophysical Tables to Manual Materials Handling) properly. As a result, they are intimidated, confused, and uncertain. New technologies, such as computer vision, artificial intelligence, and machine learning could alleviate these concerns. Lastly, practitioners struggle with gathering, collating, aggregating, and managing the massive amount of MSD risk assessment data. Even with clear research that defines the physical risk factors for MSD and the availability of validated MSD risk assessment tools, it will be challenging to reduce the societal and financial burden of workplace injuries if they are not usable by practitioners.

Opportunity
Research to Reality: Experience with the RNLE in the ISO 11228-2 Standard on Lifting
Robert R. Fox, Chair, US TAG to ISO TC159/SC3

According to surveys of the ergonomics assessment tools used by certified professional ergonomists (Dempsey et al. 2005, Lowe et al. 2019), the Revised NIOSH Lift Equation (RNLE) is the most commonly used tool. Since the publication of the RNLE, users of the equation have had questions concerning the use and interpretation of this tool. Furthermore, developments and changes in industrial manual material handling practices have emphasized a need for applications and extensions of the RNLE that were not necessarily considered by its original developers, such as for small lot material delivery (Fox and Peacock, 1995).

The purpose of this presentation will be to examine the interaction of practitioner needs with researcher directions and priorities and how, in the case of the RNLE, they were able to come together over the years in the eventual publication of a revised ISO standard, ISO 11228-1 on Lifting, lowering and carrying (ISO 11228-1, 2021). The development of the extensions, particularly of the Variable Lift Index (VLI), will be discussed, including how it was driven largely by the needs of industry and changes in manual handling practices. Also discussed will be a review of the research on the RNLE conducted during the ISO 11228-1 revision that led to more explicit guidance on interpreting the RNLE.

Emerging Technologies
Emerging Technologies and Their Potential for MSD Prevention
Maury A. Nussbaum, Virginia Tech, Blacksburg, VA, USA

Diverse technological advancements and commercial developments are occurring that can have broad and

substantial beneficial impacts on work-related musculoskeletal disorders (MSDs). A variety of wearable sensors and occupational exoskeletons have emerged and are being offered by increasing numbers of suppliers, with expanding functionalities and capabilities and at decreasing costs. These technologies open many new opportunities for MSD research and practice, potentially enhancing both MSD risk assessment and control.

Traditionally, many measures relevant to MSDs could only be obtained easily in a laboratory setting. Now, though, it is increasingly feasible and cost-effective to obtain such measures in the field. As examples, there are wireless systems to measure muscle activity, whole-body kinematics, and physiological responses, including systems with sensors embedded in garments. However, it remains unclear in many cases what should be done with such "big data" (e.g., what are the best models or tools). Further, there are risks that such data could be used inappropriately (e.g., employee surveillance).

Exoskeletons (EXOs) are not a new technology, but it is only since 2015 that systems intended for occupational use became commercially available. Though specific data are difficult to obtain, it is likely that the number of these systems in use is on the order of 100,000. Extant evidence regarding the efficacy of occupational EXOs is emerging rapidly, and clearly suggests the potential for this technology to reduce physical demands (e.g., muscle activity and energy expenditure). Yet, it is also becoming clear that EXOs are not a "magic bullet"; rather, there are complex influences of EXO technologies, worker characteristics, and task demands. More work is needed to identify or predict effective applications and to better understand the potential adverse effects of EXO use (e.g., on discomfort or balance). Importantly, evidence of effectiveness remains very limited (i.e., does EXO use reduce the risk of an MSD?), and there does not yet seem to be a consensus on whether EXOs can be considered as PPE or PPT.

Some suppliers are making rather strong claims of these emerging technologies, but new evidence is needed to identify specific benefits that can be expected and to ensure that unintended consequences are avoided. Consider as examples that wearable systems are being used to monitor worker kinematics and to provide feedback to minimize "risky" working methods, and EXOs are being used to reduce physical demands in diverse tasks. There is concern that these technologies support a shift in focus away from the traditional ergonomic approach of "fitting the task to the person", or that the technologies are used as justification to increase workload. The specific role(s) and appropriate uses of these technologies should thus be considered carefully.

In summary, the panelists will present their views on challenges, knowledge gaps, and research and practice opportunities for MSDs prevention.

REFERENCES

Andarawis-Puri A, Flatow E and Soslowski L (2015) Tendon basic science: development, repair, regeneration, and healing. Journal of Orthopaedic Research, 33, 780-784.

Barbe M, Gallagher S, Massicotte V, Tytell M, Popoff S, and Barr-Gillespie A (2013) The interaction of force and repetition on musculoskeletal and neural tissue responses and sensorimotor behavior in a rat model of work-related musculoskeletal disorders. BMC Musculosskeletal Disorders, 14.

Brinckmann P, Biggemann M and Hilweg D (1988) Fatigue Fracture of Human Lumbar Vertebrae. Clinical Biomechanics, 3 (Suppl. 1): S1–S23.

Crea S, Beckerle P, De Looze M, De Pauw K, Grazi L, Kermavnar T, … Veneman J (2021) Occupational exoskeletons: A roadmap toward large-scale adoption. Methodology and challenges of bringing exoskeletons to workplaces. Wearable Technologies, 2, e11.

David GC (2005) Ergonomic methods for assessing exposure to risk factors for work-related musculoskeletal disorders. Review Occup Med (Lond). May;55(3):190-9.

Dempsey PG, McGorry RW, Maynard WS (2005) A survey of tools and methods used by certified professional ergonomists. Applied Ergonomics, 36:489–503.

Eliasson K, Palm P, Nyman T, and Forsman M (2017). Inter- and intra- observer reliability of risk assessment of repetitive work without an explicit method. Applied Ergonomics. Volume 62, 1-8.

Fox RR and Peacock JB (1995) The Ergonomics of Small Lot Materials Delivery. The Konz/Purswell Occupational Ergonomics Symposium, Institute for Ergonomics Research, Department of Industrial Engineering, Texas Tech University, Lubbock, TX, April 8.

Gallagher S, Marras W, Litsky A, Burr D, Landoll J and Matkovic V (2007) A Comparison of Fatigue Failure Responses of Old versus Middle-Aged Lumbar Motion Segments in Simulated Flexed Lifting. Spine, 32, 1832–1839.

ISO 11228-1:2021, Ergonomics — Manual handling — Part 1: Lifting, lowering and carrying, second edition 2021-10.

Lowe BD, Dempsey PG, and Jones EM (2019) Ergonomics Assessment Methods Used by Ergonomics Professionals, Applied Ergonomics, 81:1-8).

McGowan B, Reid CR, Bao S, and Kapellusch J (2019) Return on Investment of Ergonomics Interventions – Discussion Panel. Proceedings of the Human Factors and Ergonomics Society Annual Meeting 63(1), 978–979..

National Research Council and Institute of Medicine (2001) Musculoskeletal Disorders and the Workplace: Low Back and Upper Extremities, Washington, DC: National Academy Press.

Oakman J, Kinsman N, Weale V and Stuckey R (2022) A qualitative exploration of tools used by WHS professionals for the prevention of musculoskeletal disorders. Safety Science. Volume 149.

Schechtman H and Bader D (2002) Fatigue damage of human tendons. J. Biomech, 35, 347-353.

Stephens R, Fatemi A, Stephens R and Fuchs H (2001) Metal Fatigue in Engineering (2nd Edition ed.). New York: John Wiley & Sons.

Sun HB, Andarawis-Puri N, Li Y, Fung DT, Lee JY, Wang VM, Basta-Pljakic J, Leong DJ, Sereysky JB, Ros SJ, Klug RA, Braman J, Schaffler MB, Jepsen KJ, and Flatow EL (2010) Cycle-dependent matric remodeling gene expression response in fatigue-loaded rat patellar tendons. Journal of Orthopaedic Research, 28, 1380-1386.

Takala E, Pehkonen I, Forsman M, Hansson G, Mathiassen S, Neumann P, Sjøgaard G, Veiersted K, Westgaardand R and Winkel J (2010) Systematic evaluation of observational methods assessing biomechanical exposures at work. Scandinavian Journal of Work, Environment & Health. Vol. 36, No. 1, January, 3-24.

Weightman B (1976) Tensile fatigue of human articular cartilage. Journal of Biomechanics, 9, 193-200.