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SYMPOSIUM
PROCEEDINGS

OCTOBER 13-14, 2020
VIRTUAL CONFERENCE

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Preface - Exoskeleton Track

Since formalizing into a User-Centered Design meeting in 2018, the ErgoX Symposium has demonstrated that a symbiotic approach to improving the design of technology and equipment is possible. With the goal to improve safe and effective technology user adoption, ErgoX offers a virtual and physical space to status the latest in technology evolution, research, and application and their intersection with human-system interaction and integration. This event, hosted annually by the Human Factors and Ergonomics Society (HFES), is a single example of the growing demand for safe and effective technology development found through multi-disciplinary and cross-market collaboration of cognitive and physical research and their resulting application to end user technology adoption. This year's event in particular led to an attendance representation of professionals from academia (22%), industry, which included health care and insurance (38%), government/military (21%), consulting (4%), and students (14%). This preface is specific to the Exoskeleton Track from the 2020 ErgoX Symposium held virtually online for the first time October 13-14, 2020.

Year by year, the exoskeleton market has continued to expand, with recent trend information showing compounded annual growth rates (CAGR) of 29% between 2020 and 2024 for medical exoskeleton devices[1] or, in another example, general exoskeleton market growth from $1.5 Billion USD in 2019 to $4.4 Billion USD by the end of 2025 or a CAGR of 18.43%[2]. However, what remains to be seen on this market is how the global impact from the COVID-19 global pandemic affects the continued growth, particularly in the area of human research studies, supply chain, and manufacturing and development. As such, the Exoskeleton Track Chairs invited guest speaker, Dr. Mark Weir of Ohio State University's College of Public Health, where Dr. Weir had a special session discussion panel on viral infectious impact to workplace environment infrastructure and exoskeleton device materials. His talk was titled "Controlling SARS-CoV-2 on Critical and Sensitive Infrastructure Lessons on Limited Environmental Data for Infectious Diseases".

Another way to look at this increasing demand for safe and effective exoskeletons can be seen in both private and public funding of human-exoskeleton research. Exoskeleton developers, end use customers, and third party evaluators in industry (manufacturing, food services, construction, warehousing, etc.), military (warfighter and logistics), and medical rehabilitation domains continue to fund studies on end user task and application efficacy, longitudinal health impact, and ergonomic and safety. Additionally, United States based public and non-profit grant funding sources continue to expand their funding availability, such as seen from National Institute for Occupational Safety and Health (NIOSH), National Science Foundation (NSF), National Institutes of Health (NIH), Department of Defense, and the ASTM International Exo Technology Center of Excellence. Day One's Keynote Speaker, Dr. Bob Scheidt from the NSF touched on these opportunities available through some of the grant opportunities offered, such as that of the Mind, Machine and Motor Nexus grant, known as M3X. His talk was titled "Research Support for Research Related to Exoskeletons and Their Use".

In addition to market growth, examples of research impact from the exoskeleton market can be shown through the continued creation of consensus standards. As of the end of 2020 and since its creation in 2017, the ASTM F48 Exoskeleton & Exosuit Standards Committee has produced six standards around developing technology terminology (F3323-20), device maintenance (F3392-20), task performance and environmental use considerations (F3427-20 and F3443-20), end user training (F3444-20), and device labeling and information availability (F3358-20). However, as noted by International Standards Session speaker, Dr. Bill Billotte, this is just the beginning as much work remains to be done in order to attain international consensus on test methods and device certification.

As is done each year during the Exoskeleton Track, attendees are surveyed in order to better understand research gaps and opportunities for the exoskeleton market workforce. Maturity between 2018 and 2019 saw a reduction in the number of gaps from 20 to seven. As shown in Figure 1, when asked during the 2020 symposium what the major focus for 2021 would be, attendees responded by further reducing the gaps, going from seven to five. These remaining gaps identified and ranked by majority included (1) What Metrics are Right?, (2) Size, Shape & Fit, (3) Task Matching & Applicability, (4) Longitudinal Effects, and (5) Implementation Considerations (note that 3 and 4 were actually tied in rank). While these responses are aggregated into large categories, open ended responses further highlighted the need for comprehensive standards that will be able to quantify the near and long term cognitive (user-system interfacing, user experience, usability, etc.) and physical (anthropometry, biomechanics, ergonomics, safety, etc.) effects on the users wearing these devices. Day Two's Keynote Speaker, Dr. Bruce Bradtmiller from Anthrotech spoke to some of these physical considerations around designing for the variability in size and shape of people during his talk on "Mind the Gap – Anthropometric Data To Design (Why is it so hard?)".

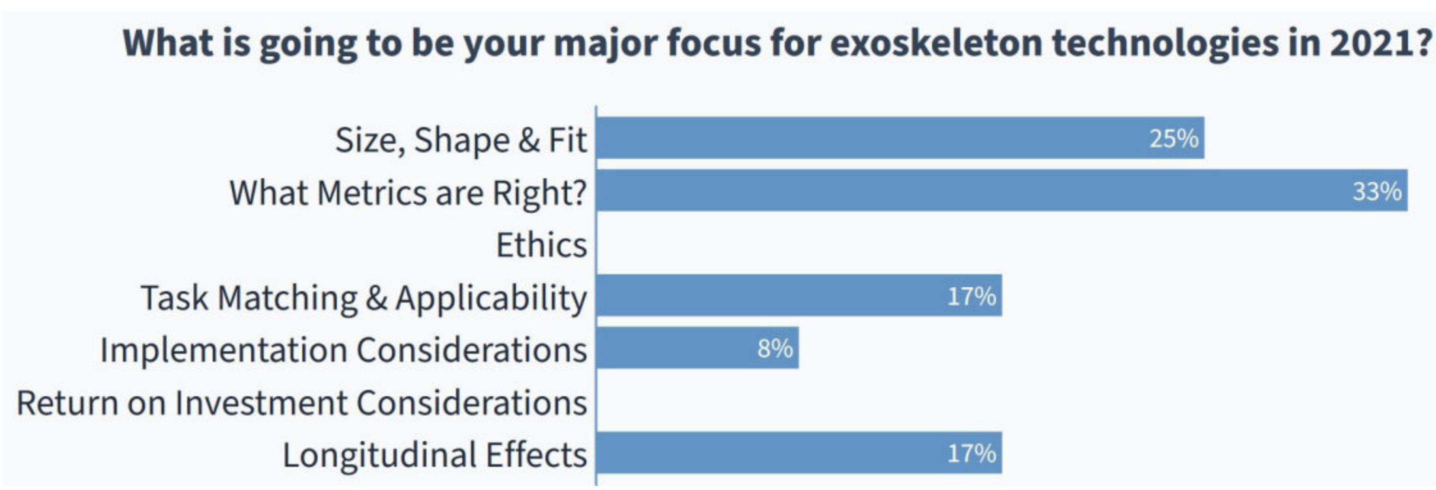

Figure 1. – 2021 Areas of Concentration

New this year and to enhance the virtual ErgoX experience, three concurrent breakout happy hour sessions were held that provided an open forum for discussions on important topics including “Industrial/Logistics Exoskeletons: PPE vs. Tools”, “Improving Exoskeleton Usefulness, Usability, and Desirability”, and “Running the Gauntlet: Funding to Research to Design to Utilization”. Lively participation in each session yielded open discussions on exoskeleton design, research, and implementation, with many participants presenting their experiences and challenges within their workplaces or research environments. Although these sessions took place before the survey was distributed, the discussions that took place underscored the gaps identified in Figure 1.

As with any technology evolution, the symbiotic relationship envisioned as the end state with ideal system design and high market ubiquity is separated by a valley of useful, usable, and desirable gaps. By continuing to focus on these user-centered design concepts in addition to good business acumen, the market of exoskeletons can continue to mature. As with previous years, the Exoskeleton Track for ErgoX will continue to carry this torch of progress into the next ErgoX Symposium event planned for Fall 2021.

Christopher R. Reid, PhD
President-Elect, Human Factors & Ergonomics Society
ErgoX Symposium Chair
ErgoX Exoskeleton Track Symposium Chair

Donald R. Peterson, PhD, MS, FAIMBE
ErgoX Exoskeleton Track Symposium Co-Chair

William S. Marras, PhD, CPE
ErgoX Exoskeleton Track Symposium Co-Chair

Hongwei Hsiao, PhD
ErgoX Exoskeleton Track Symposium Co-Chair
ErgoX Robotics Track Symposium Chair

[1]*COVID-19 Impacts: Medical Exoskeleton Market Will Accelerate at a CAGR of Almost 29% Through 2020-2024: Focus on Development of 3D-Printed Medical Exoskeletons to Boost Growth: Technavio.* Business Wire, 24 July 2020, www.businesswire.com/news/home/20200724005276/en/COVID-19-Impacts-Medical-Exoskeleton-Market-Accelerate-CAGR.

[2]*Exoskeleton Market Research Report by Type (Mobile and Stationary), by Technology (Active, Passive, and Semi-Passive), by Product, by End User - Global Forecast to 2025 - Cumulative Impact of COVID-19.* Market Report, Aug. 2020, www.reportlinker.com/p05940587/Exoskeleton-Market-Research-Report-by-Type-by-Technology-by-Product-by-End-User-Global-Forecast-to-Cumulative-Impact-of-COVID-19.html?utm_source=GNW.

Exoskeleton Program

October 13, 2020

Session	Speakers
Keynote: The National Science Foundation - Research Support for Research Related to Exoskeletons and Their Use	Bob Scheidt, National Science Foundation
Vendor Talks	Moderator: Chris Reid, The Boeing Company Paul Nicholson, Hero Wear Janne Pylvas, Myontec
Research Methods 1: Size/Shape/Fit, What Metrics Are Right?	Moderator: Joseph Parham, US Army Soldier Systems Center Divya Srinivasan, Virginia Tech University Kevin Purcell, US Public Army Health Center Jason C. Gillette, Iowa State University
Developer Session	Moderator: Chris Reid, The Boeing Company Ben Wolff, Sarcos Robotics Ryan Porto, General Motors and Johan Sleman, Bioservo Samuel Reimer, Ottobock
COVID-19 & Exoskeletons	Moderator: Don Peterson, Northern Illinois University/ATSM Mark Weir, Ohio State University

Exoskeleton Program

October 14, 2020

Session	Speakers
Keynote: Mind the Gap - Anthropometric Data to Design (Why is it so hard?)	Bruce Bradtmiller, Anthrotech
Sponsor Talks	Moderator: William Marras, Ohio State University George Brogmus, Liberty Mutual Kari Babski Reeves, BCPE
User Session	Moderator: Kendra Betz, VA National Center for Patient Safety Kristen Hohl, Shirley-Ryan Ability Lab Cathy White, Dow Chemical Yonnel Giovanelli, SNCF Material Directorate - France
Research Methods 2: ROI Considerations, Task Matchin/Applicability, Implementation Considerations	Moderator: Leia Stirling, University of Michigan Carisa Harris-Adamson, UC San Francisco/ Berkeley Conor Walsh, Harvard Wyss Institute Kurt Mudie, AUS Defense Science and Technology Group
Research Methods 3: Longitudinal Effects, Ethics	Moderator: William Marras, Ohio State University Meghan O’Donovan, US Army Soldier Center Julie Brazier, Ford Motor Company Dov Greenbaum, Yale University
Standards Status	Moderator: Krystyna Gielo-Perczak, University of Connecticut William Billotte, ASTM Exo Technology Center of Excellence

Exoskeleton Sessions

October 13, 2020

Keynote: The National Science Foundation - Research Support for Research Related to Exoskeletons and Their Use

Bob Scheidt, National Science Foundation

In this talk, Bob Scheidt presented funding opportunities at the National Science Foundation related to exoskeletons and their use for augmenting human sensorimotor performance. Particular focus was given to the Mind, Machine, and Motor Nexus (M3X) Program and to the Future of Work at the Human-Technology Frontier (FW-HTF) Program.

Vendor Talks

Moderator: Chris Reid, The Boeing Company

Paul Nicholson, Hero Wear

Janne Pylvas, Myontec

Research Methods 1: Size/Shape/Fit, What Metrics Are Right?

Moderator: Joseph Parham, US Army Natick Soldier Systems Center

Physical Demands and Learning Associated with Using A State-of-the-art Whole-body Powered Exeskeleton

Divya Srinivasan, Virginia Tech University

View recording here.

Despite the rapid development and progress of powered exoskeleton technologies in recent years, little is known about how a complex whole-body system interacts wit, and influences human operators. As an initial step towards facilitating the practical adoption and assessment of powered exoskeletons in industrial environments, two studies were completed. The first study aimed to assess how using a whole-body powered exoskeleton affects physical demands of expert human operators. Seven expert participants (5M, 2F) performed two industry-relevant tasks – bilateral load carriage and repeated one-handed lifting/lowering – both with and without the exoskeleton. Participants completed the load carriage task at five different load levels and the lifting/lowering task at 7 different load levels, ranging from low (~ 5kg) to high (~50 kg). Results on muscle activities of trunk and leg musculature will be reported. The second study aimed to capture the change in muscle activities and kinematics as novice operators learnt to operate a complex exoskeleton, over repeated sessions. Seven (7M) novice operators were introduced to, and trained in the use of the exoskeleton over 5 sessions; to perform a range of tasks including gait (level, ramp and step up/down/over), load carriage, and manual material handling. Dr. Srinivasan summarized key results of how muscle activities and control strategies changed as individuals learnt to operate the exoskeleton better over repeated sessions.

Measuring Exosystem Operator Use Intent: The Exosystem Use Intent Model

Kevin Purcell, US Public Army Health Center
View slides here.

To measure a user's psychological intent to utilize an exosystem technology to complete industrial work tasks, this proposed methodology, the Exosystem Use Intent model (EUI) and subsequent questionnaire, is presented. Utilizing a modified TAMII structure, EUI measures a user's cognitive flow from exogenous (external) factors through endogenous (internal) factors. To make this methodology broad, flexible, and easy to apply a questionnaire format using 4 existing human factor constructs were chosen: usability, workload, situational awareness (SA), and trust in automation (TiA). Any of these constructs can be broken out separately.

Lab and Field Studies to Assess if Exoskeleton Usage Reduces Muscle Fatigue Risk

Jason C. Gillette, Iowa State University
View slides here.

Exoskeletons are challenging to assess using standard biomechanical and ergonomic techniques. Video and observation can predict which job tasks have higher fatigue risk, but do not account for support provided by exoskeletons. We measure percent maximum voluntary contraction and duty cycle with electromyography (EMG) to determine whether a job task is above the ACGIH threshold limit value (TLV) for fatigue with and without an exoskeleton. In addition, we use video and/or inertial measurement units to measure job task duty cycles and movements that are matched with lab-based EMG values for postures, tool weights, and exoskeleton usage to predict fatigue risk. Using field-based EMG results, Whittier Tunnel construction tasks fell into three exoskeleton usage categories: reduced fatigue risk but task still over TLV, reduced fatigue risk from above to below TLV, and reduced fatigue risk but task below TLV. We also applied lab-based EMG results to motion data collected in the Whittier Tunnel to predict task fatigue risk with and without exoskeleton usage. While field-based studies provide 'real world' data, lab-based studies allow for systematic testing that can be widely applied to predictive models. We suggest comparing field-based EMG results to combined lab and field-based results to validate predictive fatigue models.

Developer Session

Moderator: Chris Reid, The Boeing Company

The Present and Future of Full Body Wearable Robots

Ben Wolff, Sarcos Robotics

The successful pairing of man and machine, represented by robotics solutions that augment humans, including wearable exoskeletons, has the potential to make our workforce safer and more productive. Human augmentation robots bring together the best of what people and machines have to offer-combining human experience, wisdom, intuition and judgment with the strength, endurance and precision of machines. The benefits of these robots will transform the industrial workforce as we know it, enabling a larger, more diverse pool of workers to enhance output and efficiencies, and doing so more safely than ever before.

The future opportunity in the evolution of robotic solutions will be the integration of emerging technologies like artificial intelligence (AI) and machine learning (ML). AI and ML, when leveraged correctly, present an opportunity to create greater synergies between man and machine. Striking the right balance of technology integration and human thought will ultimately deliver economic and safety benefits typically associated with automation, but for tasks that are too complex, random or diverse to be effectively performed without a human involved.

In-field Evaluation of the Ironhand on Automotive Assembly Tasks

Ryan Porto, General Motors and Johan Sleman, Bioservo

The Ironhand system is an active soft exoskeleton for the hand, designed to improve the health for workers that perform grasp intensive, repetitive and static work tasks. The solutions derive from the healthcare sector where clinical trials have shown that the soft robotic gloves improve grip strength. A field test in a manufacturing facility was essential to evaluate the ability of the Ironhand to reduce the physical demands of operator’s hands while completing automotive assembly work-related tasks. This presentation will review the testing and feasibility study of the Ironhand at a General Motors vehicle assembly plant in Orion, Michigan. Bioservo provided details about the durability study for specific assembly tasks and show the glove development and refinement that took place during the trials. In addition, General Motors provided a user status update and summarize some of the assessment strategies used to evaluate the Ironhand.

Limits of Automation - Industrial Exoskeletons are a Response

Samuel Reimer, Ottobock

View slides here.

Despite increasing automation, sophisticated robotics, and digitalization, there is still an inevitable degree of manual labor and manufacturing necessary across the developed world. Humans step in where automation and/or robotics are no longer economical and frequently fill jobs that are ergonomically highly distressing. Ottobock, the market leader in prosthetics and orthotics and a valued partner for the US veterans association, has introduced industrial exoskeletons as part of a response for these limiting factors and provides ergonomic relief for manual labor and workers worldwide across industries. Dr. Reimer, responsible for the global business development for Ottobock’s exoskeleton portfolio, presented Ottobock’s industrial exoskeleton portfolio and popular use-cases and discussed the current limits of automation. Furthermore, he demonstrated how industrial exoskeletons play a pivotal role in manual labor and how they increase health and safety subjectively and through peer-reviewed research, and how they maintain musculoskeletal health throughout a worker’s life.

COVID-19 & Exoskeletons

Moderator: Don Petereson, Northern Illinois University/ATSM

Controlling SARS-CoV-2 on Critical and Senstive Infrastructure Lessons on Limited Environmental Data for Infectious Diseases

Mark Weir, Ohio State University

View slides here.

The COVID-19 pandemic has demonstrated a clear lack in preparation through a variety of areas.

Clearly there were limitations in out medical and PPE supplies and distribution networks. While this was dealt with effectively in hindsight, this is just the more obvious issue. A startling deficiency in research preparedness was also made clear, that in regards to the evidence base and capabilities to rapidly assess exposure to a novel virus in a variety of environments. To intervene on a pathogenic hazard, knowledge on its fate and transport in the environment, how humans interact with the environment to drive or limit their own exposures, and the microbiology of the pathogen's survival are the minimum critical knowledge points. In essence the complex system of systems that make up the environmentally driven exposure and disease transmission network is not well known. Conducted in patchwork, research has shown that while most pathogens behave physically to other particles similar to their physical size and characteristics, how they survive disinfectants, persist in the environment, and how humans behave in these environments are all shifting unknowns. This presentation gave an overview of the limitations in our knowledge and data that prevents our ability to model the fate and transport, persistence, and human exposure factors that make assessing environmental interventions for pathogens so challenging or outright impossible. A path forward to determine how to make these types of models adaptive for this and future pandemics on critical infrastructure was discussed.

October 14, 2020

Keynote: Mind the Gap - Anthropometric Data to Design (Why Is It So Hard?)

Bruce Bradtmiller, Anthrotech

View slides here.

Ancient Egyptians measured people to make custom-fit clothing and funerary sarcophagi as early as 2100 BC. More recently, say in the 1880s, anthropologists got involved and started measuring large groups of people for population studies and for product application. More recently still, measurements are available from various 3D scanning devices. We are drowning in data. But clothing doesn't fit, female school bus drivers can't reach the pedals, and Air Force pilots are dropped from training programs because their Buttock-Knee Length is too short.

This presentation explores the mis-match between the data that have been collected and the data that are needed for design. This includes situations where a dimension is measured for one application, but is then applied–inappropriately, to a different problem where the assumptions no longer hold. It also explores the problem of accommodating a variety of people into a single size of an item (whether the item itself is one-size or multiply-sized). And it explores the different approaches that are needed when the product is soft, such as clothing or COVID respirators, versus cases where the product is hard, such as exoskeletons or airplane cockpits.

Sponsor Talks

Moderator: William Marras, Ohio State University

George Brogmus, Liberty Mutual

Kari Babski Reeves, BCPE

User Session

Moderator: Kendra Betz, VA National Center for Patient Safety

Powered Rehabilitation: What We've Gained

Kristen Hohl, Shirley-Ryan Ability Lab

Multiple lower limb exoskeletons are available for clinical utilization to facilitate addressing gait impairments and improving walking function for patients with various neurological diagnoses. This presentation discussed how the introduction of these technologies into the clinical setting has the potential to improve patient outcomes by means of providing a unique and distinct walking intervention strategy. Furthermore, it discusses how this incorporation has the potential positively impact the therapists in terms of ergonomics, effort and decreasing risk for injury.

Wearable Robotics: A Skeleton You Might Want in Your Closet

Cathy White, Dow Chemical

View slides here.

The word "exoskeleton" may lead to images of a suit such as Ironman. Though we would love to fly in the air with superhuman powers, industrial exoskeletons are not quite the same. However, they do have a recognized potential in the industrial market to protect workers by reducing the hazards of physically demanding jobs. Potential applications of this technology have been tested and studied at Dow. Considerations on how to pilot and implement exoskeletons in the field were shared.

From Innovation to the Integration of Exoskeleton

Yonnel Giovanelli, SNCF Material Directorate - France

View slides here.

Following a workshop maintenance on rolling stock carried out in 2014, the Head of the SNCF Rolling stock launched an experimental project on the New Technologies of Physical Assistance (NTPA) and a project on a multi assistance exoskeleton SHIVA Exo. The objective is to check whether they are suitable for the maintenance of trains or not. The establishment of a NTPA modifies the work, and then it is important to understand the stakes and the impacts, the gains and the potential risks in order to anticipate them during the phases of design and experimentation. Before presenting the design methods used iteratively, we will present the safety culture and the Organisational and human factors approach and about the physical behavior in which our global approach to NTPAs fits. Finally we will present the questions and points of vigilance regarding the integration of NTPAs. What are the possible consequences?

Research Methods 2: ROI Considerations, Task Matching/ Applicability Implementation Considerations

Moderator: Leia Stirling, University of Michigan

Exoskeletons in Construction: Applications, Promoters, and Barriers to Their Safe Implementation and Acceptance

Carisa Harris-Adamson, UC San Francisco/Berkeley

Construction workers continue to experience high rates of work-related musculoskeletal disorders (WMSDs) - 11% higher than all other industry sectors in 2016. The back and the shoulder were the most impacted body regions, respectively accounting for 43% and 16% of all cases, with a median of 8 and 25 lost workdays. This high burden of WMSDs is attributed to the high physical demands of construction work, involving overuse associated with frequent and repetitive exposures to well-documented risk factors such as lifting, bending, carrying, use of hand-held tools, or non-neutral/ prolonged static posture. The use of passive exoskeletons (EXOs) offers a new solution to control exposures to physical risk factors during construction work tasks, with the potential to reduce WMSD risks, expand accessibility to construction jobs, and even enhance performance. Although earlier work has demonstrated that using an ASE or BSE can reduce physical demands on the shoulders or the back through reduced muscle activity and physical discomfort during simulated overhead work and during stooped/lifting work, relatively few studies have tested EXOs in construction; thus the potential adverse consequences of EXO use are not sufficiently understood for their safe widespread adoption. We will explore a large ongoing study designed to understand relevant stakeholders' opinions on the potential applications, promoters and barriers to the acceptance of exoskeleton technologies in construction. After introducing stakeholders to the concept of exoskeletons, a survey was used to gather important details regarding their potential adoption and use.

Lightweight and Nonrestrictive Exosuits for the Clinic, Community, and Workplace

Conor Walsh, Harvard Wyss Institute

This talk gave an overview of our work on developing lightweight and nonrestrictive wearable robot technologies for augmenting and restoring human performance and how we characterize their performance through biomechanical and physiological studies so as to further the scientific understanding of how humans interact with such machines. Our efforts are the result a multidisciplinary team of students and research staff with backgrounds in engineering, materials science, apparel design, industrial design, biomechanics, and physical therapy, in addition to valuable collaborations with colleagues from Harvard, Boston University, and beyond. Our long term vision is for ubiquitous soft wearable robots that can be worn all day, every day, in the community, clinic, and workplace.

The Identification of Target Use-Cases and Applications for Exoskeletons in the Australian Defence Force

Kurt Mudie, AUS Defense Science and Technology Group

View slides here.

The Australian Army contains more than 50 diverse employment specialisations and soldiers are exposed to a number of different physically demanding tasks. The aim of this paper was to identify target use-cases that may benefit from the implementation of exoskeletons. A list of physically demanding tasks performed by Australian Army personnel was clustered to identify the most common physically demanding activities. Further, a systematic review of studies investigating the incidence of musculoskeletal injuries in international military populations were collated to highlight the most frequent injury types and most commonly injured regions on the body. When physically demanding tasks were clustered, lifting and marching were the most common activities performed by Australian Army personnel. The systematic review identified the most commonly injured regions on the body were to the ankle, knee, shoulders, and lower back. Exoskeletons that provide targeted support to the most common physically demanding tasks and the identified body regions may offer the greatest potential for augmenting performance and reducing injury incidence in military populations. Besides the targeted development of exoskeletons, future research is needed to investigate the efficacy of wearable assistive technologies to reduce the risk of musculoskeletal injuries amongst military personnel.

Research Methods 3: Longitudinal Effects, Ethics

Moderator: Bill Marras, Ohio State University

Characterizing Adaptation to an Ankle Exoskeleton System: Why Individual Variability Matters

Meghan O'Donovan, US Army Soldier Center

View slides here.

Human augmentation systems, such as exoskeletons, claim to offload effort while improving operator performance. However, previous studies often report initial increased muscle or metabolic activity with exoskeleton use and individual operator adaptation periods appear variable. Currently, there is no scientific explanation for individual adaptation variability highlighting a critical gap in the field of military exoskeleton research to address. Presented here are the justification, complete methods and initial results from an ongoing study designed to determine which baseline operator characteristics (e.g., gait, cognition, anthropometry, and proprioception) are related to short- and long-term adaptation to an ankle-based exoskeleton. Results included examining gait as characterized by normalized stride length (NSL) during exoskeleton walking.

Preliminary Results of a 18-Month Field Study on Arm Support Exoskeletons in a Unionized Manufacturing Environment

Julie Brazier, Ford Motor Company

This talk provided an overview of an 18-month field study exploring the impact of passive shoulder devices on the reduction of musculoskeletal discomfort and injury within automotive manufacturing. Preliminary results were shared, along with a discussion around the benefits and opportunities of deploying with a unionized workforce.

Exoskeletons: Ethical, Legal, and Social Considerations

Dov Greenbaum, Yale University

View slides here.

As technology advances, exoskeletons are becoming more common in various different sectors, ranging from therapeutics to military. As with all emerging technologies, the advancements in the field of exoskeletons raise various legal, ethical and social considerations. Some issues are clear and have relatively simple solutions, such as social justice considerations relating to access to these expensive devices and the ability to obtain insurance reimbursements for their use for therapy. Other areas are also familiar due to common Hollywood tropes, such as the ethics of using these technologies in police enforcement and the military, particularly when they are semi-autonomous. Some considerations are futuristic, such as the regulatory considerations related to using these technologies in sporting competitions; these concerns are also related to more philosophical considerations of where to draw the line between human therapy and human enhancement. But perhaps, some of the most interesting legal questions arise when exoskeletons are paired with predictive artificial intelligence and/or integrated neurologically into the subject. In these situations, the law must deal with foundational considerations of proximate cause and free will, perhaps even forcing the legal discipline to reassess long-standing ideas. This presentation aimed to address all of the aforementioned considerations.

Standards Status

Moderator: Krystyna Gielo-Perczak, University of Connecticut

ASTM Exo Technology Center of Excellence: Projects and Activities Update

William “Bill” Billotte, ASTM Exo Technology Center of Excellence

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This briefing gave the latest status of standards development and education projects funded by the CoE, as well as future directions and planned activities, including the Request for Proposals for 2021.

Robotics Program

Session	Speakers
October 13, 2020	
Keynote: Robotics Research and the Future of Work	Jordan Berg, National Science Foundation
Research Section 1: Human-Robot Communication	Ranjana Mehta, Texas A&M University Chang Nam, North Carolina State University HeeSun Choi, Texas Tech University
Research Section 2: Robotics Safety	Robert Radwin, University of Wisconsin-Madison Peregrin Spielholz, The Boeing Company Jessie Yang, University of Michigan
Partnership Opportunities	Dawn Castillo, NIOSH Center for Occupational Robotics Research (NIOSH CORR) Carole Franklin, Robotics Industries Association (RIA) Cara Mazzarini, Advanced Robotics for Manufacturing Institute (ARM) Jeremy Marvel, Nastional Institute of Standards and Technology (NIST)
October 14, 2020	
Keynote: Bringing a Human Factors Perspective to Emerging Intelligent Autonomy Technologies	Marc Steinberg, Office of Naval Research
Research Section 3: Simulation and Methods	Moderator: Jeremy Marvel, National Institute of Standards and Technology Bilge Mutlu, University of Wisconsin-Madison Shelly Bagchi and Megan Zimmerman, National Institute of Standards and Technology
Research Section 4: Emerging Applications	Thenkurussi “Kesh” Kesavedas, University of Illinois at Urbana Masoud Gheisari, University of Florida Fadi Fathallah, University of California, Davis
Closing Panel Discussion: Challenges and Priorities for Human-Centered Robotics	Moderators: Hongwei Hsiao, NIOSH; Jeremy Marvel, NIST; Robert Radwin, University of Wisconsin-Madison Russell Taylor, Johns Hopkins University Nadine Sarter, University of Michigan Oussama Khatib, Stanford University

Robotics Sessions

October 13, 2020

Keynote: Robotics Research and the Future of Work

Jordan Berg, National Science Foundation

View slides here.

This talk describes the NSF "Future of Work at the Human-Technology Frontier" (FW-HTF) program, in particular the interactions expected between technology-centric research, human-centric research, and social- or economic-centric research. It is stressed that these interactions should be present in every submitted proposal, and articulated as the core of the project's Intellectual Merit. These interactions are explored in the context of a fictional manufacturing example, and further illustrated using recently funded projects from the FW-HTF program. The talk concludes with an account of the FW-HTF program funding history, and a list of relevant NSF personnel.

Research Section 1: Human-Robot Communication

Moderator: Ranjana Mehta, Texas A&M University

Operator Fatigue and Trust in Collaborative Robotics: A Neuroergonomics Perspective

Ranjana Mehta, Texas A&M University

Measuring trust, an important element of effective human-robot collaborations (HRC), has largely relied on subjective responses and thus cannot be readily used for adapting robots to shared operation, particularly with shared-space robotics. Additionally, whether trust in such HRCs differ under altered operator states or with sex remains unknown. This presentation compares subjective and brain-based metrics of trust, along with task performance, when both human (e.g., fatigue and sex) and robot (e.g., automation level, and robot reliability) factors are manipulated. While women distrust robot when unreliable, both men and women over-trust robot under "fatigue" states despite low robot reliability. Brain-based metrics, collected using functional near infrared spectroscopy, indicated that low robot reliability increased neural "cost" of maintaining task performance, and this was exacerbated under greater operator fatigue states. These findings, while preliminary, provide a strong foundation for future investigations on better understanding the interplay of human factors and trust in HRC as well as in developing more diagnostic and deployable neuroergonomic measures of trust.

Making Co-Robots Effectively Learn Their Optimal Behavioral Strategy while Interacting with Human Workers

Chang Nam, North Carolina State University

View recording here.

Reinforcement learning (RL) using explicit human feedback has been used to enable robots to learn its optimal behavioral strategy in dynamic environments, because an explicit reward function can be easily adapted. However, it is very demanding and tiresome for a human to continuously and explicitly generate feedback. Therefore, the development of implicit approaches is of high relevance. This study aims at demonstrating that intrinsically generated EEG-based human feedback in RL can successfully be used to implicitly improve gesture-based robot control during human-robot interaction.

Human Perception and Behaviors During Human-Robot Communication: Importance and Research Needs

HeeSun Choi,Texas Tech University

Communication between human users and robots is critical for effective and safe human-robot interaction, as more robots are now working collaboratively with human users in a shared environment. While robots must accurately detect and understand the users' commands, behaviors, and states, they also need to communicate their current status, cued actions, and underlying intents and goals. Successful robot-to-human communication helps users complete collaborative tasks, avoid hazards and collisions, and develop trust towards robots. Intended outcomes of robot-to-human communication include 1) increasing the user's alertness or direct attention to specific stimuli (attentional level); 2) updating the user's understanding and knowledge relating to a robot's performance and functionality (cognitive level); and 3) demanding users make specific manual responses, such as press a button or hand over or take over a part, or spatial actions, such as walking out of a robot's path (behavioral level).

Various aspects of communication system designs influence the user's perceptions and behaviors towards human-robot communication. Indirect, or implicit, robot communication conveys information through legible and predictable trajectories, gestures, and gaze behaviors, while a direct, or explicit, communication uses one or more modalities, such as a visual display or auditory sounds, to present relevant information. This presentation includes current examples for robot-to-human communication designs and empirical studies investigating the effectiveness of various designs for status and intent communication. The presentation also discusses three key considerations for developing and evaluating robot-to-human communication; usage type (e.g., service or industrial), perceived autonomy, and consequences of communication failures. Finally, research needs are addressed in four categories: communication and interface design, user perception and behaviors, influencing factors, and test methods and measures.

Research Section 2: Robotics Safety

Moderator: Robert Radwin, University of Wisconsin-Madison

Considerations for the Integration of People of Automation in Manufacturing Processes

Peregrin Spielholz, The Boeing Company

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Automation in factories around world continues to increase. The equipment and the efficiencies gained have improved the competitiveness of manufacturing. This has led to large changes in work content and shop environments in recent years. Changing levels of automation includes more collaborative robots/automation, mobile robots and networked systems. Introducing automation can have effects on psychosocial demand and control, safety climate, mental workload and vigilance. Future work could focus on more definition of human systems requirements and product specifications to better enable automation development and implementation. Additional development of tools and processes to assess human factors of automated systems would enable effective implementation of future collaborative and hybrid systems.

Human-Robot Collaboration in Manufacturing for Reducing Operator Strain and Enhancing Productivity

Robert Radwin, University of Wisconsin-Madison

Rather than focusing on replicating human capabilities, which is extremely challenging, robotic development should focus on building competences that are complementary to uniquely human capabilities. A deeper understanding of how robots can augment, as opposed to artificially replicate, human cognitive and physical work capabilities, can open new frontiers, for example, performing manual handling tasks while avoiding musculoskeletal injuries, enabling multitasking in cognitively demanding jobs, or expanding employment opportunities for individuals with disabilities or aging. While industrial robots are typically separated from humans in cages due to safety concerns and they work independently of humans, collaborative robots are designed to be safe around humans and work together by limiting their power and speed of movement. In order to eliminate tasks from jobs that are straining to human workers and allocate those tasks to a robot, we used a bi-objective optimization using a mixed-integer linear program to find task-allocation solutions that were Pareto optimal. We showed that some combinations of task assignments yield reduced strain at the cost of longer makespan time, while some combinations yield reductions in makespan time but no improvement in strain, where other combinations yield improvements in both the strain and makespan time. Based on our optimization method, we explored how collaborative robot tasks assignments impact both physical workload and mental workload. We concluded that collaborative robots can be used to help lower human physical stress while increasing productivity, but proper robot task allocation is critical; if done indiscriminately, just because a robot can do a task, it doesn't always improve the job for the operator and in some cases can reduce productivity or increase physical and mental workload rather than improving the job.

Modeling Trust Dynamics in Human-Anatomy Teaming

Jessie Yang,University of Michigan

View slides here.

Trust in automation, or more recently trust in autonomy, has received extensive research attention in the past three decades. The majority of prior literature adopted a “snapshot” view of trust and typically evaluated trust through questionnaires administered at the end of an experiment. This “snapshot” view, however, does not acknowledge that trust is a dynamic variable that can strengthen or decay over time. To fill the research gap, I introduce our recent work in modeling trust dynamics when a human interacts with a robotic agent over time. We develop a personalized trust prediction model and learn its parameters using Bayesian inference. The proposed model adheres to three properties of trust dynamics characterizing human agents’ trust development process de facto and delivers superior prediction performance

Partnership Opportunities

Moderator: Dawn Castillo, National Institute for Occupational Safety and Health (NIOSH)

NIOSH Center for Occupational Robotics Research (NIOSH CORR)

Dawn Castillo

View slides here.

The National Institute for Occupational Safety and Health (NIOSH) is the federal agency charged with conducting research to improve worker safety, health, and well-being. NIOSH established the Center for Occupational Robotics Research (CORR) in 2017 to proactively address worker safety and health implications associated with dramatic advances in robotics technology. This presentation provides a brief background on NIOSH and the CORR, describes partnership opportunities, and provides examples of NIOSH partnerships to advance the safety and health of humans working with and alongside robots.

Robotics Industries Association (IRA)

Carole Franklin

View recording here.

Advanced Robotics for Manufacturing Institute (ARM)

Cara Mazzarini

National Institute of Standards and Technology (NIST)

Jeremy Marvel

The National Institute of Standards and Technology (NIST) is a federal research laboratory focused on supporting industry standards, advancing technology, and improving U.S. competitiveness in the global economy and the quality of life. NIST accomplishes these by developing measurement science (test methods, metrics, and metrological artifacts) to assess and assure accurate and repeatable measures that impact commerce and everyday life. In this presentation, Dr. Jeremy Marvel describes the many different means and mechanisms by which researchers in industry, academia, and government can collaborate with NIST personnel and leverage NIST facilities and equipment. Such opportunities range from formalized industry partnerships such as contracts and SBIR awards, to student internships and post-doctoral research positions. Details of these programs and the means by which interested parties can pursue partnerships are discussed, and links to NIST informational resources and offices are provided.

October 14, 2020

Keynote: Bringing a Human Factors Perspective to Emerging Intelligent Autonomy Technologies

Marc Steinberg, Office of Naval Research

View slides here.

Research Section 3: Simulation and Methods

Moderator: Jeremy Marvel, National Institute of Standards and Technology

Designing Intuitive Interfaces for Human-Robot Collaboration

Bilge Mutlu, University of Wisconsin-Madison

View recording here.

Immersive Interface Metrology for Human-Robot Interface

Shelly Bagchi and Megan Zimmerman, National Institute of Standards and Technology

View slides here.

Research Section 4: Emerging Applications

Moderator: Thenkurussi “Kesh” Kesavadas, University of Illinois at Urbana

Medical Robotics: Challenges and Opportunities

Thenkurussi “Kesh” Kesavadas, University of Illinois at Urbana

View slides here.

Robot assisted surgical systems are fast becoming ubiquitous in operating rooms around the world. From da Vinci™ surgical robot to Mako RIO™ orthopedic robot arm, such new systems are presenting unique challenges to healthcare centers and hospitals, such as – training, outcome assessment and credentialing of professionals. To meet these challenges virtual reality (VR) simulators are emerging as a key solution. This presentation will highlight the challenges and opportunities for the design, development, and implementation of a new robotic systems with focus on simulation and human factors. Simulation framework for recreating the realistic safety hazard scenarios commonly observed in robotic surgical systems, which can be used to prepare surgical trainees for handling safety-critical events during procedures is discussed. We further discuss validation and implementation of such system. Finally, we will explore the future of robotics with the advancements of AI and Machine Learning.

UAS4Safety & Safety4UAS: Unmanned Aerials Systems and Construction Safety

Masoud Gheisari, University of Florida

View slides here.

The Unmanned Aerial System (UAS) has the potential to strongly affect construction and safety performance on the jobsites. UASs can move faster than humans into inaccessible, hard-to-reach, and unsafe areas of jobsites and can be equipped with various types of sensors to transfer valuable data to safety managers and assist with onsite construction and safety monitoring. This presentation will first review a series of our studies on UAS4Safety: how UASs can be used as safety manager assistant drones on the construction jobsites and how such technology and their generated aerial visual contents might affect the current approach of conducting safety planning and monitoring on construction jobsites. We will also review our other studies on Safety4UAS: how UASs can be safely integrated into construction processes and understanding the health and safety implications of having construction crews work collaboratively with UASs on construction jobsites.

Personal Collaborative Robots in Agriculture

Fadi Fathallah, University of California, Davis

View slides here.

California is the nation's leading producer of strawberries. Strawberry harvesting is a very labor-intensive task causing many workers to suffer from musculoskeletal disorders, especially low back disorders (LBDs). The industry needs a means of controlling LBDs, while maintaining acceptable productivity levels. Harvest aids may be detrimental to worker's health due to the current near-continuous picking practice. Deployment speeds and optimal rest breaks are currently being investigated. Low-cost collaborative robots may provide an alternative harvesting approach that integrates worker postural status (stooped posture) and productivity data (instrumented cart) to reduce the risk of LBDs.

Closing Panel Discussion: Challenges and Priorities for Human-Centered Robotics

Moderators: Hongwei Hsiao, NIOSH; Jeremy Marvel, National Institute of Standards and Technology; Robert Radwin, University of Wisconsin-Madison

Challenges and Priorities for Medical Robots

Russell Taylor, Johns Hopkins University

This brief talk discusses insights gathered over nearly thirty years of research on medical robotics, both at IBM and at Johns Hopkins University. The goal of this research has been the creation of a three-way partnership between physicians, technology, and information to improve healthcare. Broadly, the primary application areas include: 1) surgery and interventional medicine; 2) rehabilitation; and 3) nursing, clinical care, and logistics. Key challenges common to all these areas include: 1) capability challenges (technology and devices, human-machine interfaces, information & AI); 2) deployability challenges (systems engineering, verification & validation, manufacturing, training, etc.); and 3) application-specific challenges (regulatory, sterility, disinfection, etc.). One important emerging theme is development of autonomous robotic systems for healthcare applications. Taylor explores this by discussing the use of information and varying levels of autonomy in surgical robots. He also discusses some recent efforts at Johns Hopkins University to develop a teleoperated robot for remotely controlling ventilators in infectious disease environments, in order to greatly reduce the time and PPE consumption required for short routine visits into a contaminated ICU. He discusses the current system prototype and then discuss future directions and opportunities for autonomous robots in clinical care.

Why and How Human-Robot Interaction Breaks Down: Priorities for Creating Human-Center Robotics

Nadine Sarter, University of Michigan

Enabling Robots to Interact Cooperatively and Safely with Humans

Oussama Khatib, Stanford University

View slides here.

Robotics is undergoing a major transformation in scope and dimension with accelerating impact on the economy, production, and culture of our global society. The generations of robots now being developed will increasingly touch people and their lives. They will explore, work, and interact with humans in their homes, workplaces, in new production systems, and in challenging field domains. The emerging robots will provide increased support in domestic, health, manufacturing, and service applications, as well as in agriculture, mining, underwater, hostile environments. Combining the cognitive abilities and experience of the human with the strength, dependability, reach, and endurance of robots will fuel a wide range of new robotic applications. The discussion focuses on design concepts, control architectures, task primitives and strategies that bring human modeling and skill understanding to the development of this new generation of collaborative robots. The work will be illustrated on diverse applications including Ocean One, a bimanual humanoid robotic diver designed to bring intuitive haptic physical interaction to oceanic environments.

Exoskeleton Speakers

Kendra Betz is a Physical Therapist and RESNA credentialed Assistive Technology Professional with an accomplished 25-year career with the Veterans Health Administration. Kendra's areas of clinical specialization include Spinal Cord Injury (SCI) rehabilitation, assistive technology, adaptive sports and patient safety. Kendra holds an adjunct faculty position at the University of Pittsburgh, Department of Rehabilitation Science and Technology, and teaches regularly at national and international forums. Her expertise and contributions are recognized by induction into the National SCI Association Hall of Fame, the Air Force Association's Employee of the Year Award, and the Clinical Excellence Award and Therapy Leadership Council Distinguished Lecture Award from the Academy of SCI Professionals.

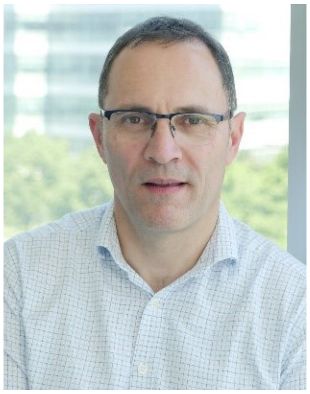
Julie Brazier, CPE is an Ergonomic Technical Specialist at Ford Motor Company. Ms. Brazier received a Bachelor and Masters Degree in Human Kinetics, specializing in Ergonomics from the University of Windsor. Practicing ergonomics at Ford Motor Company for 20 years, she has worked on future model programs, assessing the ergonomic risk of the design for assembly. In 2011, Ms. Brazier moved to the Powertrain Operations Division where she defines global standard ergonomic processes and procedures. Prior to working at Ford, Julie worked at Chrysler as a Plant Ergonomist and Work In Progress as an Ergonomics Consultant.

Dr. William "Bill" Billotte is the Director of Global Exo Technology Programs and the Executive Director of the ASTM Exo Technology Center of Excellence with ASTM International. Formerly, he was a scientist with the National Institute of Standards and Technology (NIST) and the vice chairman of the ASTM F48 Exoskeletons and Exosuits committee. Bill spent the past 17 years providing scientific and technical advice to federal agencies, first responders, and international organizations on topics including exoskeletons, critical infrastructure protection, CBRNE detection, and first responder equipment. His scientific curiosity and passion for helping others has led him to work on a host of diverse projects. Bill advocated and aided the establishment of the ASTM F48 committee and is working on their long-term strategy and research agendas. He spent a year abroad as a visiting scientist on the European Union's critical infrastructure protection team at the Joint Research Centre in Italy, where he provided technical assistance to their working groups to help inform EU policies and international standards. He sponsored a forum through the National Academy of Sciences to convene experts from the federal, private, international, and non-government sectors to exchange information and ideas to improve preparedness and capabilities for disasters that involve accidental or intentional contamination with CBRN agents. He coordinated federal programs that produced over 50 homeland security focused national standards and over 100 reports on first responder equipment. Bill has received several awards including the US Department of Commerce's Gold Medal Award for Heroism. Bill holds a Ph.D. in Biology from the University of Dayton, a Master of Science in Engineering from Wright State University, and a Bachelor of Mechanical Engineering from The Georgia Institute of Technology.

Dr. Bruce Bradtmiller, a physical anthropologist, is the owner and president of ANTHROTECH, a small business engaged in the collection, analysis, and application of human body size data to ergonomics, design, and sizing problems. Since joining the firm in 1983 Dr. Bradtmiller has designed, conducted, and directed a number of military and civilian body size surveys and other anthropometric research projects. His team recently conducted a major anthropometric survey of US Marines Corps and US Army to update its historic ANSUR survey. More than 14,000 uniformed military personnel were measured and scanned with 3D scanners. Following those surveys, his team completed data collection for a smaller US Navy anthropometric survey, but then used the larger Army data set to create a virtual Navy database with many more dimensions. Currently, his team is collecting anthropometric data on the nation's law enforcement officers to better accommodate that population in its vehicular workspace.

Dr. Krystyna Gielo-Perczak is an Associate Professor in Residence in the Biomedical Engineering Department at the University of Connecticut. Her research interests include biomechanical modelling, musculoskeletal system simulation, control theory, and the application of a systems approach to prevent musculoskeletal injuries. By combining these disciplines, she crosses the boundaries of traditional research approaches to improve the design of exoskeletons and robotics. She has authored more than 100 peer-reviewed publications and presentations and serves on the editorial boards of several journals. Dr. Gielo-Perczak served as both chair for 14 years and program co-chair for six years of the Individual Differences in Performance Technical Group of the Human Factors and Ergonomic Society. In these roles, she worked to increase the group's diversity.

Dr. Jason Gillette received a B.S. degree in Engineering Science, an M.E. degree in Engineering Mechanics, and a Ph.D. degree in Biomedical Engineering/Engineering Mechanics from Iowa State University in 1991, 1993, and 1999. From 1999 to 2002, he was a Postdoctoral Scholar with the Center for Biomedical Engineering at the University of Kentucky. He is currently an Associate Professor and the Director of Graduate Education with the Department of Kinesiology at Iowa State University. His research interests include biomechanics, ergonomics, and injury mechanisms. He utilizes video, force, and EMG measurements combined with musculoskeletal modeling to analyze human motion and estimate loading on the human body. Dr. Gillette is a member of the ASTM International F48 Exoskeletons and Exosuits Committee. One of his current projects involves assessing a passive shoulder support exoskeleton in lab-based, manufacturing, and construction settings using EMG and motion analysis to quantify effects on muscle activation and fatigue.



After a career as a classical ergonomist in a consulting firm, **Yonnel Giovanelli** joined the SNCF in 2005. Since 2015, he has been in charge of the Exoskeleton project for the equipment department. His team has developed with Ergosanté Technologie and Cogitobio a multi-assistance passive exoskeleton. He is an Associate lecturer at Reims Champagnes Ardennes Sports University and is beginning a doctorate program about the place of humans in a specific design process with iterative loops based on physical behaviour and Organisational and Human factors.

Professor **Dov Greenbaum**, Interdisciplinary Center Herzliya, Israel, has degrees and postdocs from Yeshiva University, Yale University, the University of California, Berkeley, Stanford University and ETH Zurich. Dov's doctoral research focused on informatics and big data. Dov is a licensed attorney before the State of California and the United States Patent and Trademark Office, and is a Certified Information Privacy Professional. Dov has practiced law as a litigator in Silicon Valley and as a patent prosecutor in Israel, where he worked in the area of exoskeletons, among other areas of technology. Dov teaches various courses at the intersection of law and technology at the Interdisciplinary Center (IDC) Herzliya and directs the Zvi Meitar Institute for Legal Implications of Emerging Technologies. He has a joint appointment at Yale University in Molecular Biophysics and Biochemistry and Singapore Management University in the area of artificial intelligence.

Dr. **Carisa Harris**, PhD, CPE is an Associate Professor in the Department of Medicine at the University of California at San Francisco, is the Director of the UCSF/UC Berkeley Ergonomics Research & Graduate Training Program and the Deputy Director of the Northern California Center of Occupational & Environmental Health. Dr. Harris and her team performs research in a variety of areas focused on understanding and preventing work related injuries and improving human performance, productivity and health. Her team is developing and/or testing a variety of exposure assessment devices (wearables) for primary and secondary prevention purposes and performs various intervention studies on occupational tasks with high risk of musculoskeletal injuries, such as the implementation of passive exoskeletons in construction work.

Kristen Hohl, PT, DPT, NCS currently divides her time as an outpatient physical therapist focusing on treating individuals with neurological diagnoses and working in Dr. Arun Jayaraman’s Max Nader Center for Rehabilitation and Technologies and Outcomes Lab at the Shirley Ryan AbilityLab in Chicago, IL. Kristen received her Bachelor of Science in Biology from Denison University in 2009 and her Doctor of Physical Therapy from University of Pittsburgh in 2012. She earned her APTA Board certification in Neurologic Physical Therapy in 2017. Kristen has established herself as a leading clinician using various technologies, most notably robotic exoskeletons and their implementation into clinical practice. She is certified in the use of over a half dozen lower limb robotic technologies.

Kurt Mudie completed a Bachelor of Sports and Exercise Science (Honours) in 2012, a PhD in Biomechanics in 2017 at Western Sydney University and a two year Postdoctoral research fellowship at Victoria University in 2018. Kurt joined Defence Science and Technology (DST) in 2018 as a Biomechanist and predominantly supports the Assistive Technology and Fight Recorder research programs, working collaboratively between military stakeholders, universities and industry.

William S. Marras holds the Honda Chair in the Department of Integrated Systems Engineering at the Ohio State University and serves as the Director of the Spine Research Institute at the Ohio State University. Dr. Marras holds joint academic appointments in the Department of Orthopaedic Surgery, the Department of Neurosurgery, and the Department of Physical Medicine & Rehabilitation. His research is centered on understanding multidimensional causal pathways for spine disorders through quantitative epidemiologic evaluations, laboratory biomechanical studies, personalized mathematical modeling, and clinical studies of the lumbar and cervical spine. His findings have been published in over 250 peer-reviewed journal articles, hundereds of refereed proceedings, and numerous books and book chapters including a book entitled “The Working Back: A Systems View.” He holds Fellow status in six professional societies including the American Society for the Advancement of Science (AAAS) and has been widely recognized for his contributions through numerous national and international awards including two Volvo Awards for Low Back Pain Research and an honorary Sc.D. degree. Professor Marras has been active in the National Research Council (NRC) having served on over a dozen boards and committees and has served as Chair of the Board on Human Systems Integration for multiple terms. He has also served as Editor-in-Chief of Human Factors and is currently Deputy Editor of Spine and is the past President of the Human Factors and Ergonomics Society (the world’s largest such society). Dr. Marras is an elected member of the National Academy of Engineering (the National Academy of Science, Engineering and Medicine), recorded a TEDx talk entitled “Back Pain and your Brain” and has been featured on NPR’s All Things Considered.

Meghan O'Donovan is a Biomechanics Research Engineer and Principal Investigator at the Center for Military Biomechanics at the US Army Soldier Center. Her research experience includes both fundamental research topics such as military biomechanics, load carriage, marksmanship mechanics, and Soldier physical performance, as well as more applied areas including military equipment testing, in-field assessments, and military exoskeleton evaluations. She has been with the Soldier Center for 10 years and previously presented this work at the International Congress on Soldier Physical Performance in Quebec.

Joseph Parham is a Research Anthropologist at the US Army Soldier Center, where his research focuses on physical accommodation, design, modeling, and analysis of anthropometric data. He served as the Field Supervisor for the 2010-2012 US Army Anthropometric Survey and has worked in extensively in developing military and industrial standards concerned with Human Systems Integration. Prior to joining the Soldier Center, Joe worked as an Operations Research Analyst for the US Army Materiel Systems Analysis Activity and spent over two years deployed in Iraq and Afghanistan.

Ryan Porto is a Technical Specialist in Ergonomics at General Motors. Mr. Porto received a Bachelor of Human Kinetics and a Masters in Human Performance from the University of Windsor. For the past 13 years, he has worked with design and manufacturing engineering, managing new program launches in all sectors of the industry including Vehicle, Powertrain and Advanced Propulsion. Ryan leads the advancement of virtual human simulation in product and manufacturing for GM’s Global Ergonomics program. He also provides technical support to the development and implementation of evolving wearable technologies. Ryan is a member of the Ergonomic task force at the United States Council for Automotive Research (USCAR) and a member of the Automotive Exoskeleton Group (AExG), sponsored via the Wearable Robotics Association.

Kevin Purcell is an Ergonomist with the US Army Public Health Center (PHC). He holds a Master’s degree in Human Factors and Ergonomics from San Jose State University, completing his thesis work at NASA Ames Research Center on human-machine interfaces. He also holds a Project Management Professional certification, and is currently project lead for ASTM’s F48.02 Exoskeletons and Exosuits - Usefulness and Usability work group.

Current projects for the Army PHC include field work exoskeletons in industrial environments, as well as work on Health Hazard Assessments, and Army industrial ergonomic risk mitigation projects.

Dr. Donald R. Peterson is a tenured Professor of Mechanical Engineering and the Dean of the College of Engineering and Engineering Technology at Northern Illinois University. He is also a joint professor in the Department of Biomedical Engineering at Texas A&M University and a Fellow of the American Institute for Medical and Biological Engineering (AIMBE). Dr. Peterson is a graduate of Worcester Polytechnic Institute, earning degrees in Aerospace Engineering (BS) and Biomechanical Engineering (BS) and a graduate of the University of Connecticut, earning degrees in Mechanical Engineering (MS) and Biomedical Engineering (PhD). Dr. Peterson has over 25 years of experience in biomechanical engineering and medical research, which has been focused on measuring and modeling injury biomechanics and human, organ, and/or cell performance, including exposures to various physical stimuli and the subsequent biological responses. His research has involved the investigation of injury mechanisms and human–device interaction and has led to the generation of new technologies and systems, such as personal protection technologies, occupational exoskeleton systems, robotic assist devices for hemiplegic rehabilitation, long-duration biosensor monitoring and reporting systems, novel surgical and dental devices and instruments, smart medical devices for home patient care, and biotechnology systems. Some of Dr. Peterson's research has been focused on hand-arm vibration exposures from tool use and he serves as a US delegate on the International Standards Organization Technical Committee (ISO/TC) 108/SC4 on Human Exposure to Mechanical Vibration and Shock. Based on his research and development work on exoskeleton technologies, he is currently serving as the Chair of the ASTM Committee F48 on Exoskeletons and Exosuits. Dr. Peterson has published over 115 peer-reviewed scholarly works and is the Editor-in-Chief for “The Biomedical Engineering Handbook”, published by CRC Press.

Dr. Christopher Reid is a Human Factors & Ergonomics Associate Technical Fellow for Boeing’s Environment Health & Safety (EHS) Organization in Charleston, SC. He is a recent Visiting Scholar to the Ohio State University's Spine Research Institute, partnering with Director Dr. William S. Marras on the safety of exoskeletons for Boeing workers. He is a graduate of the University of Central Florida, earning degrees in Electrical Engineering Technology (BS) and Industrial Engineering (MS, PhD). Prior to Boeing, Dr. Reid worked for Lockheed Martin on astronaut spacesuit assessment as a Human Factors & Ergonomics Discipline Lead at NASA Johnson Space Center and as a Human Factors Engineer for the US Army Natick Soldier Systems Center assessing Warfighter personal protective equipment. Outside of work, Dr. Reid is the Secretary Treasurer of the Human Factors & Ergonomics Society (HFES), Associate Editor for the Theoretical Issues in Ergonomics Sciences Journal, Special Issue Editor for the Human Factors Journal, Chair of the Annual ErgoX Exoskeleton Symposium, and Chair of the Human Factors & Ergonomics Subcommittee for the ASTM F48 standard on Exoskeletons/Exosuits. In 2018, his collective work on Boeing industrial exoskeletons earned him a Rising Star Award from the National Safety Council.

Dr. Samuel Reimer is responsible of the global business development and product management of Ottobock's exoskeleton portfolio, Paexo. He joined Ottobock in the Summer of 2019 after several years in management consulting at the Boston Consulting Group. There he focused on mergers and acquisitions, transformations and pricing strategies for the healthcare and medical device practice areas. He lives in Hamburg, Germany, holds a degree in Biomedical Engineering from Imperial College London and UC Davis and a PhD in biomechanics and robotics from the Technical University of Munich, Germany.

Bob Scheidt earned MS and PhD degrees from Northwestern University in Biomedical Engineering under the supervision of Prof. Andrew Kertesz and Zev Rymer. His dissertation focused on the effects of mechanical and visual constraints on sensorimotor adaptation during reaching. In his post-doc, he worked on time series modeling of motor adaptation with Sandro Mussa-Ivaldi at the Rehabilitation Institute of Chicago. Before taking a faculty position at Marquette University in 2000, Dr. Scheidt served as systems engineer at Baxter Healthcare and as a Senior Research Scientist at Medical Research Labs, Inc. Dr. Scheidt is currently serving a 4-year term with the National Science Foundation as a Program Director for the Mind, Machine and Motor Nexus (M3X) program, the Future of Work and the Human-Technology Frontier (FW-HTF), and the National Robotics Initiative (NRI 2.0). Dr. Scheidt founded and co-directs the Neuromotor Control Laboratory at Marquette University, which uses robotic tools and simple virtual reality systems to probe how the human nervous system uses sensory information to optimize movements and interactions with the physical environment. Their work seeks to acquire knowledge needed to develop technologies, training strategies and therapeutic interventions for facilitating motor learning in healthy individuals and for promoting rehabilitation in patients with neuromotor injury or neurodevelopmental disorders.

Johan Sleman (Senior Assessment Consultant at Bioservo) is a licensed Physical Therapist with a degree from Saxion University of Applied Science, in Enschede, The Netherlands. His clinical experience is within the field of Sports Physical Therapy. He has vast experience with exoskeleton implementation and has worked in collaborative projects with global companies such as General Motors, General Electrics and Toyota.

Dr. Divya Srinivasan is an Assistant Professor in the Industrial & Systems Engineering Department at Virginia Tech. With a background in motor control and biomechanics, she obtained a PhD in Biomedical Engineering from the University of Michigan Ann Arbor. Her research focuses on assessments and improvement of human health and performance in occupational settings. She is currently leading/co-leading several federally-funded as well as industry-sponsored research projects, investigating the effectiveness of industrial exoskeletons for tasks in multiple industrial sectors. Notable among these is a new NSF project funded in 2017 by the Future of Work at the Human Technology Frontier program. In this project, VT partners with Sarcos Robotics, towards the design and evaluation of powered whole-body exoskeletons. The focus of this project is threefold: (1) To holistically quantify operator demands for operating complex powered exoskeletons, including both physical and cognitive control costs; and with special considerations to diverse user-characteristics and learning. (2) To understand whether exoskeleton assistance can be adaptively controlled, specific to user state and task intent. (3) To develop AR-based perception augmentation, to improve human awareness of exoskeleton state and enhanced situational awareness in industrial environments.

Leia Stirling is an Associate Professor in Industrial and Operations Engineering at the University of Michigan. Her research quantifies human performance and human-machine fluency to assess performance augmentation, advance exoskeleton control algorithms, mitigate injury risk, and provide relevant feedback to subject matter experts across domains. She received her B.S. (2003) and M.S. (2005) in Aeronautical and Astronautical Engineering from the University of Illinois at Urbana-Champaign, and her Ph.D. (2008) in Aeronautics and Astronautics from MIT. She was a postdoctoral researcher at Boston Children's Hospital and Harvard Medical School (2008-2009), on the Advanced Technology Team at the Wyss Institute for Biologically Inspired Engineering (2009-2012), then an Assistant Professor at MIT (2013 – 2019). She joined the faculty at the University of Michigan in 2019.

Candy Tefertiller, PT, DPT, PhD, NCS is the Director of Physical Therapy at Craig Hospital. Candy received a B.S in Biology from Mount Olive College and a Master's in Physical Therapy from East Carolina University. She then completed a Doctorate of Physical Therapy degree from Rocky Mountain Health Care University and received a PhD in Clinical Sciences from the University of Colorado. Candy has been working in the field of neurological rehabilitation since 2000 and is also a certified neurological clinical specialist. She has been involved in numerous research projects and has focused much of her career on interventions, program development and research promoting recovery after neurologic injury. Candy is a member of the American Physical Therapy Association and the Neurology Section.

Conor Walsh is the Paul A. Maeder Professor of Engineering and Applied Sciences at the John A. Paulson Harvard School of Engineering and Applied Sciences. He is the is the founder of the Harvard Biodesign Lab, which brings together researchers from the engineering, industrial design, apparel, clinical and business communities to develop new disruptive robotic technologies for augmenting and restoring human performance. Example application areas include, enhancing the mobility of healthy individuals, restoring the mobility of patients with gait deficits, assisting those with upper extremity weakness to perform activities of daily living and preventing injuries of workers performing physically strenuous tasks. His multidisciplinary research spans engineering, biology and medicine and has led to multiple high impact scientific papers. Multiple technologies from the lab have been translated to products including the ReStore soft exosuit from ReWalk Robotics and back support soft exosuit from Verve Inc. He is the winner of multiple awards including the Presidential Early Career Award for Scientists and Engineers and the MIT Technology Review Innovator Under 35 Award.

Mark H. Weir has a BS and Ph.D. in Environmental Engineer focusing on water and wastewater systems design and complex systems modeling focused on bioaerosol modeling for bioterror agents, respectively. He is a boundary scientist conducting research at the convergence of engineering, healthcare, and environmental controls using the within the general framework of quantitative risk analysis. The methodology he is developing considers the world as a complex system of systems. Therefore, he researches how to consider the complex system of how a pathogen survives in the environment and infects a person are link and can be controlled. As such he has modeled pathogen survival, environmental transmission, and infection risks for a wide spectrum of pathogens, in all environmental matrices and modes of transmission. As an Assistant Professor in the Sustainability Institute and the College of Public Health at Ohio State University has continued this research program. At the outset of the COVID-19 pandemic, he has been assisting with the State of Ohio’s response, firefighter equipment safety and cleaning plans, mass transportation decontamination, OH Department of Rehabilitation and Corrections decision making, statewide and on-campus wastewater monitoring and OSU campus reopening safety planning among other response actions.

Cathy White is a Global EH&S Project Leader at Dow. She earned a Bachelor of Science degree and a Master of Science degree in Industrial and Operations Engineering from the University of Michigan. Cathy is a Certified Professional Ergonomist, Certified Safety Professional, and Certified Industrial Hygienist. She has spent the last twenty years working in various positions in engineering, industrial hygiene, and personal safety. She currently is leading innovation projects in EHS mobility solutions to achieve breakthroughs in EHS performance at Dow. Cathy is the former chair of the AIHA Ergonomics Committee and a member of the ASTM Training Task Group of the ASTM F48 Exoskeleton and Exosuit Committee.

Ben Wolff serves as the Chairman, CEO and is the largest shareholder of Sarcos Robotics. In this role, he oversees the strategic direction of the company and engages with the company's partners, customers and investors.

Prior to joining Sarcos, Wolff served as Chief Executive Officer, President and Chairman at Pendrell Corporation from 2009 to 2014. In 2003, Wolff co-founded Clearwire Corporation, where he served as President, CEO and Co-Chairman. Clearwire was sold to Sprint in 2013 for more than $14 billion. Wolff has also served as President of Eagle River Investments, an investment fund focused on telecom and technology investments.

Wolff previously served as a Director of the Cellular Telecommunications Industry Association (CTIA) and is currently a member of the Board of Visitors of Northwestern School of Law at Lewis & Clark College in Portland, Oregon.

Wolff earned his law degree from Northwestern School of Law, Lewis & Clark College in Portland, Oregon in 1994, and his Bachelor of Science degree from California Polytechnic State University in 1991.

Robotics Speakers

Shelly Bagchi is an Electrical Engineer at the National Institute of Standards and Technology in Gaithersburg, Maryland. She received her Masters in Electrical Engineering from the Georgia Institute of Technology in 2015, and her Bachelors in Computer Engineering from the George Washington University in 2013. Her research interests are in human-robot interaction, situational awareness, and augmented reality. She previously co-taught the introductory Artificial Intelligence class in Georgia Tech's Online Masters in Computer Science program, a program which has enrolled over 10,000 students. She participates in the ASTM Standards Committee E57 on 3D Imaging Systems and the IEEE Study Group on Metrology for Human-Robot Interaction. Shelly also serves as an organizer for the 'Test Methods and Metrics for HRI' Workshop, which occurs annually at the ACM/IEEE International Conference on Human-Robot Interaction, as well as the 'Artificial Intelligence for Human-Robot Interaction' Symposium, part of the annual AAAI Fall Symposium Series.

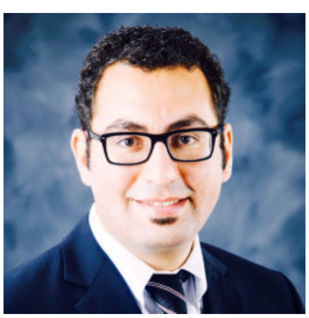
Jordan M. Berg serves as a Program Officer in the Engineering Directorate of the US National Science Foundation. His research interests include nonlinear and geometric control, soft robotics, human-machine systems, and the modeling, simulation, design, and control of nano- and micro-systems. He received the BSE and MSE in Mechanical and Aerospace Engineering from Princeton University in 1981 and 1984, and the PhD in Mechanical Engineering and Mechanics and the MS in Mathematics and Computer Science from Drexel University in 1992. In 1996 he joined the faculty of the Mechanical Engineering Department of Texas Tech University, where he remained until 2018. He began at NSF as a rotator in 2014, and returned as a permanent employee in 2018. At NSF he co-directs the Dynamics, Control, and Systems Diagnostics program in the Division of Civil, Mechanical, and Manufacturing Innovation, and has served on several cross-cutting programs, including the Future of Work at the Human-Technology Frontier: Core Research, Foundational Research in Robotics, EFRI Continuum, Compliant, and Configurable Soft Robotics Engineering, National Robotics Initiative 2.0, Cyber Physical Systems, and the National Artificial Intelligence Research Institutes. He is a Fellow of ASME.

Dawn Castillo is the Director of the Division of Safety Research at the National Institute for Occupational Safety and Health (NIOSH). She is also the NIOSH manager for the Center for Occupational Robotics Research, the Center for Motor Vehicle Safety, and the Traumatic Injury Prevention Program. She is an injury epidemiologist and has authored numerous articles, book chapters, and technical documents on a variety of occupational injury topics, including occupational injuries among young workers, older workers, fire fighters, and workplace violence. Ms. Castillo received her Master of Public Health in epidemiology from the University of California, Los Angeles.

Dr. HeeSun Choi is an assistant professor in the Department of Psychological Sciences at Texas Tech University. Her research interests are in safety issues related to attentional impairment and cognitive declines, with a particular focus on the older adult and industry worker populations. Her current research projects include perceived risks and safety behaviors involving collaborative robots and cognitive impacts of virtual reality and robotics technologies. Dr. Choi received her MS and PhD in Human Factors and Applied Cognition from North Carolina State University. Prior to joining Texas Tech, she worked for the National Institute for Occupational Safety and Health (NIOSH) as a research fellow in the Division of Safety Research and the Center for Robotics Research.

Fadi Fathallah is a Professor in the Department of Biological and Agricultural Engineering at the University of California, Davis. Dr. Fathallah has over 30 years of experience conducting studies on workers in various industries, including farmworkers in the past two decades. He directs the University of California Agricultural Ergonomics Research Center and its Occupational Biomechanics Laboratory, and is Associate Director of the NIOSH-supported Western Center for Agricultural Health and Safety. His research focuses on development and evaluation of interventions to help reduce musculoskeletal disorders among farmworkers. Dr. Fathallah also directs the USDA California AgrAbility Program, which provides assistance to disable California farmers, farmworkers, and their families. Dr, Fathallah has served on the Board of Directors of the Board of Certification in Professional Ergonomics (BCPE) (2013-2019), and is Editor of the Journal of Agricultural Safety and Health. Prior to joining UC Davis in 1999, he was a Senior Research Associate at the Liberty Mutual Research Center for Safety and Health in Hopkinton, Massachusetts. He received a BS from Texas Tech University in Industrial Engineering in 1986, an MS from Virginia Tech in Industrial Engineering and Operations Research (Human Factors Engineering track) in 1988, and a PhD from Ohio State University in Industrial Systems Engineering (Ergonomics and Occupational Biomechanics track) in 1995.

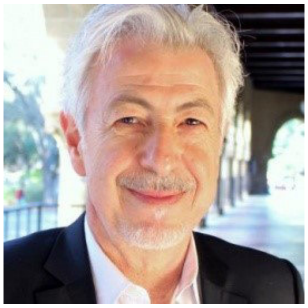
Carole Franklin is the Director of Standards Development for the Robotic Industries Association (RIA). She leads RIA's standards development activities in developing the ANSI and ISO Robot Safety Standards. Before joining RIA, Carole spent over four years with management consulting firm Booz Allen Hamilton, where she led projects on business process improvement, internal communications, and executive communications. Prior to Booz Allen, Carole worked for Ford Motor Company for ten years in the market research department, where she led consumer research projects and tracking studies, providing engineers with crucial customer input to help prioritize design attributes and product quality improvement efforts. Her career has been spent translating the needs of end-users into actionable guidance for engineers and leaders – and vice versa. Carole holds BA and MBA degrees from the University of Michigan.



Masoud Gheisari is an Assistant Professor in the Rinker School of Construction Management at the University of Florida (UF). He received his Ph.D. in Building Construction from Georgia Tech and is currently leading the Human-Centered Technology in Construction (HCTC) research group at UF. He has worked and published extensively in the fields of Virtual and Augmented Reality (VR/AR) and human-Robot/UAV interaction within the construction domain. His research has been supported by various funding organizations such as the National Science Foundation (NSF), U.S. Department of Labor, Center for Construction Research and Training (CPWR), and ELECTRI International. Dr. Gheisari is serving on the American Society of Mechanical Engineers (ASME) B30.32 Safety subcommittee to prepare the first standard on UAS uses in inspection, testing, maintenance, and material-lifting operations.

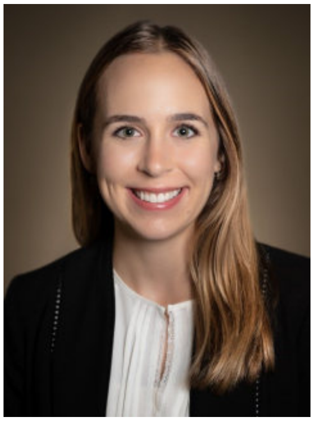
Dr. Hongwei Hsiao serves as Chief of the Protective Technology Branch and Coordinator for the Center for Occupational Robotics Research at the National Institute for Occupational Safety and Health (NIOSH). He received his degrees from Cornell University and the University of Michigan and has held engineering and management positions in both the manufacturing industry and the U.S. Government. He also has taught human factors engineering in academia. Dr. Hsiao has headed numerous programs and projects in safety research. He also coordinates development of strategic goals for the NIOSH robotics center and manages center resources and seminars. The Center addresses worker safety and integration with caged robots, collaborative robots, mobile robots, exoskeletons, autonomous equipment, drones, and artificial intelligence. His research covers human-robot interface, statistics and big data, anthropometry and biometrics, biomedical engineering, construction safety, and health protection. He manages several laboratories for NIOSH, including the Virtual Reality, Anthropometry Research, High Bay, Vehicle Safety, Digital Modeling, Human Factors, Robotics Research, and Sensor Development Laboratories. An editorial board member for eight scientific journals, Dr. Hsiao has written or contributed over 170 publications and patents in human factors and engineering innovation for injury control. He was credentialed as a Silvio O. Conte Senior Biomedical Research Service Fellow by the Government Executive Resources Board in 2003.

Thenkurussi "Kesh" Kesavadas, PhD is the founder Director of the Health Care Engineering Systems Center at the University of Illinois at Urbana-Champaign. He is a professor of Industrial and Enterprise Systems Engineering, and holds faculty appointments in the Department of Computer Science, the Department of Electrical and Computer Engineering and with the Carle-Illinois College of Medicine at the university. His current research focuses on medical robotics and virtual reality for medicine. Kesavadas has widely published in the areas of medical robotics, VR, medical simulation and manufacturing. He is also an inventor of products that were successfully commercialized. In 2008, Kesavadas developed the world's first stand-alone virtual reality Robotic Surgical Simulator called RoSS™ that is used around the world to train residents and medical students. This invention led to forming Simulated Surgical Systems to commercialize RoSS™. Before joining Illinois, Kesavadas was a professor in the Department of Mechanical and Aerospace Engineering at the State University of New York at Buffalo (NY) where, in 1996, he founded one of the first Virtual Reality labs in the US. Kesavadas received his Ph.D. from the Pennsylvania State University, an M.S. from Indian Institute of Technology, Madras, and a bachelor's degree from the University of Calicut.



Oussama Khatib received his Doctorate degree in Electrical Engineering from Sup'Aero, Toulouse, France, in 1980. He is Professor of Computer Science at Stanford University. His work on advanced robotics focuses on methodologies and technologies in human-centered robotics including humanoid control architectures, human motion synthesis, interactive dynamic simulation, haptics, and human-friendly robot design. He is Co-Editor of the Springer Tracts in Advanced Robotics series, and has served on the Editorial Boards of several journals as well as the Chair or Co-Chair of numerous international conferences. He co-edited the Springer Handbook of Robotics, which received the PROSE Award. He is a Fellow of IEEE and is a member of the National Academy of Engineering. He is the President of the International Foundation of Robotics Research (IFRR). Professor Khatib is a recipient of the Japan Robot Association (JARA) Award in Research and Development. In 2010 he received the IEEE RAS Pioneer Award in Robotics and Automation for his fundamental pioneering contributions in robotics research, visionary leadership, and life-long commitment to the field. Professor Khatib received the 2013 IEEE RAS Distinguished Service Award in recognition of his vision and leadership for the Robotics and Automation Society, in establishing and sustaining conferences in robotics and related areas, publishing influential monographs and handbooks and training and mentoring the next generation of leaders in robotics education and research. In 2014, Professor Khatib received the 2014 IEEE RAS George Saridis Leadership Award in Robotics and Automation.

Jeremy A. Marvel is a research scientist and project leader at the U.S. National Institute of Standards and Technology (NIST) in Gaithersburg, MD. Dr. Marvel received the bachelor's degree in computer science from Boston University, Boston, MA, the master's degree in computer science from Brandeis University, Waltham, MA, and the Ph.D. degree in computer engineering from Case Western Reserve University, Cleveland, OH. Prior to NIST, Dr. Marvel was a research scientist at the Institute for Research in Engineering and Applied Physics at the University of Maryland, College Park, MD. He joined the Intelligent Systems Division at NIST in 2012, and has over sixteen years of robotics research experience in industry, academia, and government. His research interests include intelligent and adaptive solutions for robot applications, with particular attention paid to human-robot and robot-robot collaborations, multirobot coordination, industrial robot safety, machine learning, perception, and automated parameter optimization. Dr. Marvel currently leads a team of scientists and engineers in metrology efforts at NIST toward the performance evaluation of human-robot teams, and developing tools to enable small and medium-sized enterprises to effectively deploy robot solutions.



Cara Mazzarini is the Technology Portfolio Manager for Advanced Robotics for Manufacturing (ARM). Cara develops, curates, and maximizes the value of ARM's portfolio of innovative technologies. Cara advises organizational investment decisions, provides data for decision-making, prioritizes team and resource allocation, and manages aggregate risk of the projects across the portfolio. Through this work, Cara helps to fulfill ARM's mission of increasing U.S. global competitiveness by accelerating innovative technologies and workforce programs that make robots more accessible to U.S. manufacturers. Prior to joining ARM, Cara worked as a Program Manager for NAVSEA, the civilian engineering Command for the US Navy. Cara established and managed a cybersecurity program for Aircraft Carrier mechanical and electrical industrial controls systems. She led the strategic planning, budgeting, and oversight of projects to secure these internet of things (IoT) ship systems from digital attacks. Cara is a graduate of Villanova University with a bachelor's degree in Mechanical Engineering and a certificate in Cybersecurity from the Naval Postgraduate School.

Ranjana Mehta is an Associate Professor in the Department of Industrial and Systems Engineering at Texas A&M University. She is also a graduate faculty with the Texas A&M Institute for Neuroscience at Texas A&M University, director of the NeuroErgonomics Laboratory, co-director of the Texas A&M Ergonomics Center, and a faculty fellow with the Center for Population Health and Aging and the Center for Remote Health Technologies and Systems. She received her MS and PhD from Virginia Tech, MEng from University at Buffalo, and BE from Mumbai University. She examines the mind-motor-machine nexus to understand, quantify, and predict human performance when interacting with emerging technologies (unmanned, collaborative, and wearable systems) in safety-critical extreme environments (e.g., emergency response, oil and gas). Applied research and technology development efforts in her lab focus augmenting, and supporting embodied cognition through equitable multimodal interface designs, wearable technologies, fluent and trustworthy human-robotic interactions, and brain-computer interfaces.

Bilge Mutlu is an associate professor of computer science, psychology (affiliate), and industrial engineering (affiliate) at the University of Wisconsin–Madison where he directs the Human-Computer Interaction Laboratory and co-directs the Collaborative Robotics Laboratory. His research program focuses on building human-centered methods and principles to enable the design of robotic technologies and their successful integration into the human environment. He teaches the undergraduate and graduate curriculum in human-computer interaction on the UW–Madison campus. Dr. Mutlu has an interdisciplinary background that combines design, computer science, and social and cognitive psychology and a PhD in Human-Computer Interaction from Carnegie Mellon University. He is a former Fulbright fellow and recipient of the NSF CAREER award. His research has received 17 best paper awards and nominations and recognition in international press including the Economist, New Scientist, and Discovery News.

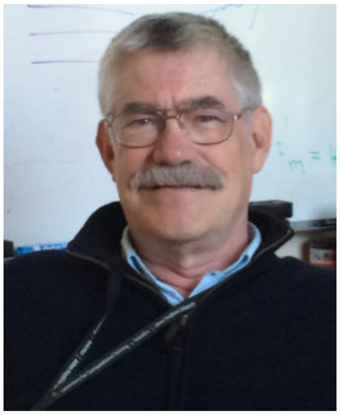
Chang S. (CS) Nam is a Professor of Industrial and Systems Engineering at North Carolina State University. He is also an affiliated faculty in the UNC/NCSU Joint Department of Biomedical Engineering as well as the Department of Psychology. Nam teaches and conducts basic and applied research in human factors and ergonomics engineering to advance the science of Human-Computer Interaction (HCI), including brain-computer interfaces, social cognitive and affective neuroscience, computational neuroscience, human-centered AI, and neural correlates of trust in human-robot interaction. His research has been supported by the National Science Foundation (NSF), Air Force Research Laboratory (AFRL), Air Force Office of Scientific Research (AFOSR), and the Laboratory for Analytic Sciences (LAS), UNC/NCSU Rehabilitation Engineering Center (REC). He has received the NSF CAREER Award (2010), Outstanding Researcher Award (2010-2011), and Best Teacher Award (2010-2011). He is a recipient of the 2018 US Air Force Summer Faculty Fellowship Program (AFSFFP) Award and the 2019 Leland S. Kollmorgen Spirit of Innovation Award from the HFES Augmented Cognition TG. Dr. He is the main editor (with Drs. Nijholt and Lotte) of Brain-Computer Interfaces Handbook: Technological and Theoretical Advances (CRC Press) and "Neuroergonomics: Principles and Practices (Springer). Currently, Nam serves as the Editor-in-Chief of the journal Brain-Computer Interfaces.

Professor Robert Radwin is the Duane H. and Dorothy M. Blumke Professor in industrial and systems engineering and biomedical engineering at the University of Wisconsin-Madison. He investigates new ways to measure and quantify physical stress in the workplace, utilizing signal processing, computer vision and machine learning. His expertise is sought after as a consultant to industry and government for ergonomics in manufacturing and product design. Professor Radwin has received numerous awards as an innovator and researcher, is a fellow of five professional societies, has served on prestigious national committees, and is the reviews track editor for the journal Human Factors and associate editor for the journal IISE Transactions on Occupational Ergonomics and Human Factors. He is founding chair of the University of Wisconsin-Madison Department of Biomedical Engineering and is a Discovery Fellow at the Wisconsin Institute for Discovery.

Dr. Nadine Sarter is the Richard W. Pew Collegiate Professor in Industrial and Operations Engineering and serves as the Director of the Center for Ergonomics at the University of Michigan, Ann Arbor, MI. She teaches courses in cognitive ergonomics and organizational safety. Her main research interests include human-automation/robot interaction, the design of tactile and multimodal interfaces, human error/error management, attention/interruption management, and the design of decision support systems. Her research is conducted in application domains such as aviation, military operations, and the modern car cockpit. Professor Sarter serves as Associate Editor for the Human Factors journal and is a member of the National Academy of Engineering.

Peregrin Spielholz is currently the Senior Manager for Commercial Product Development in EHS Engineering at Boeing. He has over 25 years of experience working in the fields of safety and ergonomics. Peregrin received his Bachelor and Master degrees in Industrial Engineering from the University of Michigan, and his PhD from the University of Washington in Occupational Health Sciences. He is a Certified Professional Ergonomist and Certified Safety Professional. Peregrin has over 50 peer-reviewed publications and is an affiliate assistant professor at the University of Washington.

Marc Steinberg has been the Science of Autonomy Program Officer at the Office of Naval Research (ONR) from the creation of that program in 2009, and is now also a member of the team that manages the Science of Artificial Intelligence program. His program focuses on highly multi-disciplinary research to develop the foundations of these areas in terms of rigorous mathematical methods, general scientific principles, new experimental paradigms, and theory-based tools to facilitate adoption such as for verification and validation, safety, and robustness. Some of the types of fields that are involved include dynamics and control theory, planning, optimization, machine learning, information theory, game theory, physics, human factors, and related fields such as biology, oceanography, cognitive science, psychology, and neuroscience. Prior to coming to ONR, he worked in multiple positions within the naval laboratory system for 20 years, and reached the level of technical fellow. As a laboratory researcher, he worked on basic and applied research projects exploring neural network and knowledge-based forms of artificial intelligence, autonomous control, vehicle management systems, prognostics and health management, aviation safety, and robust, adaptive, nonlinear, and reconfigurable control. He has authored or co-authored papers across this range of subjects, and received numerous professional society awards for his contributions including the Derek George Astridge Award for Contribution to Aerospace Safety (British Institution of Mechanical Engineers), the Dr. George Rappaport Best Paper Award (IEEE), the 2nd Best Paper of Conference Award for AIAA Guidance, Navigation, and Control Conference, and has twice-won Pathfinder Best Paper awards for AUVSI Unmanned Systems North America. In 2014, he received the Navy Meritorious Service Award for his contributions. He has B.S. and M.S degrees in Mechanical Engineering from Lehigh University and a second M.S. degree in Industrial and Human Factors Engineering.



Russell H. Taylor received his Ph.D. in Computer Science from Stanford in 1976. After spending 1976 to 1995 as a Research Staff Member and research manager at IBM Research, he moved to Johns Hopkins University, where he is the John C. Malone Professor of Computer Science with joint appointments in Mechanical Engineering, Radiology, and Surgery and is also Director of the Laboratory for Computational Sensing and Robotics (LCSR) and of the (graduated) NSF Engineering Research Center for Computer-Integrated Surgical Systems and Technology (CISST ERC). His research interests include medical robotics and computer-integrated interventional medicine. He is a Member of the National Academy of Engineering, a Fellow of the IEEE, of the AIMBE, of the MICCAI Society, of the National Academy of Inventors, and of the Engineering School of the University of Tokyo. He has also received numerous awards, including the Maurice Mueller Award, the IEEE Robotics Pioneer Award, the IEEE EMBS Technical Field Award, and the Honda Prize.

Dr. Jessie Yang is an Assistant Professor in the Department of Industrial and Operations Engineering at the University of Michigan. She also has a courtesy appointment at the School of Information and is an affiliated faculty at Michigan Robotics. Dr. Yang received her B.Eng. in Electrical and Electronic Engineering, and her M.Eng, and Ph.D. in Mechanical and Aerospace Engineering (Human Factors), all from Nanyang Technological University, Singapore. Dr. Yang's main research interest lies in human-agent interaction in safety-critical domains including transportation, healthcare, and defense. Her research has been sponsored by the Army Research Lab, AAA Foundation for Traffic Safety, Toyota Research Institute and Mcity.

Megan Zimmerman is a research scientist at the National Institute of Standards and Technology (NIST). Megan joined NIST in 2016 and has been active within the human-robot-interface (HRI) community since then. Megan's primary fields of expertise include human robot interaction and alternative robot control interfaces, including Virtual Reality and Tangible User Interfaces. Megan is currently leading efforts at NIST to generate public datasets for human-human and human-robot teaming.