Centers for Disease Control and Prevention

NIOSH Science Blog

Exoskeletons: Potential for Preventing Work-related Musculoskeletal Injuries and Disorders in Construction Workplaces

February 3, 2022 by Sang D. Choi, PhD, MPH(c), MS, CSP, CPE; Douglas Trout, MD, MHS; Scott Earnest, PhD, PE, CSP; and CDR Elizabeth Garza, MPH, CPH

Construction workers are at high risk for work-related musculoskeletal disorders (WMSDs). One potential tool to prevent WMSDs is the use of exoskeletons, which are assistive devices that can be suitable for construction and other industrial work (see related NIOSH pages on robotics and the Center for Occupational Robotics Research). Exoskeletons can be categorized as passive or active. Passive exoskeletons support a posture or movement using unpowered mechanisms (e.g., springs, dampers, or counterbalance forces), whereas active exoskeletons involve powered force/torque generating elements (e.g., electric motors, pneumatics, or hydraulics). Presently, passive exoskeletons are typically predominant in the commercial market and in the industrial developments (Zhu et al., 2021). Exoskeletons can play a role similar to personal protective equipment in situations where fixed engineering controls are not possible. The last several years have seen continued and increasing interest in the use of wearable exoskeletons in the prevention of WMSDs in construction workplaces because of cost, portability, and potential effectiveness. This blog provides: (1) summaries of recent research on exoskeletons used in construction, organized by function/body part associated with job task specifics; and (2) an up-to-date discussion of the benefits and challenges of exoskeleton use in the construction trades with focus on prevention of WMSDs.

Background

Workers in the construction industry are known to have increased rates of WMSDs, conditions involving the soft tissues of the body (including muscles, tendons, nerves, cartilage, and other supporting structures) that can be caused or exacerbated by sudden or sustained exposure to repetitive motion, force, vibration, and awkward positions during work.

The economic burden of construction industry workers compensation costs brought on by WMSDs in the United States has been estimated to be more than $2 billion annually (Liberty Mutual 2021). A survey study by Choi et al. (2007) of commercial construction contractors found that sprains/strains and back injuries due to heavy manual material handling activities were the most common type of injury and illness, accounting for approximately 65 percent of all cases. An analysis of data from the National Health Interview Survey (Luckhaupt 2019) highlighted the need to prevent work-related low back pain – a condition affecting almost 40 million U.S. workers. This analysis showed that workers in construction occupations are more likely to experience low back pain than those in other occupations, and workers 45-64 years old have more pain than their younger counterparts. A recent study in the Center for Disease Control and Prevention's Morbidity and Mortality Weekly Report (Kaur 2021) examined the rate and cost of WMSD claims from overexertion among Ohio construction workers during 2007–2017 and found that WMSD claims from overexertion were highest among workers aged 35–44 years; however, the average claim was higher and resulted in more days away from work among workers aged 45–54 years and 55–64 years.

Actions to Reduce WMSDs in Construction Workers

Extensive information is available providing ergonomic solutions that reduce overexertion and other risk factors for WMSDs in construction (NIOSH 2006, CPWR 2021). NIOSH's Simple Solutions Ergonomics for Construction Workers provides examples of trade-specific simple solutions/best practices. Choi et al. (2016) also provides a critical analysis of work-related musculoskeletal disorders and practical solutions for various construction occupations/trades. The specific type(s) of solutions which should be adopted at construction sites requires involvement of workers, managers, and occupational health & safety professionals to understand the physical activities, the WMSD risks associated with those activities, and the range of possible solutions (Wang 2017).

Implementing the hierarchy of controls is the recommended strategy to organize WMSD prevention efforts in the construction industry. Prevention through Design (PtD) techniques are also important to eliminate or minimize various ergonomic hazards found in construction. In the hierarchy of controls, physical elimination of hazards is the primary objective. However, risk mitigation often also depends on administrative and personal protective equipment (PPE).

Recent Studies of Exoskeleton Use in Construction

Lower back support (manual material handling tasks including lifting/lowering or carrying construction materials)

Antwi-Afari et al. (2021) examined the effects of passive exoskeleton systems on spinal biomechanics (i.e., muscle activity) and subjective responses (i.e., ratings of perceived discomfort, perceived musculoskeletal pressure, and system usability) during manual repetitive handling tasks among construction workers. The study found that passive exoskeleton systems could reduce internal muscle forces, characteristics of muscle extension, and spinal forces in the lumbar region and can reduce the risk of developing WMSDs. In addition, a reduced level of perceived discomfort in the lower back was observed while using the exoskeleton system with increased lifting load, implying reduced lower back loading (Antwi-Afari et al., 2021). An experimental study by Gonsalves et al. (2021) assessed a commercially available passive back support exoskeleton for rebar workers and found that the use of the exoskeletons reduced lower back muscle activities (3%–11%) and discomfort for different body parts, except for the chest region, while significantly reducing the time to place and tie rebar. Another study by Ogunseiju et al. (2021) assessed the effects of a commercially available passive back-support exoskeleton (Laevo V2.56) on discomfort to body parts and subjective usability for simulated floor laying tasks. Their findings showed that the exoskeleton reduced discomfort in the lower back and lower leg/thigh, but increased discomfort in the chest as an unintended consequence during flooring tasks.

Upper body or upper extremities support (manual above the shoulders work including sustained postures in forearms/upper arms)

de Vries et al. (2021) analyzed the effect of a passive arm-support exoskeleton on shoulder muscle activity and perceived exertion associated with plastering activities such as applying gypsum to the ceiling, screeding, and finishing with a plastering spatula. Their findings showed that shoulder muscle activation and perceived exertion were both reduced when working with a passive arm-support exoskeleton during plastering tasks. A stronger reduction in perceived exertion was observed for overhead working. However, for applying gypsum on the wall (which involved more varied movements in multiple directions [e.g., movements opposite to those supported by the exoskeleton]), the study found no reduction in perceived exertion (de Vries et al., 2021). Jain et al. (2021) introduced a novel passive arm exoskeleton for construction workers' lifting/carrying tasks. This exoskeleton has a number of features which could make it highly suitable for construction workers. The exoskeleton has torsion springs and arm bracing designed to generate assistive torque (rotational force) at the elbow and wrist joints and can fully support approximately 18 pounds. Because this device only targets the elbow and wrist, suitable attachments can be introduced which might aid the workers' shoulder muscles (Jain et al., 2021).

Lower body/knee support (manual ground level work including sustained body postures involving the legs)

Chen et al. (2021) presented information on lightweight wearable knee-assistive exoskeletons for kneeling and squatting tasks in construction. Their findings showed reduction in knee extension/flexion muscle activation (up to 39%) during stand-to-kneel and kneel-to-stand tasks. Knee-ground contact forces/pressure were also reduced (up to 15%) under knee assistive exoskeleton use during single-leg kneeling. Increasing assistive knee torque redistributed the subject's weight from the knees contacting the ground to both feet. A knee-assistive exoskeleton system for construction workers was proposed by South Korean researchers (Yu et al., 2008). This study utilized a modular-type exoskeleton system and corresponding sensors to assist construction workers with their lower limb movements. Using the motor-powered exoskeleton, the upper and lower leg muscle activation was reduced by approximately 20%.

Research Needs

The NIOSH Center for Occupational Robotics Research has identified research needs in the broader field of robotics, some of which are applicable to exoskeletons. An important goal of researchers and occupational health/safety professionals is to help construction workers and workplaces with interventions that reduce known risks of WMSDs while advancing productivity and work quality. Good understanding of specific work tasks and ergonomic principles are needed to guide intervention research related to exoskeleton use for the many work tasks performed in construction. For example, brick masons typically have work requirements of repetitive forward bending and awkward/forceful posture above the shoulder. A thorough understanding of these trade/task-specific requirements is necessary in developing an exoskeleton to reduce work-related back and shoulder muscle loads. Among concrete and insulation workers and roofers, knee injuries are common due to prolonged kneeling and squatting during laying tiles, installing and replacing materials, patching concrete, and placing and nailing shingles. In depth understanding of lower extremity biomechanics is necessary to develop a knee assist exoskeleton which may be helpful for reducing direct pressure on the knee joint and quadricep muscle knee forces (Zhu et al., 2021).

Benefits and Challenges of Exoskeleton Use in Construction Trades

The benefits and challenges of exoskeleton use are still not clear. Safety and health professionals must ensure that the use of a new exoskeleton technology does not create additional hazards or risks to workers. Current challenges and benefits for exoskeleton use in construction are listed below. The list below is adopted and modified from Zhu et al. (2021).

Potential Benefits

- Exoskeletons have the potential to serve as an ergonomic intervention to assist construction workers who are performing manual repetitive handling tasks and reduce risk of WMSD.
- Exoskeletons have demonstrated, in some uses, to be simple, lightweight, comfortable and easy-to-use by workers.
- Exoskeletons can help managers and safety and health professionals to mitigate the risks of developing WMSDs among construction workers and enhance worker safety.

Potential Challenges

More research is needed to determine the:

- Generalizability of results. Most existing exoskeleton assessments were conducted in laboratory settings, involving healthy, young participants, making it difficult to generalize the results to actual worksites and to other populations (such as older workers or those who have experienced physical disabilities or previous injuries).
- Impact on time-to-completion measures, product flow rates, and/or work quality.
- Acceptability of specific exoskeletons by workers.
- Cost-benefit comparison between construction trade-specific applications of exoskeletons and other interventions.
- Potential risks of exoskeleton use such as friction and shear injury from contact with body regions; joint hyperextension risks; unintended contact, collision, vibration, and overexertion; and worker instability.

If you have used or contemplated using exoskeletons in your construction workplace, tell us about your experience in the comment section below.

Sang D. Choi, PhD, MPH(c), MS, CSP, CPE, is Professor & Director of the Center for OESH and Coordinator of the Construction Safety Program in the Department of Occupational & Environmental Safety & Health at the University of Wisconsin – Whitewater.

Douglas Trout, MD, MHS, is Deputy Director, Office of Construction Safety and Health at NIOSH.

Scott Earnest, PhD, PE, CSP, is the Associate Director for Construction Safety and Health at NIOSH.

CDR Elizabeth Garza, MPH, CPH, is Coordinator for the Construction Program in the Office of Construction Safety and Health at NIOSH.

Resources

Laborers' Health and Safety Fund of North America. Ergonomics

NIOSH MSD Program

Construction interventions

References

Antwi-Afari MF, Li H, Anwer S, Li D, Yu Y, Mi HY, Wuni IY [2021]. Assessment of a passive exoskeleton system on spinal biomechanics and subjective responses during manual repetitive handling tasks among construction workers. Safety Science 142: 105382.

Chen S, Stevenson DT, Yu S, Mioskowska M, Yi J, Su H, Trkov M [2021]. Wearable knee assistive devices for kneeling tasks in construction. IEEE/ASME Transactions on Mechatronics 26(4): 1989-1996.

Choi SD, Hudson L, Kangas P, Jungen B, Maple J, Bowen C [2007]. Occupational ergonomic issues in highway construction surveyed in Wisconsin, United States. Industrial Health 45(3): 487-493.

Choi SD, Yuan L, Borchardt JG [2016]. Musculoskeletal disorders in construction – Practical solutions from the literature. Professional Safety 61(1): 26-32.

CPWR Ergonomics Training Programs and Resources [2021].

de Vries AW, Krause F, de Looze MP [2021]. The effectivity of a passive arm support exoskeleton in reducing muscle activation and perceived exertion during plastering activities. Ergonomics 64(6): 712-721.

Gonsalves NJ, Ogunseiju OR, Akanmu AA, Nnaji CA [2021]. Assessment of a passive wearable robot for reducing low back disorders during rebar work. Journal of Information Technology in Construction 26: 936-952.

Jain S, Verma H, Khan AA [2021]. Ergonomic support system for construction worker's hand arm for lifting tasks. Journal of Physics 1950: 012051.

Kaur H, Wurzelbacher SJ, Bushnell PT, et al [2021]. Workers' compensation claim rates and costs for musculoskeletal disorders related to overexertion among construction workers — Ohio, 2007–2017.

MMWR (Morb Mortal Wkly Rep) 70 (16).

Liberty Mutual Workplace Safety Index [2021].

Lowe, B., Dick, R.B., Hudock, S., Bobick, T. Wearable Exoskeletons to Reduce Physical Load at Work. NIOSH Science Blog. March 4, 2016.

Luckhaupt SE, Dahlhamer, JM, Conzales GT, Lu ML, Groenewold M, Sweeney MH, Ward BW [2019]. Prevalence, recognition of work-eelatedness, and effect on work of low back pain among U.S. workers. Annals of Internal Medicine. https://doi.org/10.7326/M18-3602

Ogunseiju O, Gonsalves N, Akanmu A, Nnaji C [2021]. Subjective evaluation of passive back-support exoskeleton for flooring work. EPiC Series in Built Environment 2: 10-17.

Wang X, Dong XS, Choi SD, Dement J [2017]. Work-related musculoskeletal disorders among construction workers in the United States from 1992 to 2014. Occupational and Environmental Medicine 74(5): 374-380. doi: 10.1136/oemed-2016-103943.

Yu SN, Lee SH, Lee HD, Han CS [2008]. Design and feasibility verification of a knee assistive exoskeleton system for construction workers. Robotics and Automation in Construction (Chapter 19): 307-328.

Zhu Z, Dutta A, Dai F [2021]. Exoskeletons for manual material handling – A review and implication for construction applications. Automation in Construction 122: 103493.

February 3, 2022 by Sang D. Choi, PhD, MPH(c), MS, CSP, CPE; Douglas Trout, MD, MHS; Scott Earnest, PhD, PE, CSP; and CDR Elizabeth Garza, MPH, CPH

Construction, Musculoskeletal Disorders, Robotics, Wearable Technologies

One comment on "Exoskeletons: Potential for Preventing Work-related Musculoskeletal Injuries and Disorders in Construction Workplaces"

Greeter's in stores should be allowed to use standing stools.

Reply

Post a Comment

Your email address will not be published. Required fields are marked *

Comment *

Name

Email

Post Comment

Page last reviewed: February 3, 2022

Page last updated: February 3, 2022