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Topics in Construction Safety and Health
Ergonomic Hazards and WMSDs:
An Interdisciplinary Annotated Bibliography

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Ergonomic Hazards and WMSDs: An Interdisciplinary Annotated Bibliography

Abbe, O. O., et al. (2011). "Modeling the relationship between occupational stressors, psychosocial/physical symptoms and injuries in the construction industry." *International Journal of Industrial Ergonomics* 41(2): 106-117.

Injury statistics place the construction industry as a high-risk industry, making it necessary to investigate factors that influence accidents to be able to protect workers. Research was carried out to investigate the relationship existing among occupational stressors, psychological/physical symptoms and accident/injury and work days lost outcomes as experienced by manual workers engaged in a range of industrial construction occupations. Some of the occupational stressors significantly associated with self-reported and OSHA logged injuries were training, job certainty and safety climate of the company. The OSHA logged injuries were associated with the occurrence of headaches and feelings of tenseness on the job. These results imply that non-physical stressors should be included as a potential input associated with injuries in injury risk models for construction workers. Relevance to industry: Traditional approaches to workers' safety in the construction industry have focused on the physical and biomechanical aspects of work by improving tools, equipment and task completion methods. The impact of psychosocial factors, specifically stress as experienced by construction workers, is an area of growing research, which is yielding results that suggest overall work safety on the construction site should take into account psychosocial aspects of work. © 2010 Elsevier B.V.

Albers, J., et al. (2005). "Identification of ergonomics interventions used to reduce musculoskeletal loading for building installation tasks." *Appl Ergon* 36(4): 427-439.

Skilled workers in the mechanical and electrical installation (M/EI) building and construction trades experience high rates of disabling work-related musculoskeletal disorders (WMSDs). The M/EI trades involve installing piping; heating, ventilation and air conditioning (HVAC), and electrical systems in residential, commercial, and industrial buildings. In the absence of an ergonomics standard in the United States, some building and construction contractors, including M/EI sector contractors, have implemented various ergonomics interventions on their worksites on a voluntary basis. However, no data were available to determine the type of voluntary control measures being implemented, the task-specific hazards for which control measures needed to be developed or refined, and perceived barriers to improving hazard control. As part of a larger effort to obtain this data, the National Institute for Occupational Safety and Health (NIOSH) organized a stakeholder meeting to gather information regarding ergonomics interventions or "best practices" by M/EI contractors and tradespeople. The attendees included 39 industry representatives, 17 construction ergonomics researchers from government and academia, and four ergonomics consultants with experience in the construction industry. Participants spent more than 50% of time meeting in small trade-specific breakout sessions. According to the participants, tasks common to the three trades included (1) drill holes and shoot fasteners; (2) place and install systems, and (3) lift and carry materials and equipment. Engineering interventions described in the stakeholder meeting included tools, equipment, and engineered building materials; administrative controls largely consisted of training and education programs and modifications of work and management practice. Most participants believed that there were significant limits to the impact individual contractors and tradespeople could have in leading ergonomics improvement in the building and construction industry.

Albers, J. T. and S. D. Hudock (2007). "Biomechanical assessment of three rebar tying techniques." *Int J Occup Saf Ergon* 13(3): 279-289.

The National Institute for Occupational Safety and Health (NIOSH) conducted a study of ironworkers to evaluate their risk for developing back and hand injuries from hand-tying reinforcing steel bar and to investigate whether power tying tools can be an effective intervention for the prevention of work-related musculoskeletal disorders. A field investigation of biomechanical loading when using 3 techniques to tie together rebar was conducted. Researchers measured employees' wrist and forearm movement with goniometers and videotaped and analyzed trunk postures. Manually tying rebar at ground level involved sustained deep trunk bending and rapid, repetitive, and forceful hand-wrist and forearm movements. Using a power tier significantly reduced the hand-wrist and forearm movements and allowed the ironworkers to use one free hand to support their trunk posture while tying. Adding an extension handle to the power tier allowed the ironworkers to tie rebar while standing erect, minimizing sustained trunk flexion.

Albert, A. and M. R. Hallowell (2013). "Safety risk management for electrical transmission and distribution line construction." *Safety science* 51(1): 118-126.

Prior research has established that electrical contractors involved in the construction and maintenance of electrical transmission and distribution (T&D) lines are at extremely high risk of electrocution. The result of inadvertent contact with T&D lines often is death or severe injury that involves damage to internal organs, musculoskeletal disorders, neurological damages and severe burns. The Electrical Safety Foundation International has demonstrated that contact with overhead power lines has been the single largest cause of electrical fatalities over the last decade. To reduce this disproportionate injury rate, electrical contractors implement many strategies such as the use of rubber insulating equipment, and locking devices. Unfortunately, these strategies are often cost-prohibitive in certain construction and maintenance scenarios. Therefore, electrical contractors are faced with complex decisions that involve comparing the cost of injury prevention with the expected safety benefit. This paper presents research that objectively evaluated the risk associated with common T&D construction tasks and the effectiveness of specific injury prevention techniques. The research team then developed a decision support framework that provides electrical contractors with objective safety and cost feedback given specific project characteristics. The results indicate that many of the effective strategies implemented to reduce T&D electrical injuries are very costly (e.g., de-energizing lines). Consequently, under most conditions, the costs of injury prevention far outweigh the cost savings associated with the reduction of injury rates. The implication of these findings is that T&D electrical contractors must highly value the non-monetary benefits of injury prevention in order to improve safety in their sector.

Amasay, T., et al. (2009). "Validation of tri-axial accelerometer for the calculation of elevation angles." *International Journal of Industrial Ergonomics* 39(5): 783-789.

One of the main issues in occupational studies focusing on musculoskeletal disorders of the upper extremity is how to best quantify workers' exposures to risk factors during a workday. Direct measurement is preferred because it is objective and provides precise measurements. To measure elevation angle exposure of the upper extremity, accelerometers are commonly used. The main problem with the use of accelerometers is the fact that they are sensitive to linear acceleration and can only assess two axes of rotation. In the present study the Virtual Corset, a pager-sized, battery powered, tri-axial linear accelerometer with an integrated data logger, was validated in vitro for the reconstruction of elevation angles under static conditions and angle error prediction under dynamic conditions. For static conditions, the RMS angle error was less than 1°. Under dynamic conditions the elevation angle error was influenced by the radius and angular acceleration. However, the angle error was predicted well with an RMS difference of 3°. It was concluded that the Virtual Corset can be used to accurately predict arm elevation angles under static conditions. Under dynamic conditions, an

understanding of the motion being studied and the placement of the Virtual Corset relative to the joint are necessary.

Anderson, A. M., et al. (2007). "A biomechanical analysis of anterior load carriage." *Ergonomics* 50(12): 2104-2117.

Front load carriage is a common occupational task in some industries (e.g. agriculture, construction), but, as compared to lifting tasks, relatively little research has been conducted on the biomechanical loading during these activities. The focus of this study was to explore the low back biomechanics during these activities and, specifically, to examine the effects of load height and walking speed on trunk muscle activity and trunk posture. Eleven male participants participated in two separate front load-carriage experiments. The first experiment called for carrying a barbell (with weight corresponding to 20% of elbow flexion strength) at three heights (knuckle height, elbow height and shoulder height) at a constant horizontal distance from the spine. The second experiment called for participants to carry a bucket of potatoes weighing 14 kg at the same three heights, but with no further restrictions in technique. In both experiments, the participants performed this task while either standing still or walking at a self-selected speed. As they performed these tasks, the activity levels of the right-side muscle of the rectus abdominis, external oblique, biceps brachii, anterior deltoid and three levels (T9, T12 and L3) of the erector spinae were sampled. Mid-sagittal plane trunk posture was also quantified using three magnetic field-based motion sensors at T9, T12 and L3. The results showed a significant effect of both walking speed and load height on trunk posture and trunk muscle activity levels in both the barbell and bucket experiments. In the barbell experiment, the walking trials generated 43% more trunk muscle activity than the standing trials. Trials at shoulder height produced 11% more muscle activity than trials at elbow height in the T9 erector spinae muscles and 71% more muscle activity in the anterior deltoid. In the bucket experiment, trunk muscle activity responded in a similar fashion, but the key result here was the quantification of the natural hyperextension posture of the spine used to balance the bucket of potatoes. These results provide insight into muscle activation patterns in dynamic settings, especially (load) carrying biomechanics, and have implications in industrial settings that require workers to carry loads in front of their bodies.

Anton, D., et al. (2003). "Method for quantitatively assessing physical risk factors during variable noncyclic work." *Scand J Work Environ Health* 29(5): 354-362.

Myoelectric activity of the finger flexors of two groups of workers, heavy equipment operators (N=25) and mechanics (N=25), was sampled to determine the intensity and duration of forceful exertions during normal tasks. Data were reduced with a modification of the exposure variation analysis (EVA), called clustered EVA (CEVA), using three intensity and two duration categories. A two-way, mixed-effects, repeated-measures analysis of variance evaluated the percentage of sampled work time in each CEVA category.

Anton, D., et al. (2007). "Effect of aviation snip design and task height on upper extremity muscular activity and wrist posture." *J Occup Environ Hyg* 4(2): 99-113.

Hand tools described as ergonomic in design are intended to reduce exposure to physical risk factors associated with work-related musculoskeletal disorders. Additionally, using the right tool for the job is believed to reduce exposure and, consequently, risk of disease. Sheet metal workers frequently use a cutting tool called aviation snips when fabricating and installing ductwork. The purpose of this laboratory simulation study was to determine the effect of (1) aviation snip design; and (2) work height on muscle activity, wrist posture, and user satisfaction among sheet metal workers. We hypothesized that specific aviation snips designs would be most appropriate for use at specific heights. Twenty-three sheet metal workers used three different designs of aviation snips to make curved cuts in

sheet metal placed both at waist height and shoulder height. Conventional circular snips, straight snips, and an alternate design of offset snips were used. Upper extremity muscle activity was measured with surface electromyography, wrist posture was measured with electrogoniometry, and user satisfaction was rated by the participants on a survey. Statistically significant effects of snip design and task height on muscle activity, wrist posture, and user satisfaction were observed. However, no snip was preferable for all dependent variables. Work height had a greater effect on muscle activity and wrist posture than snip design. Field studies are indicated to determine the long-term effect of snip design on physical risk factors and risk of musculoskeletal disorders.

Anton, D., et al. (2013). "The effect of lift teams on kinematics and muscle activity of the upper extremity and trunk in bricklayers." *J Orthop Sports Phys Ther* 43(4): 232-241.

STUDY DESIGN: Workplace-simulation study using a crossover design. **OBJECTIVES:** To evaluate the effect of lift teams on trunk and upper extremity kinematics and muscle activity among bricklayers. **BACKGROUND:** Healthcare practitioners often instruct individuals with work-related musculoskeletal disorders in proper lifting techniques. Bricklayers are especially affected by lifting-related musculoskeletal disorders. Lift teams are a possible intervention for reducing exposure to heavy lifting. **METHODS:** Eighteen apprentice bricklayers constructed walls with concrete blocks alone (1 person) and in 2-person lift teams. Peak shoulder and trunk kinematics and normalized mean surface electromyography of the upper trapezius, lumbar paraspinals, and flexor forearm muscles were collected bilaterally. Differences between construction methods and rows 1, 3, and 6 of the wall were calculated with repeated-measures analyses of variance. **RESULTS:** Working in lift teams required less trunk flexion ($P = .008$) at row 1 but more sidebending at row 6 ($P < .001$) than working alone. Dominant-side lumbar paraspinal activity was lower at row 3 ($P = .008$) among lift-team workers. Lift-team peak shoulder flexion was lower at row 3 ($P = .002$), whereas abduction was higher at rows 1 ($P = .007$) and 6 ($P < .001$). Concomitantly, nondominant upper trapezius activity and flexor forearm activity were significantly higher for lift teams at row 6 ($P < .001$ and $P = .007$). Block moment arm was significantly greater for lift teams at all rows ($P \leq .002$). **CONCLUSION:** Working in lift teams may be a beneficial intervention for reducing trunk flexion and lumbar paraspinal activity when bricklayers work at heights between the knees and waist, but lift teams are not recommended at higher working heights.

Anton, D., et al. (2005). "Effect of concrete block weight and wall height on electromyographic activity and heart rate of masons." *Ergonomics* 48(10): 1314-1330.

Work-related musculoskeletal disorders (MSDs) are common among construction workers, such as masons. Few interventions are available to reduce masons' exposure to heavy lifting, a risk factor for MSDs. The purpose of this study was to determine whether one such intervention, the use of light-weight concrete blocks (LWBs), reduces physiological loads compared to standard-weight blocks (SWBs). Using a repeated measures design, 21 masons each constructed two 32-block walls, seven courses (rows) high, entirely of either SWBs or LWBs. Surface electromyography (EMG), from arm and back muscles, and heart rate was sampled. For certain muscles, EMG amplitudes were slightly lower when masons were laying LWBs compared to SWBs. Upper back and forearm extensor EMG amplitudes were greater for the higher wall courses for both block weights. There were no significant differences in heart rate between the two blocks. Interventions that address block weight and course height may be effective for masons.

Anton, D., et al. (2001). "The effect of overhead drilling position on shoulder moment and electromyography." *Ergonomics* 44(5): 489-501.

The effect of overhead drilling tasks on electromyographic (EMG) activity and shoulder joint moment was examined in this study. Twenty subjects simulated an overhead drilling task using a close, middle and far reach position while standing on either a lower or a higher step of a stepladder. Root mean square amplitude (AMP) of EMG activity from the dominant side anterior deltoid, biceps brachii and triceps brachii muscles was used to determine muscular load. Digital video was used to determine shoulder joint moment using 2-dimensional static link segment modelling in the sagittal plane. The results demonstrated that, compared to the far reach position, using the close reach position significantly decreased anterior deltoid AMP and biceps brachii AMP and moment, but increased triceps brachii AMP. Compared to the lower step, using the higher step significantly decreased anterior deltoid AMP and triceps AMP and moment, while increasing biceps AMP in the close position. There was no significant change noted in EMG median frequency indicating that fatigue was minimized. Moment increased monotonically with AMP. The findings indicated that workers performing overhead tasks should work close to their body in order to minimize shoulder forces. The implications of this recommendation are discussed.

Antonucci, A., et al. (2017). "Effect of Bit Wear on Hammer Drill Handle Vibration and Productivity." *J Occup Environ Hyg* 14(8): 642-651.

INTRODUCTION: The use of large electric hammer drills exposes construction workers to high levels of hand vibration that may lead to hand arm vibration syndrome and other musculoskeletal disorders. The aim of this laboratory study was to investigate the effect of bit wear on drill handle vibration and drilling productivity (e.g., drilling time per hole). **METHODS:** A laboratory test bench system was used with an 8.3 kg electric hammer drill and 1.9 cm concrete bit (a typical drill and bit used in commercial construction). The system automatically advanced the active drill into aged concrete block under feed force control to a depth of 7.6 cm while handle vibration was measured according to ISO standards (ISO 5349 and 28927). Bits were worn to 4 levels by consecutive hole drilling to 4 cumulative drilling depths: 0, 1900, 5700 and 7600 cm. **RESULTS:** Z-axis handle vibration increased significantly ($p < 0.05$) from 4.8 to 5.1 m/s^2 (ISO weighted) and from 42.7 to 47.6 m/s^2 (unweighted) when comparing a new bit to a bit worn to 1900 cm of cumulative drilling depth. Handle vibration did not increase further with bits worn more than 1900 cm of cumulative drilling depth. Neither x- nor y- axis handle vibration was effected by bit wear. The time to drill a hole increased by 58% for the bit with 5700 cm of cumulative drilling depth compared to a new bit. **CONCLUSION:** Bit wear led to a small but significant increase in both ISO weighted and unweighted z-axis handle vibration. Perhaps more important, bit wear had a large effect on productivity. The effect on productivity will influence a worker's allowable daily drilling time if exposure to drill handle vibration is near the ACGIH Threshold Limit Value (1). Construction contractors should implement a bit replacement program based on these findings.

Armstrong, T., et al. (2008). "Risk factors for carpal tunnel syndrome and median neuropathy in a working population." *J Occup Environ Med* 50(12): 1355-1364.

OBJECTIVE: To assess whether work-related physical activities are associated with Carpal tunnel syndrome (CTS), even when controlling for personal risk factors. **METHODS:** A cross-sectional assessment of 1108 workers from eight employers and three unions completed nerve conduction testing, physical examination, and questionnaires. CTS was defined by median neuropathy and associated symptoms. **RESULTS:** Eighteen workers had CTS and 131 had evidence of median neuropathy. CTS was highest among construction workers (3.0%) compared to other subjects (<1%). Logistic regression models for median neuropathy both personal and work-related risk factors. Work-related exposures were estimated by two methods: self-report and job title based ratings. **CONCLUSIONS:** Both work and personal factors mediated median nerve impairment. Construction

workers are at an increased risk of CTS so awareness should be raised and interventions should specifically target this risk group.

Baek, W. and G. Sheean (2007). "Occupational dystonia affecting truncal muscles in a bricklayer." *Mov Disord* 22(2): 284-285.

(Case of a neurological disorder caused by poor ergonomic work conditions)

Baker, R., et al. (2015). "Triage for action: Systematic assessment and dissemination of construction health and safety research." *Am J Ind Med* 58(8): 838-848.

Background: Research translation too often relies on passive methods that fail to reach those who can impact the workplace. The need for better research to practice (r2p) approaches is especially pressing in construction, where a disproportionate number of workers suffer serious injury illness. Methods: A triage process was designed and used to systematically review completed research, assess r2p readiness, establish priorities, and launch dissemination follow-up efforts. A mixed quantitative and qualitative approach was used. Results: The process proved effective in ensuring that significant findings and evidence-based solutions are disseminated actively. Key factors emerged in the selection of follow-up priorities, including availability of partners able to reach end users, windows of opportunity, and cross-cutting approaches that can benefit multiple dissemination efforts. Conclusions: Use of a systematic triage process may have an important role to play in building r2p capacity in construction safety and health. *Am. J. Ind. Med.* 58:838-848, 2015. © 2015 Wiley Periodicals, Inc.

Berrios-Torres, S. I., et al. (2003). "World Trade Center rescue worker injury and illness surveillance, New York, 2001." *Am J Prev Med* 25(2): 79-87.

BACKGROUND: The September 11, 2001, terrorist attacks on the World Trade Center in New York City, New York, prompted an unprecedented rescue and recovery response. Operations were conducted around the clock, involved over 5000 workers per day, and extended into months following the attacks. The City of New York Department of Health and Mental Hygiene and the Centers for Disease Control and Prevention implemented prospective surveillance to characterize rescue worker-related injury and illness and to help guide public health interventions. METHODS: From September 11 to October 11, 2001, personnel reviewed medical records at four Manhattan hospital emergency departments (EDs), and healthcare providers completed data collection forms at five temporary Disaster Medical Assistance Team (DMAT) facilities located at the site. Rescue workers included construction workers, police officers, firefighters, emergency medical service technicians, or Urban Search and Rescue workers. Data collected included demographic characteristics, injury type, illness, and disposition. RESULTS: Of 5222 rescue worker visits, 89% were to DMAT facilities and 12% to EDs. Musculoskeletal conditions were the leading cause of visits (19%), followed by respiratory (16%) and eye (13%) disorders. Incidence rates were estimated based on total injuries and/or illnesses reported times 200,000 (100 equivalent full-time workers in 1 year at 40 hours per week x 50 weeks per year), then divided by the total number of hours worked. Eye disorders (59.7) accounted for the highest estimated injury and illness rate, followed by headache (46.8). One death, 52 hospital admissions, and 55 transports were reported. Findings underscored the need to coordinate distribution and enforcement of personal protective equipment use, purchase of diagnostic equipment to diagnose corneal abrasions, and distribution of health advisories. CONCLUSIONS: This system provided objective, timely information that helped guide public health interventions in the immediate aftermath of the attacks and during the prolonged rescue and recovery operations. Lessons learned can be used to guide future surveillance efforts.

Blankenheim, A., et al. (2015). "Use of the Meta-posture™ Program in the Construction Industry." *Procedia Manufacturing* 3: 4421-4428.

This pilot study was conducted to test the effectiveness of Blankenheim Services' Meta-Posture™ Program for keeping construction workers safe. The Meta-Posture™ Program is a proprietary set of whole-body postures meant to promote strength and flexibility as well as joint and nerve health. This program was crafted to decrease the time needed for an exercise routine compared to typical stretch programs. Additionally, modified postures specified by symptoms have been pre-determined as a rehabilitation tool. The study consisted of a tested and control group with a total of 21 participants. All of the participants were asked to complete an assessment which included a series of surveys and two functional tests. Two postures were then taught each day over a series of four days to the tested group. Following the completion of the Meta-Posture™ Program, all participants were asked to retake the preliminary assessment. A follow-up survey was distributed three weeks later. It was hypothesized that the tested participants would improve their lifting mechanics and productivity, report a greater sense of well-being, and increase their perceived safety within the working environment. The results showed that 78% of the tested subjects improved their lifting mechanics. Results also indicate the tested participants raised productivity in completing a floor level light assembly simulation task by 7.7%. Survey responses suggested that tested participants reported decreased discomfort and feeling more energized. Other evidence regarding the Meta-Posture™ Program affecting perceptions of safety and affinity toward their employer was not substantial. Desired future research includes testing the Meta-Posture™ Program in a more controlled study and creating an objective scoring system for lifting mechanics.

Blood, R. P., et al. (2012). "Whole-body vibration in heavy equipment operators of a front-end loader: Role of task exposure and tire configuration with and without traction chains." *J Safety Res* 43(5-6): 357-364.

Introduction: This study measured whole-body vibration (WBV) exposures in front-end loader operators, and evaluated the effects of traction chains and work tasks on their WBV exposures. **Method:** WBV exposures were measured and compared across three different front-end loader tire configurations: (a) stock rubber tires, (b) rubber tires with ladder chains, and (c) rubber tires with basket chains. The operators completed three distinct standardized tasks: driving on a city street, simulated plowing, and a simulated scooping and dumping task. A portable data acquisition system collected tri-axial time weighted and raw WBV data per ISO 2631-1 and 2631-5 standards. In addition, Global Positioning System (GPS) data were collected in order to compare loader speeds across tire conditions and the standardized tasks. **Results:** Relative to the stock rubber tires, both types of tire chains significantly increased WBV exposures with the ladder chains having substantially higher WBV exposures compared to basket chains. Additionally, there were task dependent differences in WBV exposures. During the driving task, the z-axis (up and down) was the predominant exposure; the plowing task had a more even distribution of exposure across all three axes; while during scooping and dumping task, the x-axis (fore and aft) had the highest WBV exposures. The GPS data indicated that there were significant speed differences across tasks but not between the basket and ladder chain conditions. **Conclusions:** Tires with ladder chains increased the front-end loader operators' exposure to WBV above the ISO 2631-1 recommended eight hour action limit increasing risk for adverse health effects. Although more expensive, basket chains are recommended over ladder chains since they substantially lowered the front-end loader operator's exposures and may ultimately reduce vibration related wear and tear on the vehicle. **Impact on Industry:** In order to reduce a heavy equipment vehicle (HEV) operator's chances for developing low back pain, this study provides information that health and safety professionals can use to reduce whole-body vibration (WBV) exposures when operating front-end wheel loaders with traction chains. © 2012 National Safety Council and Elsevier Ltd.

Boatman, L., et al. (2012). "Creating the Climate for Making Ergonomic Changes." CPWR Report.

The purpose of this study is to learn about attitudes toward implementing ergonomic change in California construction work in the unionized sector. Our specific goal was to assess current perceptions and attitudes among construction professionals toward overcoming barriers and obstacles and voluntarily implementing ergonomic solutions.

Boatman, L., et al. (2015). "Creating a climate for ergonomic changes in the construction industry." *Am J Ind Med* 58(8): 858-869.

Background: Ergonomic solutions that have gained acceptance in other industries are often considered not applicable to a construction work environment, even though the industry is characterized by high physical work demands. Methods: We conducted 50 key informant interviews with 23 contractor representatives and 27 union staff, plus 4 focus groups with a total of 48 workers. Results: Many workers hold the belief that WMSDs are inevitable as part of the job, and did not consistently believe that changing the nature of the work could prevent that injury or pain. The interviewees reported limited availability and accessibility of tested and effective tools that both reduce physical demand and also get the job done efficiently and effectively. Yet for each major obstacle to implementation of ergonomics in the industry identified, the construction professionals we interviewed offered a variety of solutions. Conclusions: Contractors, unions, and workers need to work together to find actions that work within the parameters of the current economic environment. *Am. J. Ind. Med.* 58:858-869, 2015. © 2015 Wiley Periodicals, Inc.

Bodner, T., et al. (2014). "Safety, health, and well-being of municipal utility and construction workers." *J Occup Environ Med* 56(7): 771-778.

OBJECTIVE: To provide a baseline description of psychosocial workplace stressors and supports along with safety, injury, health, and well-being indicators in a sample of utility and construction workers for a National Institute for Occupational Safety and Health-funded Total Worker Health intervention study. METHODS: Survey responses and health assessments were collected from a total of 349 employees in two municipal utility departments. RESULTS: Participants demonstrated poor weight control and body mass index and provided reports of frequent poor health habits, injury, and pain. Although safety climate was good, less desirable levels of psychosocial workplace stressors and supports were observed. These stressors and supports were found to relate with many of the health, injury, and pain indicators. CONCLUSIONS: These results demonstrate the need for workplace interventions to promote and protect construction worker health and the importance of the psychosocial work environment.

Borstad, J. D., et al. (2009). "A longitudinal analysis of the effects of a preventive exercise programme on the factors that predict shoulder pain in construction apprentices." *Ergonomics* 52(2): 232-244.

Construction apprentices are at risk for developing shoulder pain with increasing exposure to repetitive overhead work. Risk may decrease if shoulder biomechanics are optimised and if risk factors that contribute to shoulder pain onset are identified. This prospective cohort study examined demographic and work-related factors and shoulder pain onset over 2 years in a cohort of 240 construction apprentices. Approximately 50% of the sample (n = 117) performed a home exercise programme intended to have a protective effect, while the other 50% served as controls. The proportion of new-onset shoulder pain in the control group was higher than in the exercise group. Regression analysis identified four factors related to new-onset shoulder pain: previous neck pain; working in hot, cold or humid conditions; subject height; and bending and twisting the back. This information may assist employers and workers in preventing shoulder pain. By knowing factors

predictive of shoulder pain development in construction workers, employers can take measures to protect workers and may secondarily decrease medical expenses and maintain productivity. Previous neck pain, working in extreme environmental conditions and being shorter all increased a worker's risk of developing shoulder pain. Exercises to optimise shoulder biomechanics have a small effect on preventing shoulder pain development. © 2009 Taylor & Francis.

Borstad, J. D. and P. M. Ludewig (2002). "Comparison of scapular kinematics between elevation and lowering of the arm in the scapular plane." *Clin Biomech (Bristol, Avon)* 17(9-10): 650-659.

OBJECTIVE: To compare scapular orientation during both the concentric (elevation) and eccentric (lowering) phases of scapular plane abduction in subjects with and without shoulder impingement. **DESIGN:** Mixed model analysis of variance with one between-subjects factor (group) and within-subjects factors of phase, humeral angle, and trial. **BACKGROUND:** Abnormal scapular kinematics have been identified in shoulder impingement patients during the concentric phase of arm elevation, and under static conditions. Because abnormal scapular motion is observed clinically during the eccentric phase of arm elevation, analysis of this phase of motion is warranted. **METHODS:** Twenty-six symptomatic and 26 healthy subjects performed five repetitions of humeral scapular plane abduction. An electromagnetic tracking device described three-dimensional scapular kinematics during arm elevation and lowering. Angular values for scapular anterior/posterior tipping in the sagittal plane, upward/downward rotation in the scapular plane, and internal/external rotation in the transverse plane were calculated. Scapular orientation relative to the thorax at humeral angles of 40 degrees, 60 degrees, 80 degrees, 100 degrees, and 120 degrees was statistically tested for effects of phase and trial, or for interactions of phase with group or humeral angle. **RESULTS:** Internal rotation was significantly increased in the eccentric phase for both groups at the 100 degrees angle ($P < 0.05$) and for the symptomatic group only at the 120 degrees angle ($P < 0.05$). Scapular anterior tipping was significantly decreased during the eccentric phase in both groups at the 80 degrees ($P < 0.001$), 100 degrees ($P < 0.0001$), and 120 degrees ($P < 0.0001$) angles. **CONCLUSIONS:** Small but statistically significant differences in scapular tipping and internal rotation during the eccentric phase of arm elevation were identified at higher humeral angles in both subject groups, while no significant phase differences for scapular upward rotation or for scapular variables at lower humeral angles were found. Averaged across phases, the symptomatic group demonstrated significant reductions in upward rotation at lower humeral elevation angles, and significant increases in anterior tipping at higher elevation angles as compared to the healthy group. **RELEVANCE:** Normal and abnormal scapular kinematics during varying types of motion need to be understood in order to optimally design rehabilitation programs for individuals with impingement syndrome.

Buchholz, B., et al. (2003). "Quantification of ergonomic hazards for ironworkers performing concrete reinforcement tasks during heavy highway construction." *J Occup Environ Hyg* 64(2): 243-250.

A study was conducted to assess the ergonomic hazards of ironwork job tasks associated with concrete reinforcement work at a large highway construction site. PATH (posture, activity, tools, and handling) analysis, a work-sampling method, was used to provide task-based estimates of the percentage of time ironworkers spent in specified postures of the trunk, arms, and legs; performed activities; used tools; and handled loads. A total of 2128 PATH observations were made of 17 ironworkers performing 5 job tasks: (1) ground-level reinforcement bar (rebar) construction, (2) wall rebar construction, (3) ventilation rebar construction, (4) preparation work, and (5) supervising. Nonneutral trunk postures were observed frequently (exceeding 30%) and manual material handling (MMH) was the most commonly observed activity (exceeding 20%) for all job tasks except supervising. The percentage of time workers spent in specific postures, activities performed, tool use, and MMH activities differed significantly between the five main job tasks, even when supervising was excluded

from the analysis. It was concluded that ironworkers are exposed to significant ergonomic hazards when performing concrete reinforcing tasks, and that opportunities exist for the implementation of ergonomic interventions. Further, the results of this study can be used to target specific hazardous tasks for ergonomic interventions and confirms the need to use a task-based exposure assessment strategy to properly assess ergonomic risk profiles for nonstructured jobs such as construction.

Burgel, B. J., et al. (2015). "Work-related health complaints and injuries, and health and safety perceptions of latino day laborers." *Workplace Health and Safety (AAOHN)* 63(8): 350-361.

This study describes socio-demographic, health, and work factors as well as health and safety perceptions of day laborers who reported work-related health complaints and injuries. The researchers completed a secondary data analysis of 217 interviews conducted in 2009 with day laborers in a large city. The participants reported 83 health complaints or injuries (38%) that had occurred during the prior 12 months, with 57 of these complaints or injuries resulting in lost work time. Pain and soreness of the back were the most prevalent health complaints or injuries; 66% of participants did not report their injuries, 62% reported no health and safety training, 96% reported they needed personal protective equipment (PPE), and 63% were provided with PPE. Latino day laborers reported a high 12-month prevalence of work-related health complaints and injuries. Ongoing policy work is needed to encourage injury reporting by day laborers and the provision of health and safety training and PPE to this group of workers. Copyright © 2015 The Author(s).

Caban-Martinez, A. J., et al. (2011). "Application of handheld devices to field research among underserved construction worker populations: a workplace health assessment pilot study." *Environ Health* 10: 27.

BACKGROUND: Novel low-cost approaches for conducting rapid health assessments and health promotion interventions among underserved worker groups are needed. Recruitment and participation of construction workers is particularly challenging due to their often transient periods of work at any one construction site, and their limited time during work to participate in such studies. In the present methodology report, we discuss the experience, advantages and disadvantages of using touch screen handheld devices for the collection of field data from a largely underserved worker population. **METHODS:** In March 2010, a workplace-centered pilot study to examine the feasibility of using a handheld personal device for the rapid health assessment of construction workers in two South Florida Construction sites was undertaken. A 45-item survey instrument, including health-related questions on tobacco exposure, workplace safety practices, musculoskeletal disorders and health symptoms, was programmed onto Apple iPod Touch(R) devices. Language sensitive (English and Spanish) recruitment scripts, verbal consent forms, and survey questions were all preloaded onto the handheld devices. The experience (time to survey administration and capital cost) of the handheld administration method was recorded and compared to approaches available in the extant literature. **RESULTS:** Construction workers were very receptive to the recruitment, interview and assessment processes conducted through the handheld devices. Some workers even welcomed the opportunity to complete the questionnaire themselves using the touch screen handheld device. A list of advantages and disadvantages emerged from this experience that may be useful in the rapid health assessment of underserved populations working in a variety of environmental and occupational health settings. **CONCLUSIONS:** Handheld devices, which are relatively inexpensive, minimize survey response error, and allow for easy storage of data. These technological research modalities are useful in the collection and assessment of environmental and occupational research data.

Caban-Martinez, A. J., et al. (2010). "Self-reported joint and back pain among Hispanic construction workers: A pilot workplace musculoskeletal assessment." *Journal of Musculoskeletal Research* 13(2): 49-55.

Construction workers are frequently exposed to awkward work postures and physical demands that can lead to work-related musculoskeletal disorders. There has been limited development of assessment and outreach strategies targeting this highly mobile workforce in general and especially among Hispanic construction workers. We report the prevalence of joint pain from a convenience sample of Hispanic construction workers. A workplace musculoskeletal disorder assessment was undertaken coinciding with construction-site lunch truck visits among 54 workers employed at two large South Florida construction sites. A 45-item questionnaire preloaded onto handheld devices was utilized to record field data. Forty-seven percent of Hispanic workers reported joint pain 30 days prior to interview date, of whom 87% indicated these joint problems interfered with work activities. Over 63% reported experiencing low back pain that lasted at least a whole day during the past 3 months. Right and left knees were the most frequently reported painful joints (both 34%). Musculoskeletal disorders as evident by joint pain, appears to be prevalent among Hispanic construction workers. Workplace ergonomic prevention strategies that reduce musculoskeletal disorders using innovative recruitment and engagement methods (such as during lunch truck construction-site visits) may improve opportunities to reduce joint pain and damage. © 2010 World Scientific Publishing Company.

Caban-Martinez, A. J., et al. (2014). "Construction workers working in musculoskeletal pain and engaging in leisure-time physical activity: Findings from a mixed-methods pilot study." *Am J Ind Med* 57(7): 819-825.

Background: While exercise has been shown to be beneficial for some musculoskeletal pain conditions, construction workers who are regularly burdened with musculoskeletal pain may engage less in leisure-time physical activity (LTPA) due to pain. In a small pilot study, we investigate how musculoskeletal pain may influence participation in LTPA among construction workers. Methods: A sequential explanatory mixed-methods design was employed using a jobsite-based survey (n=43) among workers at two commercial construction sites and one focus group (n=5). Results: Over 93% of these construction workers reported engaging in LTPA and 70% reported musculoskeletal pain. Fifty-seven percent of workers who met either moderate or vigorous LTPA guidelines reported lower extremity pain (i.e., ankle, knee) compared with 21% of those who did not engage in either LTPA (P=0.04). Focus group analyses indicate that workers felt they already get significant physical activity out of their job because they are "moving all the time and not sitting behind a desk." Workers also felt they "have no choice but to work through pain and discomfort [as the worker] needs to do anything to get the job done." Conclusion: Pilot study findings suggest that construction workers not only engage in either moderate or vigorous LTPA despite musculoskeletal pain but workers in pain engage in more LTPA than construction workers without pain. *Am. J. Ind. Med.* 57:819-825, 2014. © 2014 Wiley Periodicals, Inc.

Chávez, S. and C. E. Altman (2017). "Gambling with life: Masculinity, risk, and danger in the lives of unauthorized migrant roofers." *Am J Ind Med* 60(6): 537-547.

Background: This paper examines the occupational experiences of unauthorized immigrants employed in one of the most dangerous occupations in the United States: roofing. Methods: We draw on 40 in-depth interviews with return migrants in Guanajuato, Mexico, to examine how the adoption of masculinity, dangerous working conditions, the labor market structure, and absence of legal status exacerbates injuries for unauthorized roofers. Findings: Undocumented men return to Mexico injured with chronic pain, health complications, and trauma. We find that men "do gender" that is adopt masculine beliefs, when they skirt safety practices, police each other's behaviors, withhold their

emotions, experience heightened stress, and engage in poor health behaviors. It is a combination of dangerous working conditions, economic insecurity, and men seeking to fulfill their masculine roles that all combine to create unsafe working conditions and lead to injuries. © 2017 Wiley Periodicals, Inc.

Cheng, T., et al. (2013). "Data Fusion of Real-Time Location Sensing and Physiological Status Monitoring for Ergonomics Analysis of Construction Workers." *Journal of Computing in Civil Engineering* 27(3): 320-335.

Previous research and applications in construction resource optimization have focused on tracking the location of material and equipment. There is a lack of studies on remote monitoring for improving safety and health of the construction workforce. This paper presents a new approach for monitoring ergonomically safe and unsafe behavior of construction workers. The study relies on a methodology that utilizes fusion of data from continuous remote monitoring of construction workers' location and physiological status. To monitor construction workers activities, the authors deployed nonintrusive real-time worker location sensing (RTLS) and physiological status monitoring (PSM) technology. This paper presents the background and need for a data fusion approach, the framework, the test bed environment, and results to some case studies that were used to automatically identify unhealthy work behavior. Results of this study suggest a new approach for automating remote monitoring of construction workers safety performance by fusing data on their location and physical strain.

Chiou, S. S., et al. (2008). "Kinematics and kinetics of gait on stilts: identification of risk factors associated with construction stilt use." *Ergonomics* 51(12): 1814-1829.

This study investigated kinematics and kinetic strategies and identified risk factors associated with gait on stilts. A six-camera motion-analysis system and two force platforms were used to test 20 construction workers for straight walking or turning, with or without carrying tools while wearing safety shoes or stilts at different heights. The results indicated that gait on stilts is characterised by increases in stride length, step width and the percentage of double support period, decreases in cadence, minimum foot clearance and a weaker heel-strike and push-off. Stilts place greater joint loadings on lower extremities to compensate for the added weight and limitation in joint mobility. Smaller foot clearances found for gait on stilts constitute an increased risk for tripping over obstacles. Workers may need to avoid prolonged use of stilts to alleviate stresses on the joints. This study was conducted to determine to what extent stilts alter the gait strategies and to explain the compensatory movements. Prior to this study, there has been little substantive research to evaluate the stresses and potential injuries associated with stilts.

Choi, S. D. (2009). "Safety and ergonomic considerations for an aging workforce in the US construction industry." *Work* 33(3): 307-315.

The US construction workforce is aging as millions of baby boomers move toward retirement age. Older workers make a substantial contribution to construction in terms of skills and experience. However, construction is still one of the most physically demanding occupations, hence the health implications for older workers. Descriptions of injuries, illnesses and fatalities among older workers in the US construction industry from recent literature are presented along with the practical health and safety interventions that have been proposed including: ergonomic interventions, wellness programs, worksite housekeeping, training, and safety climate. Understanding the risks and hazards in specific industries could help identify training and intervention requirements to meet the challenges facing aging workers in these occupational groups.

Choi, S. D. (2010). "Ergonomic assessment of musculoskeletal discomfort of iron workers in highway construction." *Work* 36(1): 47-53.

OBJECTIVE: The purpose of this study is to ergonomically evaluate the risk of work-related musculoskeletal injuries of the iron workers in highway construction. Two specific job duties are analyzed: (1) tying the vertical, pier support systems, and (2) tying rebar on a horizontal bridge deck. **PARTICIPANTS:** Eleven right-handed male subjects participated in this study. The eleven rodworkers (5 pier tiers and 6 deck tiers) were recruited from a heavy and highway/bridge building project. **METHODS:** The ergonomic assessment tools included the BodyMap instrument for measuring potential ergonomic concerns, and a handgrip dynamometer for measuring the maximum voluntary contraction (MVC) and applied grip force of the rebar-tying tasks. **RESULTS:** This study suggests that there is a significant risk for injury and musculoskeletal disorders among iron workers performing these designated tasks. Findings also show that the ergonomic issues of greatest concern are the discomforts in the lower back and right wrist/hand of the rodworkers. **CONCLUSIONS:** The ergonomic assessment techniques could assist the early identification of work-related musculoskeletal concerns and help prioritize jobs for intervention in the construction field.

Choi, S. D. (2012). "A study of trade-specific occupational ergonomics considerations in the U.S. construction industry." *Work* 42(2): 215-222.

OBJECTIVE: The aim of this survey study was to identify trade-specific ergonomic issues, and discuss practical solutions to reduce work-related musculoskeletal disorders (WMSDs) and injuries in the construction industry. **METHOD:** Thirty-two construction firms in the Midwestern United States completed the final survey questionnaire. Twelve different construction skilled trades participated included: general contractor, road, heavy and highway, concrete, electrical, carpentry, landscaping, plumbing, roofing, steel erection, street lighting/traffic signal, and utility construction. Total workforce of the participating companies numbered 11,118 employees. **RESULT:** More than 90% of the participants in the survey had a written safety program; however, the majority of the firms did not have a trade-specific ergonomic intervention. The survey revealed that construction constructors perceived safety (worker well-being) as a high priority in their company. This study suggested that construction skilled-trade jobs the construction worker to employ trade-specific hand tools and working body positions that may contribute to different types of WMSD risks, body parts injured, and injury sources. Possible practical construction trade-specific ergonomic solutions might be considered including: selection of ergonomic hand tools, reduction of weight of construction materials, and promotion of wellness exercises. **CONCLUSION:** This paper may imply that need for more trade-specific ergonomics program elements to help alleviate the work-related musculoskeletal problems in the construction field.

Choi, S. D. (2015). "Aging Workers and Trade-Related Injuries in the US Construction Industry." *Saf Health Work* 6(2): 151-155.

The study was designed to identify any trends of injury type as it relates to the age and trade of construction workers. The participants for this study included any individual who, while working on a heavy and highway construction project in the Midwestern United States, sustained an injury during the specified time frame of when the data were collected. During this period, 143 injury reports were collected. The four trade/occupation groups with the highest injury rates were laborers, carpenters, iron workers, and operators. Data pertaining to injuries sustained by body part in each age group showed that younger workers generally suffered from finger/hand/wrist injuries due to cuts/lacerations and contusion, whereas older workers had increased sprains/strains injuries to the ankle/foot/toes, knees/lower legs, and multiple body parts caused by falls from a higher level or overexertion. Understanding these trade-related tasks can help present a more accurate depiction of

the incident and identify trends and intervention methods to meet the needs of the aging workforce in the industry. © 2015, Occupational Safety and Health Research Institute.

Choi, S. D., et al. (2007). "Occupational ergonomic issues in highway construction surveyed in Wisconsin, United States." *Ind Health* 45(3): 487-493.

This study discusses the workplace ergonomic issues in highway construction, and the safe work practices associated with the prevention of ergonomic-related injuries and illnesses in the construction field. In order to achieve the study objectives, a survey was designed and sent to Wisconsin based construction contractors. To design an adequate questionnaire, the research team first conducted a pilot study. The findings from the pilot survey provided a clear direction in creating the final survey. The survey results indicated that hand and finger injuries due to cutting operations and back injuries due to the manual handling of heavy materials to be the most frequent construction task/injury combination. All of the construction firms surveyed had a safety program; however, most of the contractors did not have a site-specific ergonomics program. The construction workers were usually walking/working on the ground, ladder and scaffold, and spent significant amount of time for the manual lifting or carrying heavy materials. The findings from this study may assist safety and health professionals in the construction industry in making effective changes for improving health and productivity.

Courtney, T. K., et al. (2002). "Disabling occupational injury in the US construction industry, 1996." *J Occup Environ Med* 44(12): 1161-1168.

In 1996 the US construction industry comprised 5.4% of the annual US employment but accounted for 7.8% of nonfatal occupational injuries and illness and 9.7% of cases involving at least a day away from work. Information in the published literature on the disability arising from construction injuries is limited. The construction claims experience (n = 35,790) of a large workers' compensation insurer with national coverage was examined. The leading types and sources of disabling occupational morbidity in 1996 in the US construction industry were identified. Disability duration was calculated from indemnity payments data using previously published methods. The average disability duration for an injured construction worker was 46 days with a median of 0 days. The most frequently occurring conditions were low back pain (14.8%), foreign body eye injuries (8.5%), and finger lacerations (4.8%). Back pain also accounted for the greatest percentage of construction claim costs (21.3%) and disability days (25.5%). However, the conditions with the longest disability durations were sudden-onset injuries, including fractures of the ankle (median = 55 days), foot (42 days), and wrist (38 days). Same-level and elevated falls were the principal exposures for fractures of the wrist and ankle, whereas elevated falls and struck by incidents accounted for the majority of foot fractures. Manual materials handling activities were most often associated with low back pain disability. The results suggest that these most disabling injuries can be addressed by increasing primary prevention resources in slips and falls and exposures related to injuries of sudden-onset as well as in reducing manual materials handling and other exposures associated with more gradual-onset injuries.

Cutlip, R., et al. (2000). "A comparison of different postures for scaffold end-frame disassembly." *Appl Ergon* 31(5): 507-513.

Overexertion and fall injuries comprise the largest category of nonfatal injuries among scaffold workers. This study was conducted to identify the most favourable scaffold end-frame disassembly techniques and evaluate the associated slip potential by measuring whole-body isometric strength capability and required coefficient of friction (RCOF) to reduce the incidence of injury. Forty-six male construction workers were used to study seven typical postures associated with scaffold end-frame disassembly. An analysis of variance (ANOVA) showed that the isometric forces (334.4-676.3 N)

resulting from the seven postures were significantly different ($p < 0.05$). Three of the disassembly postures resulted in considerable biomechanical stress to workers. The symmetric front-lift method with hand locations at knuckle height would be the most favourable posture; at least 93% of the male construction worker population could handle the end frame with minimum overexertion risk. The static RCOF value resulting from this posture during the disassembly phase was less than 0.2, thus the likelihood of a slip should be low.

Dale, A. M., et al. (2012). "Using process evaluation to determine effectiveness of participatory ergonomics training interventions in construction." *Work* 41(Supplement 1): 3824-3826.

The construction industry continues to experience high rates of musculoskeletal injuries despite the widespread promotion of ergonomic solutions. Participatory ergonomics (PE) has been suggested as one approach to engage workers and employers for reducing physical exposures from work tasks but a systematic review of participatory ergonomics programs showed inconclusive results. A process evaluation is used to monitor and document the implementation of a program and can aid in understanding the relationship between the program elements and the program outcomes. The purpose of this project is to describe a proposed process evaluation for use in a participatory ergonomics training program in construction workers and to evaluate its utility in a demonstration project among floor layers.

Dale, A. M., et al. (2017). "Facilitators and barriers to the adoption of ergonomic solutions in construction." *Am J Ind Med* 60(3): 295-305.

BACKGROUND: Rates of musculoskeletal disorders in construction remain high. Few studies have described barriers and facilitators to the use of available ergonomic solutions. This paper describes these barriers and facilitators and their relationship to the level of adoption. **METHODS:** Three analysts rated 16 proposed ergonomic solutions from a participatory ergonomics study and assessed the level of adoption, six adoption characteristics, and identified the category of adoption from a theoretical model. **RESULTS:** Twelve solutions were always or intermittently used and were rated positively for characteristics of relative advantage, compatibility with existing work processes and trialability. Locus of control (worker vs. contractor) was not related to adoption. Simple solutions faced fewer barriers to adoption than those rated as complex. **CONCLUSIONS:** Specific adoption characteristics can help predict the use of new ergonomic solutions in construction. Adoption of complex solutions must involve multiple stakeholders, more time, and shifts in culture or work systems. *Am. J. Ind. Med.* 60:295-305, 2017. (c) 2017 Wiley Periodicals, Inc.

Dale, A. M., et al. (2016). "Evaluation of a participatory ergonomics intervention in small commercial construction firms." *Am J Ind Med* 59(6): 465-475.

BACKGROUND: Work-related musculoskeletal disorders (WMSD) among construction workers remain high. Participatory ergonomics (PE) interventions that engage workers and employers in reducing work injury risks have shown mixed results. **METHODS:** Eight-six workers from seven contractors participated in a PE program. A logic model guided the process evaluation and summative evaluation of short-term and intermediate impacts and long-term outcomes from surveys and field records. **RESULTS:** Process measures showed good delivery of training, high worker engagement, and low contractor participation. Workers' knowledge improved and workers reported changes to work practices and tools used; contractor provision of appropriate equipment was low (33%). No changes were seen in symptoms or reported physical effort. **CONCLUSIONS:** The PE program produced many worker-identified ergonomic solutions, but lacked needed support from contractors. Future interventions should engage higher levels of the construction organizational system to improve

contractor involvement for reducing WMSD. *Am. J. Ind. Med.* 59:465-475, 2016. (c) 2016 Wiley Periodicals, Inc.

Dale, A. M., et al. (2016). "Observed use of voluntary controls to reduce physical exposures among sheet metal workers of the mechanical trade." *Appl Ergon* 52: 69-76.

Introduction: Little is known about the transfer into the workplace of interventions designed to reduce the physical demands of sheet metal workers. Methods: We reviewed videos from a case series of 15 sheet metal worksite assessments performed in 2007-2009 to score postures and physical loads, and to observe the use of recommended interventions to reduce physical exposures in sheet metal activities made by a NIOSH stakeholder meeting in 2002. Results: Workers showed consistent use of material handling devices, but we observed few uses of recommended interventions to reduce exposures during overhead work. Workers spent large proportions of time in awkward shoulder elevation and low back rotation postures. Conclusions: In addition to the development of new technologies and system designs, increased adoption of existing tools and practices could reduce time spent in awkward postures and other risks for musculoskeletal disorders in sheet metal work. © 2015 Elsevier Ltd and The Ergonomics Society.

Dale, A. M., et al. (2011). "Evaluation of anti-vibration interventions for the hand during sheet metal assembly work." *Work* 39(2): 169-176.

OBJECTIVE: Occupational use of vibrating hand tools contributes to the development of upper extremity disorders. While several types of vibration damping materials are commercially available, reductions in vibration exposure are usually tested in the laboratory rather than in actual work environments. This study evaluated reductions in hand vibration with different vibration damping interventions under actual work conditions. METHODS: Three experienced sheet metal assemblers at a manufacturing facility installed sheet metal fasteners with a pneumatic tool using no vibration damping (bare hand) and each of six anti-vibration interventions (five different gloves and a viscoelastic tool wrap). Vibration was measured with tri-axial accelerometers on the tool and the back of the hand. RESULTS: Unweighted mean vibration measured at the hand showed reduced vibration ($p < 0.001$) for all six interventions (range = 3.07-5.56 m/s^2) compared to the bare hand condition (12.91 m/s^2). CONCLUSIONS: All of the interventions were effective at reducing vibration at the hand during testing under usual work conditions. Field testing beyond laboratory-based testing accounts for the influences of worker, tools, and materials on vibration transmission to the body from specific work operations.

Dale, A. M., et al. (2011). "Variability and misclassification of worker estimated hand force." *Appl Ergon* 42(6): 846-851.

Ergonomic studies often use worker estimated hand force reproduced on a dynamometer to quantify force exposures but this method has not been well-studied in real work settings. This study evaluated the validity of worker estimates of hand force in a field study and determined the misclassification of worker estimated hand force exposures compared to directly measured forces. Eight experienced sheet metal assemblers completed (1/4)-inch diameter fastener installations using 6 different pneumatic tools. Grip forces were recorded by a pressure mat and were compared to worker estimated forces demonstrated on a dynamometer. Directly measured and worker estimated readings showed moderate correlations (0.53-0.67) for four installation tools and fair to moderate for two tools. The coefficient for variation of force estimates was 65% within repeated subject trials and 78% between averaged subject trials but 69% between subject trials during actual tool installations. Misclassification of worker estimated exposures varied by two cut-points: 29% using 4.0 kg and 49%

using 6.0 kg. The force match procedure may provide adequate differentiation of high and low exposures in some settings, but is likely to result in substantial misclassification in other settings.

Dale, A. M., et al. (2015). "Comparison of musculoskeletal disorder health claims between construction floor layers and a general working population." *Occup Environ Med* 72(1): 15-20.

OBJECTIVES: Compare rates of medical insurance claims for musculoskeletal disorders (MSD) between workers in a construction trade and a general worker population to determine if higher physical exposures in construction lead to higher rates of claims on personal medical insurance. **METHODS:** Health insurance claims between 2006 and 2010 from floor layers were frequency matched by age, gender, eligibility time and geographic location to claims from insured workers in general industry obtained from MarketScan. We extracted MSD claims and dates of service from six regions of the body: neck, low back, knee, lower extremity, shoulder and distal arm, and evaluated differences in claim rates. **RESULTS:** Fifty-one per cent of floor layers (n=1475) experienced musculoskeletal claims compared with 39% of MarketScan members ($p < 0.001$). Claim rates were higher for floor layers across all body regions with nearly double the rate ratios for the knee and neck regions (RR 2.10 and 2.07). The excess risk was greatest for the neck and low back regions; younger workers had disproportionately higher rates in the knee, neck, low back and distal arm. A larger proportion of floor layers (22%) filed MSD claims in more than one body region compared with general workers (10%; $p < 0.001$). **CONCLUSIONS:** Floor layers have markedly higher rates of MSD claims compared with a general worker population, suggesting a shifting of medical costs for work-related MSD to personal health insurance. The occurrence of disorders in multiple body regions and among the youngest workers highlights the need for improved work methods and tools for construction workers.

Dasgupta, P. S., et al. (2016). "Does drywall installers' innovative idea reduce the ergonomic exposures of ceiling installation: A field case study." *Appl Ergon* 55: 183-193.

Objective: The study was conducted to assess an intervention suggested by the workers to reduce the physical or ergonomic exposures of the drywall installation task. **Methods:** The drywall installers were asked to brainstorm on innovative ideas that could reduce their ergonomic exposures during the drywall installation work. The workers proposed the idea of using a 'deadman' (narrow panel piece) to hold the panels to the ceiling while installing them. The researcher collected quantitative exposure data (PATH, 3DSSPP) at the baseline and intervention phases and compared the phases to find out any change in the exposure while using the 'deadman'. **Results:** Results showed that ergonomic exposures (such as overhead arm and awkward trunk postures and heavy load handling) were reduced at the intervention phase while using the 'deadman' with an electrically operated lift. **Conclusion:** The concept of the 'deadman', which was shown to help reduce musculoskeletal exposures during ceiling installation, can be used to fabricate a permanent ergonomic tool to support the ceiling drywall panel. © 2016 Elsevier Ltd and The Ergonomics Society.

Davis, K. G., et al. (2010). "Investigating reduced bag weight as an effective risk mediator for mason tenders." *Appl Ergon* 41(6): 822-831.

Masonry workers face some of the highest physical demands in the construction industry where large bags of masonry material weighing 42.7 kg are commonly handled by mason tenders who mix the mortar, distribute mortar and bricks/blocks, and erect/dismantle scaffolding throughout the day. The objective of this study was to determine the effectiveness of using half-weight bags (21.4 kg) on reducing the biomechanical loading, physiological response, and perceived exertions. Ten male subjects performed asymmetric lifting tasks simulating unloading bags from a pallet. Muscle activity, trunk kinematics, heart rate, blood pressure and subjective rating data were collected. Spine loads were predicted from a well-validated EMG-assisted model. Bag weight, lift type, bag height at origin,

and asymmetry at destination significantly impacted the spine loads. While there was a 50% reduction in bag weight, the peak loads for the half-weight bags were only 25% less than the more available full-weight bags (a reduction of about 320 N of shear and 1000 N of compression). Lifts allowing movement of the feet reduced the loads by about 22% in shear and 27% in compression compared to constrained postures. Interestingly, cumulative spine loads were greater for the lighter bags than the heavy bags (approximately 40%). The subjective ratings of exertion and risk were significantly lower for the lighter bags. RELEVANCE TO INDUSTRY: The reduction in peak spine loading for the half-weight bags, particularly at the higher heights and when the feet were allowed to move could significantly reduce the injuries of masonry workers. However, there were trade-offs with cumulative loads that may minimize the reduced risk. Overall, given the limited amount of time lifting bags, the reduction of peak loads.

DeArmond, S., et al. (2011). "Individual safety performance in the construction industry: development and validation of two short scales." *Accid Anal Prev* 43(3): 948-954.

In the current research a short measure of safety performance is developed for use in the construction industry and the relationships between different components of safety performance and safety outcomes (e.g., occupational injuries and work-related pain) are explored within the construction context. This research consists of two field studies. In the first, comprehensive measures of safety compliance and safety participation were shortened and modified to be appropriate for use in construction. Evidence of reliability and validity is provided. Both safety compliance and safety participation were negatively related to occupational injuries, yet these two correlations were not statistically different. In the second study, we investigated the relationships between these two components of safety performance and work-related pain frequency, in addition to replicating Study 1. Safety compliance had a stronger negative relationship with pain than safety participation. Implications for research are discussed.

Dewlaney, K. S., et al. (2012). "Safety risk quantification for high performance sustainable building construction." *Journal of Construction Engineering and Management* 138(8): 964-971.

A recent study found that Leadership in Energy and Environmental Design (LEED) certified buildings have a recordable injury rate that is 9% higher than traditional, non-LEED buildings. A follow-up study showed that there are distinct aspects of the design elements and means and methods of construction used to achieve LEED certification that have negative impacts on worker safety. The research described in this paper builds on previous knowledge by quantifying the percent increase in base-level safety risk resulting from the design strategies and construction methods implemented to earn specific LEED credits. A total of 26 interviews and 11 validation interviews were conducted with designers and contractors who had completed an average of four LEED projects, 100 traditional projects, in their average of 18 years of experience in the architecture, engineering, and construction industry. The results indicate that design elements and means and methods of construction implemented to achieve 12 of the 49 LEED credits increase the frequency of injuries or exposure to known, high risk environments. The most significant impacts are a 36% increase in lacerations, strains, and sprains from recycling construction materials; a 24% increase in falls to lower level during roof work because of the installation of on-site renewable energy (e.g., PV panels); a 19% increase in eye strain when installing reflective roof membranes; and a 14% increase in exposure to harmful substances when installing innovative wastewater technologies. These results can be used to understand the safety impacts of sustainable building design, will enhance designer awareness, and help contractors to better prioritize safety resources. © 2012 American Society of Civil Engineers.

Dong, R. G., et al. (2004). "An evaluation of the standardized chipping hammer test specified in ISO 8662-2." *Ann Occup Hyg* 48(1): 39-49.

OBJECTIVES: Prolonged exposure to severe chipping hammer vibration may cause hand-arm vibration syndrome. A reliable test method is required to select appropriate tools and assist in the development of better chipping hammers. In the present study, the ISO standardized test method (ISO 8662-2, 1992) was examined through an investigation of the vibration characteristics of chipping hammers operating on the energy absorber specified in the standard. **METHODS:** The energy absorber and test setup were designed and constructed based on those specified in the standard. The experiment employed six subjects and used two pneumatic chipping hammers and three different feed forces (50, 100 and 200 N). The subject posture was the same as that specified in the standard. **RESULTS:** The vibration emission at the tool dominant frequency (or air blow rate) generally declined with an increase in feed force, thus decreasing the frequency-weighted accelerations. The increase in feed force, however, resulted in an increase in the unweighted vibration emission at high frequencies. The chipping hammer vibration emission operating on the energy absorber at the high feed force (200 N) was inconsistent. **CONCLUSIONS:** The measurement method has a good repeatability except at a high feed force. The feed force has a significant effect on the vibration emission. The single feed force specified in the standard may not be sufficient to test the tool behaviors. Multiple levels of feed force should be used for the chipping hammer test. Doing so may provide a more appropriate basis for tool screening.

Dong, X. S., et al. (2014). "Risks of a lifetime in construction Part I: Traumatic injuries." *Am J Ind Med* 57(9): 973-983.

Background: Estimates of occupational risk are typically computed on an annual basis. In contrast, this article provides estimates of lifetime risks for fatal and nonfatal injuries among construction workers. A companion paper presents lifetime risks for occupational illnesses. **Methods:** Using 2003-2007 data from three large data sources, lifetime risk was computed based on the number of fatal and nonfatal injuries per 100 FTEs for a working lifespan of 45 years. **Results:** For a working life in construction, the risk of fatal injuries were approximately one death per 200 FTE, and the leading causes were falls and transportation incidents. For nonfatal injuries resulting in days away from work, the adjusted lifetime risk was approximately 78 per 100 FTEs, and the leading causes were contact with objects/equipment, overexertion, and falls to a lower level. **Conclusions:** Lifetime risk estimates help inform both workers and policymakers. Despite improvements over the past decades, risks in construction remain high. *Am. J. Ind. Med.* 57:973-983, 2014. © 2014 Wiley Periodicals, Inc.

Dong, X. S., et al. (2011). "Chronic diseases and functional limitations among older construction workers in the United States: a 10-year follow-up study." *J Occup Environ Med* 53(4): 372-380.

OBJECTIVES: To examine the health status of older construction workers in the United States, and how occupation and the aging process affect health in workers' later years. **METHODS:** We analyzed six waves (1998 to 2008) of the Health and Retirement Study, a longitudinal survey of US residents age 50+. The study sample totaled 7200 male workers (510 in construction trades) in the baseline. Multiple logistic regression and paired t tests were conducted to compare health outcomes across occupations and within individuals over time. **RESULTS:** Compared with white-collar workers, construction workers had increased odds of arthritis, back problems, chronic lung disease, functional limitations, work disability, and work-related injuries after controlling for possible confounders. **CONCLUSIONS:** Safety and health interventions, as well as retirement and pension policy, should meet the needs of older construction workers, who face increasingly chronic health conditions over time.

Dong, X. S., et al. (2012). "Chronic back pain among older construction workers in the United States: a longitudinal study." *Int J Occup Environ Health* 18(2): 99-109.

This study assessed chronic back pain among older construction workers in the United States by analyzing data from the 1992-2008 Health and Retirement Study (HRS), a large-scale longitudinal survey. Fixed-effects methods were applied in the multiple logistic regression model to explore the association between back pain and time-varying factors (e.g., employment, job characteristics, general health status) while controlling for stable variables (e.g., gender, race, ethnicity). Results showed that about 40% of older construction workers over the age of 50 suffered from persistent back pain or problems. Jobs involving a great deal of stress or physical effort significantly increased the risk of back disorders and longest-held jobs in construction increased the odds of back disorders by 32% (95% CI: 1.04-1.67). Furthermore, poor physical and mental health were strongly correlated with back problems. Enhanced interventions for construction workers are urgently needed given the aging workforce and high prevalence of back disorders in this industry.

Dong, X. S., et al. (2015). "Long-term health outcomes of work-related injuries among construction workers-findings from the National Longitudinal Survey of Youth." *Am J Ind Med* 58(3): 308-318.

Background: This study examined the relationship between work-related injuries and health outcomes among a cohort of blue-collar construction workers. Materials and Methods: Data were from the National Longitudinal Survey of Youth, 1979 cohort (NLSY79; n=12,686). A range of health outcomes among blue-collar construction workers (n=1,435) were measured when they turned age 40 (1998-2006) and stratified by these workers' prior work-related injury status between 1988 and 2000. Univariate and multivariate analyses were conducted to measure differences among subgroups. Results: About 38% of the construction cohort reported injuries resulting in days away from work (DAFW); another 15% were injured but reported no DAFW (NDAFW). At age 40, an average of 10 years after injury, those with DAFW injury had worse self-reported general health and mental health, and more diagnosed conditions and functional limitations than those without injury. This difference was statistically significant after controlling for major demographics. Discussion: Adverse health effects from occupational injury among construction workers persist longer than previously documented. *Am. J. Ind. Med.* 58:308-318, 2015. © 2015 Wiley Periodicals, Inc.

Dong, X. S., et al. (2017). "Baby boomers in the United States: Factors associated with working longer and delaying retirement." *Am J Ind Med* 60(4): 315-328.

Objectives: This study estimated the self-reported probability of working full-time past age 62 (P62) or age 65 (P65) among four cohorts of Americans born between 1931 and 1959. Methods: Data from the Health and Retirement Study (HRS) were analyzed. Respondents in four age cohorts were selected for comparison. Multivariable linear regression models were used to assess cohort differences in P62 and P65 while adjusting for covariates. Results: P62 and P65 increased among boomers despite worsened self-rated health compared to the two preceding cohorts, with 37% and 80% increases among mid-boomers in construction trades. Cohort differences in P62 and P65 remained after controlling for covariates. Changes in pensions, income inequity, and education were significantly associated with work expectations, but SSA policy was not. Conclusions: Baby boomers expect to work longer than their predecessors. Efforts to improve work quality and availability for older workers are urgently needed, particularly in physically demanding occupations. *Am. J. Ind. Med.* 60:315-328, 2017. © 2017 Wiley Periodicals, Inc. © 2017 Wiley Periodicals, Inc.

Dunning, K. K., et al. (2010). "Costs by industry and diagnosis among musculoskeletal claims in a state workers compensation system: 1999-2004." *Am J Ind Med* 53(3): 276-284.

Background Musculoskeletal disorders (MSDs) are a tremendous burden on industry in the United States. However, there is limited understanding of the unique issues relating to specific industry sectors, specifically the frequency and costs of different MSDs. Methods Claim data from 1999 to 2004 from the Ohio Bureau of Workers' Compensation were analyzed as a function of industry sector (NAICS industry-sector categories) and anatomical region (ICD-9 codes). Results Almost 50% of the claims were lumbar spine (26.9%) or hand/wrist (21.7%). The majority of claims were from manufacturing (25.1%) and service (32.8%) industries. The industries with the highest average costs per claim were transportation, warehouse, and utilities and construction. Across industries, the highest costs per claim were consistently for the lumbar spine, shoulder, and cervical spine body regions. Conclusion This study provides insight into the severity (i.e., medical and indemnity costs) of MSDs across multiple industries, providing data for prioritizing of resources for research and interventions. © 2009 Wiley-Liss, Inc.

Entzel, P., et al. (2007). "Best practices for preventing musculoskeletal disorders in masonry: stakeholder perspectives." *Appl Ergon* 38(5): 557-566.

Brick masons and mason tenders report a high prevalence of work-related musculoskeletal disorders (WMSDs), many of which can be prevented with changes in materials, work equipment or work practices. To explore the use of "best practices" in the masonry industry, NIOSH organized a 2-day meeting of masonry stakeholders. Attendees included 30 industry representatives, 5 health and safety researchers, 4 health/safety specialists, 2 ergonomic consultants, and 2 representatives of state workers' compensation programs. Small groups discussed ergonomic interventions currently utilized in the masonry industry, including factors affecting intervention implementation and ways to promote diffusion of interventions. Meeting participants also identified various barriers to intervention implementation, including business considerations, quality concerns, design issues, supply problems, jobsite conditions and management practices that can slow or limit intervention diffusion. To be successful, future diffusion efforts must not only raise awareness of available solutions but also address these practical concerns.

Evanoff, B., et al. (2016). "Long-term symptomatic, functional, and work outcomes of carpal tunnel syndrome among construction workers." *Am J Ind Med* 59(5): 357-368.

Background: The long-term outcomes of carpal tunnel syndrome (CTS) including symptoms, functional status, work disability, and economic impact are unknown. Methods: We conducted a retrospective study of 234 active construction workers with medical claims for CTS and 249 workers without CTS claims; non-cases were matched on age, trade, and insurance eligibility. We conducted telephone interviews with cases and non-cases and collected administrative data on work hours. Results: Compared to non-cases, CTS cases were more likely to report recurrent hand symptoms, decreased work productivity/quality, decreased performance of physical work demands, and greater functional limitations. Surgical cases showed larger improvements on multiple outcomes than non-surgical cases. Minimal differences in paid work hours were seen between cases and non-cases in the years preceding and following CTS claims. Conclusions: Persistent symptoms and functional impairments were present several years after CTS diagnosis. Long-term functional limitations shown by this and other studies indicate the s prevention and treatment. © 2016 Wiley Periodicals, Inc.

Fernández-Esquer, M. E., et al. (2015). "The influence of demographics and working conditions on self-reported injuries among Latino day laborers." *Int J Occup Environ Health* 21(1): 5-13.

Background: The majority of day laborers in the USA are Latinos. They are engaged in high-risk occupations and suffer high occupational injury rates. Objectives: To describe on-the-job injuries reported by Latino day laborers, explore the extent that demographic and occupational factors predict

injuries, and whether summative measures for total job types, job conditions, and personal protective equipment (PPE) predict injuries. Methods: A community survey was conducted with 327 participants at 15 corners in Houston, Texas. Hierarchical and multiple logistic regressions explored predictors of occupational injury odds in the last year. Results: Thirty-four percent of respondents reported an occupational injury in the previous year. Education, exposure to loud noises, cold temperatures, vibrating machinery, use of hard hats, total number of job conditions, and total PPE significantly predicted injury odds. Conclusion: Risk for injury among day laborers is not only the product of a specific hazard, but also the result of their exposure to multiple occupational hazards. © W. S. Maney & Son Ltd 2015.

Fethke, N. B., et al. (2007). "Bootstrap exploration of the duration of surface electromyography sampling in relation to the precision of exposure estimation." *Scand J Work Environ Health* 33(5): 358-367.

OBJECTIVES: This study examined the effect of sampling duration, in units of work cycles, on the precision of estimates of exposure to forceful exertion obtained with surface electromyography (EMG). **METHODS:** Recordings of the activity of the flexor digitorum superficialis, extensor digitorum, and upper trapezius muscles over 30 consecutive work cycles were obtained for a random sample of 25 manufacturing workers, each of whom was performing a unique production task representing a portion of the whole job. The mean root-mean-square amplitude and the 10th, 50th, and 90th percentiles of the distribution function of the amplitude probability were calculated for each cycle. Bootstrap analyses were used to examine the precision of the summary measures as the sampling duration increased incrementally from 1 to 30 work cycles. Precision was estimated by calculating the coefficient of variation (CV) of the bootstrap distributions at each sampling duration increment. **RESULTS:** The average minimum sampling duration for a bootstrap distribution CV of 15% ranged from 2.0 (SD 1.5) cycles to 7.5 (SD 9.6) cycles, depending on muscle and summary measure. For a 5% CV, the average minimum sampling duration ranged from 11.9 (SD 9.0) to 20.9 (SD 10.5) cycles. **CONCLUSIONS:** The results suggest that sampling as few as three work cycles was sufficient to obtain a bootstrap distribution CV of 15% for some of the muscles and summary measures examined in this study. While limited to machine-paced, cyclic manufacturing work, these results will assist the development of exposure assessment strategies in future epidemiologic studies of physical risk factors and musculoskeletal disorders.

Fethke, N. B., et al. (2011). "Comparison of biomechanical loading during use of conventional stud welding equipment and an alternate system." *Appl Ergon* 42(5): 725-734.

We investigated the effect of an alternative welding system designed to reduce exposure to extreme trunk flexion on measures of trunk inclination and muscle activity. Among 10 participants, data were collected while using conventional stud welding equipment and while using the alternate system. Paired t-tests were used to compare results between the two welding systems. Mean trunk inclination angle was reduced with the alternate system (34.4 degrees versus 9.7 degrees, $p < 0.01$). Percent time with trunk inclination angles greater than 60 degrees was also reduced (40.0% versus 4.7%, $p < 0.01$). In general, the alternate system resulted in less desirable upper trapezius muscle activity levels. The alternate system appears to be effective in reducing exposure to extreme trunk flexion among stud welders. Continued development of the system should explore features designed to reduce shoulder forces and improve productivity.

Fethke, N. B., et al. (2016). "Reduction of Biomechanical and Welding Fume Exposures in Stud Welding." *Ann Occup Hyg* 60(3): 387-401.

The welding of shear stud connectors to structural steel in construction requires a prolonged stooped posture that exposes ironworkers to biomechanical and welding fume hazards. In this study, biomechanical and welding fume exposures during stud welding using conventional methods were compared to exposures associated with use of a prototype system that allowed participants to weld from an upright position. The effect of base material (i.e. bare structural beam versus galvanized decking) on welding fume concentration (particle number and mass), particle size distribution, and particle composition was also explored. Thirty participants completed a series of stud welding simulations in a local apprenticeship training facility. Use of the upright system was associated with substantial reductions in trunk inclination and the activity levels of several muscle groups. Inhalable mass concentrations of welding fume (averaged over ~18 min) when using conventional methods were high (18.2 mg m⁻³ for bare beam; 65.7 mg m⁻³ for through deck), with estimated mass concentrations of iron (7.8 mg m⁻³ for bare beam; 15.8 mg m⁻³ for through deck), zinc (0.2 mg m⁻³ for bare beam; 15.8 mg m⁻³ for through deck), and manganese (0.9 mg m⁻³ for bare beam; 1.5 mg m⁻³ for through deck) often exceeding the American Conference of Governmental Industrial Hygienists Threshold Limit Values (TLVs). Number and mass concentrations were substantially reduced when using the upright system, although the total inhalable mass concentration remained above the TLV when welding through decking. The average diameters of the welding fume particles for both bare beam (31±17 nm) through deck conditions (34±34 nm) and the chemical composition of the particles indicated the presence of metallic nanoparticles. Stud welding exposes ironworkers to potentially high levels of biomechanical loading (primarily to the low back) and welding fume. The upright system used in this study improved exposure levels during stud welding simulations, but further development is needed before field deployment is possible.

Forde, M. S., et al. (2005). "Prevalence of musculoskeletal disorders in union ironworkers." *J Occup Environ Hyg* 2(4): 203-212.

The prevalence of musculoskeletal disorder (MSD) symptoms and doctor-diagnosed musculoskeletal disorders (DDMDs) were estimated among union construction ironworkers by a telephone-administered questionnaire. Of 1996 ironworkers eligible, 1566 were contacted and 981 were interviewed. The prevalence of self-reported MSD symptoms was high for the lower back (56%), wrist/hands/fingers (40%), knees (39%), and shoulders (36%). The most common DDMDs were tendonitis (19%), ruptured disk in the back (18%), bursitis in the shoulder (15%), and carpal tunnel syndrome (12%). Generally, the prevalence of DDMDs and MSD symptoms increased with duration of employment. In age-adjusted logistic regression analyses, those who worked 25 to 35 years were more likely to have tendonitis (odds ratio [OR] 7.1, 95% confidence interval [CI] 3.116.6), shoulder bursitis (OR 13.7, 95% CI 3.160.4), knee bursitis (OR 5.1, 95% CI 1.025.1), and ruptured intervertebral back disk (OR 6.7, 95% CI 2.617.5). The effect of prior injury was also consistently high (upper extremities, OR 4.6; lower extremities OR 5.1; lower back, OR 6.0). Among workers without prior injuries, MSD symptoms were more frequent for the lower back in structural ironwork (OR 1.7, 95% CI 1.12.6), and for the upper extremity in concrete reinforcement ironwork (OR 1.9, 95% CI 1.22.9). These findings suggest that some musculoskeletal morbidity in construction ironworkers may be work related and thus preventable.

Fulmer, S., et al. (2006). "Factors influencing ergonomic intervention in construction: trunkman case study." *New Solut* 16(3): 235-247.

This case study examines factors affecting the use of equipment designed to prevent lower back strain in laborers who pour concrete on major highway construction sites. Qualitative methods of organizational analysis were used to characterize factors identified from interviews and participant observation. The major obstacles to the use of the control on site were 1. Managers placing a low

priority on ergonomics. 2. Safety officers' limited power in organizational hierarchies. 3. Rationalizing, rather than challenging, resistance to change. 4. Lack of a forum to share knowledge about interventions. Several organizational factors impeded the adoption of a technically effective, low-cost safety control on the site studied. The implementation of the control ultimately resulted from actions taken by the investigators, suggesting that safety programs present at the site are not always adequate to realize feasible interventions.

Garber, S., et al. (2014). "Safety & Health Information: Improving Online Access & Delivery." *Professional Safety* 59(05): 59-65.

In 2000, Center for Construction Research and Training (CPWR) launched the electronic Library of Construction Occupational Safety and Health (eLCOSH) as a free online source of research and training information on the topic of construction safety and health. By 2010, it had grown to contain nearly 2,000 items, with more than 30,000 unique visitors each month, including safety and health professionals, researchers, workers, contractors and trainers. The site's content had also diversified. For example, a search on noise brings up presentations, videos, images of noisy situations, toolbox talks, handouts for use by trainers or employers, as well as recent research findings and studies on noise and hearing conservation....

Gatti, U., et al. (2013). "Using workforce's physiological strain monitoring to enhance social sustainability of construction." *Journal of Architectural Engineering* 19(3): 179-185.

Sustainability is often described in terms of the triple bottom line, which refers to its environmental, economic, and social dimensions. However, the economic and environmental impacts of decisions have been easier to determine than have been the social impacts. One area of social sustainability that is particularly applicable to construction projects is that of construction workforce safety and well-being. This is a critical part of sustainability, and a socially sustainable construction industry needs to consider the safety and well-being of construction workers. However, construction activities are generally physically demanding and performed in harsh environments. Monitoring workers' physical strain may be an important step toward enhancing the social sustainability of construction. Recently introduced physiological status monitors (PSMs) have overcome the past limitations, allowing physical strain to be monitored without hindering workers' activities. Three commercially available PSMs have been selected and tested to assess their reliability in monitoring a construction workforce during dynamic activities. The results show that two of the PSMs are suitable candidates for monitoring the physiological conditions of construction workers. A survey was also conducted among industry practitioners to gain insight into industry needs and challenges for physical strain monitoring. © 2013 American Society of Civil Engineers.

Gilkey, D. P., et al. (2007). "Low back pain in Hispanic residential carpenters." *J Chiropr Med* 6(1): 2-14.

OBJECTIVE: Low back pain (LBP) is a leading cause of lost work time and has been recognized as America's number one workplace safety challenge. Low back pain is occurring at epidemic proportions among construction workers, and minority populations have been underinvestigated for risk of back injury. This project investigated the multiple potential risk factors for occupational LBP among Hispanic residential carpenters. METHODS: This investigation evaluated 241 Hispanic residential framing carpenters. Data for this study were collected using a 91-question survey. End points of interest included point, annual, and lifetime prevalence of LBP. RESULTS: Nineteen percent of respondents reported they had an episode of LBP in their lifetime. CONCLUSIONS: Hispanic residential carpenters reported less than expected prevalence of LBP compared with non-Hispanic counterparts in the same trade and location. Job tasks and personal and workplace risk factors, including psychological and morphological characteristics, affect the prevalence of LBP among Hispanic framing carpenters.

Gilkey, D. P., et al. (2007). "Low back pain among residential carpenters: ergonomic evaluation using OWAS and 2D compression estimation." *Int J Occup Saf Ergon* 13(3): 305-321.

Occupational low back pain (LBP) remains a leading safety and health challenge. This cross-sectional investigation measured the prevalence of LBP in residential carpenters and investigated ergonomic risk factors. Ninety-four carpenters were investigated for LBP presence and associated risk factors. Ten representative job-tasks were evaluated using the Ovako Working Posture Analysis System (OWAS) and ErgoMaster 2D software to measure elements of posture, stress, and risk. Job-tasks were found to differ significantly for total lumbar compression and shear at peak loading ($p < .001$), ranging from 2 956 to 8 606 N and 802 to 1 974 N respectively. OWAS indicated that slight risk for injury was found in 10 job-tasks while distinct risk was found in 7 of the 10 job-tasks. Seven of the 10 job-tasks exceeded the National Institute for Occupational Safety and Health (NIOSH) action limit of 3 400 N for low back loading. The point prevalence for LBP was 14% while the annual prevalence was 38%.

Golabchi, A., et al. (2015). "An Automated Biomechanical Simulation Approach to Ergonomic Job Analysis for Workplace Design." *Journal of Construction Engineering and Management* 141(8): 04015020.

Work-related musculoskeletal disorders (WMSDs) are reported to be the most common category of nonfatal occupational injuries that result in days away from work and are also a leading cause of temporary and permanent disability. One of the most effective approaches to preventing WMSDs is to evaluate ergonomics considerations early in the design and construction planning stage before the worker encounters the unsafe conditions. However, a lack of tools for identifying potential ergonomic risks in a proposed workplace design has led to difficulties in integrating safety and health into workplace design practice. In an effort to address this issue, this study explores a motion data-driven framework for ergonomic analysis that automates and visualizes the evaluation process in a virtual workplace. This is accomplished by coupling the ergonomic analysis with three-dimensional (3D) virtual visualization of the work environment. The proposed approach uses motion data from the 3D model of the jobsite to evaluate the risk factors that can produce excessive physical loads on the human body through a biomechanical analysis. A global risk assessment of musculoskeletal disorders is performed on worker motions first, and a biomechanical simulation is then used to further analyze unsafe motions by estimating internal loads on each selected body joint of the worker and redesigning the motion and workplace accordingly. As a case study, several tasks taking place in a construction prefabrication shop are modeled and analyzed to modify the workplace and ensure improved ergonomic safety. The results indicate that the proposed approach enables identification and minimization of awkward worker postures in the virtual model to mitigate ergonomic risk during workplace design.

Goldenhar, L. M. and P. Stafford (2015). "If you've seen one construction worksite stretch and flex program ... you've seen one construction worksite stretch and flex program." *J Safety Res* 55: 73-79.

BACKGROUND: Work-related Musculoskeletal Disorders (WMSD) account for approximately one-third of all injuries in the U.S. construction industry. Many companies have implemented stretch and flex (s/f) programs to reduce WMSD despite a lack of evidence showing effectiveness. **METHODS:** We conducted a mixed-methods study to understand (a) why employers continue devoting resources to s/f programs; (b) how programs vary; and (c) any actual or perceived benefits. **RESULTS:** Nineteen safety and health professionals were interviewed and 133 more (13.3% response rate) completed an on-line survey. Fifty-six percent had implemented an s/f program with the primary goal of reducing WMSDs; though most did not review data to determine goal achievement. Program structure varied in terms of duration, frequency, and type of stretches. There was strong agreement about mandating

attendance but not participation, due primarily to liability issues. Cost was a factor when deciding to implement a program but not for sustaining one. The majority had not implemented other ergonomic prevention activities, but many had started conducting daily safety huddles for task and safety planning. Those reporting a reduction in WMSDs agreed that it was not due to the s/f program alone and that other benefits included increased worker camaraderie, communication, and collaboration. CONCLUSION: Although there is little to no scientific evidence showing that they work as intended, construction companies continue to implement s/f programs with the goal of reducing WMSDs. Bringing work crews together for s/f activities has prompted employers to also begin conducting daily safety huddles. Although employers may not be able to link reduced WMDS to an s/f program, the ancillary benefits may warrant the time and resources. PRACTICAL APPLICATIONS: S/f programs should be only one component of a more comprehensive ergonomics prevention program. Conducting daily safety huddles at the same time also may enhance worker communication, camaraderie, collaboration and improve safety outcomes.

Goldsheyder, D., et al. (2002). "Musculoskeletal symptom survey among mason tenders." *Am J Ind Med* 42(5): 384-396.

BACKGROUND: Low back pain (LBP) constitutes a major problem in construction. The magnitude and musculoskeletal injury characteristics in certain construction trades have been studied extensively. Musculoskeletal research targeting mason tenders is limited. High physical demands of the job primarily contribute to an increased risk of LBP experienced by these laborers. METHODS: A symptom survey was conducted to determine the magnitude and musculoskeletal injury characteristics among the mason tenders, and to identify work-related activities perceived by them as contributing to their disorders. RESULTS: The findings revealed that 82% of the mason tenders experienced at least one musculoskeletal symptom in the last year. LBP was the most frequently reported symptom (65%). Due to LBP, 12% of the laborers missed work and 18% of them visited a physician. Bending or twisting the back, working in the same position or in pain, and heavy lifting they perceived as the most problematic work-related activities. The vast majority of the laborers requested job-safety training. CONCLUSIONS: The mason tenders experienced high prevalence of LBP. To address the problem a model for primary prevention of LBP was developed and implemented in the trade. The model incorporated ergonomic principles, hazard recognition, and problem solving in the training curriculum for the union instructors teaching apprentices the trade-specific skills.

Goldsheyder, D., et al. (2004). "Musculoskeletal symptom survey among cement and concrete workers." *Work* 23(2): 111-121.

Work in construction is associated with a high risk for musculoskeletal disorders and injuries. The symptom survey was conducted to determine the magnitude and musculoskeletal injury characteristics among the cement and concrete workers and identify the most problematic work-related activities and job factors that might have contributed to the occurrence of these disorders. Findings revealed that a large proportion of the laborers (77%) experienced at least one musculoskeletal disorder in the last year. Low back pain was reported as the most frequently experienced symptom (66%). 'Working while in pain' the concrete workers perceived as the major problem in the trade. Other problematic work-related activities included 'bending or twisting the back', 'work in hot, cold or wet conditions', and 'handling heavy objects'. Most of the laborers (82%) requested on-the-job safety training. Survey results combined with the outcomes of focus groups discussions and work site observations were used in the design of a training program aimed at the prevention of musculoskeletal morbidity in the trade. The program incorporated ergonomics principles, hazard recognition, safe work practices, problem solving and personal protection in the training curriculum for membership of the trade.

Haro, E. and B. M. Kleiner (2008). "Macroergonomics as an organizing process for systems safety." *Appl Ergon* 39(4): 450-458.

Hendrick is attributed with the formalization of organizational design and management (ODAM) in ergonomics [Hendrick, H.W., Kleiner, B.M., 2001. *Macroergonomics: An Introduction to Work System Design*. Human Factors and Ergonomics Society, Santa Monica, CA.]. Specifically, the method called "Macroergonomic Analysis of Structure" or MAS provides a framework and analysis of these factors and provides the context for an analysis of organizational design and management process through the MacroErgonomic Analysis and Design method (MEAD). Together, MAS and MEAD represent the formalization of staple methods in macroergonomics and can be used to organize existing tools and methods such as those that exist in systems safety and help to differentiate macroergonomics from other approaches. This article illustrates such an integrative role for macroergonomics with respect to systems safety using the example of the construction sector, a domain in which accidents, injuries and fatalities are all too common.

Hecker, S. and J. A. Gambatese (2003). "Safety in design: a proactive approach to construction worker safety and health." *J Occup Environ Hyg* 18(5): 339-342.

Hess, J., et al. (2010). "Ergonomic best practices in masonry: regional differences, benefits, barriers, and recommendations for dissemination." *J Occup Environ Hyg* 7(8): 446-455.

Within construction the masonry trade has particularly high rates of musculoskeletal disorders (MSDs). A NIOSH-sponsored meeting of masonry stakeholders explored current and potential "Best Practices" for reducing MSDs in masonry and identified potential regional differences in use of practices. To verify and better understand the regional effects and other factors associated with differences in practice use, a national telephone survey of masonry contractors was conducted. The United States was divided into four regions for evaluation: Northeast, Southeast, Midwest, and West Coast. Nine practices with the potential to reduce MSDs in masonry workers were evaluated. Masonry contractors, owners, and foremen completed 183 surveys. The results verify regional differences in use of best practices in masonry. Half-weight cement bags and autoclave aerated concrete were rarely used anywhere, while lightweight block and mortar silos appear to be diffusing across the country. The Northeast uses significantly fewer best practices than other regions. This article examines reasons for regional differences in masonry best practice, and findings provide insight into use and barriers to adoption that can be used by safety managers, researchers, and other safety advocates to more effectively disseminate ergonomic solutions across the masonry industry.

Hess, J. A., et al. (2004). "A participatory ergonomics intervention to reduce risk factors for low-back disorders in concrete laborers." *Appl Ergon* 35(5): 427-441.

Construction laborers rank high among occupational groups with work-related musculoskeletal injuries involving time away from work. The goals of this project were to: (1) introduce an ergonomic innovation to decrease the risk of low-back disorder (LBD) group membership, (2) quantitatively assess exposure, and (3) apply a participatory intervention approach in construction. Laborers manually moving a hose delivering concrete to a placement site were evaluated. The hypothesis tested was that skid plates would prevent hose joints from catching on rebar matting, and the hose would slide more easily. This would decrease the need for repetitive bending and use of excessive force. Four laborers were evaluated wearing the Lumbar Motion Monitor (LMM), a tri-axial electrogoniometer that records position, velocity and acceleration. Workers were measured during three comparable concrete pours. Worker perceptions of the innovation utility and exertion were surveyed. During initial use of skid plates, flexion increased significantly ($p < 0.001$) while velocity, acceleration and moments did not

change. After implementing a worker modification, low back velocity, acceleration and moments were significantly reduced ($p < 0.05$). Reductions in these factors have been associated with decreased risk of belonging to an occupational group with LBDs. Use of secured skid plates during horizontal concrete hose movement may in part decrease the risk of LBD group membership among concrete laborers. Crew participation resulted in skid plates being a more effective intervention. The LMM is a promising tool for quantitative assessment in construction.

Hess, J. A., et al. (2010). "Ergonomic evaluation of masons laying concrete masonry units and autoclaved aerated concrete." *Appl Ergon* 41(3): 477-483.

Masons working with concrete masonry unit block have high rates of work-related musculoskeletal disorders to the low back and shoulders associated with repetitively lifting and buttering heavy block. A new material, autoclaved aerated concrete, may reduce the risk of shoulder and back injury but, ergonomic evaluation is needed. This study evaluated shoulder exposure parameters, low back stress, and worker perceptions in two groups of journey level masons, one using CMU and the other using AAC block. Results indicate that for the left arm AAC masons spent significantly more time than CMU masons in static (38.2% versus 31.1%, respectively), and less time in slow motions (48.2% versus 52.2%, respectively) and faster motions (13.6% versus 16.7%, respectively) ($p < 0.05$). CMU masons had significantly greater shoulder and low back pain ($p = 0.009$) and they held block significantly longer than AAC masons ($p < 0.001$). Low back compressive forces were high for both materials. Masons handling AAC demonstrated less left upper extremity stress but both materials were estimated to be hazardous to the low back.

Hess, J. A., et al. (2008). "Ergonomic evaluation of an extension screw gun to improve work postures." *Occupational Ergonomics* 8(1): 27-40.

Carpenters frequently work in awkward and stooped postures. Autofeed extension screw guns (ESGs) allow certain tasks to be performed upright. This study evaluated low back and wrist motion in fifteen carpenters using a traditional screw gun (TSG) and ESG during floor level work. ESG use required a greater percentage of time in awkward wrist postures with higher velocities and accelerations, yet neither tool placed workers at risk for wrist injury. The ESG resulted in significantly less low back flexion, left-sided bending and twisting, velocity and acceleration. The probability of low back disorder group membership risk was 53% with TSG use and 47% with ESG use. Carpenters liked using ESGs and reported less exertion when using them. The ESG's autofeed feature enhanced productivity. Training may be important to further reduce back flexion and improve tool maintenance, and design changes would improve ESGs overall.

Hess, J. A., et al. (2010). "The impact of drywall handling tools on the low back." *Appl Ergon* 41(2): 305-312.

Carpenters and other construction workers who install drywall have high rates of strains and sprains to the low back and shoulder. Drywall is heavy and awkward to handle resulting in increased risk of injury. The purpose of this study was to evaluate several low-cost coupling tools that have the potential to reduce awkward postures in drywall installers. Five coupling tools were evaluated using the Lumbar Motion Monitor that measures trunk kinematics and predicts probability of low back disorder group membership risk (LBD risk). Workers answered surveys about their comfort while using each tool. The results indicate that use of the 2-person manual lift and the J-handle provide the best reduction in awkward postures, motions, low back sagittal moment, and LBD risk. The two-person manual lift appears to be the safest method of lifting and moving drywall, though using the two-person J-handle also significantly reduces injury risk. Given that carpenters are skeptical about using

equipment that can get in the way or get lost, a practical recommendation is promotion of two-person manual lifting. For single-person lifts, the Old Man tool is a viable option to decrease risk of MSDs.

Hess, J. A., et al. (2012). "Alternatives to lifting concrete masonry blocks onto rebar: biomechanical and perceptual evaluations." *Ergonomics* 55(10): 1229-1242.

This study examined the use of and barriers to H-block and high lift grouting, two alternatives to lifting concrete masonry blocks onto vertical rebar. Peak and cumulative shoulder motions were evaluated, as well as adoption barriers: H-block cost and stakeholder perceptions. Results indicated that using the alternatives significantly decreased peak shoulder flexion ($p < 0.001$). A case study indicated that building cost was higher with H-block, but the difference was less than 2% of the total cost. Contractors and specifiers reported important differences in perceptions, work norms, and material use and practices. For example, 48% of specifiers reported that use of high lift grouting was the contractor's choice, while 28% of contractors thought it must be specified. Use of H-block or high-lift grouting should be considered as methods to reduce awkward upper extremity postures. Cost and stakeholders' other perceptions present barriers that are important considerations when developing diffusion strategies for these alternatives. PRACTITIONER SUMMARY: This study provides information from several perspectives about ergonomic controls for a high risk bricklaying task, which will benefit occupational safety experts, health professionals and ergonomists. It adds to the understanding of shoulder stresses, material cost and stakeholder perceptions that will contribute to developing effective diffusion strategies.

Hinze, J., et al. (2006). "Analysis of construction worker injuries that do not result in lost time." *Journal of Construction Engineering and Management* 132(3): 321-326.

Attempts to examine the root causes of injuries in the construction industry have been largely focused on fatalities and other serious injuries. These efforts were undertaken with the assumption that the root causes of serious injuries could lead to identifying approaches that could prevent the recurrence of similar injuries in the future and that these approaches would also be successful in eliminating many minor injuries. While some injuries may be either minor or serious depending on small differences in worker position, etc., that assumption does not appear to be valid for most injuries. The trends of causes leading to minor injuries are often quite different from those resulting in serious injuries. With this assumption, an examination was conducted to profile nearly 136,000 construction worker injuries, most of which did not result in lost time. Results indicate that these injuries, not resulting in lost time, generally do not fit the profile of injuries that result in fatalities or that are serious. Over half of the injuries in the present study were associated with lacerations (usually of the fingers and hand) and injuries sustained by the lumbar spine, upper extremities, or eyes. The percentage of injuries that involved lacerations was considerably higher for construction than for all other industries. The costs of injuries were found to be quite varied, depending on the part of the body that was injured.

Hoffmeister, K., et al. (2015). "Ergonomics Climate Assessment: A measure of operational performance and employee well-being." *Appl Ergon* 50: 160-169.

Ergonomics interventions have the potential to improve operational performance and employee well-being. We introduce a framework for ergonomics climate, the extent to which an organization emphasizes and supports the design and modification of work to maximize both performance and well-being outcomes. We assessed ergonomics climate at a large manufacturing facility twice during a two-year period. When the organization used ergonomics to promote performance and well-being equally, and at a high level, employees reported less work-related pain. A larger discrepancy between measures of operational performance and employee well-being was

associated with increased reports of work-related pain. The direction of this discrepancy was not significantly related to work-related pain, such that it didn't matter which facet was valued more. The Ergonomics Climate Assessment can provide companies with a baseline assessment of the overall value placed on ergonomics and help prioritize areas for improving operational performance and employee well-being.

Horwitz, I. B. and B. P. McCall (2004). "Disabling and fatal occupational claim rates, risks, and costs in the Oregon construction industry 1990-1997." *J Occup Environ Hyg* 1(10): 688-698.

This study estimated injury and illness rates, risk factors, and costs associated with construction work in Oregon from 1990-1997 using all accepted workers' compensation claims by Oregon construction employees (N = 20,680). Claim rates and risk estimates were estimated using a baseline calculated from Current Population Survey data of the Oregon workforce. The average annual rate of lost-time claims was 3.5 per 100 workers. More than 50% of claims were by workers under 35 years and with less than 1 year of tenure. The majority of claimants (96.1%) were male. There were 52 total fatalities reported over the period examined, representing an average annual death rate of 8.5 per 100,000 construction workers. Average claim cost was \$10,084 and mean indemnity time was 57.3 days. Structural metal workers had the highest average days of indemnity of all workers (72.1), highest average costs per claim (\$16,472), and highest odds ratio of injury of all occupations examined. Sprains were the most frequently reported injury type, constituting 46.4% of all claims. The greatest accident risk occurred during the third hour of work. Training interventions should be extensively utilized for inexperienced workers, and prework exercises could potentially reduce injury frequency and severity.

Howard, J., et al. (2010). "Twenty years of NIOSH construction research." *J Safety Res* 41(3): 187-188.

This year marks the 20th anniversary of the Construction Research Program at the National Institute for Occupational Safety and Health (NIOSH). The Program started in 1990 through a \$1 million appropriation and a Congressional mandate to "develop a comprehensive prevention program directed at health problems affecting construction workers by expanding existing NIOSH activities in areas of surveillance, research, and intervention." The United States Congress provided additional direction and funding over the next five years, adding new focus areas such as traumatic injury, musculoskeletal disorders, surveillance, and intervention research. Support was provided for a cooperative agreement for an external National Construction Center with the aim to develop prevention-oriented strategies and programs, to provide linkages to the construction community, and to coordinate applied research. Before 1990, construction safety and health was a relatively obscure topic with few researchers specializing in this area of research. Information describing safety and health conditions in the industry was difficult to find. The fatality rate for the U.S. construction industry as a whole was estimated to be 25 per 100,000 full time equivalent (FTE) employees, the fatality rate for structural iron workers in 1992 was 143.3 deaths per 100,000 FTE, and the rate for electric power line installers was 149.3 deaths per 100,000 FTE. Yet, there were few regular conferences for both researchers and construction industry practitioners to share problems and solutions. When the NIOSH Construction Program was started, most decisions in safety and health were based on anecdotal information, occasionally using fatality data. There was, for instance, little awareness about non-fatal, but potentially disabling, conditions like musculoskeletal disorders or even of ergonomic interventions that would prevent these troubling conditions. Apart from confined space entry risks and hazardous waste operations, including asbestos management, there was no significant awareness of health hazards. That has changed substantially by characterizing outcomes using new data such as non-fatal injury and illness surveys, workers compensation claims, and health care utilization. Today there is a much more balanced, evidence-based perspective on the occupational safety and health needs of the construction industry. There is a rapidly expanding body of applied research that is steadily improving

in scientific quality and in ease of practical application. The collaboration between NIOSH and the National Construction Center is a model of public-private partnership in the industry. The collaboration has created a strong foundation for construction partnerships, especially as the program is poised to work with industry partners to move research to practice (r2p) in the coming years.

Hsiao, H., et al. (2008). "Effect of scaffold end frame carrying strategies on worker stepping response, postural stability, and perceived task difficulty." *Hum Factors* 50(1): 27-36.

OBJECTIVE: This study determined the most favorable strategy for carrying scaffold end frames while minimizing the risk of injuries from being struck by an object, falling, and overexertion. **BACKGROUND:** Scaffold erectors are at risk of high exposure to the aforementioned hazards associated with the dynamic human-scaffolding interface and work environments. Identifying an optimal work strategy can help reduce risk of injuries to the worker. **METHOD:** Three carrying methods, four types of work surfaces, two weights of scaffold frames, and three directions of stepping movement were tested in a laboratory with 18 construction workers. **RESULTS:** The effects of carrying method on postural instability and task difficulty rating were significant for handling the 22-kg end frame. Response time, postural instability, and perceived task difficulty rating were significantly reduced when the 9-kg end frame was used as compared with the 22-kg frame. **CONCLUSION:** The symmetric side-carrying method was the best option for handling 22-kg scaffold end frames. A 9-kg end frame (e.g., made of reinforced lightweight materials) has the potential to reduce injury risk among scaffold handlers during their scaffold erection and dismantling jobs. **APPLICATION:** Scaffold erectors may want to adopt the symmetric side-carrying method as the primary technique for handling the 22-kg scaffold end frame, which is currently the one most used in the industry.

Huang, Y. H., et al. (2007). "Corporate financial decision-makers' perceptions of workplace safety." *Accid Anal Prev* 39(4): 767-775.

This study, through a random national survey, explored how senior financial executives or managers (those who determined high-level budget, resource allocation, and corporate priorities) of medium-to-large companies perceive important workplace safety issues. The three top-rated safety priorities in resource allocation reported by the participants (overexertion, repetitive motion, and bodily reaction) were consistent with the top three perceived causes of workers' compensation losses. The greatest single safety concerns reported were overexertion, repetitive motion, highway accidents, falling on the same level and bodily reaction. A majority of participants believed that the indirect costs associated with workplace injury were higher than the direct costs. Our participants believed that money spent improving workplace safety would have significant returns. The perceived top benefits of an effective workplace safety program were increased productivity, reduced cost, retention, and increased satisfaction among employees. The perceived most important safety modification was safety training. The top reasons senior financial executives gave for believing their safety programs were better than those at other companies were that their companies paid more attention to and emphasized safety, they had better classes and training focused on safety, and they had teams/individuals focused specifically on safety.

Jacobsen, H. B., et al. (2013). "Construction Workers Struggle with a High Prevalence of Mental Distress, and This Is Associated with Their Pain and Injuries." *J Occup Environ Med* 55(10): 1197-1204.

OBJECTIVES: We aimed to investigate how mental distress was associated with pain and injuries in a convenience sample of construction workers. **METHODS:** A cross-sectional, mental health assessment was conducted in a convenience sample of construction workers (N = 172). A subsample participated in a clinical interview (n = 10). We used a cutoff (1.50 or greater) on Hopkins Symptom Checklist-25 to determine substantial mental distress and determined associations with pain and injury

outcomes. RESULTS: The prevalence of substantial mental distress was 16% in the workers. This was supported by follow-up clinical interviews where 9 of 10 workers fulfilled the criteria for a mental disorder. Substantial mental distress was associated with both injury rate and self-reported pain. CONCLUSION: This pilot study strongly suggests the need for rigorous studies on construction worker mental health and how it affects their work and well-being. Copyright © 2013 by American College of Occupational and Environmental Medicine.

Jaegers, L., et al. (2014). "Development of a program logic model and evaluation plan for a participatory ergonomics intervention in construction." *Am J Ind Med* 57(3): 351-361.

Background: Intervention studies in participatory ergonomics (PE) are often difficult to interpret due to limited descriptions of program planning and evaluation. Methods: In an ongoing PE program with floor layers, we developed a logic model to describe our program plan, and process and summative evaluations designed to describe the efficacy of the program. Results: The logic model was a useful tool for describing the program elements and subsequent modifications. The process evaluation measured how well the program was delivered as intended, and revealed the need for program modifications. The summative evaluation provided early measures of the efficacy of the program as delivered. Conclusions: Inadequate information on program delivery may lead to erroneous conclusions about intervention efficacy due to Type III error. A logic model guided the delivery and evaluation of our intervention and provides useful information to aid interpretation of results. © 2013 Wiley Periodicals, Inc.

Jorgensen, M. J., et al. (2007). "Repeatability of a checklist for evaluating cab design characteristics of heavy mobile equipment." *J Occup Environ Hyg* 4(12): 913-922.

Risk factors associated with the development of musculoskeletal discomfort and disorders during the operation of heavy mobile equipment include whole-body vibration and awkward and sustained joint postures of the shoulders, neck, and trunk. Cab design may influence awkward postures of the joints, and task duration may influence duration of exposure to awkward and static postures and whole-body vibration. To reduce exposure to risk factors related to the interface between cab design and task, it may be necessary for manufacturers to address cab design. This study assessed the repeatability of a cab design checklist developed to evaluate various design characteristics that can influence exposure to risk factors for musculoskeletal discomfort. The ability of the cab design checklist to identify posture-related deficiencies of design was also assessed. The checklist was used by two administrators across 10 pieces of heavy construction equipment. Video analysis was performed to quantify postures of the neck, shoulder, and trunk; correlation analysis was used to determine whether specific questions from the checklist were associated with the identification of awkward postures. The repeatability assessment resulted in kappa coefficients ranging from 0.52 to 1.0 (good-to-excellent reproducibility) across each piece of equipment, and an overall kappa coefficient of 0.77 (excellent reproducibility) when considering all equipment together. Results from the correlation analysis showed that shoulder flexion posture was correlated with scores from the cab design checklist. However, results of the cab design checklist were not significantly correlated with shoulder abduction or awkward postures of the neck and trunk. Results suggest that the cab design checklist may be useful for identifying cab design characteristics that need further improvement and for identifying design characteristics that increase shoulder flexion. The strength of the repeatability assessment suggests that outcomes of the cab design checklist administered by different individuals may be consistent, independent of the type of equipment being assessed.

Kao, D. S., et al. (2008). "Serological tests for diagnosis and staging of hand-arm vibration syndrome (HAVS)." *Hand (N Y)* 3(2): 129-134.

The current gold standard for the diagnosis and staging of hand-arm vibration syndrome (HAVS) is the Stockholm workshop scale, which is subjective and relies on the patient's recalling ability and honesty. Therefore, great potentials exist for diagnostic and staging errors. The purpose of this study is to determine if objective serum tests, such as levels of soluble thrombomodulin (sTM) and soluble intercellular adhesion molecule-1 (sICAM-1), may be used in the diagnosis and staging of HAVS. Twenty two nonsmokers were divided into a control group (n = 11) and a vibration group (n = 11). The control group included subjects without history of frequent vibrating tool use. The vibration group included construction workers with average vibrating tool use of 12.2 years. All were classified according to the Stockholm workshop scale (SN, sensorineural symptoms; V, vascular symptoms. SN0, no numbness; SN1, intermittent numbness; SN2, reduced sensory perception; SN3, reduced tactile discrimination; V0, no vasospastic attacks; V1, intermittent vasospasm involving distal phalanges; V2, intermittent vasospasm extending to middle phalanges; V3, intermittent vasospasm extending to proximal phalanges; V4, skin atrophy/necrosis). All control subjects were SN0 V0. Seven out of 11 vibration subjects were SN1 V1, and 4 out of 11 were SN1 V2. A 10-cm³ sample of venous blood was collected from each subject. The sTM and sICAM-1 levels were determined by enzyme-linked immunosorbent assay. The mean plasma sTM levels were as follows: control group = 2.93 +/- 0.47 ng/ml, and vibration group = 3.61 +/- 0.24 ng/ml. The mean plasma sICAM-1 levels were as follows: control group = 218.8 +/- 54.1 ng/ml, and vibration group = 300.3 +/- 53.2 ng/ml. The sTM and sICAM-1 differences between control and vibration groups were statistically significant (p < 0.0002 and p < 0.001, respectively). When reference ranges provided by Hemostasis Reference Lab were used as cut-off values, all sTM and sICAM-1 levels were within range, except three vibration individuals (27%) who had sICAM-1 levels greater than the reference range. This was not statistically significant (p = 0.08). When subjects were compared based on the Stockholm workshop scale, mean plasma sTM levels were SN0 V0 group = 2.93 +/- 0.47 ng/ml, SN1 V1 group = 3.59 +/- 0.25 ng/ml, and SN1 V2 group = 3.65 +/- 0.27 ng/ml, and mean plasma sICAM-1 levels were SN0 V0 = 219 +/- 54.1 ng/ml, SN1 V1 = 275 +/- 33.5 ng/ml, and SN1 V2 = 345 +/- 54.6 ng/ml. The difference in sTM level among the three groups was statistically significant (p < 0.001). The difference in sICAM-1 level among the three groups was also statistically significant (p < 0.002). The sTM and sICAM-1 levels are statistically higher in subjects with HAVS, with levels proportional to the disease severity. However, large population studies are needed to determine the "real-life" standard reference ranges for sTM and sICAM-1.

Kidd, P., et al. (2004). "Overcoming recruitment challenges in construction safety intervention research." *Am J Ind Med* 45(3): 297-304.

BACKGROUND: Recruiting workers in small construction companies and securing their participation in voluntary safety programs or safety research poses unique challenges. Worker turnover and worksite changes contribute to difficulties in locating and enrolling participants. Economic pressures and time demands potentially threaten ongoing participation. **METHODS:** Six simulation exercises designed to reduce back and fall injuries in small construction companies were developed based on data from focus groups of workers and company owners. Working with a workers' compensation insurer, we had access to owner-operators of general, heavy, and special trade construction companies reporting less than \$10,000 in payroll expenses. Recruitment methods included a participation incentive, mailed invitations followed by phone contacts, and follow-up reminders. **RESULTS:** Despite using recruitment methods recommended in the literature, participation rates were low over a 2-year intervention period. Because of these difficulties, factors affecting participation or nonparticipation became an additional research focus. Owners' perceptions of already having a good safety record and of the time demands of participation were the most commonly cited reasons for not participating. **CONCLUSIONS:** Literature on recruitment emphasizes processes and procedures under investigator control rather than understanding potential participants' judgments

about the adequacy of their existing practices and the potential benefits of intervention participation relative to potential time and productivity trade-offs. Greater attention to such judgments may enhance recruitment and participation in under-studied and difficult to access populations.

Kim, S., et al. (2011). "Low back injury risks during construction with prefabricated (panelised) walls: effects of task and design factors." *Ergonomics* 54(1): 60-71.

New technology designed to increase productivity in residential construction may exacerbate the risk of work-related musculoskeletal disorders (WMSDs) among residential construction workers. Of interest here are panelised (prefabricated) wall systems (or panels) and facilitating an ongoing effort to provide proactive control of ergonomic exposures and risks among workers using panels. This study, which included 24 participants, estimated WMSD risks using five methods during common panel erection tasks and the influences of panel mass (sheathed vs. unsheathed) and size (wall length). WMSD risks were fairly high overall; e.g. 34% and 77% of trials exceeded the 'action limits' for spinal compressive and shear forces, respectively. Heavier (sheathed) panels significantly increased risks, although the magnitude of this effect differed with panel size and between tasks. Higher levels of risk were found in tasks originating from ground vs. knuckle height. Several practical recommendations based on the results are discussed. STATEMENT OF RELEVANCE: Panelised wall systems have the potential to increase productivity in residential construction, but may result in increased worker injury risks. Results from this study can be used to generate future panel design and construction processes that can proactively address WMSD risks.

Kim, S., et al. (2012). "The benefits of an additional worker are task-dependent: assessing low-back injury risks during prefabricated (panelized) wall construction." *Appl Ergon* 43(5): 843-849.

Team manual material handling is a common practice in residential construction where prefabricated building components (e.g., wall panels) are increasingly used. As part of a larger effort to enable proactive control of ergonomic exposures among workers handling panels, this study explored the effects of additional workers on injury risks during team-based panel erection tasks, specifically by quantifying how injury risks are affected by increasing the number of workers (by one, above the nominal or most common number). Twenty-four participants completed panel erection tasks with and without an additional worker under different panel mass and size conditions. Four risk assessment methods were employed that emphasized the low back. Though including an additional worker generally reduced injury risk across several panel masses and sizes, the magnitude of these benefits varied depending on the specific task and exhibited somewhat high variability within a given task. These results suggest that a simple, generalizable recommendation regarding team-based panel erection tasks is not warranted. Rather, a more systems-level approach accounting for both injury risk and productivity (a strength of panelized wall systems) should be undertaken.

Kim, S. S., et al. (2014). "Contractor-, steward-, and coworker-safety practice: Associations with musculoskeletal pain and injury-related absence among construction apprentices." *Int Arch Occup Environ Health* 87(5): 493-500.

Objectives: This paper sought to assess organizational safety practices at three different levels of hierarchical workplace structure and to examine their association with injury outcomes among construction apprentices. Methods: Using a cross-sectional sample of 1,775 construction apprentices, three measures of organizational safety practice were assessed: contractor-, steward-, and coworker-safety practice. Each safety practice measure was assessed using three similar questions (i.e., on-the-job safety commitment, following required or recommended safe work practices, and correcting unsafe work practices); the summed average of the responses ranged from 1 to 4, with a higher score indicating poorer safety practice. Outcome variables included the prevalence of four types of

musculoskeletal pain (i.e., neck, shoulder, hand, and back pain) and injury-related absence. Results: In adjusted analyses, contractor-safety practice was associated with both hand pain (OR: 1.27, 95 % CI: 1.04, 1.54) and back pain (OR: 1.40, 95 % CI: 1.17, 1.68); coworker-safety practice was related to back pain (OR: 1.42, 95 % CI: 1.18, 1.71) and injury-related absence (OR: 1.36, 95 % CI: 1.11, 1.67). In an analysis that included all three safety practice measures simultaneously, the association between coworker-safety practice and injury-related absence remained significant (OR: 1.68, 95 % CI: 1.20, 2.37), whereas all other associations became non-significant. Conclusions: This study suggests that organizational safety practice, particularly coworker-safety practice, is associated with injury outcomes among construction apprentices. © 2013 Springer-Verlag Berlin Heidelberg.

Kincl, L. D., et al. (2016). "Safety voice for ergonomics (SAVE) project: Protocol for a workplace cluster-randomized controlled trial to reduce musculoskeletal disorders in masonry apprentices." *BMC Public Health* 16: 362.

Background: Masons have the highest rate of overexertion injuries among all construction trades and rank second for occupational back injuries in the United States. Identified ergonomic solutions are the primary method of reducing exposure to risk factors associated with musculoskeletal disorders. However, many construction workers lack knowledge about these solutions, as well as basic ergonomic principles. Construction apprentices, as they embark on their careers, are greatly in need of ergonomics training to minimize the cumulative exposure that leads to musculoskeletal disorders. Apprentices receive safety training; however, ergonomics training is often limited or non-existent. In addition, apprenticeship programs often lack "soft skills" training on how to appropriately respond to work environments and practices that are unsafe. The SAVE program - SAFETY VOICE FOR ERGONOMICS - strives to integrate evidence-based health and safety training strategies into masonry apprenticeship skills training to teach ergonomics, problem solving, and speaking up to communicate solutions that reduce musculoskeletal injury risk. The central hypothesis is that the combination of ergonomics training and safety voice promotion will be more effective than no training or either ergonomics training alone or safety voice training alone. Methods/design: Following the development and pilot testing of the SAVE intervention, SAVE will be evaluated in a cluster-randomized controlled trial at 12 masonry training centers across the U.S. Clusters of apprentices within centers will be assigned at random to one of four intervention groups (n = 24 per group): (1) ergonomics training only, (2) safety voice training only, (3) combined ergonomics and safety voice training, or (4) control group with no additional training intervention. Outcomes assessed at baseline, at the conclusion of training, and then at six and 12 months post training will include: musculoskeletal symptoms, general health perceptions, knowledge of ergonomic and safety voice principles, and perception and attitudes about ergonomic and safety voice issues. Discussion: Masons continue to have a high rate of musculoskeletal disorders. The trade has an expected increase of 40 % in the number of workers by 2020. Therefore, a vetted intervention for apprentices entering the trade, such as SAVE, could reduce the burden of musculoskeletal disorders currently plaguing the trade. © 2016 Kincl et al.

Kittusamy, N. K. and B. Buchholz (2004). "Whole-body vibration and postural stress among operators of construction equipment: a literature review." *J Safety Res* 35(3): 255-261.

INTRODUCTION: Operators of construction equipment perform various duties at work that expose them to a variety of risk factors that may lead to health problems. A few of the health hazards among operators of construction equipment are: (a) whole-body vibration, (b) awkward postural requirements (including static sitting), (c) dust, (d) noise, (e) temperature extremes, and (f) shift work. It has been suggested that operating engineers (OEs) are exposed to two important risk factors for the development of musculoskeletal disorders: whole-body vibration and non-neutral body postures. METHOD: This review evaluates selected papers that have studied exposure to whole-body vibration

and awkward posture among operators of mobile equipment. There have been only few studies that have specifically examined exposure of these risk factors among operators of construction equipment. Thus other studies from related industry and equipment were reviewed as applicable. CONCLUSION: In order to better understand whole-body vibration and postural stress among OEs, it is recommended that future studies are needed in evaluating these risk factors among OEs.

Knezovich, M. and J. D. McGlothlin (2007). "The development and field testing of an ergonomic intervention for the preparation of footers in postframe building construction." *J Occup Environ Hyg* 4(2): D10-14.

The construction work environment is a challenging field for both industry professionals and researchers to improve working conditions in the scope of safety and health. The construction work environment is unique to most work environments in private industry because of its potential to change as work crews progress from job to job. From a standpoint of ergonomics, both identifying and correcting work hazards is often difficult because of these changing work environments. In the past decade, the incidence rates of nonfatal occupational injuries and illnesses for construction have been consistently higher than those of private industry despite a trend of reduction for both categories. The Bureau of Labor Statistics (BLS) data for 2002 shows an incidence rate of nonfatal occupational illnesses and injuries of 7.1 recordable cases per 100 workers for construction compared with 5.3 recordable cases per 100 workers for private industry. The goals of this study were to (1) develop an ergonomic intervention (a footer pad drop device) designed to reduce lowback disc compression force for a manual material handling task in which a construction crew member lifts and releases concrete footer pads into predrilled holes, (2) determine the estimated effect of the intervention on lowback compression force, (3) determine the effect of the intervention on other work intensity measures such as heart rate and self-reported ratings of perceived exertion, and (4) characterize the pre- and post-intervention mean cycle time associated with the task of interest.

Kucera, K. L., et al. (2011). "Medical care surrounding work-related back injury claims among Washington State Union Carpenters, 1989-2003." *Work* 39(3): 321-330.

OBJECTIVE: We describe medical care received through workers' compensation (WC) and union-provided insurance surrounding work-related back injuries and examine relationships between care provided and time off work among a large cohort of carpenters. METHODS AND PARTICIPANTS: Union records identified a cohort of 20,642 carpenters working in Washington State from 1989-2003 and their private health insurance claims. These data were linked to workers' compensation files from this state-run program including records of medical care. RESULTS: Over 74,000 WC medical encounters resulted from 2959 work-related back injuries. Eleven percent received private care for musculoskeletal back pain within 90 days of work-related injury; this proportion increased with increasing lost days. Delay to physical therapy was more prevalent among those out of work longest. The proportion of claimants with care from both systems and from private utilization only increased after the first 90 days and, for the subset with at least one paid lost work day, after return to work. CONCLUSIONS: Examination of medical care through both systems versus solely in workers' compensation provides a more complete understanding of back injury care while also demonstrating complexity. Differences in outcomes based upon treatment shortly after injury are worthy of further exploration.

Kucera, K. L., et al. (2009). "Predictors of delayed return to work after back injury: A case-control analysis of union carpenters in Washington State." *Am J Ind Med* 52(11): 821-830.

METHODS: Union administrative records identified 20,642 union carpenters who worked in Washington State from 1989 to 2003. The Department of Labor and Industries provided records of

workers' compensation claims and associated medical care. Work-related back claims (n = 4,241) were identified by ANSI codes (back, trunk, or neck/back) or ICD-9 codes relevant to medical care consistent with a back injury. Cases (n = 738) were defined as back injury claims with >90 days of paid lost time; controls (n = 699) resulted in return to work within 30 days. Logistic regression models estimated odds ratios and 95% confidence intervals (OR, 95% CI) of delayed return to work (DRTW). RESULTS: Thirty percent of case claims and 8% of control claims were identified by an ICD-9 code. DRTW after back injury was associated with being female (2.7, 95% CI: 1.3-5.5), age 30-44 (1.2, 95% CI: 0.9-1.7) and age over 45 (1.6, 95% CI: 1.1-2.3), four or more years union experience (1.4, 95% CI: 1.1-1.8), previous paid time loss back claim (1.8, 95% CI: 1.3-2.5), and \geq 30-day delay to medical care (3.6, 95% CI: 2.1, 6.1). Evidence of more acute trauma was also associated with DRTW. CONCLUSIONS: Use of ICD-9 codes identified claims with multiple injuries that would otherwise not be captured by ANSI codes alone. Though carpenters of younger age and inexperience were at increased risk for a paid lost time back injury claim, older carpenters and more experienced workers, once injured, were more likely to have DRTW as were those who experienced acute events.

Lee, W., et al. (2017). "An evaluation of wearable sensors and their placements for analyzing construction worker's trunk posture in laboratory conditions." *Appl Ergon* 65: 424-436.

This study investigates the effect of sensor placement on the analysis of trunk posture for construction activities using two off-the-shelf systems. Experiments were performed using a single-parameter monitoring wearable sensor (SPMWS), the ActiGraph GT9X Link, which was worn at six locations on the body, and a multi-parameter monitoring wearable sensor (MPMWS), the Zephyr BioHarness3, which was worn at two body positions. One healthy male was recruited and conducted 10 experiment sessions to repeat measurements of trunk posture within our study. Measurements of upper-body thoracic bending posture during the lifting and lowering of raised deck materials in a laboratory setting were compared against video-captured observations of posture. The measurements from the two sensors were found to be in agreement during slow-motion symmetric bending activities with a target bending of ≤ 45 degrees. However, for asymmetric bending tasks, when the SPMWS was placed on the chest, its readings were substantially different from those of the MPMWS worn on the chest or under the armpit.

LeMasters, G., et al. (2006). "Functional impairment and quality of life in retired workers of the construction trades." *Exp Aging Res* 32(2): 227-242.

This cross-sectional study compared the quality of life and physical health of retirees from the construction industry to that of retirees from more sedentary occupations. The feasibility of cooperation from the unions and their retirees for a larger health study was also examined. The mailed health survey assessed current physical functioning, role limitations as a result of poor health, pain, and past and current problems with falls and injuries. The survey was completed by 77 construction and 174 nonconstruction retirees. Results were striking with 42.1% of the construction retirees, compared to 12.9% of the male and 14.3% of female nonconstruction retirees reporting significantly poorer health. A multiple regression analysis comparing male construction to male nonconstruction retirees showed male construction retirees were almost five times more likely to report their health as being fair or poor. Further, significantly more male construction, versus male nonconstruction retirees, reported that their physical health reduced the time they were able to spend on daily activities. Almost one in five (19.4%) construction retirees described themselves as having severe to very severe pain versus 3.1% of the male nonconstruction retirees. Construction retirees reported significantly greater problems with their vision, neck and shoulders, hands and wrists, hips, knees, and ankle/feet joints. These findings suggest that with our rapidly aging population, there will be enormous physical,

emotional, and financial costs related to construction work and that prevention and intervention measures are needed for current employees in this profession.

Li, F. and R. L. Huston (2011). "A means for predicting low-back musculo-skeletal disorders from jolting and jarring of heavy equipment operators." *Theoretical Issues in Ergonomics Science* 12(4): 379-394.

This article presents a step-by-step procedure for predicting the occurrence (or non-occurrence) of lumbar spinal disorders in workers subjected to long-term, whole-body vibration exposure. The procedure consists of relatively simple steps including the use of a biodynamic computer model together with an International Organization for Standardization (ISO) standard. The underlying analysis is based upon Kane's equations and the resulting worker model is validated with experimental data provided by the National Institute for Occupational Safety and Health (NIOSH), Biodynamics Laboratory, University of Vermont, and with published data. © 2011 Taylor & Francis.

Lipscomb, H. J., et al. (2008). "Back injuries among union carpenters in Washington State, 1989-2003." *Am J Ind Med* 51(6): 463-474.

BACKGROUND: There is limited information on occupational back pain specific to carpenters despite their known exposures to recognized occupational risk factors and limited opportunities for modified work due to the predominantly heavy nature of their work. **METHODS:** By combining union records with worker's compensation claims, we describe work-related back injuries, including associated medical diagnoses, among a well-defined cohort of union carpenters between 1989 and 2003. High risk subgroups were explored based on age, gender, union tenure, and predominant type of work. Paid lost time claims were contrasted to less serious events, and injuries sustained from overexertion activities were contrasted with those sustained through more acute trauma. **RESULTS:** Back injuries occurred at an overall rate of 6.2/200,000 hours worked. Most injuries were coded in the compensation records as sprains, but there was little agreement between these nature of injury codes and ICD9 diagnosis codes. Injury rates declined most significantly over time for injuries secondary to overexertion. In multivariate analyses, we observed similar patterns of risk for the types of claims evaluated despite disparate mechanisms and severity. Those who worked predominantly in residential carpentry or drywall installation were consistently at greatest risk. **CONCLUSIONS:** Overexertion injuries from manual materials handling activities are responsible for the largest burden of back injuries among these carpenters, but a growing proportion of injuries result from acute traumatic events. Interventions are called for which specifically address risk among residential carpenters and drywall installers. These data provide additional evidence that Bureau of Labor Statistics data underestimate work-related injuries.

Lipscomb, H. J., et al. (2008). "Incident and recurrent back injuries among union carpenters." *Occup Environ Med* 65(12): 827-834.

AIMS: To describe incident and recurrent work-related back injuries among union carpenters, describe the hazard function for each and associated risk factors, and explore predictors of subsequent musculoskeletal back injury based on different definitions of the initial injury. **METHODS:** This study identified a dynamic cohort of 18 768 carpenters who worked in the State of Washington 1989-2003, their hours worked each month, and their work-related back injuries and medical claims for treatment including ICD-9 codes. Using Poisson regression we calculated rates and rate ratios (RRs) of incident and recurrent injury adjusting for age, gender, union tenure and type of carpentry work. Predictors of subsequent musculoskeletal back injury were explored based on different definitions of the incident injury, as were time periods of greatest risk following return to work. **RESULTS:** Recurrent back injuries occurred at a rate 80% higher than initial injuries. Survival curves were significantly different for incident and recurrent injuries, but patterns of relative risk were similar. Individuals with greatest

union tenure were at lowest risk, likely reflecting a healthy worker effect or lower physical exposures with seniority. Individuals with long periods of work disability with their first injury were at particularly high risk of subsequent musculoskeletal injury compared with those with no prior history (RR 2.3; 95% CI 2.0 to 2.7), as were individuals with degenerative diagnoses (RR 2.0; 95% CI 1.5 to 2.6). Risk for second injury peaked between 1000 and 1500 h after return to work and then gradually declined. CONCLUSIONS: Carpenters with long periods of work disability following back injury warrant accommodation and perhaps better rehabilitation efforts to avoid re-injury. Challenges to workplace accommodation and limited ability to clearly define readiness to return to work following injury demonstrate the need for primary prevention of back injuries through attention to engineering solutions among carpenters involved in strenuous work.

Lipscomb, H. J., et al. (2009). "Compensation costs of work-related back disorders among union carpenters, Washington State 1989-2003." *Am J Ind Med* 52(8): 587-595.

BACKGROUND: We measured resources used to provide medical care and to estimate lost productivity represented by payments for lost work time or impairment for work-related back injuries among a large cohort of union carpenters over 15 years. METHODS: Using administrative data we identified a cohort of carpenters, their hours worked, their workers' compensation claims and associated costs. After adjustment for inflation and discounting to 2006 dollars, yearly costs for injuries and payment rates based on hours worked were calculated. Using negative binomial regression, dollars paid per claim were modeled based on age, gender, union tenure, and predominant type of work of the carpenter and whether the injury resulted from overexertion or acute trauma. RESULTS: Workers' compensation costs for back injuries exceeded \$128 million dollars between 1998 and 2003, representing payments of \$0.97 for each hour of work. Costs per hour of work declined substantively over time due largely to declining overexertion injury rates. Traumatic injuries, though less common than overexertion injuries, were more expensive. Costs increased with the number of prior back injuries and with increasing age, beginning as early as age 30. CONCLUSIONS: Increasing costs even among relatively young carpenters likely reflect the heavy nature of their work rather than simply the effects of biological aging. Musculoskeletal back problems remain a common, and consequently costly, source of injury among these carpenters that needs to be addressed through engineering modifications; there are also clearly needs for prevention of the often more costly back injuries associated with acute trauma.

Lipscomb, H. J., et al. (2009). "Who is paying the bills? Health care costs for musculoskeletal back disorders, Washington State Union Carpenters, 1989-2003." *J Occup Environ Med* 51(10): 1185-1192.

OBJECTIVE: Factors associated with private health insurance payment rates for musculoskeletal back disorders were examined among a 15-year cohort of union carpenters. Payment patterns were contrasted with work-related back injury rates over time. METHODS: Negative binomial regression was used to assess payment rates; generalized estimated equations accounted for multiple observations per person and cost correlation within subjects. RESULTS: Payment rates increased after work-related injury and with the number of injuries. Increasing private payments and deductibles (inflation-adjusted and discounted) were observed in contrast with a marked decline in reported work-related injuries. CONCLUSIONS: Private insurance payments do not appear to be independent of work-related back injury. Findings suggest cost-shifting from workers' compensation to the union-provided health insurance and to the worker; they also provide a warning regarding reliance on workers' compensation statistics for surveillance of work-related disorders or disease.

Lipscomb, H. J., et al. (2009). "Health care utilization for musculoskeletal back disorders, Washington State union carpenters, 1989-2003." *J Occup Environ Med* 51(5): 604-611.

OBJECTIVE: Private health care utilization rates for musculoskeletal back disorders were contrasted to rates of work-related injuries or disorders for a large cohort of union carpenters over a 15-year period. **METHODS:** Yearly utilization rates were compared with rates of work-related back injuries or disorders. Negative binomial regression with generalized estimating equations was used to assess utilization rates based on age, gender, union tenure, type of work, and previous work-related back injuries. **RESULTS:** Private utilization rates were over twice as high in 2003 as in 1989 whereas compensation rates declined substantially. Utilization was higher among carpenters with less union tenure and increased with the number of work-related injuries. **CONCLUSIONS:** Patterns of utilization across private and workers' compensation delivery systems are not independent; we need to look broadly at sources of health care coverage to better understand the health of working populations.

Lipscomb, H. J., et al. (2006). "Injuries from slips and trips in construction." *Appl Ergon* 37(3): 267-274.

Construction injuries preceded by a slip or trip were documented using data from the building of the Denver International Airport (Denver, Colorado, USA), the largest construction project in the world at the time. Slips and trips occurred at a rate of 5/200,000 h worked accounting for 18% of all injuries and 25% of workers' compensation payments, or more than \$10 million. Slips contributed to the vast majority (85%) of same-level falls and over 30% of falls from height, as well as a significant number of musculoskeletal injuries sustained after slipping or tripping but without falling. The injury burden would have been under-recognized in analyses of most coded compensation records. In contrast to other types of injuries, the most common contributing factors were environmental in nature including conditions of walking and working surfaces, terrain and weather. Due to the very dynamic nature of construction work, reducing slips and trips will require a focus on environmental and organizational solutions that evolve as the site changes and the construction project evolves.

Lipscomb, H. J., et al. (2015). "Musculoskeletal concerns do not justify failure to use safer sequential trigger to prevent acute nail gun injuries." *Am J Ind Med* 58(4): 422-427.

Background: Acute nail gun injuries can be controlled significantly by using tools with sequential triggers and training. Concern has been raised that sequential triggers, which require that the nose piece of the gun be depressed prior to pulling the trigger, could increase risk of musculoskeletal problems. **Methods:** We conducted active injury surveillance among union carpenter apprentices to monitor acute injuries and musculoskeletal disorders between 2010 and 2013. **Results:** Acute injury risk was 70% higher with contact trip rather than sequential triggers. Musculoskeletal risk was comparable (contact trip 0.09/10,000hr (95% CI, 0.02-0.26); sequential 0.08/ 10,000hr (95% CI 0.02-0.23)). **Conclusions:** Concern about excess risk of musculoskeletal problems from nail guns with sequential triggers is unwarranted. Both actuation systems carry comparable musculoskeletal risk which is far less than the risk of acute injury; there is clearly no justification for failure to prevent acute injuries through use of the safer sequential trigger. *Am. J. Ind. Med.* 58:422-427, 2015. © 2015 Wiley Periodicals, Inc.

Lipscomb, H. J., et al. (2015). "Non-reporting of work injuries and aspects of jobsite safety climate and behavioral-based safety elements among carpenters in Washington state." *Am J Ind Med* 58(4): 411-421.

Background: Declining work injury rates may reflect safer work conditions as well as under-reporting. **Methods:** Union carpenters were invited to participate in a mailed, cross-sectional survey designed to capture information about injury reporting practices. Prevalence of non-reporting and fear of repercussions for reporting were compared across exposure to behavioral-based safety elements and three domains of the Nordic Safety Climate Questionnaire (NOSACQ-50). **Results:** The majority (>75%) of the 1,155 participants felt they could report work-related injuries to their supervisor without

fear of retribution, and most felt that the majority of injuries on their jobsites got reported. However, nearly half indicated it was best not to report minor injuries, and felt pressures to use their private insurance for work injury care. The prevalence of non-reporting and fear of reporting increased markedly with poorer measures of management safety justice (NOSACQ-50). Conclusions: Formal and informal policies and practices on jobsites likely influence injury reporting. *Am. J. Ind. Med.* 58:411-421, 2015. © 2015 Wiley Periodicals, Inc.

Lipscomb, H. J., et al. (2015). "Contrasting patterns of care for musculoskeletal disorders and injuries of the upper extremity and knee through workers' compensation and private health care insurance among union carpenters in Washington State, 1989 to 2008." *Am J Ind Med* 58(9): 955-963.

Background: Musculoskeletal symptoms and disorders (MSDs) are common reasons for visits to medical providers in the general population and they are common work-related complaints. Prior reports raise concerns as to whether declines in workers' compensation (WC) rates represent true improvement in occupational health and safety or shifting of care to other payment systems. Methods: By linking administrative records, we compared patterns of WC claims and private health care utilization for disorders of the upper extremity (UE) and knee among a large cohort of union carpenters over a 20-year period. Results: As WC claim rates declined, private health care utilization increased. The increase was muted somewhat but sustained when adjusting for other patterns of health care utilization. Conclusions: Findings suggest the decline of WC claim rates do not solely represent improved occupational safety in this population, but also a considerable shifting of care to their private insurance coverage over time. © 2015 Wiley Periodicals, Inc.

Lipscomb, H. J., et al. (2015). "Workers' compensation claims for musculoskeletal disorders and injuries of the upper extremity and knee among union carpenters in Washington State, 1989-2008." *Am J Ind Med* 58(4): 428-436.

BACKGROUND: Numerous aspects of construction place workers at risk of musculoskeletal disorders and injuries (MSDs). Work organization and the nature of MSDs create surveillance challenges. METHODS: By linking union records with workers' compensation claims, we examined 20-year patterns of MSDs involving the upper extremity (UE) and the knee among a large carpenter cohort. RESULTS: MSDs were common and accounted for a disproportionate share of paid lost work time (PLT) claims; UE MSDs were three times more common than those of the knee. Rates declined markedly over time and were most pronounced for MSDs of the knee with PLT. Patterns of risk varied by extremity, as well as by age, gender, union tenure, and predominant work. Carpenters in drywall installation accounted for the greatest public health burden. CONCLUSIONS: A combination of factors likely account for the patterns observed over time and across worker characteristics. Drywall installers are an intervention priority.

Lombardi, D. A., et al. (2011). "Work-related falls from ladders--a follow-back study of US emergency department cases." *Scand J Work Environ Health* 37(6): 525-532.

OBJECTIVES: Ladder falls comprise 16% of all US workplace fall-related fatalities, and ladder use may be particularly hazardous among older workers. This follow-back study of injured workers from a nationally representative sample of US emergency departments (ED) focused on factors related to ladder falls in three domains of the work environment: work equipment, work practices, and worker-related factors. Risk factors for fractures, the most frequent and severe outcome, were also evaluated. METHODS: Workers injured from a ladder fall, treated in one of the 65 participating ED in the occupational National Electronic Injury Surveillance System (NEISS) were asked to participate. The questionnaire included worker demographics, injury, ladder and work equipment and environment characteristics, work tasks, and activities. Multivariate logistic regression models estimated odds ratios

and 95% confidence intervals of a work-related fracture. RESULTS: Three-hundred and six workers experiencing an injury from an--on average--7.5-foot-fall from a step, extension, or straight ladder were interviewed primarily from construction, installation, maintenance, and repair professions. Injuries were most frequently to the arm, elbow or shoulder; head, neck, or face with diagnoses were primarily fracture, strain, sprain, contusion or abrasion. Workers were most frequently standing or sitting on the ladder while installing, hanging an item, or performing a repair when they fell. Ladder movement was the mechanism in 40% of falls. Environmental conditions played a role in <10% of cases. There was a significant association between fracture risk and fall height while working on the ladder that was also influenced by older work age. CONCLUSIONS: This study advances knowledge of falls from ladders to support those who specify means and methods, select equipment, and plan, supervise, or manage the performance of employees working at heights.

Lowe, B., et al. (2013). "Finger Tendon Travel Associated with Sequential Trigger Nail Gun Use." *IIE Trans Occup 1*(2): 109-118.

BACKGROUND: Pneumatic nail guns used in wood framing are equipped with one of two triggering mechanisms. Sequential actuation triggers have been shown to be a safer alternative to contact actuation triggers because they reduce traumatic injury risk. However, the sequential actuation trigger must be depressed for each individual nail fired as opposed to the contact actuation trigger, which allows the trigger to be held depressed as nails are fired repeatedly by bumping the safety tip against the workpiece. As such, concerns have been raised about risks for cumulative trauma injury, and reduced productivity, due to repetitive finger motion with the sequential actuation trigger. PURPOSE: This study developed a method to predict cumulative finger flexor tendon travel associated with the sequential actuation trigger nail gun from finger joint kinematics measured in the trigger actuation and productivity standards for wood-frame construction tasks. METHODS: Finger motions were measured from six users wearing an instrumented electrogoniometer glove in a simulation of two common framing tasks-wall building and flat nailing of material. Flexor tendon travel was calculated from the ensemble average kinematics for an individual nail fired. RESULTS: Finger flexor tendon travel was attributable mostly to proximal interphalangeal and distal interphalangeal joint motion. Tendon travel per nail fired appeared to be slightly greater for a wall-building task than a flat nailing task. The present study data, in combination with construction industry productivity standards, suggest that a high-production workday would be associated with less than 60 m/day cumulative tendon travel per worker (based on 1700 trigger presses/day). CONCLUSION AND APPLICATIONS: These results suggest that exposure to finger tendon travel from sequential actuation trigger nail gun use may be below levels that have been previously associated with high musculoskeletal disorder risk.

Ludewig, P. M. and J. D. Borstad (2003). "Effects of a home exercise programme on shoulder pain and functional status in construction workers." *Occup Environ Med 60*(11): 841-849.

Background: Repetitive or sustained elevated shoulder postures have been identified as a significant risk factor for occupationally related shoulder musculoskeletal disorders. Construction workers exposed to routine overhead work have high rates of shoulder pain that frequently progresses to functional loss and disability. Exercise interventions have potential for slowing this progression. Aims: To evaluate a therapeutic exercise programme intended to reduce pain and improve shoulder function. Methods: Construction worker volunteers were screened by history and clinical examination to test for inclusion/exclusion criteria consistent with shoulder pain and impingement syndrome. Sixty seven male symptomatic workers (mean age 49) were randomised into a treatment intervention group (n = 34) and a control group (n = 33); asymptomatic subjects (n = 25) participated as an additional control group. Subjects in the intervention group were instructed in a standardised eight week home exercise programme of five shoulder stretching and strengthening exercises. Subjects in the control

groups received no intervention. Subjects returned after 8-12 weeks for follow up testing. Results: The intervention group showed significantly greater improvements in the Shoulder Rating Questionnaire (SRQ) score and shoulder satisfaction score than the control groups. Average post-test SRQ scores for the exercise group remained below levels for asymptomatic workers. Intervention subjects also reported significantly greater reductions in pain and disability than controls. Conclusions: Results suggest a home exercise programme can be effective in reducing symptoms and improving function in construction workers with shoulder pain.

Ludewig, P. M. and T. M. Cook (2002). "Translations of the humerus in persons with shoulder impingement symptoms." *J Orthop Sports Phys Ther* 32(6): 248-259.

STUDY DESIGN: Two-group mixed-model analysis of covariance and correlation analysis. **OBJECTIVES:** To determine whether differences in humeral translations exist between patients with shoulder impingement symptoms and an asymptomatic comparison group, and if so, to determine if shoulder range-of-motion (ROM) measures are associated with abnormal translations. **BACKGROUND:** Abnormal translations of the humeral head are believed to reduce the available subacromial space and to contribute to the development or progression of shoulder impingement symptoms. These abnormal translations have also been theorized to be related to tightness of the posterior capsule and decreased shoulder ROM. **METHODS AND MEASURES:** Three-dimensional humeral translations were tracked in symptomatic construction workers and an asymptomatic comparison group while elevating the arm in the scapular plane under no-load, 2.3-kg, and 4.6-kg hand-load conditions. Between-group comparisons were made across 3 phases of motion (30 degrees-60 degrees, 60 degrees-90 degrees, and 90 degrees-120 degrees) and the association between humeral translations and cross-body adduction and shoulder internal rotation ROM measures were determined by Pearson correlation analysis. **RESULTS:** Persons with shoulder symptoms demonstrated small but significant changes in anterior-posterior translations of the humerus. These changes for the 90 degrees-120 degrees phase of humeral elevation were moderately negatively associated with available cross-body adduction ROM. **CONCLUSIONS:** The identified kinematic deviations are consistent with possible reductions of the subacromial space. Further study of relationships between posterior capsule tightness, rotator cuff function, and abnormal humeral translations is warranted to better delineate underlying kinematic mechanisms that may contribute to shoulder impingement symptoms and to refine rehabilitation techniques.

Marcum, J. and D. Adams (2017). "Work-related musculoskeletal disorder surveillance using the Washington state workers' compensation system: Recent declines and patterns by industry, 1999-2013." *Am J Ind Med* 60(5): 457-471.

BACKGROUND: Work-related musculoskeletal disorders (WMSDs) are common and place large economic and social burdens on workers and their communities. We describe recent WMSD trends and patterns of WMSD incidence among the Washington worker population by industry. **METHODS:** We used Washington State's workers' compensation compensable claims from 1999 to 2013 to describe incidence and cost of WMSD claims by body part and diagnosis, and to identify high-risk industries. **RESULTS:** WMSD claim rates declined by an estimated annual 5.4% (95% CI: 5.0-5.9%) in Washington State from 1999 to 2013, but WMSDs continue to account for over 40% of all compensable claims. High risk industries identified were Construction; Transportation and Warehousing; Health Care and Social Assistance; and Manufacturing. **CONCLUSIONS:** As documented in other North American contexts, this study describes an important decline in the incidence of WMSDs. The Washington State workers' compensation system provides a rich data source for the surveillance of WMSDs.

McCoy, A. J., et al. (2013). "Twenty years of work-related injury and illness among union carpenters in Washington State." *Am J Ind Med* 56(4): 381-388.

BACKGROUND: Individuals who work in the construction industry are at high risk of occupational injury. Robust surveillance systems are needed to monitor the experiences of these workers over time. **METHODS:** We updated important surveillance data for a unique occupational cohort of union construction workers to provide information on long-term trends in their reported work-related injuries and conditions. Combining administrative data sources, we identified a dynamic cohort of union carpenters who worked in Washington State from 1989 through 2008, their hours worked by month, and their workers' compensation claims. Incidence rates of reported work-related injuries and illnesses were examined. Poisson regression was used to assess risk by categories of age, gender, time in the union, and calendar time contrasting medical only and paid lost time claims. **RESULTS:** Over the 20-year study period, 24,830 carpenters worked 192.4 million work hours. Work-related injuries resulting in medical care or paid lost time (PLT) from work occurred at a rate of 24.3 per 200,000 hr worked (95% CI: 23.5-25.0). Medical only claims declined 62% and PLT claims declined 77%; more substantive declines were seen for injuries resulting from being struck and falls to a lower level than from overexertion with lifting. Differences in risk based on union tenure and age diminished over time as well. **CONCLUSIONS:** Significant declines in rates of reported work-related injuries and illnesses were observed over the 20-year period among these union carpenters. Greater declines were observed among workers with less union tenure and for claims resulting in PLT.

McGaha, J., et al. (2014). "Exploring physical exposures and identifying high-risk work tasks within the floor layer trade." *Appl Ergon* 45(4): 857-864.

Introduction: Floor layers have high rates of musculoskeletal disorders yet few studies have examined their work exposures. This study used observational methods to describe physical exposures within floor laying tasks. **Methods:** We analyzed 45 videos from 32 floor layers using Multimedia-Video Task Analysis software to determine the time in task, forces, postures, and repetitive hand movements for installation of four common flooring materials. We used the WISHA checklists to define exposure thresholds. **Results:** Most workers (91%) met the caution threshold for one or more exposures. Workers showed high exposures in multiple body parts with variability in exposures across tasks and for different materials. Prolonged exposures were seen for kneeling, poor neck and low back postures, and intermittent but frequent hand grip forces. **Conclusions:** Floor layers experience prolonged awkward postures and high force physical exposures in multiple body parts, which probably contribute to their high rates of musculoskeletal disorders. © 2013 Elsevier Ltd and The Ergonomics Society.

Mehta, R. K. and M. J. Agnew (2010). "Analysis of individual and occupational risk factors on task performance and biomechanical demands for a simulated drilling task." *International Journal of Industrial Ergonomics* 40(5): 584-591.

The purpose of this study was to evaluate age- and gender-dependent effects of shoulder fatigue on task performance and muscular responses of a drilling task commonly observed within the construction industry. Twelve younger (18-35 years) and ten older (45-60 years) participants, balanced by gender, were recruited from the local community. Task performance (task completion times and errors made), muscle activity of the anterior deltoid (static, mean, and peak amplitude probability density function), coactivity indices of the upper and lower arm, and perceived discomfort ratings were obtained for a series of drilling tasks at three levels of task difficulty, before and after manifestation of shoulder fatigue. To induce fatigue, participants performed a sustained sub-maximal fatigue task at 40% of their maximum voluntary shoulder exertion. Fatigue decreased task completion times, irrespective of age and gender. Higher errors were observed in the fatigued condition, especially for younger participants. Females showed higher shoulder muscle activity compared to men. Additionally,

fatigue resulted in lower shoulder APDF measures compared to the no-fatigue condition. Muscle recruitment patterns differed within the fatigue condition, with higher coactivity indices in the upper and lower arm muscles compensating for decreases in shoulder muscle activity. Task difficulty was not found to affect any dependent measures. Participants reported higher discomfort in the fatigued state; this effect was more prominent in females. Overall, this study demonstrated, through objective and subjective measures, that task performance and biomechanical demands are affected by fatigue, and that this effect varies with individual factors such as gender and age. Relevance to industry: This paper explored the influence of task demands (fatigue and task difficulty) and individual factors (gender and age) of a drilling task on the development of musculoskeletal injuries of construction workers. The results may contribute towards an understanding of the interplay of certain occupational task demands and worker characteristics on common construction tasks. © 2010 Elsevier B.V.

Memarian, B. and P. Mitropoulos (2013). "Accidents in masonry construction: The contribution of production activities to accidents, and the effect on different worker groups." *Safety science* 59: 179-186.

Masonry is a construction trade with high risk of work-related injuries. This study analyzes 141 recordable incidents that occurred over a period of 3 years in a large masonry company. The incidents were analyzed from three perspectives: First, they were analyzed with respect to the nature of events (falls, overexertion, etc.). Second, the analysis examined the production activity that the injured worker was performing. Third, the incidents were analyzed according to the injured workers' position in the crew - that is, foreman, masons, laborers, and forklift operator. The findings first identify the contribution of the different masonry activities to different types of safety incidents. Three activities - scaffold erection and dismantling, laying block and material handling are responsible for most of incidents and consequences in terms of days away from work and days with modified task. Next, the findings identify the frequency and severity of incidents for the different workers' positions, and the high incident activities for each worker role. The results indicate that the laborers have significantly higher accident rate compared to the masons. The study identifies two new areas of priority for reducing accidents in masonry construction: improving the process of scaffold erection and dismantling, and focusing on reducing laborers incidents. Finally, analysis of incidents by production activities and personnel position is an effective way to identify operations and worker groups that need to be targeted for improvement. Thus, it is strongly recommended that the contractors' incident reporting mechanism captures that information. © 2013 Elsevier Ltd.

Merlino, L. A., et al. (2003). "Symptoms of musculoskeletal disorders among apprentice construction workers." *J Occup Environ Hyg* 18(1): 57-64.

Musculoskeletal disorders (MSDs) are a major cause of work-related disability and lost-time illnesses for many occupational groups. This study determined the prevalence of musculoskeletal symptoms among young construction workers. A symptom and job factors survey was self-administered to 996 construction apprentices. Prevalence was determined by the percent of positive responses to musculoskeletal symptom questions. Odds ratios and 95 percent confidence intervals were the measures of association between prevalent musculoskeletal symptoms and demographic, leisure, and job factors and were determined by logistic regression. The low back was the site most commonly reported for job-related musculoskeletal symptoms (54.4%), which was also the most common reason for seeking care from a physician (16.8%) and missing work (7.3%). Number of years worked in the construction trade was significantly associated with knee (p -trend = 0.0009) and wrist/hand (p -trend < 0.04) MSD symptoms and was suggestive of an association with low back pain (p -trend = 0.05). "Working in the same position for long periods" was the job factor identified as most problematic, with 49.7 percent of all construction apprentices rating it as a moderate/major problem

contributing to musculoskeletal symptoms. Musculoskeletal symptoms are a significant problem among young construction workers at the beginning of their careers. Prevention strategies are needed early in the apprentice training program to reduce the potential disability associated with work-related musculoskeletal symptom disorders.

Mitropoulos, P. and M. Namboodiri (2011). "New Method for Measuring the Safety Risk of Construction Activities: Task Demand Assessment." *Journal of Construction Engineering and Management* 137(1): 30-38.

The task demand assessment (TDA) is a new technique for measuring the safety risk of construction activities and analyzing how changes in operation parameters can affect the potential for accidents. TDA is similar to observational ergonomic methods—it does not produce estimates of probabilities of incidents, but it quantifies the “task demand” of actual operations based on characteristics of the activity and independent of the workers’ capabilities. The task demand reflects the difficulty to perform the activity safely. It is based on (1) the exposure to a hazard and (2) the presence and level of observable task demand factors—that is, risk factors that can increase the potential for an accident. The paper presents the findings from the initial implementation of TDA and demonstrates its feasibility and applicability on two different operations: a roofing activity and a concrete paving operation. Furthermore, the paving case illustrates how the TDA method can compare different production scenarios and measure the effect of production variables on the accident potential. The findings indicate that the method can be applied on activities of varying complexity and can account for several risks and task demand factors as required by the user. The selection of task demand factors is a key issue for the validity of the method and requires input from the crew and safety management. The limitations of the methodology and the need for further research are discussed. Overall, TDA provides a tool that can assist researchers and practitioners in the analysis and design of construction operations.

Moir, S., et al. (2003). "Making sense of highway construction: a taxonomic framework for ergonomic exposure assessment and intervention research." *J Occup Environ Hyg* 18(4): 256-267.

Construction is one of the most hazardous industries in the United States. Occupational health research to characterize the hazards in construction work has been hampered by the lack of a systematic approach to classification of construction work and its associated hazards. A taxonomy of construction work, a nested system of classification, has been developed to systematize the collection and reporting of exposure assessment data for the characterization and reduction of hazards and the prevention of musculoskeletal injury. This taxonomy subdivides construction work into the categories of stage, operation, task, and activity. It is based on a bidding specification system already in use within the industry and thus provides a terminology common among workers, supervisors, and managers. The identification of tasks and activities that are present in multiple stages and/or trades contributes to the efficiency of exposure data collection and facilitates the generalizability to other settings for both exposure data and intervention evaluations. The taxonomy provides a framework and vocabulary that facilitates field work and participatory research activities. It can also potentially be linked to personnel and economic data for estimation of costs of safety and health problems, as well as benefits of interventions. Although developed for construction ergonomics, the taxonomic approach has application to non-routine work in other industry sectors and possibly in occupational health research other than ergonomics.

Morse, T. F., et al. (2007). "A population based survey of ergonomic risk factors in Connecticut: Distribution by industry, occupation, and demographics." *Connecticut Medicine* 71(5): 261-268.

Background: Risk factors for upper-extremity musculoskeletal disorders (MSD) include biomechanical factors (force, repetition, posture) and psychosocial factors (job stress). A population-based telephone survey of workers in Connecticut characterized these risk factors by industry, occupation, gender, and age. Findings: Risk factors were highly prevalent in the Connecticut workplace, but varied considerably by industry, occupation, gender, and age. Risk factors clustered based on (a) physically active occupations/industries (pushing/pulling, reaching, bent wrists, and tool use), (b) physically passive occupations/industries (static postures, stress, and computer use), and (c) repetitive motion exposures. Physically active patterns had the highest prevalence in construction/agriculture/mining, followed by (in order) wholesale/retail trade, utilities, manufacturing, services, government, and finance/insurance. Physically passive patterns tended to reverse this order, and repetitive motion followed a third pattern. Physically active risk factors were typically higher for males, though this varied by industry and occupation. All risk factors except for stress show a steady decrease with age. Conclusion: Almost 1,000,000 Connecticut workers are estimated to be exposed to repetitive work, bent wrists, and job stress. Workers in high exposure industries and occupations should be closely evaluated for risks, with outreach to industries for preventive ergonomic interventions as preferred to treatment for conditions that arise.

Murphy, P. L. and T. K. Courtney (2000). "Low back pain disability: Relative costs by antecedent and industry group." *Am J Ind Med* 37(5): 558-571.

Background: Previous studies of workers' compensation claims for low back pain (LBP) have revealed that the preponderance of disability is borne by a fraction of cases. However, less is known regarding the influence of occupational factors on these extreme conditions. Methods: Workers' compensation claims (n = 107,867) for LBP reported to a large, national insurer in 1992 were examined by antecedent event and industry class. In addition to summaries of the frequency and cost distribution, each factor was examined at two points on its cost distribution: one more representative of the typical case and one more representative of the case with long disability. These alternative disability indicators were introduced to explore a different perspective of LBP disability. Results: The information provided by the alternative indicators was distinct from the information provided by the traditional aggregate indicators (claim frequency and claim cost frequency). In particular, this method identified increased severity for claims in the construction and services sectors, as well as for claims arising from falls and motor vehicle crashes. Conclusions: The results suggest that the construction and service sectors confront unique challenges to prevention and management of LBP disability, LBP related to discrete antecedents such as falls and motor vehicle crashes merits consideration on the basis of exceptionally severe disability. (C) 2000 Wiley-Liss, Inc.

Nahmens, I. and L. H. Ikuma (2012). "Effects of lean construction on sustainability of modular homebuilding." *Journal of Architectural Engineering* 18(2): 155-163.

Construction activities and the built environment have an enormous effect on the environment, human health, and the overall economy. Sustainable homebuilding in all three dimensions of economic, environmental, and social effects is attainable through practical innovations and technologies. However, the greatest barrier to the widespread application of sustainable homebuilding is the higher initial costs largely attributable to the learning curve of workers building with these practical innovations and technologies, and the added cost resulting from ill-defined construction processes. To address these challenges and reach the ideal of sustainable construction, this paper proposes the use of lean construction as a viable and effective strategy, in particular the lean tool kaizen. This paper uses several case studies to showcase the effect of lean on the triple bottom line of sustainability in modular homebuilding. Each case study highlights one dimension of sustainability. Lean construction resulted in a significant environmental effect by reducing material

waste by 64%, a significant social effect by reducing or eliminating key safety hazards of excessive force, poor posture, and struck-by, and a significant economic effect by reducing production hours by 31%. Findings from this research will contribute to a better understanding of the effect of lean on homebuilding sustainability and will promote lean and safe building techniques in modular homebuilding. © 2012 American Society of Civil Engineers.

Nath, N. D., et al. (2017). "Ergonomic analysis of construction worker's body postures using wearable mobile sensors." *Appl Ergon* 62: 107-117.

Construction jobs are more labor-intensive compared to other industries. As such, construction workers are often required to exceed their natural physical capability to cope with the increasing complexity and challenges in this industry. Over long periods of time, this sustained physical labor causes bodily injuries to the workers which in turn, conveys huge losses to the industry in terms of money, time, and productivity. Various safety and health organizations have established rules and regulations that limit the amount and intensity of workers' physical movements to mitigate work-related bodily injuries. A precursor to enforcing and implementing such regulations and improving the ergonomics conditions on the jobsite is to identify physical risks associated with a particular task. Manually assessing a field activity to identify the ergonomic risks is not trivial and often requires extra effort which may render it to be challenging if not impossible. In this paper, a low-cost ubiquitous approach is presented and validated which deploys built-in smartphone sensors to unobtrusively monitor workers' bodily postures and autonomously identify potential work-related ergonomic risks. Results indicate that measurements of trunk and shoulder flexions of a worker by smartphone sensory data are very close to corresponding measurements by observation. The proposed method is applicable for workers in various occupations who are exposed to WMSDs due to awkward postures. Examples include, but are not limited to industry laborers, carpenters, welders, farmers, health assistants, teachers, and office workers.

Nimbarte, A. D., et al. (2010). "Neck disorders among construction workers: understanding the physical loads on the cervical spine during static lifting tasks." *Ind Health* 48(2): 145-153.

In this study a common yet very strenuous construction work activity, was evaluated biomechanically by studying electromyography (EMG) of the major neck muscles. The muscles studied were the sternocleidomastoid and the upper trapezius. Fifteen healthy participants (10 males and 5 females) with no history of musculoskeletal abnormalities participated in this study. The participants lifted 25%, 50%, and 75% of their maximum shoulder height static strength at neutral, maximally flexed, and maximally extended neck postures. The weight lifted as well as the neck posture significantly affected the activities of the neck muscles. Increase in the weight increased the activation of the neck muscles. The sternocleidomastoid muscle was most active at the extended neck posture, while the upper trapezius muscle was most active at the flexed neck posture. The results of this study indicate that the neck muscles play an active role during lifting and holding tasks at shoulder height. Thus, such tasks could be probable risk factors associated with neck disorders prevalent among construction workers.

Norton, J. N., et al. (2011). "Comparative vibration levels perceived among species in a laboratory animal facility." *J Am Assoc Lab Anim Sci* 50(5): 653-659.

The current study was performed to determine the vibration levels that were generated in cages on a ventilated rack by common construction equipment in frequency ranges likely to be perceived by humans, rats, and mice. Vibration generated by the ventilated rack blower caused small but significant increases in some of the abdominal, thoracic, and head resonance frequency ranges (RFR) and sensitivity frequency ranges (SFR) in which each species is most likely to be affected by and

perceive vibration, respectively. Vibration caused by various items of construction equipment at 3 ft from the cage were evaluated relative to the RFR and SFR of humans, rats, and mice in 3 anatomic locations. In addition, the vibration levels in the RFR and SFR that resulted from the use of a large jackhammer and were measured at various locations and distances in the facility and evaluated in terms of humans, rats, and mice in 3 anatomic locations. Taken together, the data indicate that a given vibration source generates vibration in frequency ranges that are more likely to affect rats and mice as compared with humans.

Nussbaum, M. A., et al. (2009). "Development of a decision support system for residential construction using panellised walls: approach and preliminary results." *Ergonomics* 52(1): 87-103.

There is a high prevalence of work-related musculoskeletal disorders (WMSDs) among residential construction workers, yet control in this industry can be difficult for a number of reasons. A decision support system (DSS) is described here to allow early assessment of both ergonomic and productivity concerns, specifically by designers. Construction using prefabricated walls (panels) is the focus of current DSS development and is based conceptually on an existing 'Safety in Construction Design' model. A stepwise description of the development process is provided, including input from end users, taxonomy development and task analysis, construction worker input, detailed laboratory-based simulations and modelling/solution approaches and implementation. Preliminary results are presented for several steps. These results suggest that construction activities using panels can be efficiently represented, that some of these activities involve exposure to high levels of WMSD risk and that several assumptions are required to allow for ease of mathematical and computational implementation of the DSS. Successful development of such tools, which allow for proactive control of exposures, is argued as having substantial potential benefit.

Paquet, V., et al. (2005). "Reliable exposure assessment strategies for physical ergonomics stressors in construction and other non-routinized work." *Ergonomics* 48(9): 1200-1219.

The objective of this research was to provide guidelines for the reliable assessment of ergonomics exposures in non-routinized work. Using a discrete-interval observational sampling approach, two or three observers collected a total of 5852 observations on tasks performed by three construction trades (iron workers, carpenters and labourers) for periods of several weeks. For each observation, nine exposure variables associated with awkward body postures, tool use and load handling were recorded. The frequency of exposure to each variable was calculated for each worker during each of the tasks on each of the days. ANOVA was used to assess the importance of task in explaining between-worker and within-worker variability in exposures across days. A statistical re-sampling method (bootstrap) was used to evaluate the reliability of exposure estimates for groups of workers performing the same task for different sampling periods. Most exposures were found to vary significantly across construction tasks within trade, and between-worker exposure variability was generally smaller than within-worker exposure variability within task. Bootstrapping showed that the reliability of the group estimates exposure for the most variable exposures within task tended to improve as the assessment periods approached 5-6 d, with marginal improvements for longer assessment periods. Reliable group estimates of exposure for the least variable exposures within task were obtained with 1 or 2 d of observation. The results of this study demonstrate that an initial estimate of the important environmental or task sources of exposure variability can be used to develop an efficient sampling strategy that provides reliable estimates of ergonomics exposures during non-routinized work.

Rajendran, S. and J. A. Gambatese (2009). "Development and initial validation of sustainable construction safety and health rating system." *Journal of Construction Engineering and Management* 135(10): 1067-1075.

This paper presents a study to develop and validate a sustainable construction safety and health (SCSH) rating system. The rating system provides an opportunity to rate projects based on the importance given to construction worker safety and health and the degree of implementation of safety and health elements. A Delphi survey using an expert panel of 12 experienced safety and health professionals representing different sectors of the construction industry was employed to develop the SCSH rating system. The study resulted in a rating system consisting of a total of 50 safety and health elements organized into 13 categories. Each category contains safety and health elements which carry credits based on their effectiveness in preventing construction worker injuries and illnesses. The rating system was initially validated based on data from 25 construction projects and found to accurately represent the safety performance of large projects. The SCSH rating system can be used as an effective tool to develop and plan construction safety and health programs and evaluate the potential safety performance of construction projects.

Ray, S. J. and J. Teizer (2012). "Real-time construction worker posture analysis for ergonomics training." *Advanced Engineering Informatics* 26(2): 439-455.

Construction activities performed by workers are usually repetitive and physically demanding. Execution of such tasks in awkward postures can strain their body parts and can result in fatigue, injuries or in severe cases permanent disabilities. In view of this, it is essential to train workers, before the commencement of any construction activity. Furthermore, traditional worker monitoring methods are tedious, inefficient and are carried out manually whereas, an automated approach, apart from monitoring, can yield valuable information concerning work-related behavior of worker that can be beneficial for worker training in a virtual reality world. Our research work focuses on developing an automated approach for posture estimation and classification using a range camera for posture analysis and categorizing it as ergonomic or non-ergonomic. Using a range camera, first we classify worker's pose to determine whether a worker is 'standing', 'bending', 'sitting', or 'crawling' and then estimate the posture of the worker using OpenNI middleware to get the body joint angles and spatial locations. A predefined set of rules is then formulated to use this body posture information to categorize tasks as ergonomic or non-ergonomic. © 2012 Elsevier Ltd. All rights reserved.

Rempel, D. and A. Barr (2015). "A universal rig for supporting large hammer drills: Reduced injury risk and improved productivity." *Safety science* 78: 20-24.

Drilling holes into concrete with heavy hammer and rock drills is one of the most physically demanding tasks performed in commercial construction and poses risks for musculoskeletal disorders, noise induced hearing loss, hand arm vibration syndrome and silicosis. The aim of this study was to (1) use a participatory process to develop a rig to support pneumatic rock drills or large electric hammer drills in order to reduce the health risks and (2) evaluate the usability of the rig. Seven prototype rigs for supporting large hammer drills were developed and modified with feedback from commercial contractors and construction workers. The final design was evaluated by laborers and electricians (N=29) who performed their usual concrete drilling with the usual method and the new rig. Subjective regional fatigue was significantly less in the neck, shoulders, hands and arms, and lower back when using the universal rig compared to the usual manual method. Usability ratings for the rig were significantly better than the usual method on stability, control, drilling, accuracy, and vibration. Drilling time was reduced by approximately 50% with the rig. Commercial construction contractors, laborers and electricians who use large hammer drills for drilling many holes should consider using such a rig to prevent musculoskeletal disorders, fatigue, and silicosis. © 2015 Elsevier Ltd.

Rempel, D., et al. (2016). "A new test bench system for hammer drills: Validation for handle vibration." *International Journal of Industrial Ergonomics*.

Workers can be exposed to high levels of hand vibration when drilling into concrete or rock using hammer drills; exposures that can cause hand arm vibration syndrome. Exposure levels may be reduced by different drill and bit designs and drilling methods, but these interventions have not been systematically evaluated. The purpose of this project was to develop a robotic test bench system for measuring handle vibration on drills in order to compare differences in drill designs, power sources, bit designs and drilling methods. The test bench is a departure from the ISO method for measuring drill handle vibration (ISO 28927-10), which requires drilling by humans. The test bench system was designed to repeatedly drill into concrete blocks under force control while productivity and handle vibration were measured. Handle vibration levels with different drills and bit sizes were similar to those collected following ISO methods. A new robotic test bench system for measuring handle vibration is presented and validated against ISO methods and demonstrates dynamic properties similar to human drilling.

Rempel, D., et al. (2010). "Field evaluation of a modified intervention for overhead drilling." *J Occup Environ Hyg* 7(4): 194-202.

Drilling holes into concrete or metal ceilings is one of the most physically demanding tasks performed in construction. The work is done overhead with rotary impact hammer drills that weigh up to 40 N. The task is associated with pain and musculoskeletal disorders at the wrist, forearm, shoulder, and back. The mechanism of injury is thought to be the high forces and non-neutral shoulder and wrist postures applied during drilling. Previously, we described a field study of a foot lever and inverted drill press intervention devices that received poor usability ratings compared with the usual method for overhead drilling based on problems with mobility and productivity. Using a participatory intervention model, feedback from construction workers (N = 13) was used to develop a new intervention design that incorporated a wheeled tripod base and a unique method of aligning the drilling column to vertical. A different group of construction workers (N = 23) evaluated usability and fatigue of the new device during their regular overhead drilling in comparison with the usual method. Four of 12 usability ratings were significantly better with the intervention device compared with the usual method. Subjective shoulder fatigue was less with the new intervention (1.1 vs. 3.3; scale 0 to 5; $p < 0.001$). This difference was supported by objective outcome measures; the mean hand forces during drilling were 26 N with the intervention compared with 245 N with the usual method. The percentage of time with the shoulder flexed or abducted to more than 60 degrees was less with the intervention compared with the usual method (21 vs. 40%; $p = 0.007$). There was significantly less head extension with the intervention compared with the usual method. There were no significant differences in overall productivity between the two methods. This study demonstrates that a new intervention device for overhead drilling has improved usability and subjective fatigue ratings compared with the usual method. These improvements are most likely due to the reduced hand forces, reduced shoulder abduction and flexion, and reduced drilling time.

Rempel, D., et al. (2009). "A new method for overhead drilling." *Ergonomics* 52(12): 1584-1589.

In the construction sector, overhead drilling into concrete or metal ceilings is a strenuous task associated with shoulder, neck and back musculoskeletal disorders due to the large applied forces and awkward arm postures. Two intervention devices, an inverted drill press and a foot lever design, were developed then compared to the usual method by construction workers performing their normal overhead drilling activities (n = 14). While the intervention devices were rated as less fatiguing than the usual method, their ratings on usability measures were worse than the usual method. The study

demonstrates that the intervention devices can reduce fatigue; however, additional modifications are necessary in order to improve usability and productivity. Devices designed to improve workplace safety may need to undergo several rounds of field testing and modification prior to implementation.

Rempel, D., et al. (2010). "Overhead drilling: comparing three bases for aligning a drilling jig to vertical." *J Safety Res* 41(3): 247-251.

PROBLEM: Drilling overhead into concrete or metal ceilings is a strenuous task done by construction workers to hang ductwork, piping, and electrical equipment. The task is associated with upper body pain and musculoskeletal disorders. Previously, we described a field usability evaluation of a foot lever and inverted drill press intervention devices that were compared to the usual method for overhead drilling. Both interventions were rated as inferior to the usual method based on poor setup time and mobility. **METHOD:** Three new interventions, which differed on the design used for aligning the drilling column to vertical, were compared to the usual method for overhead drilling by commercial construction workers (n=16). **RESULTS:** The usual method was associated with the highest levels of regional body fatigue and the poorest usability ratings when compared to the three interventions. **CONCLUSION:** Overall, the 'Collar Base' intervention design received the best usability ratings. **IMPACT ON INDUSTRY:** Intervention designs developed for overhead drilling may reduce shoulder fatigue and prevent subsequent musculoskeletal disorders. These designs may also be useful for other overhead work such as lifting and supporting materials (e.g., piping, ducts) that are installed near the ceiling. Workplace health and safety interventions may require multiple rounds of field-testing prior to achieving acceptable usability ratings by the end users.

Rempel, D. M., et al. (2007). "Development and Evaluation of a New Device for Overhead Drilling." *Professional Safety* 52(11): 30-35.

Drilling overhead into concrete is a strenuous task that is associated with shoulder, arm, neck and back musculoskeletal disorders due to the forceful and awkward aspects of the work. This common task is done to hang pipes, ducts and trays and is performed by construction workers in the electrical, pipe fitting, sheet metal, ironwork and carpentry trades. In this project, alternative devices for overhead drilling were developed in order to reduce the high shoulder loads. The design premise for the alternative devices was adopted from interventions developed on construction sites. These devices were evaluated for usability, productivity, and fatigue in two rounds of testing by 30 construction workers performing their usual overhead drilling. After each round of testing the device designs were modified based on feedback. The final design was associated with much less arm fatigue but similar productivity compared to the usual method for overhead drilling. The feedback, design suggestions and field testing by experienced construction workers was vital to the successful development of these devices. Field testing were done with real tasks, in diverse field settings, with subjects familiar with the task. Multiple rounds of field testing and redesign can significantly improve the safety and usability of new tools. Having experienced workers accessing the new tools can help with determining if and how a new tool is compatible and beneficial to current work practices.

Rosecrance, J. C., et al. (2002). "Carpal tunnel syndrome among apprentice construction workers." *Am J Ind Med* 42(2): 107-116.

BACKGROUND: In terms of lost-work time and restricted workdays, surgery, and rehabilitation, one of the most costly occupational musculoskeletal disorders is carpal tunnel syndrome (CTS). The purpose of this study was to determine the prevalence of CTS among apprentice construction workers. **METHODS:** This cross-sectional study included apprentices from four construction trades. Apprentices completed a self-administered questionnaire and received electrophysiologic studies assessing median nerve function across the carpal tunnel. A surveillance case definition for CTS was based on

characteristic hand symptoms and the presence of median mononeuropathy across the carpal tunnel. RESULTS: Of the 1,325 eligible apprentices, 1,142 (86.2%) participated in the study. The prevalence of CTS among apprentices was 8.2%; sheet metal workers had the highest rate (9.2%). In operating engineers, the prevalence of CTS was significantly higher (OR = 6.9; 95% CI = 2.6-18.2) among the heavy equipment mechanics than the drivers of those vehicles. Body mass index, age, and self-reports of working overhead were associated with prevalent CTS. Less than 15% of the apprentices with CTS sought medical attention for their disorder. CONCLUSIONS: Many construction workers begin developing CTS before or during their apprenticeship. Few apprentices seek medical attention for hand symptoms characteristic of CTS. The results of this study indicate a public health need for the implementation of prevention strategies for CTS in the construction industry.

Rosecrance, J. C., et al. (2002). "Test-retest reliability of a self-administered musculoskeletal symptoms and job factors questionnaire used in ergonomics research." *Appl Occup Environ Hyg* 17(9): 613-621.

The purpose of this study was to investigate the test-retest reliability of questionnaire items related to musculoskeletal symptoms and the reliability of specific job factors. The type of questionnaire items described in the present study have been used by several investigators to assess symptoms of musculoskeletal disorders and problematic job factors among workers from a variety of occupations. Employees at a plastics molding facility were asked to complete an initial symptom and jobs factors questionnaire and then complete an identical questionnaire either two or four weeks later. Of the 216 employees participating in the initial round, 99 (45.8%) agreed to participate in the retest portion of the study. The kappa coefficient was used to determine repeatability for categorical outcomes. The majority of the kappa coefficients for the 58 questionnaire items were above 0.50 but ranged between 0.13 and 1.00. The section of the questionnaire having the highest kappa coefficients was the section related to hand symptoms. Interval lengths of two and four weeks between the initial test and retest were found to be equally sufficient in terms of reliability. The results indicated that the symptom and job factors questionnaire is reliable for use in epidemiologic studies. Like all measurement instruments, the reliability of musculoskeletal questionnaires must be established before drawing conclusions from studies that employ the instrument.

Schneider, S., et al. (1995). "Noise, vibration, and heat and cold." *Occup Med* 10(2): 363-383.

Using information from the U.S. government and the scientific literature, the authors identify preventive strategies for specific types of injuries and categorize features of employers and workers that are associated with low injury rates. They conclude that safe working conditions are possible and are related to the attitudes of workers and management.

Schoenfisch, A. L., et al. (2013). "Work-related injuries among union drywall carpenters in Washington State, 1989-2008." *Am J Ind Med* 56(10): 1137-1148.

BACKGROUND: Drywall installers are at high-risk of work-related injury. Comprehensive descriptive epidemiology of injuries among drywall installers, particularly over time, is lacking. METHODS: We identified worker-hours and reported and accepted workers' compensation (WC) claims for a 20-year (1989-2008) cohort of 24,830 Washington State union carpenters. Stratified by predominant type of work (drywall installation, other carpentry), work-related injury rates were examined over calendar time and by worker characteristics. Expert interviews provided contextual details. RESULTS: Drywall installers' injury rates, higher than those of other carpenters, declined substantially over this period by 73.6%. Common injury mechanisms were struck by/against, overexertion and falls. Drywall material was considered a contributing factor in 19.7% of injuries. One-third of these drywall material-related injuries resulted in paid lost time, compared to 19.4% of injuries from other sources. Rates of injury were particularly high among workers with 2 to <4 years in the

union. Notable declines over time in rates of overexertion injury in which drywall material was a contributing factor were still observed after controlling for secular temporal trends. Experts highlighted changes over the past 20 years that improved both work safety and, in some cases, production. CONCLUSIONS: Declines in drywall installers' injury rates over time likely reflect, in part, enhanced workplace safety, including efforts to reduce overexertion hazards associated with handling drywall. Continued injury prevention efforts are needed, particularly for less tenured workers. Given the potential for under-reporting to WC, additional sources of health outcomes data may provide a more complete picture of workers' health.

Schoenfisch, A. L., et al. (2014). "Declining rates of work-related overexertion back injuries among union drywall installers in Washington State, 1989-2008: Improved work safety or shifting of care?" *Am J Ind Med* 57(2): 184-194.

INTRODUCTION: Construction workers are at high risk of work-related musculoskeletal back disorders, and research suggests medical care and costs associated with these conditions may be covered by sources other than workers' compensation (WC). Little is known about the back injury experience and care seeking behavior among drywall installers, a high-risk workgroup regularly exposed to repetitive activities, awkward postures, and handling heavy building materials. METHODS: Among a cohort of 24,830 Washington State union carpenters (1989-2008), including 5,073 drywall installers, we identified WC claims, visits for health care covered through union-provided health insurance and time at risk. Rates of work-related overexertion back injuries (defined using WC claims data) and health care utilization for musculoskeletal back disorders covered by private health insurance were examined and contrasted over time and by worker characteristics, stratified by type of work (drywall installation, other carpentry). RESULTS: Drywall installers' work-related overexertion back injury rates exceeded those of other carpenters (adjusted IRR 1.63, 95% CI 1.48-1.78). For both carpentry groups, rates declined significantly over time. In contrast, rates of private healthcare utilization for musculoskeletal back disorders were similar for drywall installers compared to other carpenters; they increased over time (after the mid-1990s), with increasing years in the union, and with increasing numbers of work-related overexertion back injuries. CONCLUSIONS: Observed declines over time in the rate of work-related overexertion back injury, as based on WC claims data, is encouraging. However, results add to the growing literature suggesting care for work-related conditions may be being sought outside of the WC system.

Schoenfisch, A. L., et al. (2010). "Nonfatal construction industry-related injuries treated in hospital emergency departments in the United States, 1998-2005." *Am J Ind Med* 53(6): 570-580.

BACKGROUND: This study documented the burden of nonfatal construction industry work-related injuries treated in hospital emergency departments in the United States (US) from 1998 through 2005 and described injured worker demographics and injury characteristics. METHODS: Data from the National Electronic Injury Surveillance System work-related injury supplement (NEISS-Work) were used to identify and describe construction industry-related injuries. Rates were estimated using data from the Current Population Survey. RESULTS: An estimated 3,216,800 (95% CI 2,241,400-4,192,200) construction industry-related injuries were seen in US emergency departments during the 8-year period; this represented an injury rate of 410/10,000 full-time equivalents and suggests that there are a greater number of construction injuries than reported through the Bureau of Labor Statistics' Survey of Occupational Injuries and Illnesses (BLS SOII). Common characteristics included diagnoses of laceration, sprain/strain, and contusion/abrasion; events of contact with an object/equipment, bodily reaction/exertion, and falls; and sources of injury of parts/materials; structures/surfaces; and tools/instruments/equipment. The upper extremities were most often affected. CONCLUSIONS: These data highlight the high burden of nonfatal construction industry-

related injuries. The limitations of national occupational injury data sources inherent in relying on OSHA logs highlight the utility of NEISS-Work data in occupational injury research. While data captured from emergency departments are not immune to factors that influence whether a worker or an employer reports an injury as work-related or files a workers' compensation claim, emergency department data as collected through NEISS-Work do not rely on employer involvement in order to be classified as work-related.

Schoonover, T., et al. (2010). "Prioritizing prevention opportunities in the Washington State construction industry, 2003-2007." *J Safety Res* 41(3): 197-202.

OBJECTIVE: This study compares construction industry groups in Washington State by injury severity and cost, and ranks industry groups according to potential for prevention. **METHODS:** All Washington State workers' compensation compensable claims with date of injury between 2003 and 2007 were classified into North American Industrial Classification System (NAICS) industry groups. Claims were then aggregated by injury type and industry groups were ranked according to a prevention index (PI). The PI is the average of the rank orders of the claim count and the claim incidence rate. A lower PI indicates a higher need for prevention activities. The severity rate was calculated as the number of days of time loss per 10,000 full-time equivalents (FTEs). **RESULTS:** For all injury types, construction industry groups occupy 7 of the top 15 PI ranks in Washington State. The severity rate among construction industry groups was twice that for non-construction groups for all injury types. Foundation, structure, and building exterior contractors (NAICS 2381) ranked highest in prevention potential and severity among construction industry groups for most common injury types including falls from elevation, fall on same level, struck by/against, and musculo-skeletal disorders of the neck, back, and upper extremity (WMSDs). Median claim costs by injury type were generally higher among construction industry groups. **CONCLUSIONS:** The construction industry in Washington State has a high severity rate and potential for prevention. The methods used for characterizing these industry groups can be adapted for comparison within and between other industries and states. **IMPACT ON INDUSTRY:** These data can be used by industry groups and employers to identify higher cost and higher severity injury types. Knowledge about the relative frequencies and costs associated with different injury types will help employers and construction industry associations make better informed decisions about where prevention efforts are most needed and may have the greatest impact. The results of this study can also be used by industry stakeholders to cooperatively focus on high cost and high severity injuries and explore best practices, interventions, and solutions as demonstrated by efforts to prevent musculoskeletal disorders in masonry (Entzel, Albers, & Welch, 2007). Initiating construction industry groups to focus on high cost and high severity injuries may also help prevent other types of injuries.

Schwatka, N. V., et al. (2013). "Age in relation to worker compensation costs in the construction industry." *Am J Ind Med* 56(3): 356-366.

BACKGROUND: A better understanding of how workers' compensation (WC) costs are affected by an aging US workforce is needed, especially for physically demanding industries, such as construction. **METHODS:** The relationship between age and injury type on claim costs was evaluated using a database of 107,064 Colorado WC claims filed between 1998 and 2008 among construction workers. **RESULTS:** Mean WC costs increased with increasing age for total cost ($P < 0.0001$), medical costs ($P < 0.0001$), and indemnity costs ($P < 0.0001$). For each one-year increase in age, indemnity, and medical costs increased by 3.5% and 1.1%, respectively. For specific injury types, such as strains and contusions, the association between age and indemnity costs was higher among claimants aged ≥ 65 compared to claimants aged 18-24. **CONCLUSIONS:** Our findings suggest that specific injury types may be partially responsible for the higher indemnity costs among older construction workers, compared with their younger coworkers.

Sengupta Dasgupta, P., et al. (2014). "Assessing the ergonomic exposures for drywall workers." *International Journal of Industrial Ergonomics* 44(2): 307-315.

Objective: The study was conducted to assess the ergonomic exposures to risk factors that may lead to the reported musculoskeletal injuries (especially back, neck and wrist injuries) of drywall workers. **Methods:** A hierarchical taxonomy for construction of drywall panel hanging (drywall panel fitting and installation) was developed with activities defined within the interior wall systems tasks (drywall panel, studs and insulation). Exposures were characterized for the drywall panel work with the PATH (Posture, Activity, Tools, and Handling) work-sampling observation method. Data on working postures were collected for three main body parts: legs, arms and trunk. Activities performed for each task, tools used, and manually handled loads were also recorded for each observation. **Results:** The study identified several ergonomic exposures in interior systems construction. Several risk factors were especially prevalent in the drywall panel installation task: awkward body postures such as overhead arm posture, trunk flexion, and handling of heavy drywall panels. Some tasks were observed to have combinations of these musculoskeletal risk factors, such as drywall panel installation, where the workers lifted heavy drywall panels in awkward body postures. In addition, a safety hazard frequently resulted when a worker's foot was poorly supported on a ladder while lifting heavy drywall panels to hang them on the ceiling or upper wall. **Conclusion:** The drywall panel installation task poses a severe threat to the safety and musculoskeletal health of the drywall workers. Much of this could be eliminated by reducing the burden of handling heavy and bulky drywall panels. **Relevance to industry:** The construction industry is well-documented to have high rates of injury and musculoskeletal disorders. Design of appropriate interventions requires specific knowledge of which tasks and activities involve the highest levels of exposure to relevant factors. Assessment of such factors in drywall panel hanging has provided data that will be useful to evaluate the ergonomics efficacy of future changes in task processes or tools. Feasible solutions appear to exist; effectiveness trials and worker input are needed in order to evaluate whether they could eliminate the observed exposures. © 2013 Elsevier B.V.

Seo, J., et al. (2016). "Simulation-Based Assessment of Workers' Muscle Fatigue and Its Impact on Construction Operations." *Journal of Construction Engineering and Management* 142(11).

Construction workers are frequently exposed to excessive physical demands due to repetitive lifting and material handling while performing tasks. Consequently, many construction workers suffer from a significant level of muscle fatigue that may negatively impact a project's performance. Thus, evaluating the level of muscle fatigue prior to work and implementing appropriate interventions to reduce physical demands will help to prevent adverse effects of workers' fatigue on construction operations. Even though several research efforts have suggested methodologies to evaluate muscle fatigue, the extent to which workers' muscle fatigue would affect construction performance has not yet been fully studied. To address this issue, a simulation-based framework is proposed to estimate physical demands and corresponding muscle fatigue, and thus to quantitatively evaluate the impact of muscle fatigue during construction operations. Specifically, physical demands from a planned operation modeled using discrete event simulation (DES) are estimated through biomechanical analyses. Then, the proposed dynamic fatigue models estimate the level of muscle fatigue of each worker as a function of the estimated physical demands. Workers' strategies to mitigate muscle fatigue, such as taking voluntary rests, are, in turn, modeled in the DES to understand how muscle fatigue affects time and cost performance of the planned operation. As a proof of concept, a case study on masonry work was performed to demonstrate the usefulness of the proposed framework, describing the need for taking into account muscle fatigue for operational planning due to possible excessive physical demands. The results from the case study indicate that excessive physical demands

beyond workers' capabilities result in reduction of time and cost performance. The proposed framework helps to better understand workers' response to physical demands by adding workers' capabilities as changing variables into traditional DES approaches, enabling pro-active management of human resources. Ultimately, the framework, which combines conventional interests on optimized operations in terms of time and cost with those of ergonomics, provides opportunities to take into account both workers' health and work performance in early design stages. © 2016 American Society of Civil Engineers.

Seo, J., et al. (2015). "Motion data-driven biomechanical analysis during construction tasks on sites." *Journal of Computing in Civil Engineering* 29(4): B4014005.

Work-related musculoskeletal disorders (WMSDs) are one of the major health issues that workers frequently experience due to awkward postures or forceful exertions during construction tasks. Among available job analysis methods, biomechanical models have been widely applied to assess musculoskeletal risks that may contribute to the development of WMSDs based on motion data during occupational tasks. Recently, with the advent of vision-based motion capture approaches, it has become possible to collect the motion data required for biomechanical analysis under real conditions. However, vision-based motion capture approaches have not been applied to biomechanical analysis because of compatibility issues in body models of the motion data and computerized biomechanical analysis tools. To address this issue, automated data processing is focused on to convert motion data into available data in existing biomechanical analysis tools, given the BVH motion data from vision-based approaches. To examine the feasibility of the proposed motion data processing, an experiment for both static and dynamic biomechanical analyses was conducted on lifting tasks. The results indicate that vision-based motion capture data - converted as proposed in this paper - can provide a sufficient level of detail on human kinematics to conduct biomechanical analysis, thus allowing for the identification of particular body parts where excessive forces are placed during tasks. The issues and directions of future research are also discussed to perform on-site biomechanical analysis during construction tasks. © 2014 American Society of Civil Engineers.

Shewchuk, J. P. and C. Guo (2012). "Panel stacking, panel sequencing, and stack locating in residential construction: Lean approach." *Journal of Construction Engineering and Management* 138(9): 1006-1016.

A current trend in residential construction is the use of prefabricated wall panels. Panels are manufactured at a factory, then arranged into stacks for transporting to the construction site, where they are assembled. Current approaches to planning panelized construction are focused on stacking and transport efficiency, with little consideration given to assembly. This results in excessive panel material handling during construction, increased construction lead time, and increased risk of worker overload and/or injury. This paper proposes a lean approach to panel stacking, panel sequencing, and stack locating, where panels within each stack form a continuous structure and are erected via continuous flow. The objectives are to minimize the quantity of stacks, panel material handling distance, and the work required to position and brace panels-panel interference is ignored. Few researchers have addressed this problem: a single algorithm has been reported, and this only works for certain building shapes and may provide infeasible solutions. The proposed approach and algorithm result in improved performance, have no shape restrictions, and always provide feasible solutions. Additionally, computational experiments show that the algorithm outperforms methods being employed in the construction industry today. © 2012 American Society of Civil Engineers.

Shin, G. and G. Mirka (2004). "The effects of a sloped ground surface on trunk kinematics and L5/S1 moment during lifting." *Ergonomics* 47(6): 646-659.

There are many work environments that require workers to perform manual materials handling tasks on ground surfaces that are not perfectly flat (e.g. in agriculture, construction, and maritime workplaces). These sloped ground surfaces may have an impact on the lifting strategy/technique employed by the lifter, which may, in turn, alter the biomechanical loading of the spine. Describing the changes in kinematics and kinetics of the torso is the first step in assessing the impact of these changes and is the focus of the current research. Subjects' whole-body motions were recorded as they lifted a 10 kg box while standing on two inclined surfaces (facing an upward slope: 10 degrees and 20 degrees), two declined surfaces (facing a downward slope: -10 degrees and -20 degrees), and a flat surface (0 degrees) using three lifting techniques (leg lift, back lift and freestyle lift). These data were then used in a two-dimensional, five-segment dynamic biomechanical model (top-down) to evaluate the effect of these slopes on the net moment about the L5/S1 joint. The results of this study showed an interesting interaction effect wherein the net L5/S1 moment was relatively insensitive to changes in slope angle under the back lift condition, but showed a significant effect during the leg lift and freestyle lifting conditions. The results show that under the freestyle lifting condition the peak L5/S1 moment was significantly higher for the inclined surfaces as compared to the flat surfaces (6.8% greater) or declined surfaces (10.0% greater). Subsequent component analysis revealed that both trunk flexion angle and angular trunk acceleration were driving this response. Collectively, the results of this study indicate that ground slope angle does influence the lifting kinematics and kinetics and therefore needs to be considered when evaluating risk of low back injury in these working conditions.

Shu, Y., et al. (2007). "The effect of a knee support on the biomechanical response of the low back." *J Appl Biomech* 23(4): 275-281.

Stooping and squatting postures are seen in a number of industries (e.g., agriculture, construction) where workers must work near ground level for extended periods of time. The focus of the current research was to evaluate a knee support device designed to reduce the biomechanical loading of these postures. Ten participants performed a series of sudden loading tasks while in a semisquat posture under two conditions of knee support (no support and fully supported) and two conditions of torso flexion (45 and 60 degrees). A weight was released into the hands of the participants who then came to steady state while maintaining the designated posture. As they performed this task, the EMG responses of the trunk extensors (multifidus and erector spinae) were collected, both during the "sudden loading" phase of the trial as well as the steady weight-holding phase of the trial. As expected, the effects of torso flexion angle showed significant decreases in the activation of the multifidus muscles with greater torso angle (indicating the initiation of the flexion-relaxation response). Interestingly, the results showed that the knee support device had no effect on the activation levels of the sampled muscles, indicating that the loss of the degree of freedom from the ankle joint during the knee support condition had no impact on trunk extensor muscle response. The a priori concern with regard to these supports was that they would tend to focus loading on the low back and therefore would not serve as a potential ergonomic solution for these stooping/semisquatting tasks. Because the results of this study did not support this concern, further development of such an intervention is underway.

Silverstein, B., et al. (2002). "Use of a prevention index to identify industries at high risk for work-related musculoskeletal disorders of the neck, back, and upper extremity in Washington State, 1990-1998." *Am J Ind Med* 41(3): 149-169.

Background: The prevention of work-related musculoskeletal disorders such as carpal tunnel syndrome and low back disorders has been a focus of international prevention efforts including regulation. This study examines workers compensation claims in Washington State to provide baseline

data from which to assess the need and the effects of prevention activities. Methods: Washington State Fund workers compensation claims for general and selected specific hand/wrist, elbow, shoulder, and back disorders in 1990-1998 as well as general self-insured compensable (four or more lost workdays) claims data were examined. Payroll hours were used to calculate claims incidence rates per 10,000 full-time equivalent employees (FTEs). We created a prevention index (PI) to rank industries by averaging the ranks of their number of claims and their claims incidence rate. The focus was on nontraumatic soft tissue musculoskeletal disorders (NTST-MSDs). Results: Between 1990-1998, there were 392,925 State Fund accepted claims for N TST-MSDs of the neck, back, and upper extremity resulting in \$2.6 billion in direct costs and 20.5 million lost workdays. The average claims incidence rate (CIR) was 355 NTST-MSDs per 10,000 FTEs. The NTST-MSD CIR decreased significantly less than that for all other claims ($P = 0.05$) but the CIR for upper extremity NTST-MSDs did not significantly decrease over the study period. There were no significant changes in the CIRs for sciatica (4.9 per 10,000 FTEs) and rotator cuff syndrome (15.3 per 10,000 FTEs), whereas the CIR for epicondylitis (10.6 per 10,000 FTEs) increased and for carpal tunnel syndrome (24.5 per 10,000 FTEs) decreased significantly over the study period. Based on the prevention index, the top five industries for combined State Fund and Self-Insured Compensable NTST-MSDs were Trucking and Courier Services (SIC 421), Nursing Homes (SIC 805), Masonry (SIC 174), Air Transportation (SIC 451), and Residential Construction (SIC 152). Using Washington Industrial Classes (WIC), temporary workers in assembly and administrative services were also high on the prevention index. Conclusions: NTST-MSDs continue to be a large and costly problem in Washington State. While the incidence rates for some NTST-MSDs are decreasing, the overall rate is not decreasing as fast as the rate for all other claims. In some cases, the rate is stable (sciatica, rotator cuff syndrome) or increasing (epicondylitis). Heavy manual handling and repetitive work characterize the industries with the highest risk. © 2002 Wiley-Liss, Inc.

Sobeih, T., et al. (2009). "Psychosocial Factors and Musculoskeletal Disorders in the Construction Industry." *Journal of Construction Engineering and Management* 135(4): 267-277.

Musculoskeletal disorders (MSDs) constitute more than half of the total injuries and illnesses within the construction industry. The aim of this study was to assess the prevalence of MSD among construction workers and identify the psychosocial and physical risk factors associated with their occurrence using an on-site survey instrument. One hundred forty seven construction workers (representing three trades) participated in the study. The 1-year prevalence of MSD was high with 61.2% reporting severe symptoms and 39.7% having some functional impairment due to MSD. Physical task requirement was the most important factor associated with MSD reflecting the physical nature of construction work. Economic and performance factors were the most stressful psychosocial factors reported and significantly increased the risk of reporting MSD. The findings of this research underscore the independent role that psychosocial factors play in the health and safety of construction workers. Understanding this role is imperative for practitioners and academics alike in the quest to make construction a safer work environment for all workers.

Sparer, E. H., et al. (2015). "Length of time spent working on a commercial construction site and the associations with worker characteristics." *Am J Ind Med* 58(9): 964-973.

Background: Construction workers move frequently from jobsite to jobsite, yet little is documented about length of stay on-site and associations with worker characteristics. Method: Using cross-sectional data, we investigated associations between worker characteristics (including trade and musculoskeletal pain) and length of stay on-site (dichotomized as <1 month, $n=554$, and ≥ 1 month, $n=435$). Results: Approximately, 56% of workers remained on the worksite for at least 1 month. Length of stay was significantly associated with workers' race/ethnicity, union status, title, trade, and musculoskeletal pain (P -values<0.05). Trades associated with longer length of stay included pipefitters

and plumbers. Trades associated with shorter length of stay included operators and piledrivers. Workers with single-location pain had 2.21 times (95%CI: 1.52, 3.19) the odds of being short-term versus long-term, adjusting for trade, title, and race/ethnicity. Conclusion: The length of stay and associated characteristics provide important insight into how workers come and go on construction sites and the methodological challenges associated with traditional intervention evaluations. © 2015 Wiley Periodicals, Inc.

Spector, J. T., et al. (2011). "Burden of work-related knee disorders in Washington State, 1999 to 2007." *J Occup Environ Med* 53(5): 537-547.

OBJECTIVE: To describe the burden of knee work-related musculoskeletal disorders (WMSDs). METHODS: Knee WMSDs were identified using Washington State Fund workers' compensation data from 1999 to 2007 and analyzed by cost, industry, occupation, and claims incidence rates. RESULTS: Knee WMSDs accounted for 7% of WMSD claims and 10% of WMSD costs. The rate of decline in claims incidence rates for knee WMSDs was similar to the rate of decline for all other WMSDs. Industries at highest risk for knee WMSDs included construction and building contractors. Occupations of concern included carpenters and truck drivers in men and nursing aides and housekeepers in women. CONCLUSIONS: Between 1999 and 2007, Washington State Fund knee WMSDs were widespread and associated with a large cost. Identification of specific occupational knee WMSD risk factors in high-risk industries is needed to guide prevention efforts.

Tak, S., et al. (2011). "Physical ergonomic hazards in highway tunnel construction: overview from the Construction Occupational Health Program." *Appl Ergon* 42(5): 665-671.

This report provides an overview of physical ergonomic exposures in highway construction work across trades and major operations. For each operation, the observational method "PATH" (Posture, Activity, Tools and Handling) was used to estimate the percentage of time that workers spent in specific tasks and with exposure to awkward postures and load handling. The observations were carried out on 73 different days, typically for about 4 h per day, covering 120 construction workers in 5 different trades: laborers, carpenters, ironworkers, plasterers, and tilers. Non-neutral trunk postures (forward or sideways flexion or twisting) were frequently observed, representing over 40% of observations for all trades except laborers (28%). Kneeling and squatting were common in all operations, especially tiling and underground utility relocation work. Handling loads was frequent, especially for plasterers and tilers, with a range of load weights but most often under 15 pounds. The results of this study provide quantitative evidence that workers in highway tunnel construction operations are exposed to ergonomic factors known to present significant health hazards. Numerous opportunities exist for the development and implementation of ergonomic interventions to protect the health and safety of construction workers.

Tak, S., et al. (2009). "Variability in risk factors for knee injury in construction." *J Occup Environ Hyg* 6(2): 113-120.

This study investigated sources of variance in exposure to risk factors for knee pain in a variety of highway construction trades, operations, and tasks. Over 15,000 discrete observations of leg postures and weights handled were made on 120 construction workers in five construction trades, in nine operations over 79 days. The contributions of trade, operation, task, and worker to the variability in work time spent kneeling, squatting, and carrying loads were evaluated with multilevel random effects models. Construction operation and task explained about 20% to 30% of total variation in kneeling, squatting, and carrying loads. There was a large unexplained component of variance thought to represent day-to-day variability of exposure within task. Reliable assessments of knee exposures require multiple days to accommodate the high variability of exposures among operations and tasks

and over time. These sources of variability should be carefully considered in efforts to estimate exposures to knee loading for epidemiologic or intervention studies. Homogenous exposure groups are not easily defined from the readily available organizational features of construction work.

Turner, J. A., et al. (2000). "Predictors of chronic disability in injured workers: a systematic literature synthesis." *Am J Ind Med* 38(6): 707-722.

BACKGROUND: Loss of productive life among injured workers potentially could be prevented by clearer knowledge of disability risk factors. Despite the number of studies that have examined predictors of disability, there have been no systematic literature reviews integrating multiple risk factor domains. Such a synthesis could help to define important gaps in knowledge, inform future study designs most likely to successfully address these gaps, and highlight the importance of secondary (disability) prevention to public health policy. A systematic synthesis of the literature on risk factors for chronic or recurrent disability in injured workers was performed to meet this need. **METHODS:** Articles were identified through a MEDLINE search, personal file searches, and requests to experts. Information concerning study methods and results was abstracted from 20 articles that met the inclusion criteria (population-based or prospective cohort studies). **RESULTS:** The most frequently identified predictors of prolonged disability were older age and greater baseline pain and functional disability. Lumbar symptoms, smaller company size, and construction work were significant predictors in several, but not all, studies. Risk factors did not appear to differ for back versus mixed injuries. **CONCLUSIONS:** Several risk factors for prolonged disability were identified. Research is needed to develop and test multivariate models of worker, workplace, health care, and administrative risk factors for prolonged and recurrent disability in order to refine and target interventions.

Viswanathan, M., et al. (2006). "Field evaluation of a continuous passive lumbar motion system among operators of earthmoving equipment." *International Journal of Industrial Ergonomics* 36(7): 651-659.

Operating heavy mobile construction equipment is often associated with elevated rates of low back discomfort. However, few formal studies have evaluated interventions that may reduce low back discomfort among these workers. The objective of this study was to determine the effectiveness of a continuous passive lumbar motion system (CPLMS), which is an additional lumbar seat support that can cyclically inflate and deflate, in reducing low back discomfort among operators of heavy earth-moving equipment. This was a quasi-experimental intervention study with multiple observations in which body part discomfort surveys were collected from an intervention and a control group during normal working days. The intervention group also completed a CPLMS preference survey after completing use of the CPLMS for 646 h. Results from the body part discomfort survey showed no significant difference in low back discomfort between mornings and evenings for the first seven days, but a significant difference on the eighth and final day for the intervention group. In the control group, there was a significant difference between mornings and evenings on three out of five days for the low back discomfort score, where, the evening score was always higher than the morning score for all days. In addition, comparisons between the control and intervention groups indicated that the difference between morning and evening low back discomfort rating approached significance ($p = 0.06$). The CPLMS preference survey showed that 54% of the operators felt very comfortable using the CPLMS, 36% wanted one for their equipment, and 54% showed interest in experimenting with the CPLMS for a longer time period. Results from this study suggest that the use of this intervention may effectively reduce the development rate of low back discomfort experienced by operators of heavy earth-moving equipment throughout the work day. **Relevance to industry:** This study indicates that providing an intervention that promotes dynamic changes and improving lumbar curvature during prolonged static sitting in a whole body vibration environment may have a positive effect by reducing the development rate of low back discomfort.

Waehrer, G. M., et al. (2007). "Costs of occupational injuries in construction in the United States." *Accid Anal Prev* 39(6): 1258-1266.

This paper presents costs of fatal and nonfatal injuries for the construction industry using 2002 national incidence data from the Bureau of Labor Statistics and a comprehensive cost model that includes direct medical costs, indirect losses in wage and household productivity, as well as an estimate of the quality of life costs due to injury. Costs are presented at the three-digit industry level, by worker characteristics, and by detailed source and event of injury. The total costs of fatal and nonfatal injuries in the construction industry were estimated at \$11.5 billion in 2002, 15% of the costs for all private industry. The average cost per case of fatal or nonfatal injury is \$27,000 in construction, almost double the per-case cost of \$15,000 for all industry in 2002. Five industries accounted for over half the industry's total fatal and nonfatal injury costs. They were miscellaneous special trade contractors (SIC 179), followed by plumbing, heating and air-conditioning (SIC 171), electrical work (SIC 173), heavy construction except highway (SIC 162), and residential building construction (SIC 152), each with over \$1 billion in costs.

Wang, D., et al. (2017). "Assessing Work-Related Risk Factors on Low Back Disorders among Roofing Workers." *Journal of Construction Engineering and Management* 143(7): 04017026.

The construction industry has one of the worst occupational health and safety records of all industries. In recognition of this, several innovative safety techniques have been introduced to mitigate undesired events before they occur, including safety risk assessment. However, evaluation of safety risk is challenging due to the dynamic nature of the construction work environment and lack of reliable references. This study (1) compares safety risk of different construction trades in terms of common hazard types and sources of injuries, and (2) proposes safety risk quantification models by occupations, which can play a role as a safety reference for reliable safety risk assessment. Using occupational injury data, two relative injury indexes, relative fatality and relative days away injury indexes, were used to compare relative safety among 19 different construction occupations as well as the construction average. Each relative injury index of an occupation was further decomposed into hazard types, sources of injury, and injury scenarios. Based on comparative relative injury index data, a tree-based safety risk quantification model was proposed. The findings indicate each occupation has a unique pattern of safety data structure in terms of hazards and sources of injuries. In addition, the same occupation had different hazard types and sources of injury that can lead to different injury severities. A construction project typically involves numerous workers and resources. The safety risk analysis presented in this paper can be used as a general safety reference by safety managers to understand the dynamic nature of safety risk. It can also aid in preparing safety actions, such as inspections or training, more effectively by focusing on high-risk occupations, hazard types, or sources of injury.

Wang, X., et al. (2017). "Work-related musculoskeletal disorders among construction workers in the United States from 1992 to 2014." *Occup Environ Med* 74(5): 374-380.

OBJECTIVES: Examine trends and patterns of work-related musculoskeletal disorders (WMSDs) among construction workers in the USA, with an emphasis on older workers. **METHODS:** WMSDs were identified from the 1992-2014 Survey of Occupational Injuries and Illnesses (SOII), and employment was estimated from the Current Population Survey (CPS). Risk of WMSDs was measured by number of WMSDs per 10 000 full-time equivalent workers and stratified by major demographic and employment subgroups. Time series analysis was performed to examine the trend of WMSDs in construction. **RESULTS:** The number of WMSDs significantly dropped in the US construction industry, following the overall injury trends. However, the rate of WMSDs in construction remained higher than in all industries combined; the median days away from work increased from 8 days in 1992 to 13 days in

2014, and the proportion of WMSDs for construction workers aged 55 to 64 years almost doubled. By occupation, construction labourers had the largest number of WMSD cases, while helpers, heating and air-conditioning mechanics, cement masons and sheet metal workers had the highest rates of WMSDs. The major cause of WMSDs in construction was overexertion, and back injuries accounted for more than 40% of WMSDs among construction workers. The estimated wage loss for private wage-and-salary construction workers was \$46 million in 2014. CONCLUSIONS: Construction workers continue to face a higher risk of WMSDs. Ergonomic solutions that reduce overexertion—the primary exposure for WMSDs—should be adopted extensively at construction sites, particularly for workers with a higher risk of WMSDs.

Weinstein, M. G., et al. (2007). "A roadmap to diffuse ergonomic innovations in the construction industry: there is nothing so practical as a good theory." *Int J Occup Environ Health* 13(1): 46-55.

Despite the availability of resources and practices that would reduce work-related morbidity and mortality in the construction industry, their diffusion to workers has been slow, partly because the ties between management and trade workers are weak. In promoting an innovation, it is necessary to target the stakeholders who will be making the decisions related to it. The authors' focus is on ergonomics, but their observations may be applied more broadly to other areas of intervention-effectiveness research.

Welch, L. and R. Baker (2015). "Introduction to the collection on research to practice in the construction industry." *Am J Ind Med* 58(8): 807-808.

Introduction to special AJIM issue

Welch, L., et al. (2009). "Musculoskeletal disorders among construction roofers—physical function and disability." *Scand J Work Environ Health* 35(1): 56-63.

OBJECTIVES: This study investigated the relationships between work demands, chronic medical and musculoskeletal conditions, aging, and the ability to remain on the job in a longitudinal study of 979 construction roofers between the ages of 40 and 59 years. METHODS: In a phone interview at baseline and 1 year later, the participants were asked about the presence of medical conditions and musculoskeletal disorders, work limitations and work accommodations, and social and economic functioning. RESULTS: Among the workers for whom a musculoskeletal disorder was their most serious condition at baseline, 8% left roofing due to a health condition during the first year of follow-up. A comparison between those who left and those who stayed identified older age and lower physical functioning as statistically significant predictors of leaving the trade. Workers with a musculoskeletal disorder and who, in the baseline interview, reported receiving some type of job accommodation for their musculoskeletal disorder had an odds ratio of 0.24 ($P=0.07$) for leaving work by the time of the 1-year follow-up when compared with workers with a musculoskeletal disorder and no job accommodation. The workers with three or more work limitations were also more likely to leave roofing, but this association disappeared after adjustment for other factors. CONCLUSIONS: Musculoskeletal conditions among roofers are strongly associated with work limitation, missed work, and reduced physical functioning, factors that are predictive of premature departure from the workforce. Job accommodation was provided for 31% of the roofers with a musculoskeletal disorder, and it was associated with a reduced likelihood of subsequently leaving roofing for health-related reasons.

Welch, L. S. (2009). "Improving work ability in construction workers—let's get to work." *Scand J Work Environ Health* 35(5): 321-324.

(Intro to special journal issue on aging, health and work limitations/ability/accomodations in construction.)

Welch, L. S., et al. (2008). "Age, work limitations and physical functioning among construction roofers." *Work* 31(4): 377-385.

BACKGROUND: To investigate the intersection of aging with work limitations, chronic medical and musculoskeletal conditions, and physical functioning we undertook a cross-sectional study of U.S. construction roofers who were current union members between the ages of 40 and 59. **METHODS:** Participants were asked about the presence of medical conditions and musculoskeletal disorders (MSDs); the Work Limitations Questionnaire, the SF-12, and other validated assessments of social and economic impact of injury were included. **RESULTS:** Sixty-nine percent had at least one of these conditions in the previous two years; 31% missed work. Workers with medical and musculoskeletal conditions were older, had the highest prevalence of work activity limitations, and had the lowest SF-12 scores. **CONCLUSIONS:** Older age was associated with the presence of a medical condition, and with reduced physical functioning. Medical and musculoskeletal conditions were strongly associated with work limitation, missed work, and reduced physical functioning. Older workers may be at higher risk of disability retirement compared to younger workers with similar medical conditions and work limitations.

Welch, L. S., et al. (2010). "Impact of musculoskeletal and medical conditions on disability retirement-a longitudinal study among construction roofers." *Am J Ind Med* 53(6): 552-560.

BACKGROUND: To assess the intersection of work demands, chronic medical and musculoskeletal conditions, aging, and disability, we initiated a longitudinal study of construction roofers who were current union members between the ages of 40 and 59. **METHODS:** Participants were asked about the presence of medical conditions and musculoskeletal disorders; the Work Limitations Questionnaire, the SF-12, and other validated assessments of social and economic impact of injury were included. **RESULTS:** Factors at baseline that predicted leaving for a health-related reason were older age, lower physical functioning, work limitations, and having missed work. Those who left roofing for a health-related reason were much more likely to have a lower economic score at the 1 year interview. **CONCLUSIONS:** Medical and musculoskeletal conditions are strongly associated with work limitation, missed work, and reduced physical functioning; these factors are also associated with premature departure from the workforce.

Welch, L. S. and K. Hunting (2003). "Injury surveillance in construction: what is an "injury", anyway?" *Am J Ind Med* 44(2): 191-196.

BACKGROUND: Over the last decade, there has been a decline in injuries with days away from work in construction, associated with an increase in injuries with restricted work activity only. **METHODS:** We abstracted demographics, diagnosis, cause-of-injury, and hospital discharge information for 481 workers from one large construction project treated in an urban Emergency Department (ED). The project safety team provided data on all injuries from this site, including first aid cases. **RESULTS:** This site had fewer injuries with days away from work than expected from national rates. Two hundred and fifty-six injuries were reported on the OSHA log, and of those 93 entailed days away from work; 1,515 injuries were considered first aid/medical only. We used a sample of the data to estimate that the site classified as "recordable" 128 of the 481 ED-treated injuries from this site (27%). **CONCLUSIONS:** The pattern of injury varies depending on the subset of injuries examined. Lost time injuries, as reported in BLS data, record fewer lacerations and eye injuries, and more strains and sprains. No one surveillance system presents the full spectrum of occupational injury. Tracking all injuries allow early recognition of injury risks, and therefore can lead to more effective prevention.

Welch, L. S., et al. (2015). "Best practices for health and safety technology transfer in construction." *Am J Ind Med* 58(8): 849-857.

Background: Construction continues to be a dangerous industry, yet solutions that would prevent injury and illness do exist. Prevention of injury and illness among construction workers requires dissemination, adoption, and implementation of these effective interventions, or "research to practice" (r2p). Methods: CPWR recruited participants with experience and insight into effective methods for diffusion of health and safety technologies in this industry for a symposium with 3 group sessions and 3 breakout groups. The organizers reviewed session notes and identified 141 recommendations, which were then assigned to 13 over-arching themes. Results: Recommendations included a guide for researchers on patenting and licensing, a business case model, and in-depth case studies including development, testing, manufacturing, marketing, and diffusion. Conclusions: A more comprehensive understanding of the health and safety technology transfer landscape, the various actors, and their motivators and goals will help to foster the successful commercialization and diffusion of health and safety innovations. *Am. J. Ind. Med.* 58:849-857, 2015. © 2015 Wiley Periodicals, Inc.

Wellman, H., et al. (2004). "Work-Related Carpal Tunnel Syndrome (WR-CTS) in Massachusetts, 1992-1997: Source of WR-CTS, Outcomes, and Employer Intervention Practices." *Am J Ind Med* 45(2): 139-152.

Background: The Massachusetts Sentinel Event Notification System for Occupational Risks (MASS SENSOR) receives reports of work-related carpal tunnel syndrome (WR-CTS) cases from (1) workers' compensation (WC) disability claims for 5 or more lost work days; and (2) physician reports (PR). Methods: From 1992 through 1997, 1,330 WC cases and 571 PR cases completed follow-back surveys to provide information on industry, occupation, attributed source of WR-CTS, outcomes, and employer intervention practices. Results: Sixty-four percent of the respondents had bilateral CTS and 61% had surgery, both of which were proportionally more frequent among WC cases. Office and business machinery was the leading source of WR-CTS (42% of classifiable sources) in every economic sector except construction, followed by hand tools (20%). Managers and professional specialty workers were the most likely to report employers' interventions and were up to four times more likely to report equipment or work environment changes than higher risk groups. Conclusions: State-based surveillance data on the source of WR-CTS provided valuable information on how and where to implement interventions. New occurrences of WR-CTS are likely, especially in the highest risk industries where very few cases reported primary prevention measures (e.g., changes to equipment or work environment) implemented by their employers. © 2004 Wiley-Liss, Inc.

West, G. H., et al. (2016). "An analysis of permanent work disability among construction sheet metal workers." *J Occup Environ Hyg* 59(3): 186-195.

BACKGROUND: Causes of permanent work disability in the sheet metal industry are not well characterized. METHODS: Pension records were used to compare causes of disability among sheet metal workers and the U.S. working population. Subgroup analysis examined the major causes of sheet metal worker disability. RESULTS: Musculoskeletal disorders (MSDs), circulatory disease, and injuries were leading causes of sheet metal worker disability (47.2%, 13.7%, 10.9% of awards, respectively). Award distribution differed from the U.S. working population ($P < 0.0001$); MSDs and injuries accounted for higher proportions of sheet metal worker awards, particularly at spine, shoulder, and knee. CONCLUSIONS: Higher proportions of awards caused by MSD or injury among sheet metal workers may reflect higher rates of work-related injuries and MSDs, a high likelihood of disability with construction work given the same impairment, or higher prevalence of other conditions in the general

population. Prevention requires task-specific ergonomic innovations and proven participatory interventions.

Winnemuller, L. L., et al. (2004). "Comparison of ergonomist, supervisor, and worker assessments of work-related musculoskeletal risk factors." *J Occup Environ Hyg* 1(6): 414-422.

In primary prevention efforts to reduce the incidence of work-related musculoskeletal disease (MSD), many employers will use supervisor or worker assessments for initial evaluation of MSD risk factors. This cross-sectional study examined the ability of supervisors and workers to accurately assess the presence of MSD risk factors at four work sites in four different industries, examining five jobs that represented six primary categories of risk factors: posture, force, repetition, impact, lifting, and vibration. Thirty-seven supervisors and 55 workers assessed the jobs they oversee or perform through the use of a 14-item questionnaire. Their assessments were compared with detailed ergonomist job analyses to determine their accuracy in identifying the presence or absence of MSD risk factors. In assessing the absence or presence of all risk factors, agreement with the ergonomist was found 81% of the time for supervisors and 77% of the time for workers. Overall, supervisors and workers overestimated the presence of risk in assessing the jobs. Supervisors and worker assessments appear promising in recognizing risk in initial ergonomic assessments.

Wu, J. Z., et al. (2009). "Analysis of musculoskeletal loadings in lower limbs during stilts walking in occupational activity." *Ann Biomed Eng* 37(6): 1177-1189.

Construction workers often use stilts to raise them to a higher level above ground to perform many tasks, such as taping and sanding on the ceiling or upper half of a wall. Some epidemiological studies indicated that the use of stilts may place workers at increased risk for knee injuries or may increase the likelihood of trips and falls. In the present study, we developed an inverse dynamic model of stilts walking to investigate the effects of this activity on the joint moments and musculoskeletal loadings in the lower limbs. The stilts-walk model was developed using the commercial musculoskeletal simulation software AnyBody (version 3.0, Anybody Technology, Aalborg, Denmark). Simulations were performed using data collected from tests of four subjects. All subjects walked without or with stilts through a 12-m straight path. The moments of the knee, hip, and ankle joints, as well as forces in major muscles or muscle groups in the lower limbs, for stilts walking were compared with those for normal walking. Our simulations showed that the use of stilts may potentially increase the peak joint moment in knee extension by approximately 20%; induce 15% reduction and slight reduction in the peak joint moments in ankle plantar flexion and hip extension, respectively. The model predictions on the muscle forces indicated that the use of stilts may potentially increase loadings in five of eight major muscle groups in the lower extremities. The most remarkable was the force in rectus femoris muscle, which was found to potentially increase by up to 1.79 times for the stilts walking compared to that for the normal walking. The proposed model would be useful for the engineers in their efforts to improve the stilts design to reduce musculoskeletal loadings and fall risk.

Yuan, L. (2013). "The effects of the position and size of drywall on the physical demands for installers."

The present study utilized an integrated biomechanical modeling approach that was previously developed by the researcher to investigate the effects of position and size of drywall on the physical demands for drywall installers.

Yuan, L. and B. Buchholz (2014). "The effects of position and size of drywall on the physical demands for installers." *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* 58(1): 1612-1616.

The present study utilized an integrated biomechanical modeling approach that was previously developed by the researchers to investigate the effects of position and size of drywall on the physical demands for drywall installers. If the drywall sheets were stored vertically instead of flat, it reduced the required muscle contraction forces and joint reaction forces at the low back and shoulder approximately 8% on average during drywall installation. In particular, the L4/L5 disc compression forces and the absolute values of L4/L5 anterior-posterior shear forces decreased 6.1% and 8.5%, respectively, and at the shoulder during lifting the forces of rotator cuff muscles decreased 9.8%, and the coracohumeral ligament forces decreased 12.8%. The reaction forces at both the GH (glenohumeral) and SC (sternoclavicular) joints were reduced 7.2% and 3.6%, respectively. The larger size (e.g., 4x12 and 4x16) of drywall sheets increased the physical burden for the installers tremendously and could expose them to a higher risk of musculoskeletal injuries and disorders. In some simulations the average low back lateral shear forces increased to 1675 N and 2152 N, respectively. These forces are well above the 1000 N recommended for a single lift. These results indicated that it would be physically too difficult or even impossible for one person alone to lift bigger and heavier drywall sheets. Therefore, sound engineering (e.g., lifting tables) and/or administrative (e.g., two-person team work) solutions to handling oversized drywall sheets are strongly recommended.

Yuan, L., et al. (2016). "An integrated biomechanical modeling approach to the ergonomic evaluation of drywall installation." *Appl Ergon* 53: 52-63.

Three different methodologies: work sampling, computer simulation and biomechanical modeling, were integrated to study the physical demands of drywall installation. PATH (Posture, Activity, Tools, and Handling), a work-sampling based method, was used to quantify the percent of time that the drywall installers were conducting different activities with different body segment (trunk, arm, and leg) postures. Utilizing Monte-Carlo simulation to convert the categorical PATH data into continuous variables as inputs for the biomechanical models, the required muscle contraction forces and joint reaction forces at the low back (L4/L5) and shoulder (glenohumeral and sternoclavicular joints) were estimated for a typical eight-hour workday. To demonstrate the robustness of this modeling approach, a sensitivity analysis was conducted to examine the impact of some quantitative assumptions that have been made to facilitate the modeling approach. The results indicated that the modeling approach seemed to be the most sensitive to both the distribution of work cycles for a typical eight-hour workday and the distribution and values of Euler angles that are used to determine the "shoulder rhythm." Other assumptions including the distribution of trunk postures did not appear to have a significant impact on the model outputs. It was concluded that the integrated approach might provide an applicable examination of physical loads during the non-routine construction work, especially for those operations/tasks that have certain patterns/sequences for the workers to follow. © 2015 Elsevier Ltd and The Ergonomics Society.

Yuan, L. and M. Buvens (2015). "Ergonomic Evaluation of Scaffold Building." *Procedia Manufacturing* 3: 4338-4341.

The present study evaluated the ergonomic hazards that are associated with scaffold building/erecting for one of the local construction companies and proposed recommendations for solution/control measures to mitigate those hazards. Ergonomic hazards were identified based on field observation and conversation with workers, superintendents/foremen, and managers. REBA (Rapid Entire Body Assessment) was used to estimate the risks of entire-body injuries and disorders. Building/erecting scaffolds requires lifting/carrying heavy and bulky materials, awkward postures (e.g., reaching and holding overhead, and kneeling on the scaffolds), and repetitive motions (e.g., hammering the cuplocks). Exposure to these hazards lead to a high risk of musculoskeletal injuries and

disorders, especially to the back and shoulder, for scaffold builders. Discussion among the researcher and the pertinent personnel of the company was made during presentation of the research findings, so recommendations for control measures could be better communicated. The recommendations include, but are not limited to: installing scaffold hoist pulley system or other hoist assistance systems, training provided to all field personnel on ergonomics of scaffold building/erecting, proper work-rest scheduling, and workplace stretching program. © 2015 The Authors

