Ergonomic Interventions for Steel Manufacturing Workers

Hazards are ever-present in the steel plant environment, and a heightened awareness and emphasis on safety is a necessary priority for our industry. This monthly column, coordinated by members of the AIST Safety & Health Technology Committee, focuses on procedures and practices to promote a safe working environment for everyone.

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Don B. Daily SAFETY GRANT
To Promote Steel Industry Safety and Health

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Introduction

Musculoskeletal disorders (MSDs) continue to be a critical occupational health issue in the United States. It was reported that MSDs account for 33% of all workplace injuries and illnesses that require days away from work.[3,5] Workers in the steel manufacturing industry are often exposed to occupational tasks that require high strength and endurance, which results in high incidence of MSDs among this group of individuals.[1,4,6,15] In 2014, with the help of the Don B. Daily Safety Grant, the investigators were able to form a research team to investigate the MSD risks among steel manufacturing workers and the ergonomic interventions that could be used to reduce these risks.

Over the past two decades, ergonomic interventions have demonstrated their effectiveness in reducing MSD-related risks in different occupational settings. Previous researchers have conducted ergonomic studies in a number of industries, such as agriculture,[12,13] fishing,[16,17] construction[14,19] and retail,[2] and successfully implemented ergonomic interventions to reduce injury risks. However, efforts in reducing MSD risk among steel manufacturing workers with the use of ergonomic interventions have been limited.

The investigators' previous study identified multiple tasks in a steel manufacturing plant that could potentially increase the risk of MSDs among steel workers.[18] Therefore, the main goal of this study was to design ergonomic interventions in order to reduce the incidence of MSDs among steel manufacturing workers. It was hypothesized that, in general, reduced muscle activity and more neutral body postures will be observed when the proposed ergonomic interventions are used.

Methodology

Participants — Eight male participants were recruited from the West Virginia University student population. Their average age, body weight and height were 26.2 years (SD 2.2 years), 67.3 kg (SD 10.3 kg) and 174.6 cm (SD 8.5 cm), respectively. All participants were free from any MSDs during the past 18 months. In addition, in order to eliminate the potential confounding gender effect, female subjects were excluded from the current study. The experiment procedure was approved by the West Virginia University Institutional Review Board. Written, informed consents were obtained from all subjects prior to the data collection.

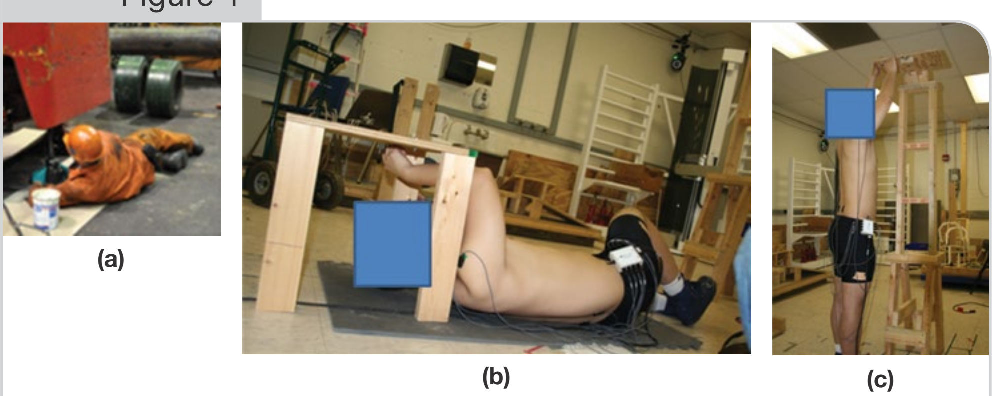
Instrumentation and Apparatus — Muscular electromyography (EMG) data were collected from the left brachioradialis (LB), right brachioradialis (RB), left trapezius (LT), right trapezius (RT), left deltoid (LD), right deltoid (RD), left erector spinae (LES) and right erector spinae (RES) using bipolar surface electrodes (Bagnoli™, Delsys, Boston, Mass., USA) with a sampling frequency of 1,024 Hz. The sampling locations can be found in previous studies.[10,11,20] Participants' lumbar and trunk kinematics performance was also recorded using a magnetic field-based motion tracking system (Motion Star, Ascension, Burlington, Vt., USA); three motion sensors were secured over the skin of the spinous processes of the C7, T12 and S1 vertebrae, and standard preparation procedure was taken according to previous studies.[8,9] The electromyography and trunk kinematics data were synchronized and processed using motion monitor software (Innovative Sports Training, Chicago, Ill., USA) with a sampling frequency of 1,024 Hz. Custom-made apparatuses were implemented to simulate the real working environment in the current study. A force/torque sensor with six degrees of freedom (ATI Industrial Automation, Apex, N.C., USA) was used to record the magnitude hand force exertions in lab simulations, and real-time graphical force output feedback was displayed on an LCD screen using MyoResearch XP analysis software (Noraxon USA Inc., Scottsdale, Ariz., USA).

Intervention Design and Experimental Protocol — Four high-risk tasks were investigated, and ergonomic interventions were designed for each task. Each task's performance included two segments; in the first segment, task performance without the use of ergonomic intervention was simulated, and in the second segment, a new work method with the use of ergonomic intervention was simulated. Both segments were conducted in a laboratory setting. When data collection started, participants first performed a series of maximum voluntary contraction (MVC) trials to collect the maximum EMG. These maximum EMG data were later used for normalization. Participants were then asked to perform the following tasks.

***Tractor Maintenance Task* —** During the investigators' visit to the steel manufacturing plant, they observed that the tractor maintenance task involved a significant amount of awkward working postures. Workers needed to lie down on the ground most of the time and conduct prolonged overhead tasks. These postures create stress on workers' neck and shoulder muscles. Therefore, the investigation team proposed to the tractor maintenance team the idea of adding a ground pit and hypothesized that by conducting regular maintenance tasks in the ground pit, workers could use more natural postures, which could significantly reduce the tension on their neck and shoulder muscles and thus reduce the risk level of MSDs. In the simulation study, participants were asked to finish a typical tractor maintenance task (tighten a bolt with wrench) using two different postures: a supine posture (Figure 1b) and a standing posture simulating the use of ground pit (Figure 1c). Each subject performed six trials of this task (three repetitions at each condition) in a completely randomized order. One minute of rest was provided between trials. Muscular activities were collected with EMG electrodes and saved for further analysis.

***Coil-Wrapping Task* —** The coil-wrapping task was another high-risk task. This task involves prolonged trunk flexion, which has been identified by previous literature as a risk factor for the development of lower back pain.[7] The investigators proposed to introduce a hydraulic lift under the steel coil in order to elevate its height during the coil-wrapping task. In this way, workers could adopt more natural working postures.

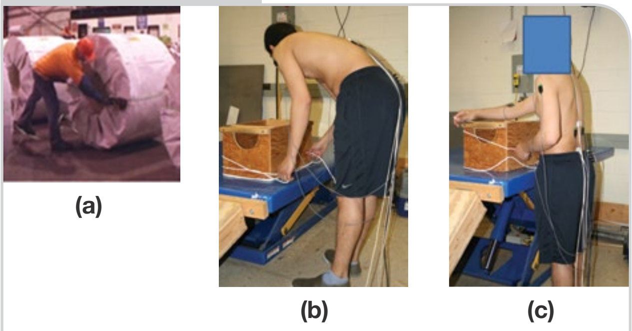
Figure 1



Tractor maintenance task performed in a steel manufacturing plant (a). Lab simulation of the maintenance task without using a ground pit (b). Lab simulation of the maintenance task while using a ground pit (c).

The simulation task required participants to perform wrapping tasks at two different coil heights: 75 cm above ground level (without hydraulic lift) and 125 cm above ground level (with hydraulic lift) (Figures 2a–2c). Subjects were required to perform simulated coil-wrapping tasks. In the segment without intervention, participants were required to rotate the trunk to the right side and bend the trunk forward, while in the segment with intervention, participants performed the same task in a more upright posture.

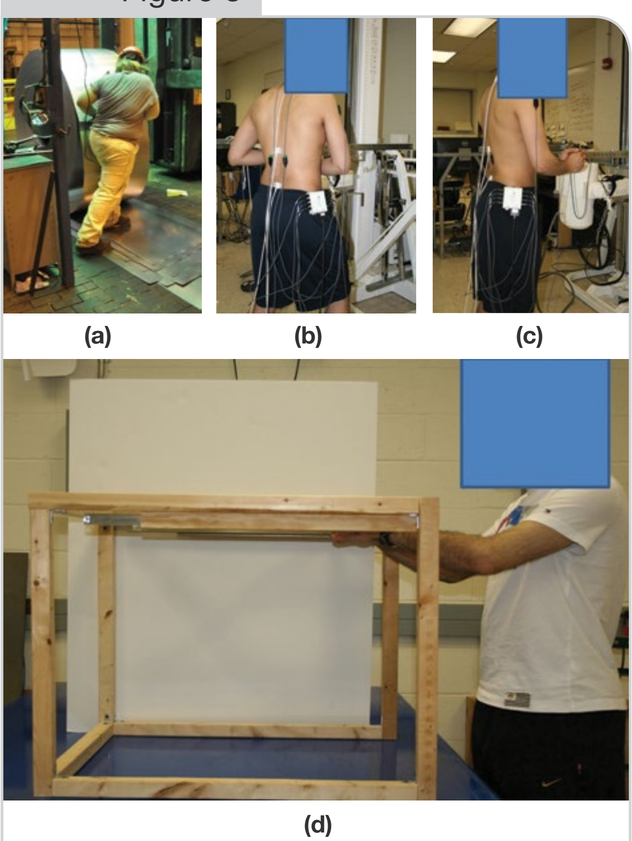
Figure 2



Coil-wrapping task performed in a steel manufacturing plant (a). Lab simulation of the coil-wrapping task without intervention (b). Lab simulation of the coil-wrapping task with intervention (c).

Steel Sample-Cutting Task — The steel sample-cutting task has been reported in the previous study.[18] When performing this task, workers need to maintain a twisted trunk posture and exert a large pushing force on a handheld metal-cutting saw to cut down sheets of steel as samples (Figure 3a). In this study, the investigators designed and built a new apparatus for the metal cutting task: this structure (Figure 3d) will help workers to use a more neutral standing posture and exert equal forces with both hands. The task simulation required participants to perform metal-cutting tasks with and without this intervention (Figures 3b and 3c). The task without intervention requires participants to adopt a staggered foot posture, lean forward about 20° and exert 50N of horizontal force (simulated pushing force) and 20N of vertical force (simulated holding force for the hand tool) on a metal handle that is attached to a force sensor. Tasks performed with intervention require participants to adopt a natural standing posture and exert only 50N of horizontal force.

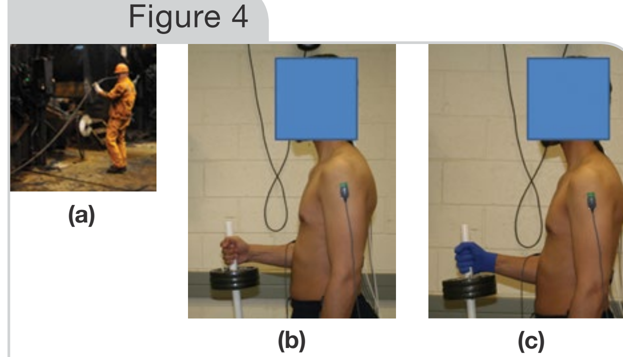
Figure 3



Steel sample-cutting task performed in a steel manufacturing plant (a). Lab simulation of a steel sample-cutting task without intervention (b). Lab simulation of a steel sample-cutting task with intervention (c). A prototype of the sample-cutting apparatus (d).

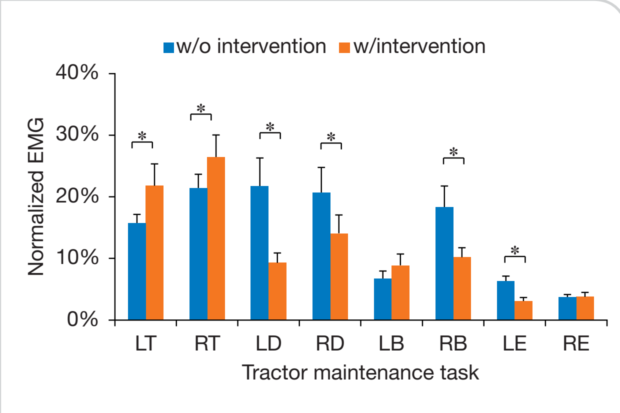
Machine Maintenance Task — The machine maintenance task was also reported in the previous study.[18] When conducting daily machine maintenance tasks, the accumulation of grease on the tools and cables significantly increases the difficulty of task performance (Figure 4a). The investigators proposed to use anti-slip gloves. An experiment was conducted to quantify the effect of anti-slip gloves on trunk and upper extremity muscle activities during tool-handling tasks. In this task,

Figure 4



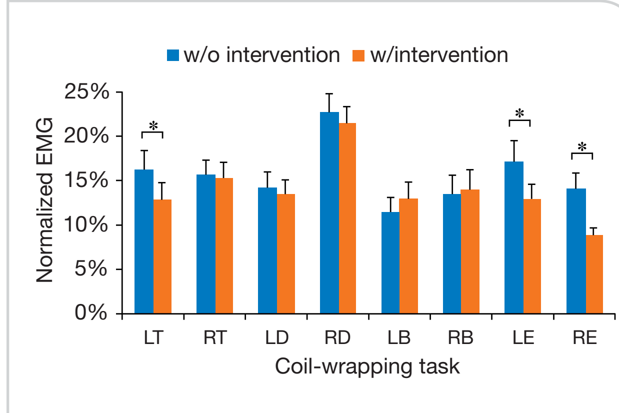
The machine maintenance task performed in a steel manufacturing plant (b). Lab simulation of the machine maintenance task without intervention (b). Lab simulation of the machine maintenance task with intervention (c).

Figure 5



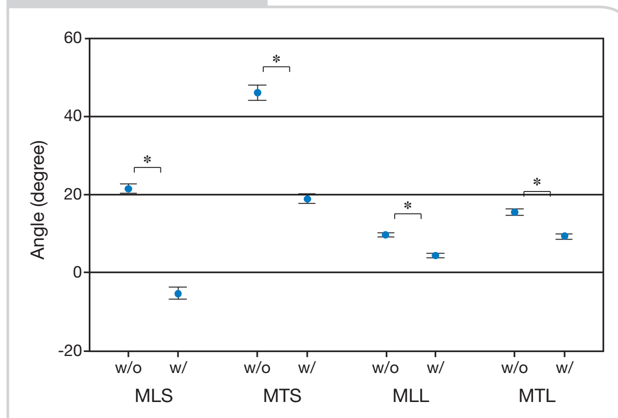
The normalized electromyography (EMG) when performing simulated maintenance tasks for the left trapezius (LT), right trapezius (RT), left deltoid (LD), right deltoid (RD), left bracioradialis (LB), right bracioradialis (RD), left erector spinae (LE), and right erector spinae (RE). "*" indicates significant difference between conditions. Bars indicate the corresponding standard errors.

Figure 6



The normalized EMG when performing simulated coil wrapping tasks. See Figure 5 for explanations of abbreviations and symbols.

Figure 7



Trunk kinematics when performing simulated coil-wrapping tasks with and without intervention on the maximum lumbar sagittal angle (MLS), maximum trunk sagittal angle (MTS), maximum lumbar lateral angle (MLL) and maximum trunk lateral angle (MTL). "*" indicates significant difference between conditions. Bars indicate the corresponding standard errors.

grease was applied to the handle of a weight (10 lbs.). Participants were asked to hold the weight using their dominant hands with and without wearing the anti-slip gloves (Figures 4b and 4c).

Data Processing and Statistical Analyses — The raw EMG data were filtered with a high-pass frequency of 10 Hz, a low-pass frequency of 500 Hz, and a notch filter of 60 Hz and its aliases. The data were then full-wave rectified, and a half-second moving window was used to further smooth the profile. Next, EMG data were normalized with regard to MVC EMG for each muscle. The lumbar flexion angle was defined as the angular difference between T12 and S1 motion sensors, while the trunk angle was calculated as the angle between the vertical (normal) line and the line between the C7 and S1 motion sensors. The student's t-test was used to analyze muscle activity differences between different conditions. The criterion p-value was 0.05 for all statistical analysis.

Results and Discussion

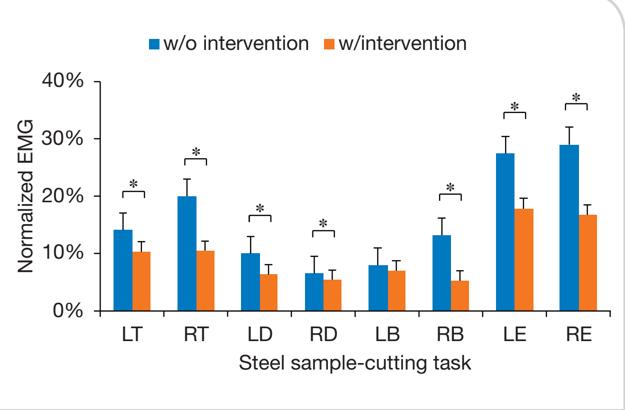
For the tractor maintenance task, results showed that all muscles' normalized EMG [except left brachioradialis (p-value = 0.25) and right erector spinae (p-value = 0.948)] were significantly influenced by different working postures in the task (Figure 5). By introducing the ground pit into the task, there was a significant reduction of muscle stress in the neck region. This result shows that the use of a ground pit in this task could potentially reduce MSD risks in the neck region. However, the use of ground pit also elevated the muscle activity among deltoid muscles, which shows a potentially increased risk of shoulder injury.

For the coil-wrapping task, the results showed that among all eight muscles, the left trapezius (p-value <0.001), left erector spinae (p-value = 0.007) and right erector spinae (p-value <0.001) were significantly affected by the intervention (Figure 6). This result showed that by adjusting the coil height to a more preferable level, workers could finish the same amount of work with much reduced muscle exertion. This change of muscle exertion could potentially increase productivity and reduce fatigue level. Meanwhile, trunk kinematics data showed that the use of this intervention reduced the maximum lumbar flexion angle and the maximum trunk flexion angle in both sagittal and lateral planes (Figure 7). These changes could potentially reduce the risk for lower back pain.

For the steel sample-cutting task, the results of analyses showed that all muscles except the left brachioradialis (p-value = 0.307) were significantly affected by the intervention (Figure 8). Specifically, with the help of the intervention, participants could finish the same task with much less muscle exertion. Meanwhile, the improved working posture significantly reduced subjects' trunk flexion in both sagittal and frontal planes (Figure 9).

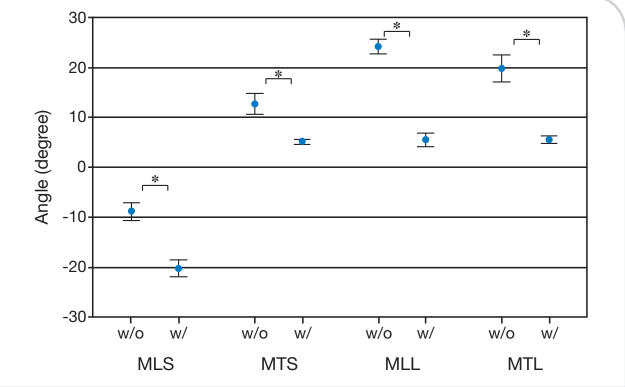
Finally, for the machine maintenance task, the use of anti-slip gloves significantly reduced the neck, shoulder, arm and lower back muscle activities (Figure 10).

Figure 8



The normalized EMG when performing simulated steel sample-cutting tasks. See Figure 5 for explanations of abbreviations and symbols.

Figure 9



Trunk kinematics when performing steel sample-cutting tasks with and without intervention. See Figure 7 for explanations of abbreviations and symbols.

Conclusions

To summarize the investigators' findings, introducing a ground pit to the regular tractor maintenance task could significantly reduce workers' neck stress. Adjusting the height of a coil to workers' shoulder level could reduce whole body muscle stress and generate more neutral trunk and lower extremity postures. Moreover, when performing the steel sample-cutting task, the apparatus proposed in this study may reduce the required hand force and consequently reduce upper extremity and lower back muscle stress. Finally, the use of anti-slip gloves could decrease the risks of MSDs to the neck, lower back, shoulder and arm during task performance. In conclusion, the proposed ergonomic interventions tested in this study all showed potential of reducing MSD risk for steel manufacturing workers.

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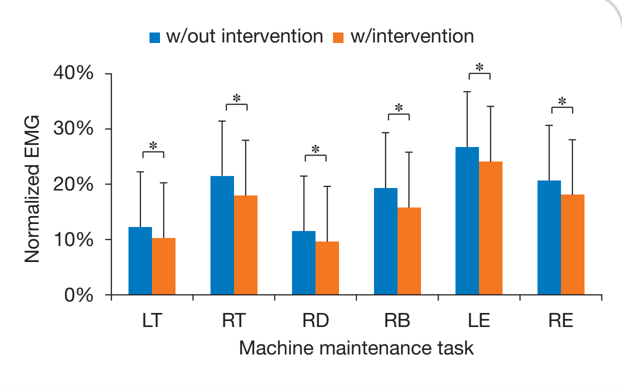
Figure 10



The normalized EMG when performing simulated machine maintenance tasks. See Figure 5 for explanations of abbreviations and symbols.

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