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Ergonomic assessment of musculoskeletal discomfort of iron workers in highway construction

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Abstract. *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.

Keywords: Ergonomic assessment, musculoskeletal disorders, body discomfort, physical exertion, posture, iron worker, rebar tying, highway construction

1. Introduction

The construction industry is consistently ranked among the most dangerous occupations and accounts for a disproportionately large percentage of all work-related illnesses, injuries, and deaths in the United States [6]. The boom in construction is so widespread that project delays and shortage in materials and labor are common [22]. In 2002, about 1 in 5 construction workers worked 45 hours or more a week. Construction workers may occasionally work evenings, weekends, and holidays to finish a job or take care of an emergency [3]. According to the BLS, the construction industry had the highest incidence rate of any U.S. industry from 1992 to 2002, for all recorded cases. These injuries are not only detrimental to workers but are costly as well. The BLS [2] reported that 25% of all workers' compensation costs are associated with construction injuries. Considering that construction only accounts for about 6% of the workforce [13], this is a serious overrepresentation.

The existing data show construction workers to be at significant risk of musculoskeletal injury, specifically related to the work they do [19]. For years the construction industry has been associated with increased rates of work-related musculoskeletal disorders (WMSDs), a condition involving the soft tissues of the body, including muscles, tendons, nerves, cartilage, and oth-

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er supporting structures, that is caused by exposure to work-related factors [8]. Construction work is often associated with tasks involving forceful exertions that are excessive or prolonged, such as heavy lifting or prolonged grasping; awkward postures that are maintained for extended periods; pressure from hard surfaces or sharp edges on body tissues; vibration from tools and machinery; and environmental factors such as extreme temperatures and humidity [21]. Musculoskeletal disorders in the workplace are very significant and costly national health problem as they account for about 70 million physician office visits in the United States annually and an estimated 130 million total health care counters including outpatient, hospital, and emergency room visits [15]. Conservative estimates of the economic burden imposed by work-related musculoskeletal disorders in the United States, as measured by compensation costs, lost wages, and lost productivity, are between $45 and $54 billion annually [8].

Paquet, Punnett, and Buchholz [16] measured the frequency of exposure to manual materials handling (MMH) activities, and observed other exposures for construction work such as loads handled, body postures, tools handled and hand grasps. They characterized manual handling by iron workers, carpenters and laborers during highway construction operations. They found that the iron workers were the most frequently observed in MMH activities, and loads (tools and materials) were handled more than 40% of the time for each job task. Also, workers frequently observed in awkward trunk postures, and a power grasp (mostly performed with one hand) was frequently used during MMH activities. Paquet et al. [16] also mentioned that the frequency of manual materials handling exposures differed significantly among job tasks for each trade evaluated, demonstrating the importance of task-based exposure measures for evaluating ergonomic exposures. Similar findings by Goldsheyder et al. [8] and Schneider [19] showed that different types of work might account for the differences in pain localization among workers in construction trades and the proportional prevalence of musculoskeletal symptoms for different body regions vary from trade to trade.

With this in mind, the current exploratory work intended to point out the potential risks of work related musculoskeletal disorders for the type of activities that the iron workers encounter on a daily basis in highway construction. The job task that is the focus of this project is that of the "rodworkers." Rodworkers are the iron workers whose job it is to place and secure iron, used to reinforce concrete for concrete structures including bridge supports pillars, decks and sections of highway. It is apparent from observing the job duties of the rodworkers that they are engaged in repetitive activities requiring them to bend, twist, turn, lift, carry and stand in body positions that have the potential to reduce optimal long term performance of the duties of the rod worker.

Thus, the purpose of this pilot project is to evaluate the work related musculoskeletal injuries due to repetitive motion type activities of the rodworkers. Two specific job duties are analyzed: (1) tying the vertical, pier support systems, and (2) tying rebar on a horizontal bridge deck. The author hypothesized that the subjects in the study were exceeding known limits that prevent work related musculoskeletal disorders. The author performed some testing of the motions involved in the tasks and recorded other data to assess known data to parameters that identify potential for work-related musculoskeletal disorders.

2. Methods and procedures

2.1. Participants

Eleven right-handed male subjects participated in this study. Eleven rodworkers, including 5 pier tiers and 6 deck tiers, were recruited from a heavy and highway/bridge building project in Wisconsin. The mean and standard deviation (SD) values of age, weight, and height for the participants were 37 (11.3) years, 94.5 (22.1) kg, and 182 (8.1) cm. Experience ranged from 1 to 31 years. On average, the subjects worked 41 hours per week. Two activity groups were tested. The first group is tying the deck for a bridge and the second group is tying the pier cages that support the bridge decks.

2.2. Instructions and procedure

The measuring equipment consists of an adjustable Jamar handgrip dynamometer to determine the grip strength, and an employee survey to gather information on muscular-skeletal symptoms and an ergonomic assessment of the type of work being preformed and work station. The BodyMap instrument [11] is also used to assess both frequency and intensity level of discomfort associated with musculoskeletal disorders. The pictograph recording cells were designed to allow for the simultaneous ratings of frequency (0–3, 3 being constantly) and discomfort level (0–10, 10 being extreme

Table 1
Summary of means (std. dev.) of BodyMap

Body parts	Pier tiers ($n = 5$)		Deck tiers ($n = 6$)	
	Frequency	Discomfort	Frequency	Discomfort
Eyes	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Neck	0.0 (0.0)	0.0 (0.0)	0.2 (0.4)	0.7 (1.6)
Upper Back	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Left Shoulder	0.0 (0.0)	0.0 (0.0)	0.3 (0.5)	1.3 (2.1)
Right Shoulder	1.2 (1.1)	3.4 (3.1)	0.5 (1.2)	0.8 (2.0)
Left Upper Arm	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Right Upper Arm	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Left Elbow	0.6 (0.9)	1.8 (2.5)	0.0 (0.0)	0.0 (0.0)
Right Elbow	0.8 (1.3)	1.8 (2.5)	0.8 (1.3)	2.2 (3.4)
Left Forearm	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Right Forearm	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Left Wrist	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Right Wrist	1.2 (1.1)	2.8 (2.8)	1.3 (1.0)	3.7 (2.9)
Left Hand	0.4 (0.9)	0.6 (1.3)	0.3 (0.8)	0.7 (1.6)
Right Hand	0.4 (0.9)	1.2 (2.7)	1.0 (1.1)	3.0 (3.3)
Buttocks	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Mid-to-Lower Back	1.0 (1.0)	2.8 (2.6)	1.8 (1.2)	4.7 (2.5)
Left Thigh	0.0 (0.0)	0.0 (0.0)	0.7 (1.0)	1.8 (2.9)
Right Thigh	0.0 (0.0)	0.0 (0.0)	0.3 (0.8)	0.8 (2.0)
Left Knee	1.4 (1.3)	2.8 (2.6)	0.3 (0.8)	1.0 (2.4)
Right Knee	0.8 (1.1)	2.4 (3.3)	0.3 (0.8)	1.0 (2.4)
Left Lower Leg	0.0 (0.0)	0.0 (0.0)	0.7 (1.0)	1.7 (2.6)
Right Lower Leg	0.0 (0.0)	0.0 (0.0)	1.0 (1.1)	2.3 (2.6)
Left Ankle/Foot	0.4 (0.9)	0.8 (1.8)	0.0 (0.0)	0.0 (0.0)
Right Ankle/Foot	0.0 (0.0)	0.0 (0.0)	0.3 (0.8)	0.7 (1.6)

discomfort) on 25 different body regions. Subjects were instructed to provide their honest subjective ratings for all body areas that applied. Further, they were instructed to consider and record the levels that would be appropriate over the last 30 days time. Based upon a model developed by Marley and Kumar [11], it is then possible to have a worker's evaluation categorized as: (1) "likely" to seek treatment, (2) "somewhat likely" to seek treatment, and (3) "not likely" to seek treatment. The BodyMap is not predictive of specific diagnoses. Rather it is predictive of a worker seeking treatment (or not) for his/her discomfort [7].

The subjects are informed of the correct body position to maintain while the data collection for grip strength is administered. Maximum voluntary contraction (MVC) for grip strength of the dominant hand was collected at three forearm postures (neutral, supinated, pronated), shoulder at zero degrees, and the elbow flexed at 90 degrees. The subject was asked to squeeze the handgrip dynamometer slowly, building up to his maximum, and then hold the MVC for two seconds. This follows the protocol suggested by Caldwell [5]. In order to achieve a precision of 10% or better, at least two trials were collected. Next, the estimation of applied grip force of the actual rebar-tying operation was obtained using the hand grip dynamometer. To achieve a precision of 10% or better, at least four trials were collected for the simulated deck rebar-tying operation. General data (e.g., gender, age, height, weight, dominant hand, hours worked per week) were collected from the subjects prior to the experiment.

2.3. Results and discussion

The summary of means and standard deviations for BodyMap response variables (25 body regions) has been provided in Table 1. The BodyMap revealed that the mid-to-lower back clearly stood out in terms of the perception of the frequency and discomfort level experienced during the deck tying task. The discomfort level in the mid-to-lower back for deck tying was categorized as moderate discomfort, while the frequency level was categorized as frequently. The right wrist has the second greatest frequency and discomfort level. The right and left elbow also experience some discomfort. For pier tying task, the BodyMap recorded that the right shoulder clearly stood out in terms of the perception of the frequency and discomfort level experienced during the last 30 days. The discomfort level in the right shoulder for pier tying was categorized as moderate discomfort, while the frequency was categorized as frequently as well.

Table 2
Seek treatment for musculoskeletal discomfort

Subjects / Body Parts	Pier tiers (n = 5)					Deck tiers (n = 6)					
	P1	P2	P3	P4	P5	D1	D2	D3	D4	D5	D6
Eyes											
Neck											
Upper Back											
Left Shoulder											
Right Shoulder											
Left Upper Arm											
Right Upper Arm											
Left Elbow											
Right Elbow											
Left Forearm											
Right Forearm											
Left Wrist											
Right Wrist											
Left Hand											
Right Hand											
Buttocks											
Mid-Lower Back											
Left Thigh											
Right Thigh											
Left Knee											
Right Knee											
Left Lower Leg											
Right Lower Leg											
Left Ankle/Foot											
Right Ankle/Foot											

LEGEND

	"Green" zone: not likely to seek treatment
	"Yellow" zone: somewhat likely to seek treatment
	"Red" zone: very likely to seek treatment

Table 2 depicts the zones for each subject to seek treatment for musculoskeletal discomfort of the 25 body regions. Based on the BodyMap placement scheme (see Table 2), seeking treatment for the deck tiers was scored in the body regions of neck, right/left shoulders, right elbow, right wrist, right/left hands, mid-to-lower back, right/left thighs, right/left knees, right/left legs, and right foot/ankle. For the mid-to-lower back, 67% (4 of 6) of the deck tiers were placed in "red" zone (i.e., very likely to seek treatment) followed by right hand/wrist, right elbow/shoulder, and right/left knees. As shown in Table 2, seeking treatment for the pier tiers was scored in their right shoulder, right/left elbows, right wrist, right/left hands, mid-to-lower back, and right/left knees. For the right shoulder, 60% (3 of 5) of the pier tiers were placed in "red" zone followed by right knee, right elbow, and right hand/wrist.

Findings of the BodyMap assessment triggered a further ergonomic evaluation for the decking rodworkers. Tying of rods with wire using a pliers and the bent over posture of the highway deck workers was observed and tested (see Fig. 1a,b). All the maximum voluntary contraction (MVC) was obtained from the 6 subjects using a hand grip dynamometer. The hand grip dynamometer span was adjusted to reflect the actual grip span of the pliers, and at least 4 trials of the simulated deck rebar-tying task were administrated. Table 3 shows the percentage of maximum voluntary contraction and applied grip force of the simulated rebar-tying task for the highway deck.

As seen in Table 3, the three forearm postures (neutral, supinated, pronated) for MVC grip strength measurements were compared to that of the simulated deck rebar-tying posture. Results indicated that the deck tiers were using up to 92% of their maximum grip strength for the tying of rebar using a hand tool (pliers). At the neutral and supinated forearm postures, larger grip strengths were recorded than at the pronated forearm posture (see Table 3).

Table 3
Applied grip force and %MVC of rebar-tying

Deck Tiers ($n = 6$)	Average	Std. Dev.	Range	%MVC†
MVC at forearm neutral posture (kg)	54.7	7.2	41–61	64.8%^{1}
MVC at forearm pronated posture (kg)	38.7	7.0	33–50	91.5%^{2}
MVC at forearm supinated posture (kg)	45.8	8.9	39–59	77.5%^{3}
Applied force at working posture* (kg)	35.5	2.7	32–40	

*Tying rebar (snap ties) using a pliers with the bent over posture (see Figures 1.1 & 1.2).
†%MVC^{1} = [Applied grip force for the task / MVC at forearm neutral posture] * 100.
%MVC^{2} = [Applied grip force for the task / MVC at forearm pronated posture] * 100.
%MVC^{3} = [Applied grip force for the task / MVC at forearm supinated posture] * 100.

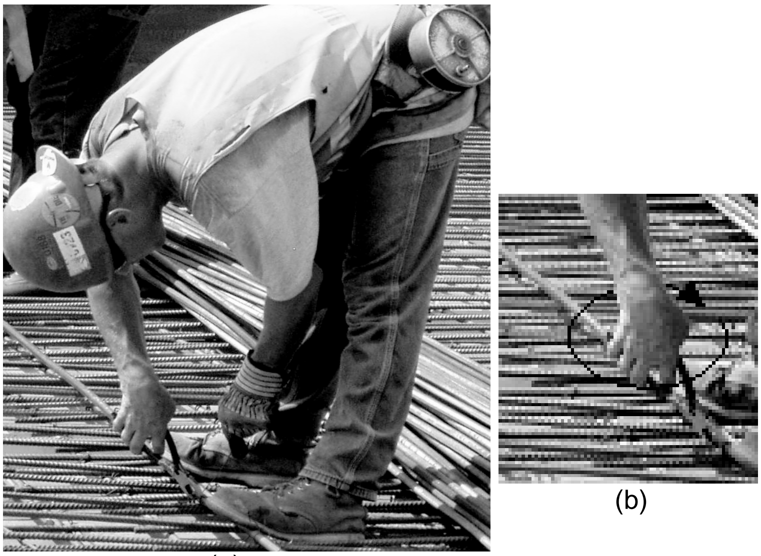

Fig. 1. (a) Deck working posture. (b) Deck tying rebar.

In discussion, it is interesting to mention here that the results of this study were very similar to past research where forearm pronated and supinated posture significantly reduced grip strength compared to the forearm neutral posture [12]. The current deck tier task (tying rebar using a pliers) required 65–92% of their maximum capability. For intermittent static work, a rough guideline is to keep the force exerted under 15–30% of the maximum capability [1,17] to avoid fatigue. The applied grip forces for the current deck rebar-tying operation were excessive and the applied grip forces could result in damage and fatigue in the wrist and forearm, as well as shoulder and back of the rodworkers. Previous research concurred that the risk of developing a hand or wrist disorder is significantly increased for workers performing highly repetitive and forceful exertions in awkward postures [9,20]. Moreover, Radwin and Smith [18] stated that the worker may lose control of the tool resulting in unintentional injury and poor work quality, when force demands exceed an operator's strength capacity.

3. Conclusions

This study demonstrated that work in rebar-tying construction had high potential risks for musculoskeletal disorders and injuries. Results from the BodyMap instrument showed that the symptoms issues of greatest concerns were the discomforts in the lower back and right wrist/hand of the rodworkers. The musculoskeletal discomfort might be as a result of the repetitive and inaccurate posture that the workers employed while bending, standing and tying rods using pliers. Additional finding revealed that the applied grip forces for the current rebar-tying operation were excessive (e.g., 65–92% of maximum capability) and could result in damage and fatigue in the body joints. The health and safety professionals in construction need to pay particular attention to the ergonomic issues identified in this paper to reduce the risk of injury and illness to their workers. It is believed that the ergonomic assessment techniques could assist the early detection of work-related musculoskeletal concerns and help prioritize jobs for intervention in the field. As stated by Marley and Kumar [11], the BodyMap has been shown to be a reliable leading indicator of musculoskeletal injury risk, and a surveillance tool for proactive ergonomic management.

The focus of ergonomic interventions here is regarding potential solutions for the wrist and back musculoskeletal disorders. One of the recommendations is to provide hand tools that are designed for the individual based on anthropometric data for that person. The cost would be minimal in comparison to the cost of a carpal tunnel syndrome case. According to Leigh et al. [10], for women (and men) with carpal tunnel syndrome, the total average costs were USD 76,697 (USD 87,917 for men). Another suggestion is to carry out a risk management assessment on hand tools. This assessment should look at, where possible, the purchasing of tools specifically designed for the job. Tool manufactures are critical links in this ergonomics process. Poorly designed hand tools increase the amount of vibration transmitted to the hands, increase the forces required to operate the tool, and increase the awkward postures and positions taken when using them. It is also important to train and supervise workers to use proper tools to minimize the risk of work-related musculoskeletal injuries. To modify the ergonomic issues associated with the lower back, the employer may seek to improve the design of jobs that minimize standing and bending (e.g., adjustable workbench at job site). As pointed by Choi [4], some other ways can be accomplished by changing work positions frequently so that working in one position is of a reasonable duration, avoiding extreme bending and twisting, allowing workers suitable rest periods to relax and exercise (pre-work stretching), and providing full instructions on ergonomic work practices.

However, it should be noted here that the results of the present study might be different from the other parts of the country when this pilot project is limited to one region. In the future, the author plans to collect a larger sampling of highway construction sites in an effort to develop a national database of ergonomic information. Further investigation is warranted to determine construction job site-specific ergonomic data collection mechanisms to develop optimal musculoskeletal disorders reduction strategies. In turn, properly applying the ergonomic assessment methods will continue to play an important role in the reduction of construction worker's illness, injury and disability.

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