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Final Report
(WSIB Grant #01023)

Reducing Risk Of Musculoskeletal Disorders and Promoting Return-To-Work Through The Use Of Rebar Tying Machines

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1.0 Plain Language Summary

The purpose of this study was to determine the potential reduction in the risk of musculoskeletal injuries to rodworkers when using an automatic rebar tying machine, and to determine the efficacy of the rebar tying machine as a rehabilitation device for the purpose of assisting injured workers in an early return to work program. The research project was divided into three phases. The first phase of the study was conducted in a controlled laboratory setting to investigate the biomechanical differences between manual tying and using the rebar-tying machine. In the second phase of the study, a field experiment was conducted to investigate the long-term health benefits of using the rebar-tying machine. The last stage of the study was also conducted in the field setting to test the efficacy of the rebar-tying machine as a rehabilitation device to assist injured workers in an early return-to-work program.

The results from the first two studies consistently showed a reduction in awkward posture of the trunk, wrist, and arms when rodworkers worked with the rebar-tying machine. The reduction in awkward wrist/hand motion and static awkward trunk poster can lead to a reduction in the risk of musculoskeletal injuries. The first two phases also revealed the tying machine's ability to tie rebar of various sizes and at the same time increase tying speed when comparing to traditional manual method in some applications. Subjective inputs from experienced rodworkers indicated that they prefer to work with the tying machine. The perception of "de-skilling" the rebar trade when using the tying machine was not found to be a factor in preventing the use of the mechanical tool. In the third phase of the study, the tying machine was evaluated for its potential promotion of early return to work. The results from the four injured rodworkers indicated the tying machine was able to accommodate their injuries, allowing the workers to return to their pre-injury job.

2.0 Executive Summary

2.1 Research Objectives

1. To determine the potential reduction in the risk of musculoskeletal injuries to rodworkers when using an automatic rebar tying machine.

2. To determine the efficacy of the rebar tying machine as a rehabilitation device for the purpose of assisting injured workers in an early return to work program.

3. To share the results with rodworkers, and other construction trades and firms so that exposure to ergonomic hazards can be eliminated or reduced.

2.2 Research Publications & Presentation at Research Conferences

Most findings have been written and submitted for publication in research journals and conferences. All of these papers can be found in the Appendix of this final report. The results of each paper will be reported below as an executive summary rather than repeating the contents of the papers. The research papers submitted to date are:

1. Vi, P., (2003). Reducing risk of musculoskeletal disorders through the use of rebar-tying machines. Applied Occupational and Environmental Hygiene, 18:1-6. (Appendix A)

2. Vi, P, and Almeida P. Using rebar tying machine to reducing awkward trunk posture while performing reinforcing steel work. Submitted to the Human Factors and Ergonomics Society 49th Annual Meeting.

3. Vi, P, and Almeida P. A field study of rebar tying machine as a tool to reduce risk of musculoskeletal injuries. Submitting to International Journal of Industrial Ergonomics. (Appendix B)

4. Vi P. Promoting early return to pre-injury job using a rebar tying machine. Submitted to Applied Occupational and Environmental Hygiene. (Appendix C)

2.3 Presentations and reports to worksite partners and trade association

Presentations and reports to worksite partners, CSAO's Labour-Management Committees, and trade association magazine are listed below. Due to the volume and redundancy with the journal article submissions, these reports and presentation have not been included in the final report.

1. "Reducing Risk Of Musculoskeletal Disorders and Promoting Return-To-Work Through The Use Of Rebar Tying Machines – Executive Summary". Presentation to Rodworkers' Labour-Management Health & Safety Committee, Toronto, ON, August, 2004.

2. "Rebar-tying machines – Part 1: An effective way to reduce upper limbs MSIs". Trade magazine article published in the Construction Safety Magazine, Volume 12 (number 4), 2003.

3. "Rebar-tying machines – Part 2: An effective way to reduce low back MSIs". Trade magazine article published in the Construction Safety Magazine, Volume 14 (number 1), 2004.

4. "More than rebar". Trade magazine article published in the NetworkNews, September 2004.

5. Final report and presentation for CSAO Rodworkers Labour-Management Committee, October, 2004.

6. Final report and presentation for CSAO Electrician Labour-Management Committee, October, 2004.

7. "A field study of rebar tying machine". Submitted to CSAO Construction Safety Magazine, November 2004.

8. "Promoting early return-to-work using a rebar tying machine". Submitted to the CSAO Construction Safety Magazine, February 2005.

2.4 Reducing risk of musculoskeletal disorders through the use of rebar-tying machines

Methodology

To evaluate the potential risk of low-back and upper limb injury and the benefits of using the rebar-tying machine, a controlled experiment with nine apprentices was conducted. The experiment took place at the International Association of Bridge, Structural, Ornamental, and Reinforcing Ironworkers Local 721 Training Centre. Simulated rebar tying tasks were performed to evaluate the biomechanical/ergonomic stresses on rodworkers. Two rebar tying methods were evaluated in this experiment: (1) manual tying, and (2) using a MAX RB392 (MAX USA, New York) rebar-tying gun. For each tying method, participants were asked to perform 50 horizontal ties of 15 mm by 15 mm rebar combination located at floor level. To evaluate the biomechanical stresses on rodworkers, rebar-tying tasks were evaluated using electrogoniometers (to measure wrist and arm angles), and electromyography (to measure low-back muscle activities).

Findings

1. For all planes of motion (flexion/extension, radial/ulnar, and pronation/supination), significant ($p<0.01$) differences in wrist and arm motions were observed between the two tying methods. In this study, tying with the rebar tying machine exposed the participants to significantly lower wrist activities (i.e. acceleration of the wrist) than when performing the tying task with pliers (i.e. manual tying).
2. Working with the rebar-tying machine significantly decreased peak loading in the lower back at the L4/L5 disc joint.
3. The cumulative loading on the back was also significantly less than during manual tying with pliers.

Implications and Recommendations

1. Based on the published TLV values in the literature (Marras and Schoenmarkling, 1993), this study found a high-risk of wrist injuries in the flexion/extension and radial/ulnar planes of motion when manually tying the rebar with pliers. Rebar tying with the rebar tying machine however, exposed workers to low-risk of wrist injury for all planes of motion.
2. Working with the rebar-tying machine significantly decreased peak loading in the lower back at the L4/L5 disc joint. The cumulative loading on the back was also significantly less than during manual tying with pliers. These reductions in low-back loading were mainly due to the workers' upright position while tying using the machine with an extension. Numerous studies have shown that reducing peak and cumulative forces on the lower back can significantly decrease the risk of low-back injury.
3. Although the rebar tying machine has shown to be a good tool to prevent risk of musculoskeletal injuries, preliminary testing in real job situations has shown some limitations. The first generation rebar tying machine limited tying capacity to 392 mm rebar size and experienced frequent jamming of the wire within the machine. Due to these limitations, it was recommended a larger rebar gun (RB650), with a capacity to tie up to 650 mm, should be used for the field study.

2.5 A Field Study of Rebar Tying Machine as a Tool to Reduce Risk of Musculoskeletal Disorders

Methodology

A before-and-after design approach was used in this study to evaluate the effectiveness of the rebar tying machine with an extension arm attachment. Only ground level rebar production was used to evaluate the intervention. Before implementing the intervention, all participants were asked to fill out a usability questionnaire regarding manual tying with pliers. Rebar tying time and trunk work postures while performing manual tying was also quantified. After the initial observation, each participant was trained and given the rebar tying machine for use in normal ground level rebar production. Each participant was allowed to use the rebar tying machine for three months. After the intervention period, each participant was asked to fill out a usability questionnaire regarding the use of the rebar tying machine. The questionnaire given after intervention was similar to the manual tying usability questionnaire. Rebar tying time and trunk work postures while performing rebar production with the tying machine was also quantified. The repeated measurement of all dependent variables (i.e., before and after) allowed comparison of the differences between the two work methods.

Findings

1. Using the traditional manual method the participants finished with an average rebar tying cycle time of 8.9 seconds. Using the rebar tying machine, the participants finished with an average rebar tying cycle time of 4.2 seconds - a decrease of 52% in comparison to the traditional method.
2. During manual tying with pliers, the highest and longest duration of trunk postures was skewed heavily in the neutral posture (<20°) and very extreme awkward trunk postures

(>60°). During machine tying, however, the distribution of the magnitude, frequency, and duration of the trunk posture was found to be concentrated between the trunk angles of greater than -10° and less than 50°.

3. The amplitude of the median and peak trunk posture level was found significantly ($p<0.05$) higher when participants tied rebar with pliers as compared to the tying machine.
4. The percentage of work time with the trunk in severe forward flexion (greater than 45°) was also evaluated. A mean value of 50.4% and 14.9% of the total work time in forward severe trunk flexion was found for manual and machine tying, respectively.
5. The self-report questionnaires identify several user preferences among the tying methods. Generally, working with the rebar tying machine was the preferred work method in several categories on the questionnaire for ground level rebar tying.

Implications and Recommendations

Based on the findings and experiences gained from this field study, the following issues should be considered when introducing and using the rebar tying machine:

1. Choose a rebar tying machine that allows tying steel rebar at a comfortable back posture. An adjustable extension arm helps to ensure that rodworkers differing in height can tie rebar in a neutral trunk posture.
2. The rebar tying machine should not be limited to rodwork. The machine can be used to tie electrical conduit and radiant heat tubes and decrease the risk of musculoskeletal injuries to electricians and heating tube installers. Furthermore, field experience has shown that the rebar tying machine can significant decrease the time to tie rebar, which in turn can improve productivity. The increase in productivity however, can be more dramatic if used by electrician or radiant heat installer since manual tying with pliers is

very slow and awkward when performed by non-rodworkers trade.

3. Select a rebar tying machine that can tie a variety of rebar sizes.
4. For slab-on-grade rebar, tying rebar with the rebar tying machine will require the use of a lightweight steel hook to lift rebar off the ground.
5. Many of the rebar tying machines on the market require warm-up during cold weather. Therefore, proper tying tension of the rebar machine should be adjusted during cold days.
6. On very hot summer days, allow the machine to cool down in a shady area during regular breaks and lunch.
7. Working with the rebar tying machine is very productive for a crew of 4-5 workers per site. One worker can use the machine to tie, while two handle and place rods under the direction of the fourth.
8. When purchasing a rebar tying machine, select a vendor that will provide on-going support and can provide regular maintenance.
9. Use the rebar tying machine to assist workers who have an injury of the low-back or hand to return-to-work.

2.6 Promoting Early Return To Pre-injury Job Using A Rebar-Tying Machine

Methodology

Two large reinforcing construction firms participated in this study. Across an eight-month period, both firms were instructed to offer an injured worker the opportunity to return to their pre-injury job using the rebar-tying machine. The purpose of providing the rebar-tying machine was to accommodate the physical limitations of the injured worker. Before implementing the intervention, all injured workers were trained in the proper use of the machine. After the training session, the injured workers were offered the opportunity to use the tying machine. After four to five weeks of using the rebar-tying machine, all injured workers were asked to fill out a questionnaire.

Findings

1. Four participants agreed to take part in this study. Two of the participants suffered lost-time injuries involving finger fractures. The other two participants had suffered a chronic low-back problem but had not taken time off work as a result.
2. Two of the workers who suffered fractures of the finger stated that they were "unable to perform" rebar-tying with pliers. The two chronic low-back pain workers stated that performing rebar-tying with pliers was "somewhat difficulty". Both of these workers stated that they were able to perform two (2) hours of rebar-tying with pliers.
3. When asked to estimate the numbers of hours the participants were able to tie rebar using the rebar tying machine, all four (4) injured workers indicated they could do so for eight hours.
4. All the items in the questionnaire were ranked in the range of "good' to "very good". Reduced wrist repetition, vibration level, and ease of use were ranked at the "very good" level. The level of comfort, hand force, hands/arms discomfort, shoulder discomfort, and back discomfort were ranked in the "fairly comfortable" range. The level of productivity while using the machine was ranked at the "good" level.

Implications and Recommendations

1. The study yields some evidence to suggest that the rebar-tying machine can assist injured workers in their return to work program. Many items on the usability questionnaire

suggested that all injured workers were comfortable in using the tying machine. The open-ended questionnaires also indicated that the rebar tying machine was favoured as a tool for rehabilitating injured rodworkers.

2. The ability of the tying machine to accommodate injured workers was found to be related to the fact that the machine can be used with only one hand and the extension arm is adjustable. The one-handed feature accommodated the two workers with finger fractures while the adjustable arm accommodated the two workers with difficulties bending forward because of low-back injuries.
3. Based on the above findings, it is recommended that the rebar-tying machine should be used to accommodate injured rodworkers in their return to work program.

Appendix A:

Reducing risk of musculoskeletal disorders through the use of rebar-tying machines

Peter Vi, Construction Safety Association of Ontario

INTRODUCTION

According to a recent study conducted by Washington State Department of Labor and Industries, Rodworkers have the highest rate (3,997 per 10,000 FTEs/Year) of non-traumatic soft tissue injuries when compared to 300 industrial occupation classes (Silverstein and Kalat, 1999). Similar findings are also found in Ontario construction industry. In Ontario, rodworkers have a higher proportion of lost-time musculoskeletal injuries of the back and upper limb body parts than the average for all construction trades (see Figure 1). The total cost of lost-time injuries (LTI) and duration of time off work is also higher for rodworkers than for the averages of all construction trades combined (see Figure 2).

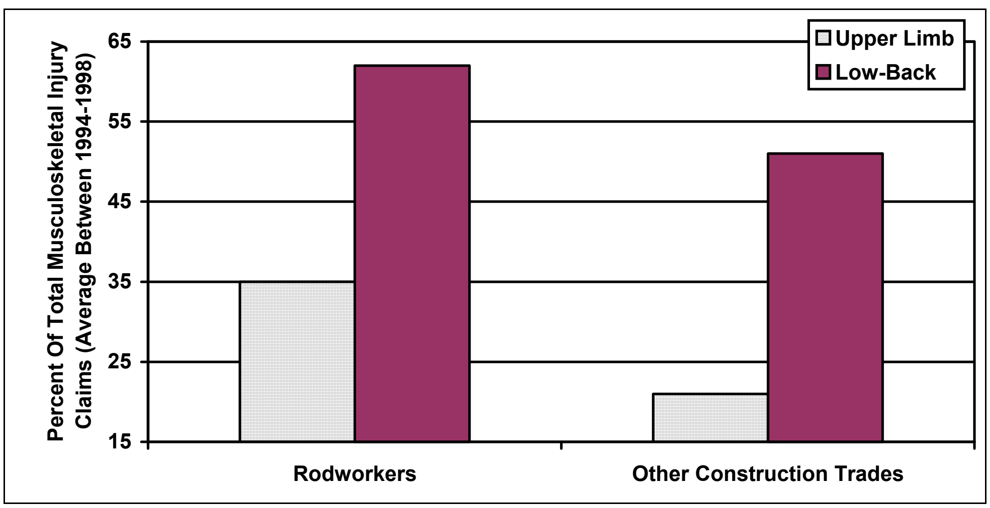

Figure 1: Non-traumatic musculoskeletal injury by construction rate group (WSIB Data: 1994-1998).

Clearly from the high LTI rate, workers compensation claim costs, and severity of injuries among rodworkers, there is a need for an effective ergonomic intervention. Recent research has suggested that to reduce physical load of rodworkers, the intervention should be directed at reducing the frequency of awkward trunk postures, particularly during ground level rebar construction (Dababneth and Waters, 2000; Paquet et al, 1999). One solution to prevent the high risk of low back and upper-extremity injury is the use of an automatic rebar-tying machine (see Figure 3). The rebar-tying machine is a powered tool (either electrical or battery) that can be placed around the intersecting segments of rebar rods. There is a trigger attached to the tool, which when depressed, will causes the tool to automatically feed the wire around the bars, twist it and automatically cut it.

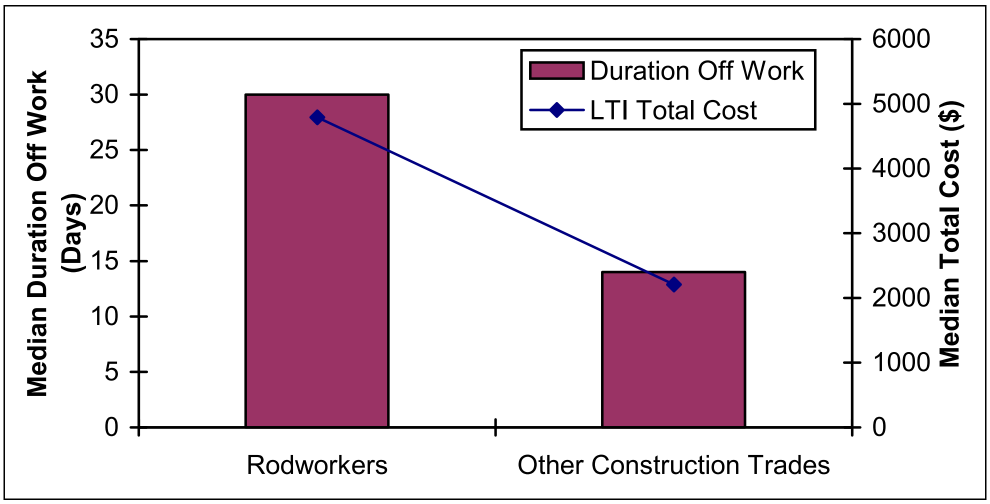

Figure 2: Median days off work and median total LTI cost per claim (WSIB Data: 1994-1998). Total cost is the sum of medical and compensation costs.

Figure 3: Working posture while working with the rebar tying machine and manually tying rebar.

There are numerous advantages of using the rebar-tying machine:

- It reduces the need for manual tying, which can decrease forceful hand exertion when working with pliers. It can also reduce hand repetition and hand/wrist twisting and bending.
- It decreases exposure to awkward posture of the trunk, which in turn will decrease muscular exertion (see Figure 3).

The objective of this report is to evaluate the potential biomechanical/ergonomic benefits, as indicated from above, of using the rebar-tying machine as an alternative work method. To accomplish this goal a controlled experiment, using rebar apprentices as participants was conducted at the rebar training school (Local 721).

Methods

Participants

Nine (9) rodworker apprentices were asked to participate in this experiment. All participants were obtained through the International Association of Bridges Structural and Ornamental Iron Workers Local 721 Training Centre.

Experimental Task

To evaluate the biomechanical/ergonomic stresses on rodworkers, simulated rebar tying tasks were performed. Two rebar tying methods were evaluated in this experiment: (1) manual tying, and (2) using a MAX RB392 (MAX USA, New York) rebar-tying gun. For each tying method, participants were asked to perform 50 horizontal ties of 15 mm by 15 mm rebar combination located at floor level.

Dependent Variables

To investigate the potential benefits and reduce risk of injury, rebar-tying tasks were evaluated using electrogoniometers (to measure wrist and arm angles), and electromyography (to measure low-back muscle activities). A Biometrics DataLOG system (Biometrics Ltd, UK) was used to record wrist and arm movement. A ProCOM data collection system (Thoughts Technology, Canada) was used to collect the Electromyography (EMG) activities.

Electrogoniometers

Marras and Shoenmarklin (1993) found a significant *positive* relationship between the position, velocity, and acceleration of the lower arm and upper extremity disorders. To determine the potential reduction in risk of injury to the distal upper extremity, the flexion/extension movements, ulnar/radial deviation, and pronation/supination movements of the lower arm were measured in this experiment. For the flexion/extension and ulnar/radial movements of the hand, the periscopic endblocks (free endings) of the twin axis XM 75 goniometers were applied to the dorsal area of the hand-tool side (see Figure 4), coincident with the middle extensor digitorium (centre axis of the hand). The fixed endblocks were applied on the hand-tool side's centre axis of the dorsal lower arm, just above the extensor retinaculum. For the pronation/supination movements of the hand-tool side, the periscopic endblock of the toriometer was applied to the distal 1/3 of the lower arm (see Figure 4), following the flexor carpi radialis tendon bilaterally. The fixed endblock of the torsiometer was placed on the proximal third of the lower arm approaching the medial epicondyle.

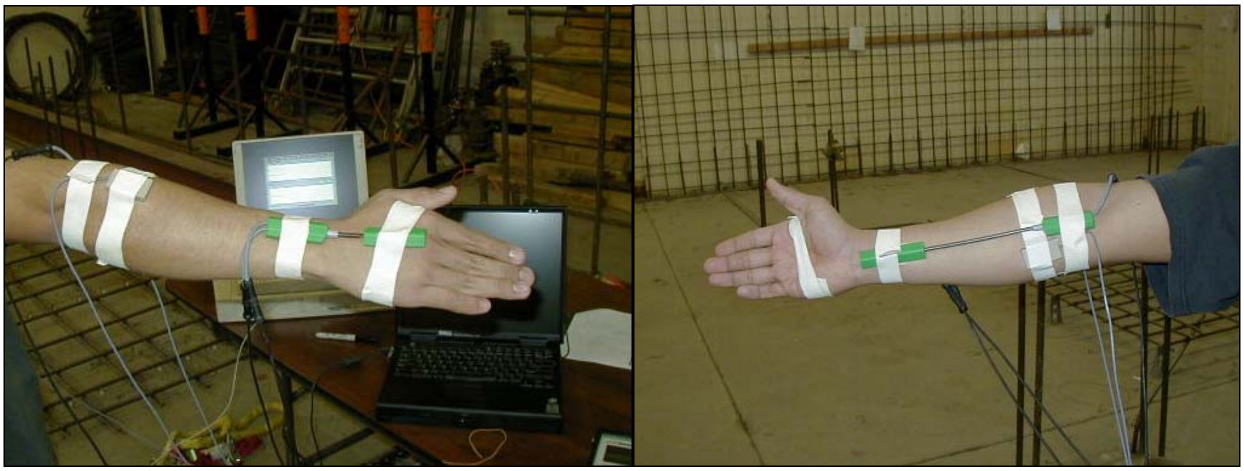

Figure 4: Goniometers placement on the lower arm.

Electromyography (EMG)

EMG signal was used in this study to indirectly quantify the peak and cumulative back compression at the L4/L5 (Wells et al, 1994). Preparation, recording, and analysis of the EMG signal were directly followed the procedures outlined by Marras (1987), NIOSH (1992), and Wells et al (1994).

Norman et al (1998) have found a significant *positive* relationship between peak and cumulative low-back compression force and low back pain. Thus, low-back compression force was measured in this study to evaluate the potential reduction in low-back compression force exposure between the intervention groups. Wells et al. (1990) have shown a linear relationship between erector spinae EMG and lumbar spine compression. Based on Wells et al (1990) findings, EMG measurement procedures as outlined by the aforementioned authors were used in this study.

Experimental Procedure

On each experimental trial, participants were asked to perform a simulated rebar tying task using manual hand tying method or with the rebar tying machine. After each experimental trial, the participants were allowed to have a 5-minute rest period before starting another experimental trial. While the participants were performing the experimental task, a videotape of the participants' working postures was recorded. Wrist posture, and muscle activities were also collected at the same time.

Data Analysis

SPSS (version 10) was used to analyze the collected data. Statistical tests with $p<0.05$ will be considered significant. Univariate analysis using Paired T-test statistics were used to determine the differences between manual tying versus the rebar gun.

Results And Discussion

Wrist Posture

The levels of mean wrist accelerations calculated for each of the two tying methods (i.e. manual tying and tying with the rebar-tying gun) during normal rebar tying task are summarized on Figure 4. For all planes of motion (flexion/extension, radial/ulnar, and pronation/supination), significant ($p<0.01$) differences in wrist and arm motions were observed between the two tying methods. In this study, tying with the rebar tying machine exposed the participants to significantly lower wrist activities (i.e. acceleration of the wrist) than when performing the tying task with the pliers (i.e. manual tying).

The wrist acceleration values were also compared to wrist injury risk benchmark values published by Marras and Schoenmarkling (1993). Based on the TLV values published by earlier research, this study found a high-risk of wrist injuries in the flexion/extension and radial/ulnar planes of motion (see Figure 5) when manually tying the rebar with the pliers. Rebar tying with the rebar tying machine however, exposed workers to low-risk of wrist injury for all planes of motion (see Figure 5).

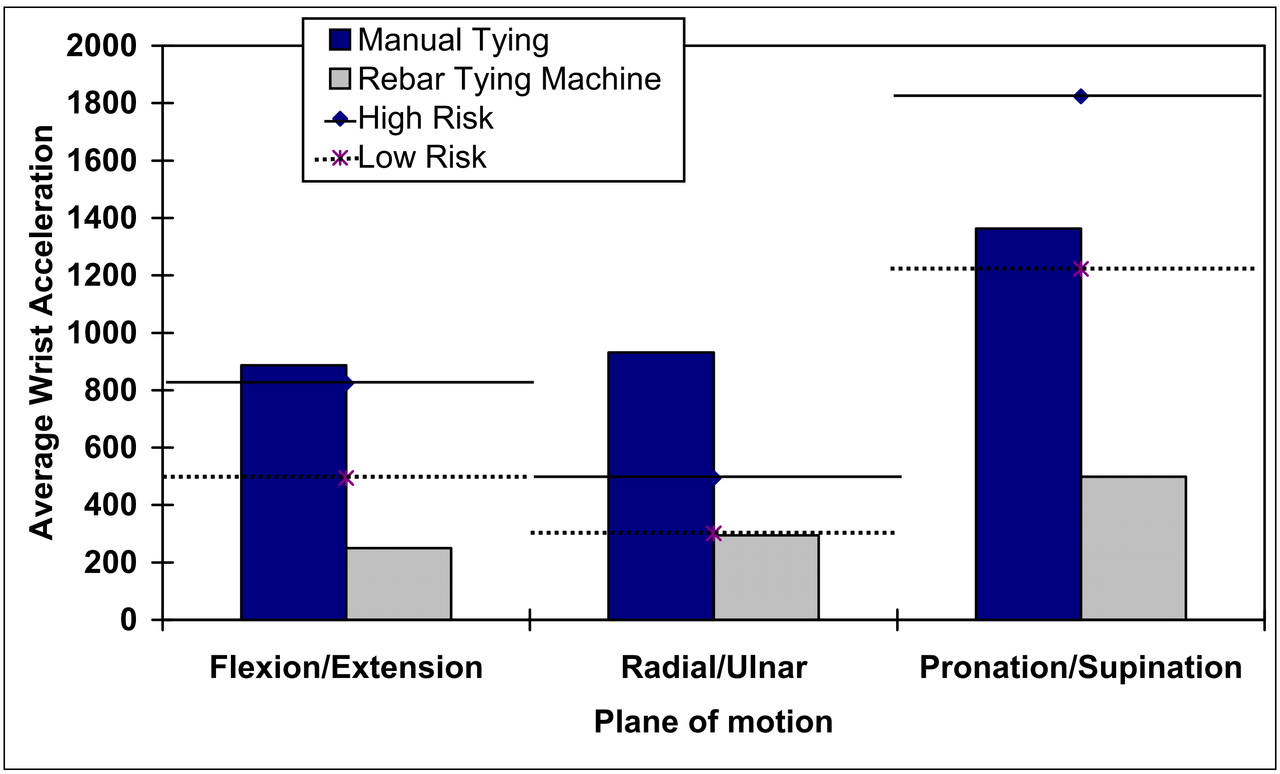

Figure 5: Average wrist acceleration for manual tying and tying with the rebar tying machine showed significant differences ($p<0.01$). High risk and low risk values were obtained from studies conducted by Marras and Schoenmarkling (1993).

Low-Back Compression Force

Summary of the overall average low-back compression force distribution for each tying method across all subjects is shown on Figure 6. As shown in Figure 7, tying rebar with the rebar tying machine significantly (p=0.018) decreased the peak loading in the lower back joint (L4/L5 disc). The cumulative loading on the back was also significantly (p=0.011) lower than manual tying with the pliers (Figure 8). The significant reduction in low-back loading was mainly due to the upright tying position when working with the rebar-tying gun (see Figure 3). Numerous studies have shown that reducing the peak and cumulative forces on the lower back can lower the risk of low back injury (Norman et al, 1998).

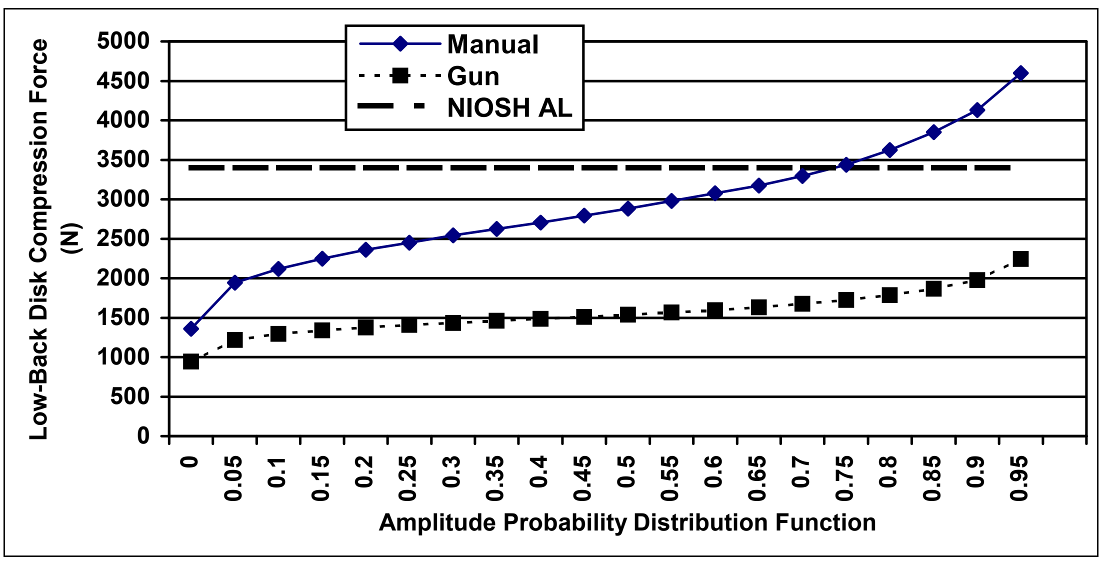

Figure 6: Mean amplitude probability distribution function for the manual and rebar-tying gun trials.

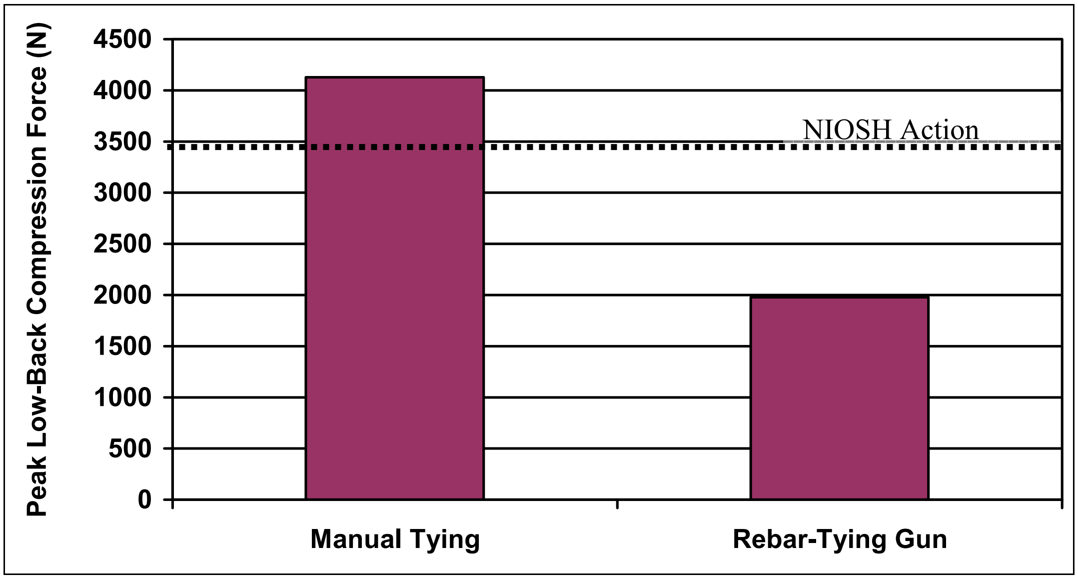

Figure 7: Tying with rebar tying gun resulted in significant (p=.018) decrease in peak loading on the lower-back (L4/L5 disc). Manual tying exposed workers to peak compression force loading that is greater than NIOSH Action Limit (3400 N).

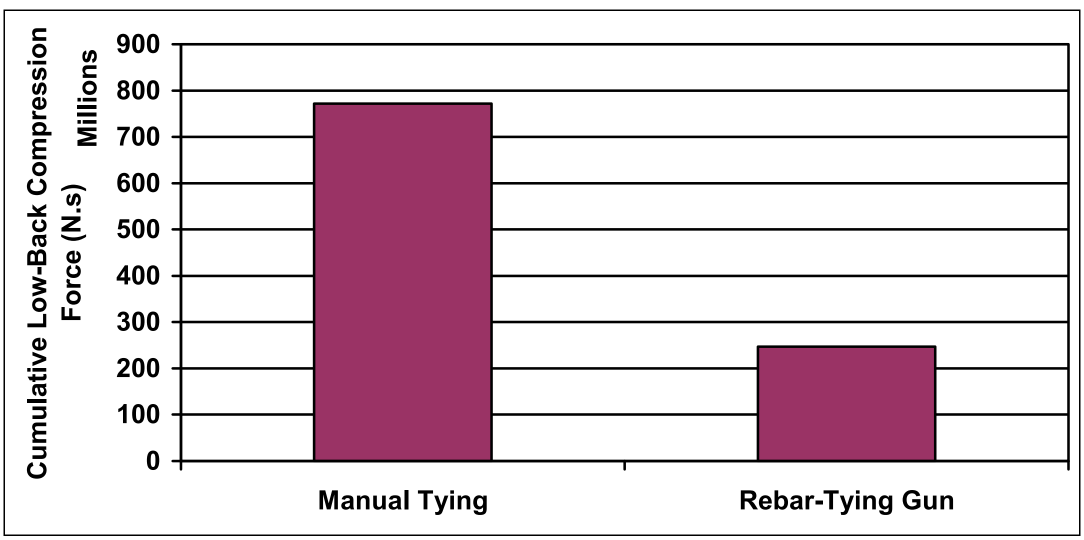

Figure 8: Using the rebar tying gun showed a significant (p=0.011) decrease in accumulated loading on the lower-back (L4/L5 disc).

Conclusion

Concrete reinforcement workers have a high rate of musculoskeletal lost-time claims. The high rate of lost-time injuries may be due to the high frequency of static awkward posture and repetitive heavy manual material handling activities. Common characteristics of awkward posture and heavy manual material handling activities during concrete reinforcement can include ground level rebar tying, and manual material handling of steel rebar. In order to prevent the risk of musculoskeletal injuries, control measures should be designed to reduce physical exertion such as frequent heavy rebar handling and use of awkward trunk postures, particularly during ground level rebar construction.

One way to decrease awkward trunk postures and physical hand exertion during ground level rebar construction is the use of automatic rebar tying machine. Phase I of this study indicates that working with the rebar tying machine can lead to decreased wrist repetitive activities such as bending, twisting, and lateral-side bending. Furthermore, working with the rebar tying machine can also lead to a decrease in static bending of the trunk which in turn decreases the peak and the cumulative compression force on the lower back joint. Based on these findings, it is concluded that working with the automatic rebar tying machine can significantly decrease the risk of musculoskeletal injuries to rodworkers.

Although the concept of a rebar tying machine has shown to be a good tool to prevent risk of musculoskeletal injuries, preliminary testing in real job situations has shown some limitation with the current rebar tying machine:

1. The MAX RB392 only allows tying of two rebar having a combined area of 150 mm^2 to 300 mm^2. Thus, the rebar gun only allows tying of approximately 40-60% of the bar being utilized on a typical project.
2. One of the major drawbacks, which we did not experience in the laboratory setting, is the fact that the gun requires regular maintenance. After two to three days of use, the tie-wire that spools out and along the jaw of the gun constantly jams on its inner

mechanics. Once jammed, it is difficult to clear the wire without the assistance of the gun manufacturer.

Currently, MAX Tools (www.maxusacorp.com) has developed a bigger rebar-tying gun (RB650) with a capacity of tying a combined area of 58 mm^2 to 750 mm^2. Preliminary testing of the RB650 rebar gun has shown that many of the problems with the smaller rebar gun have been solved. The Research Team will conduct additional applied research in real job situations to investigate the full benefits of the rebar-tying machine.

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Appendix B:

A Field Study of Rebar Tying Machine as a Tool to Reduce Risk of Musculoskeletal Disorders

Peter Vi, Construction Safety Association of Ontario

Introduction

Many construction projects such as bridges, roads, foundations, and airport runways involve concrete work. In order to improve the strength characteristics of concrete, it is reinforced with iron or steel bars. These metal bars are commonly known as 'rebar'. Before pouring the concrete, rebar is placed on the horizontal or vertical surface. After placing the rebar in a grid or matrix format, the rods are tied together at various connecting points before pouring the concrete. In construction, rebar work is commonly known as rod-busting, and workers who do the rod-busting are called rodworkers.

The risk of injury to rodworkers is well documented. According to a recent study conducted by the Washington State Department of Labor and Industries, rodworkers have the highest rate (3,997 per 10,000 FTEs/Year) of non-traumatic soft tissue injuries when compared to 300 industrial occupation classes (Silverstein and Kalat, 1999). Similar findings are also evident in Ontario, where rodworkers have a higher lost-time injury (LTI) rate due to non-traumatic musculoskeletal injury than the construction average. The proportion of non-traumatic musculoskeletal injuries of the back and upper limb body parts was also found to be higher than the construction trades average between the years 1996 and 2002 (see Figure 1).

In a study of the association between occupational factors, other determinants, and the occurrence of sciatic pain, Riihimaki et al (1989) found that rodworkers experienced an increase in the risk of sciatic pain in both a cross-sectional and a prospective study. In similar research, Wickstrom et al (1985) and Riihimaki (1985) found that reported minor back accidents (i.e. an event that differed from the normal course of work and caused sudden, unexpected strain on the musculoskeletal system) were more than ten times as common in reinforcing work than in painting. Injuries to the musculoskeletal system, as registered by insurance companies, were also over three times more common in reinforcing work than in painting. Based on these findings, Riihimaki et al (1989), Riihimaki (1985), and Wickstrom et al (1985) concluded that the heavy work of concrete reinforcement increases the risk of musculoskeletal disorders when compared with the less burdensome work of house painting. Awkward postures, manual material handling, and back accidents seem to be an important risk factor for the occurrence of back pain.

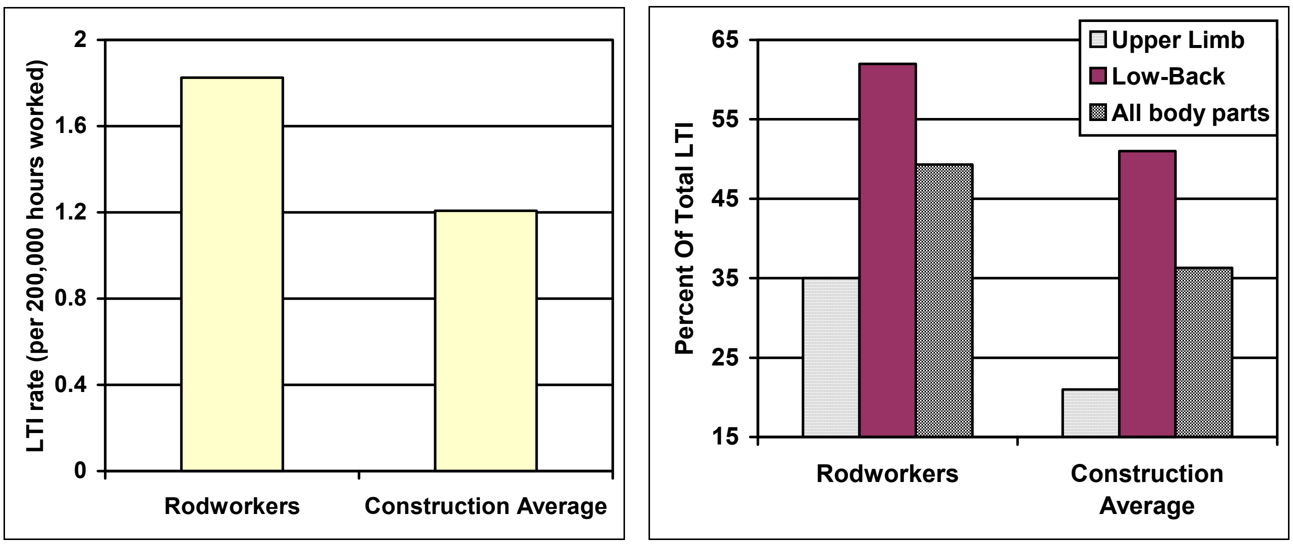

Figure 1: Lost-time injury (LTI) rate caused by non-traumatic musculoskeletal injuries (WSIB Data: 1999-2002).

Reinforcing work generally consists of two types of tasks: preparation and assembly. "Preparation" involves selecting and pulling long steel rods out of a stack and laying the rods on the work surface. "Assembly" involves tying rods together to form a steel skeleton, on which concrete is later poured by other workers. Typically, assembly (rod tying) involves 50-60% of rodwork (Saari and Wickstrom, 1978; Paquet et al, 1999). In one study, Dababneth and Waters (2000) found that rodworkers can spend up to 80% of their workday tying rebar with wires.

Work sampling studies conducted by Saari and Wickstrom (1978) and Paquet et al (1999) found that rodworkers are exposed to prolonged awkward back posture. According to Saari and Wickstrom (1978), forward-leaning (i.e. back flexion greater than 15°) was required for more than a third of the total work time during assembly (Saari et al., 1978; Paquet et al., 1999). The highest duration of awkward trunk posture (40-70% of assembly) was during floor rod tying, and during rod tying of steel rods at or below floor level.

Manual material handling (MMH) was also found to be a problem in reinforcing work. A recent study conducted by Paquet et al (1999) found that concrete reinforcement workers were involved in MMH from 12% to 19% of their entire work shift (see Figure 2). During these MMH activities, rodworkers were required to handle tools and materials more than 40% of their work time (see Figure 3). From the findings, the authors suggested that controls designed to reduce physical load should be directed at reducing the frequency of heavy rebar handling and exposure to awkward trunk postures, particularly during ground level rebar construction.

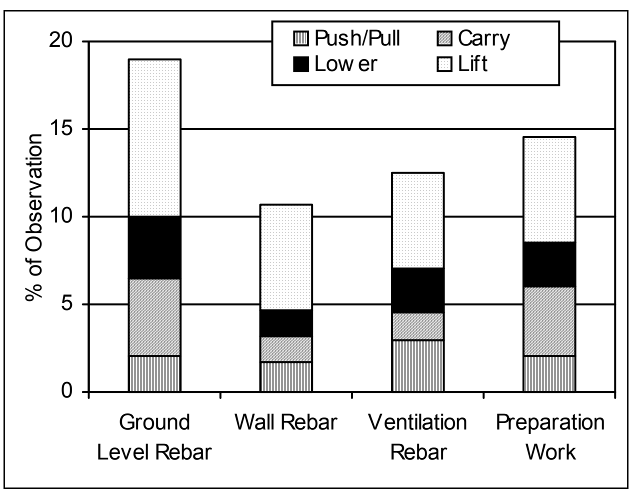

Figure 2: Frequency of manual material handling activities by task among rodworkers. Reproduced from Paquet et al (1999).

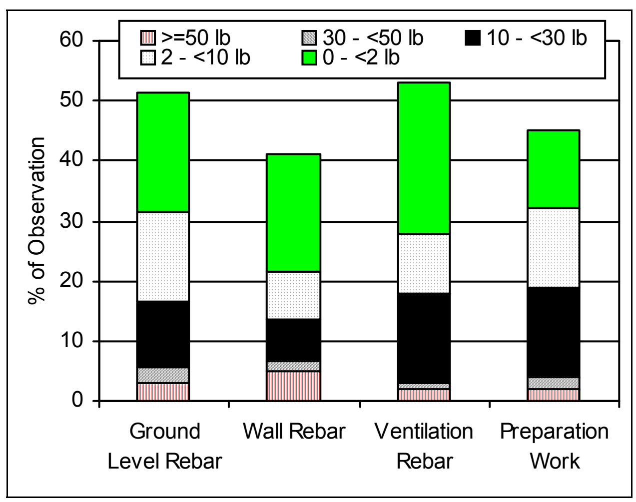

Figure 3: Frequency of loads handled by task among rodworkers. Reproduced from Paquet et al (1999).

Currently there are three methods for rebar tying.

1. Pliers – This is the traditional and most common method used by rodworkers (see Figure 4). The tool consists of a linesman's pliers with diagonal cutter and a wire spool. The pliers are used to cut, hold, and twist the wire. The wire spool is attached to a belt on the worker's waist. To tie the rebar, the worker pulls a length of wire from the spool with their hand, wraps it around the rebar with the pliers and finishes the tie by twisting the two ends of the wire, then cutting off the excess using the linesman pliers. Physical risk factors when using this method include forward back flexion and excessive bending and twisting at the wrists (Vi, 2003).
2. Pigtail – In this method the worker uses a precut wire and a twisting tool that looks like a pig's tail. When using this method, workers are required to bend forward at the back and require excessive bending and twisting at the wrists. This tying method is used mostly by non-experienced rodworkers on sites that do not require much tying.
3. Rebar tying machine - The rebar tying machine is a battery powered tool that can be placed around the intersecting segments of rebar rods. When a trigger is depressed, the tool automatically feeds the wire around the bars, twists it and cuts it automatically. Two examples of currently available rebar tying machines are MAX Rebar-tier and U-Tier (see Figure 5). Both tools function similarly. However, the MAX gun is able to tie rebar at a faster rate than the U-Tier (approximately one second per tie). Furthermore, with the attachment of an adjustable extension arm (3' to 4'), working with the MAX gun can reduce exposure to awkward trunk posture by allowing the worker to work upright (Vi, 2003). Awkward motions of the lower forearm such as bending and twisting of the wrists are also reduced (Vi, 2003).

Figure 4: Rebar tying using a rebar tying machine (left) and manual tying using pliers (right).

Dababneh and Waters (2000) reviewed the literature on the ergonomics issue of rebar tying, and concluded that properly designed powered tying tools may be the best ergonomic solution. Extended tool-body design or extended arm attachments can be used to eliminate the need for stooping when working on a horizontal platform (see Figure 6). Also, tools with a pistol grip would allow workers to tie horizontal or vertical rebar while keeping their wrist straight and reducing the need to perform high twisting or bending motion of the wrists (Vi, 2003).

Although there are many potential benefits in using the rebar tying machines, their effectiveness in a field setting has never been verified. The objective of this study was to conduct an intervention study in the field setting to verify the potential reduction in risk of musculoskeletal disorders when using a rebar tying machine with arm extension attachment as an alternative work method. A secondary objective was to evaluate the productivity differences between manual tying with pliers and using the rebar tying machine.

Figure 5: Rebar tying machines. Left: MAX RE-BAR-TIER. Right: U-TIER.

Figure 6: MAX RE-BAR-TIER with arm extension (left) and U-TIER with body extension (right). Sometimes a metal hook is used to pull the rebar off the ground so that the wire can be wrapped around the rebar without striking the ground (see left photo).

Method

Participants

Eleven (11) rodworkers participated in this experiment. All participants were unionized workers from the International Association of Bridge, Structural, Ornamental, and Reinforcing Ironworkers, Local 721. They were of average stature, 170 cm (± 7.9 cm), body weight, 84.5 kg (± 11.2 kg), and age, 47 years (± 12 year). The participants had no medical problems, and each signed an informed consent form.

Study Design

A before-and-after design approach was used in this study to evaluate the effectiveness of the rebar tying machine with an extension arm attachment. Only ground level rebar production was used to evaluate the intervention. Before implementing the intervention, all participants were asked to fill out a usability questionnaire regarding manual tying with pliers (see Appendix 1). Rebar tying time and trunk work postures while performing manual tying were also quantified. After the initial observation, each participant was trained and given the rebar tying machine for use in normal ground level rebar production. Training covered proper use of the machine, including procedures to change the spool wire, trouble shooting, and machine maintenance.

Each participant was allowed to use the rebar tying machine for three months. After the intervention period, each participant was asked to fill out a usability questionnaire regarding the use of the rebar tying machine. The questionnaire given after intervention was similar to the manual tying usability questionnaire (see Appendix 1). Rebar tying time and trunk work postures while performing rebar production with the tying machine were also quantified. The repeated measurement of all dependent variables (i.e., before and after) allowed comparison of the differences between the two work methods.

Dependent Variables

To investigate the potential benefits and reduced risks of musculoskeletal injury, rebar tying tasks were evaluated, using a subjective survey questionnaire, real-time continuous trunk posture exposure, and rebar tying time. Detailed methods of collecting these dependent variables are outlined in the following section.

Gyroscope:

The MicroStrain 3DM-G (Vermont, USA) gyroscope was used in this study to quantify real-time continuous trunk postures. The 3DM-G is a self-contained sensor system that measures the three degrees of its orientation in space with respect to Earth's cardinal axes (i.e., the Z-axis pointing down through the center of the Earth, the X-axis pointing north and the Y-axis pointing east). The measurements by the 3DM-G include pitch, roll and yaw.

The 3DM-G was attached to a Biometric DataLog II system (Biometrics Ltd, Gwent, UK) for data collection and storing. To measure the trunk posture, the 3DM-G was attached on the mid-section of the posterior scapula (see Figure 7). A sample of posture data collected on the trunk while performing rebar tying tasks is shown in Figure 8 and 9.

In this study, only the roll (flexion/extension of the trunk) orientation was measured. The 3DM-G was sampled at 100 Hz and low-pass filter at 4 Hz to reduce the high frequency noise. Trunk posture was continuously measured on all participants for duration of between two and four hours over two consecutive days. Awkward trunk posture exposure was analyzed using the amplitude probability distribution function (APDF) technique proposed by Jonsson (1982). Two exposure levels (i.e., median and peak levels) were obtained from the 50^{th} and 90^{th} percentiles of the distribution function according to Jonsson's definitions (1982). These were used to analyze the differences in exposure levels between the two work methods. Exposure variation analysis (EVA) proposed by Mathiassen and Winkel (1991) was also used to evaluate the differences in the magnitude, duration, and the distribution of the patterns of trunk posture exposure between the two rebar tying methods. Percentage of time exposed to severe trunk posture (greater than 45° flexion) was also used to evaluate the trunk posture exposure level for the two tasks (see Figure 10).

Rebar tying time:

Rebar tying time was measured in this study to evaluate the differences in productivity between the two tying methods. Measurements of tying time for manual tying and machine tying were quantified from videotapes of ground level rebar production. For each rodworker, approximately two hours of continuous video analyses of each tying method were conducted. The number of rebar ties within the period of observation was expressed as the time (in seconds) required to perform a rebar tie (i.e., seconds per tie).

Usability Questionnaire:

A self-report usability questionnaire was given to all participants before and after the three-month study period. The self-report questionnaire used in this study was based on past studies conducted by Spielbholz, Bao and Howard (2001) and Punnett L. (1998). Questions contained in the instrument asked for participant subjective estimations of overall comfort, hand force, wrist and shoulder repetition, hand/arm discomfort, shoulder discomfort, back discomfort, vibration level, ease of use, productivity, and suitability of the tool design to reduce manual work load. Participants were also asked whether they would prefer to work with the tool, recommend the tool to others, and relate additional comments about the tool. A sample questionnaire is contained in Appendix 1.

Figure 7: Rear view of the Gyroscope and DataLog II used to collect trunk posture.

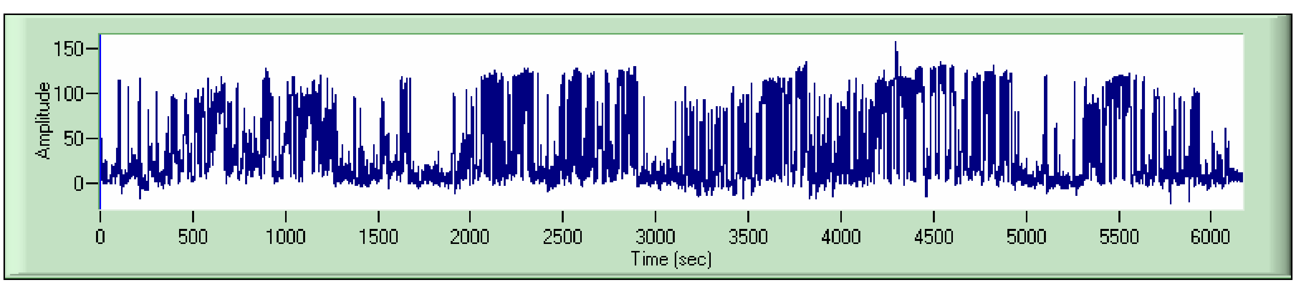

Figure 8: Field collected trunk flexion/extension angles (flexion is positive scale) while performing rebar work using pliers. The median trunk posture across the data collection period was 42.6° flexion. All data were collected using a mobile 3DM-G gyroscope.

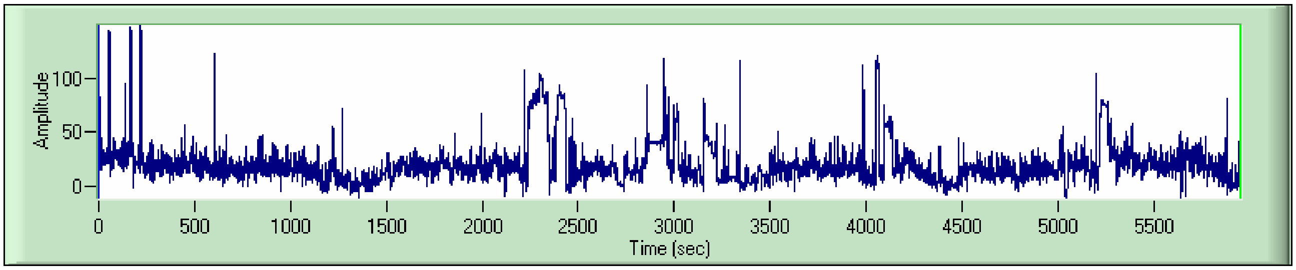

Figure 9: Field trunk flexion/extension angles (flexion is positive scale) while performing rebar work using the rebar tying machine. The median trunk posture across the data collection period was 22.3° flexion.

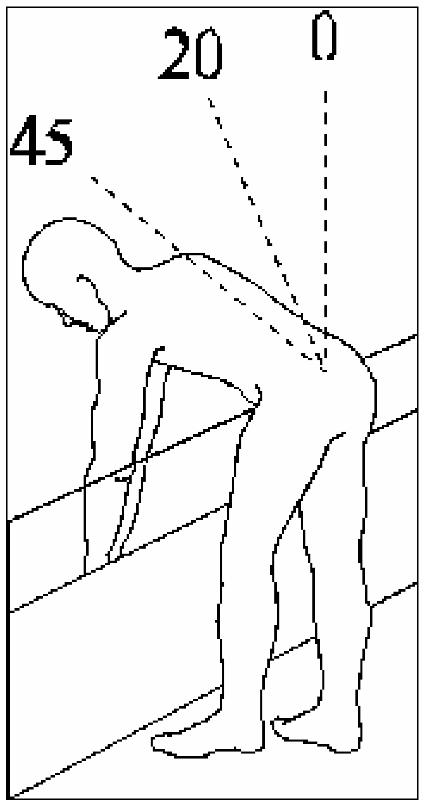

Figure 10: Trunk flexion definition used in this study.

Data Analysis:

SPSS (version 10) was used to analyze the collected data. Statistical tests with $p<0.05$ were considered significant. Univariate analysis using Paired T-test and Wilcoxon nonparametric statistics were used to determine the differences between traditional versus alternative methods.

Results

Trunk Posture

A contour graph detailing the exposure variation analyses of the trunk posture for manual tying and machine tying is shown in Figure 11 and 12. The contour graph is a 3-dimensional view illustrating the magnitude, frequency, and duration of trunk posture simultaneously during ground-level rebar work. Each tying method was separated into two different graphs for comparison. As shown in Figure 11, during manual tying with pliers, the highest level of trunk postures was heavily skewed to the far left and right ("U" shape), indicating that manual tying with pliers consisted of long periods of neutral postures (<20°) and very extreme awkward trunk postures (>60°). During machine tying however, the distribution of the magnitude, frequency, and duration of the trunk posture was found to be concentrated between the trunk angles of greater than -10° and less than 50° (see Figure 12).

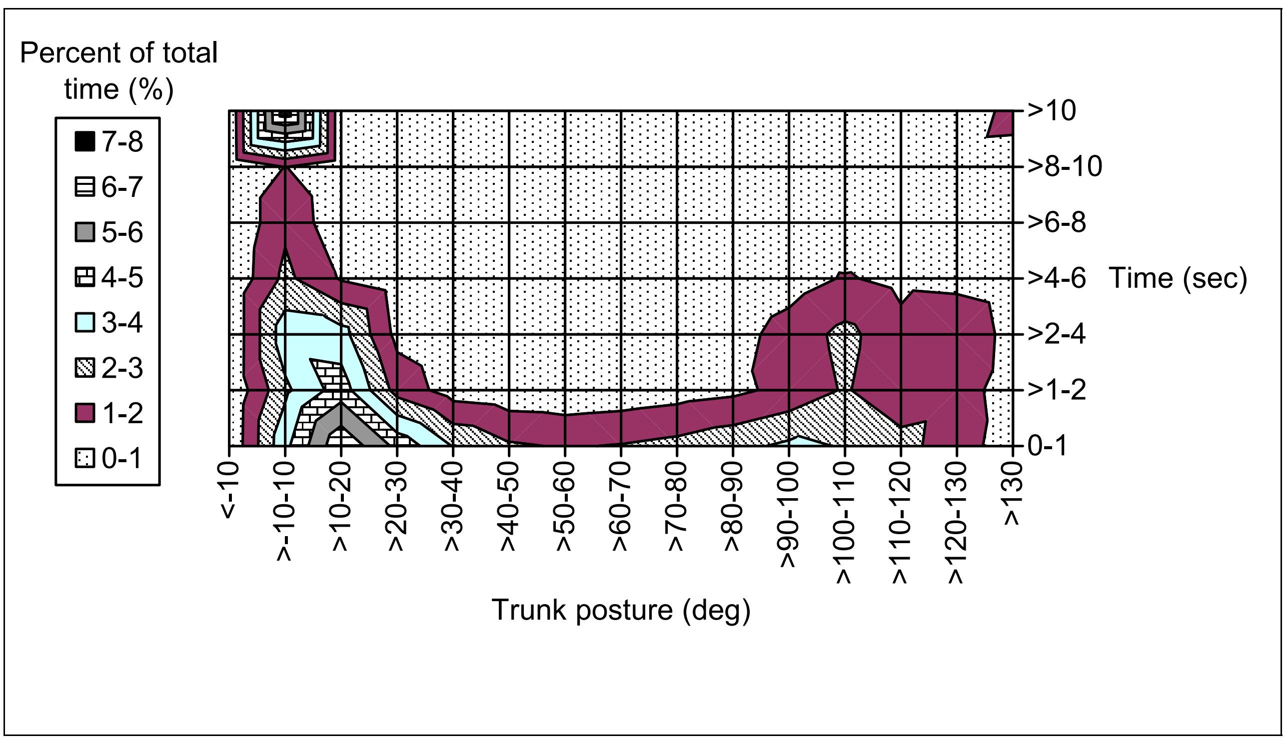

Figure 11: A contour graph detailing trunk posture while tying with pliers.

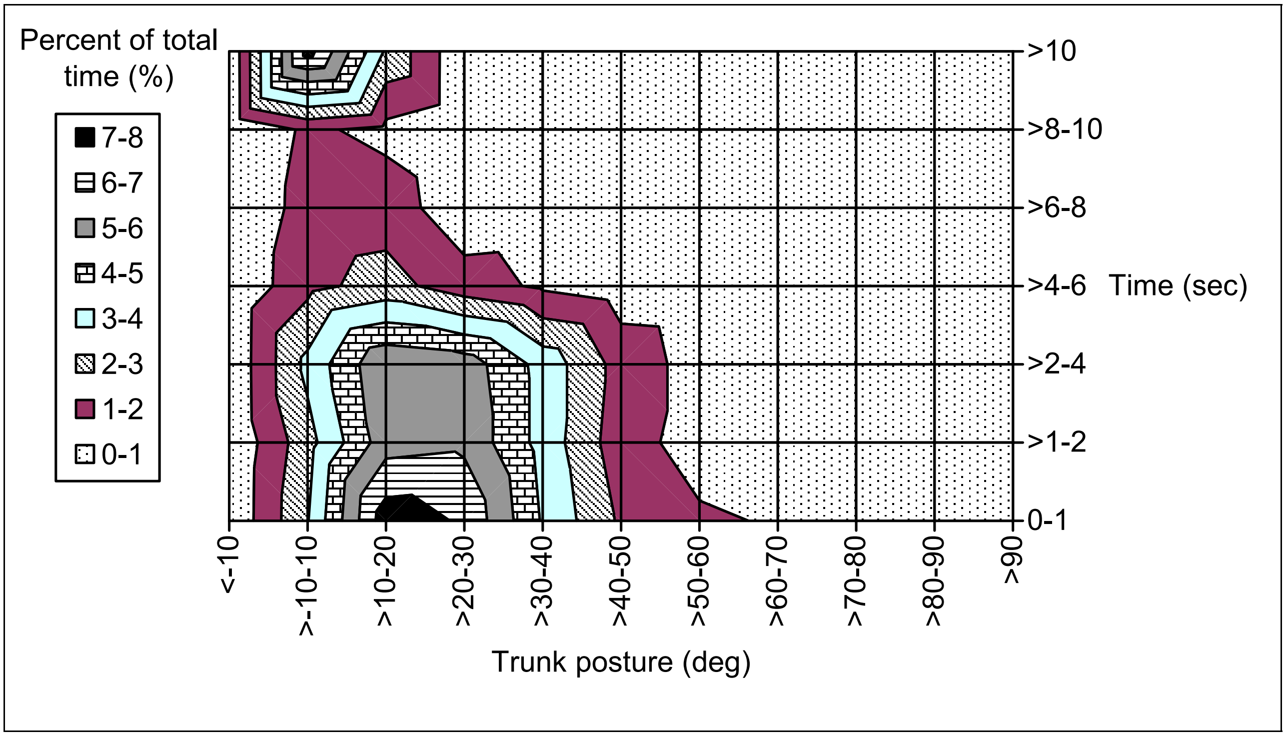

Figure 12: A contour graph detailing trunk posture while using the rebar tying machine.

A summary of the overall average trunk posture amplitude probability distribution function (APDF) for each tying method across all participants is shown in Figure 13. Each participant's trunk posture APDF is summarized on Figure 14 and 15. Large inter-subject variability in the trunk posture exposure level was observed for manual tying when compared with machine tying.

The amplitude of the median and peak trunk posture level was found significantly ($p<0.05$) higher when participants tied rebar with pliers as compared to tying machine (see Figure 16). The percentage of work time with the trunk in severe forward flexion (greater than 45°) was also evaluated. A mean value of 50.4% and 14.9% of the total work time in forward severe trunk flexion was found for manual tying and machine, respectively (see Figure 17). The differences in the duration of time in severe forward flexions between the two tying methods was found to be statistically significant ($p<0.05$).

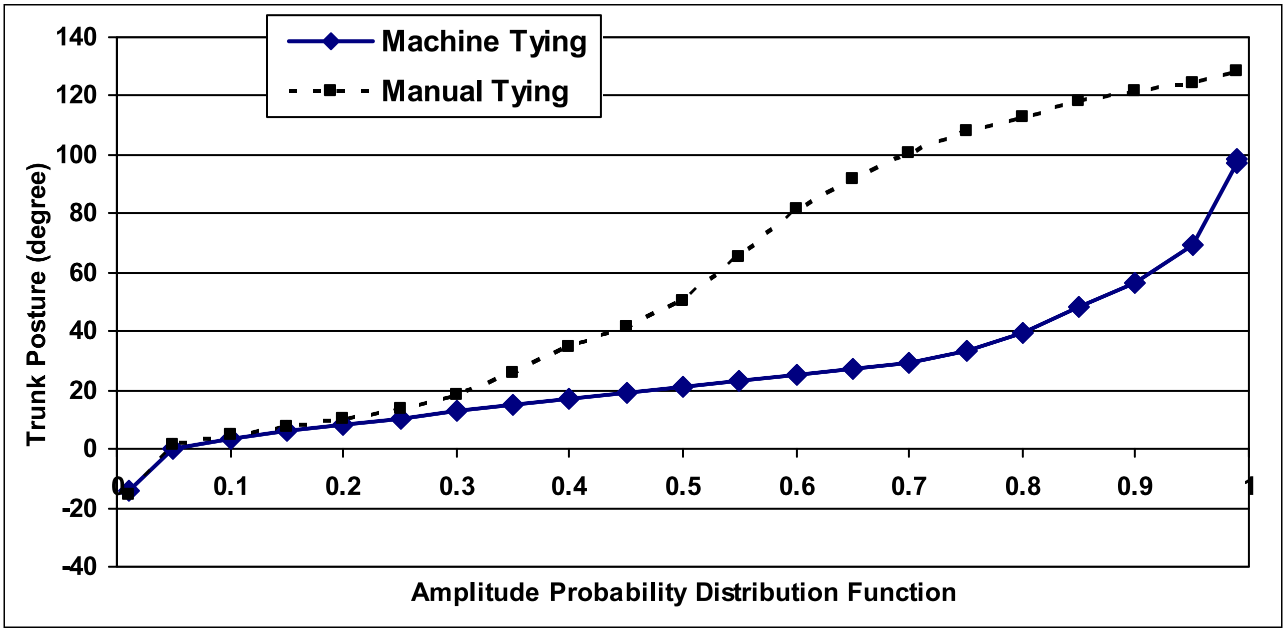

Figure 13: Average APDF of the trunk posture. Average values were obtained from individual APDF curves from Figure 14 and 15.

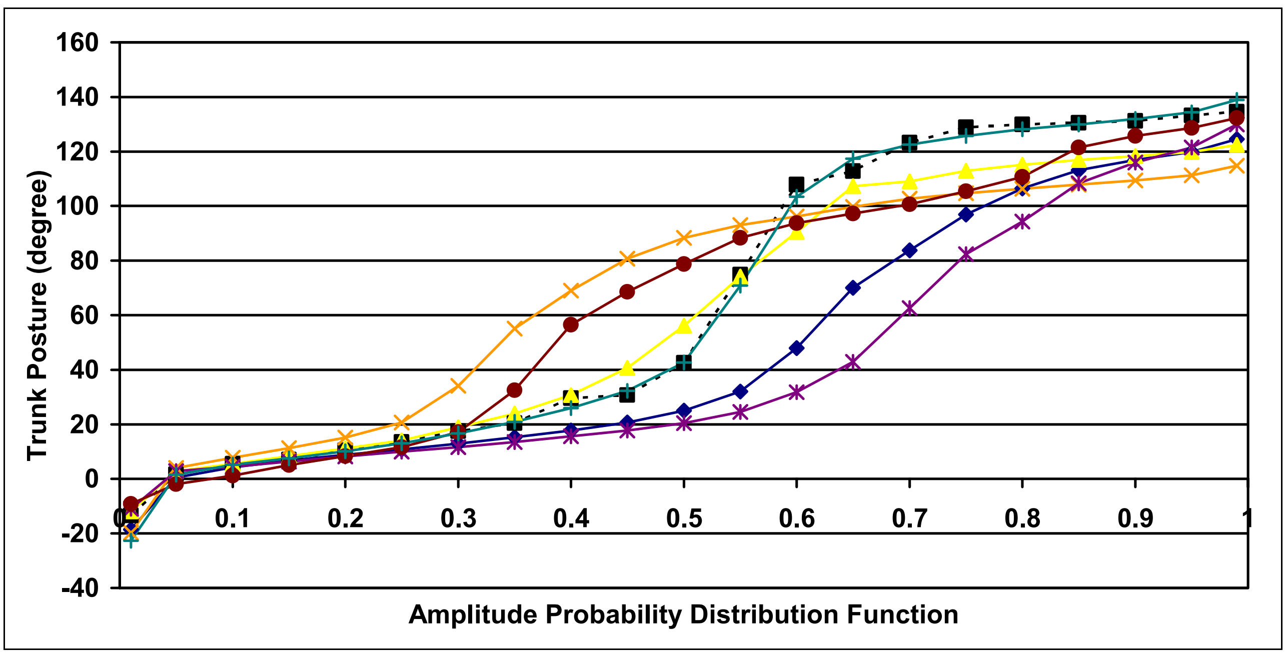

Figure 14: Individual APDF of the trunk posture during manual tying.

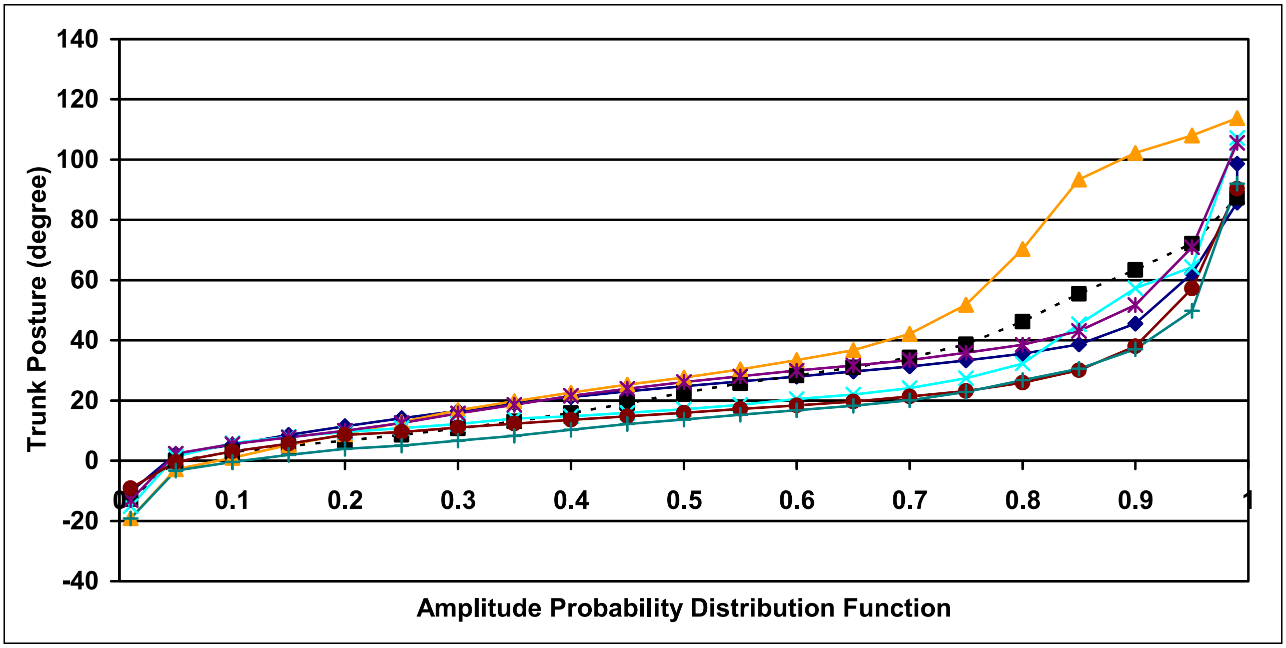

Figure 15: Individual APDF of trunk posture while using the rebar tying machine.

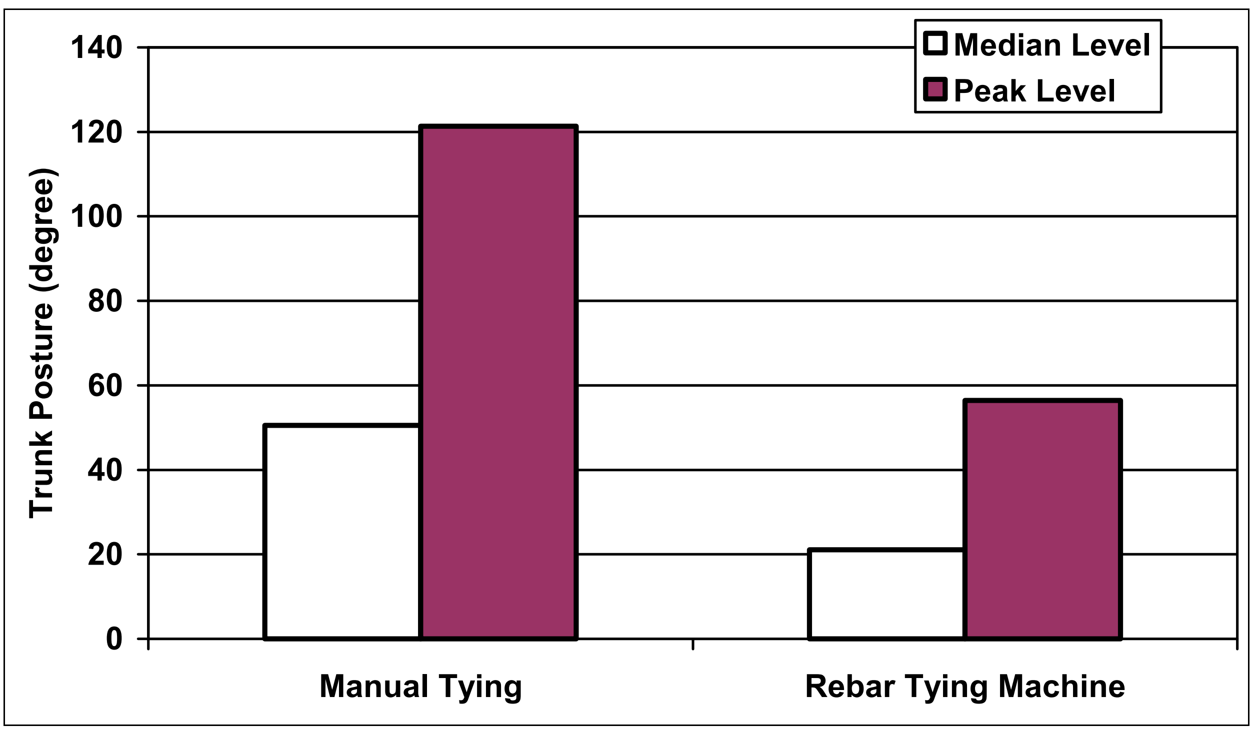

Figure 16: Median and peak trunk posture values obtained from the APDF.

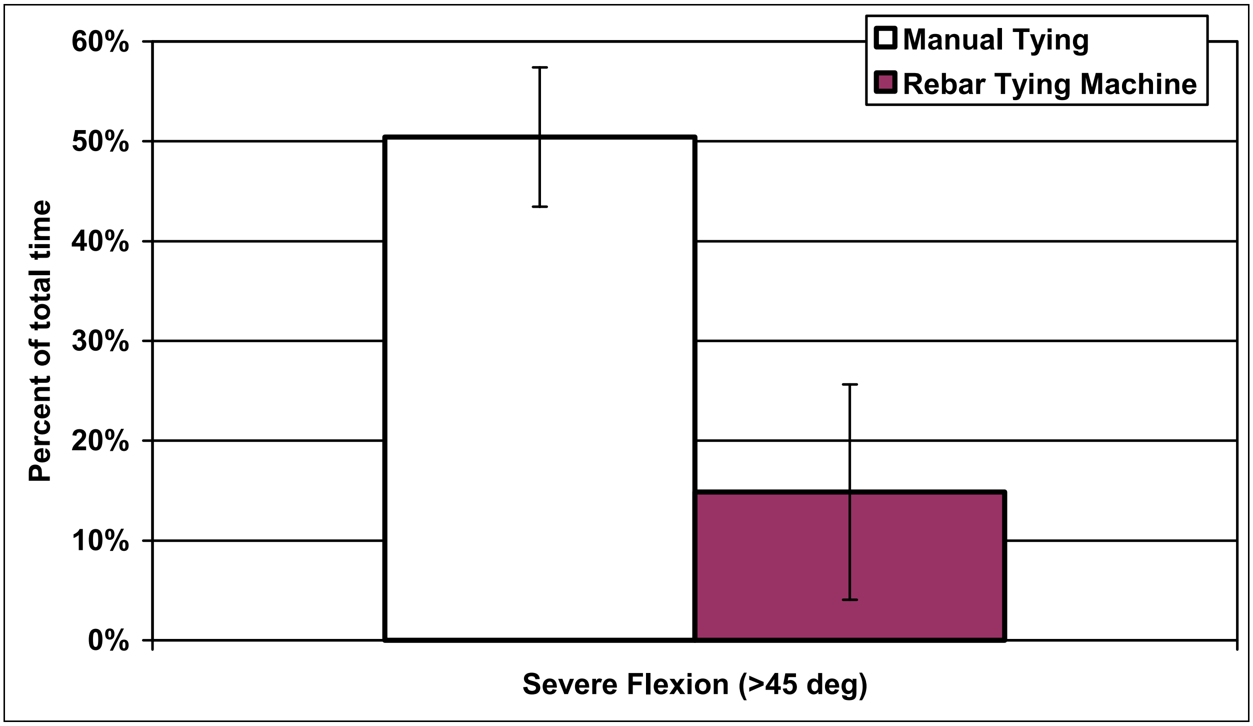

Figure 17: Percentage of time exposed to severe trunk posture (>45 degrees).

Rebar Tying Time

Paired t-test statistics revealed that there was a significant difference ($p<0.05$) in the rebar tying cycle time between the two work methods (see Figure 18). Using the traditional manual method the participants finished with an average rebar tying cycle time of 8.9 seconds. Using the rebar tying machine, the participants finished with an average rebar tying cycle time of 4.2 seconds - a decrease of 52% in comparison to the traditional method.

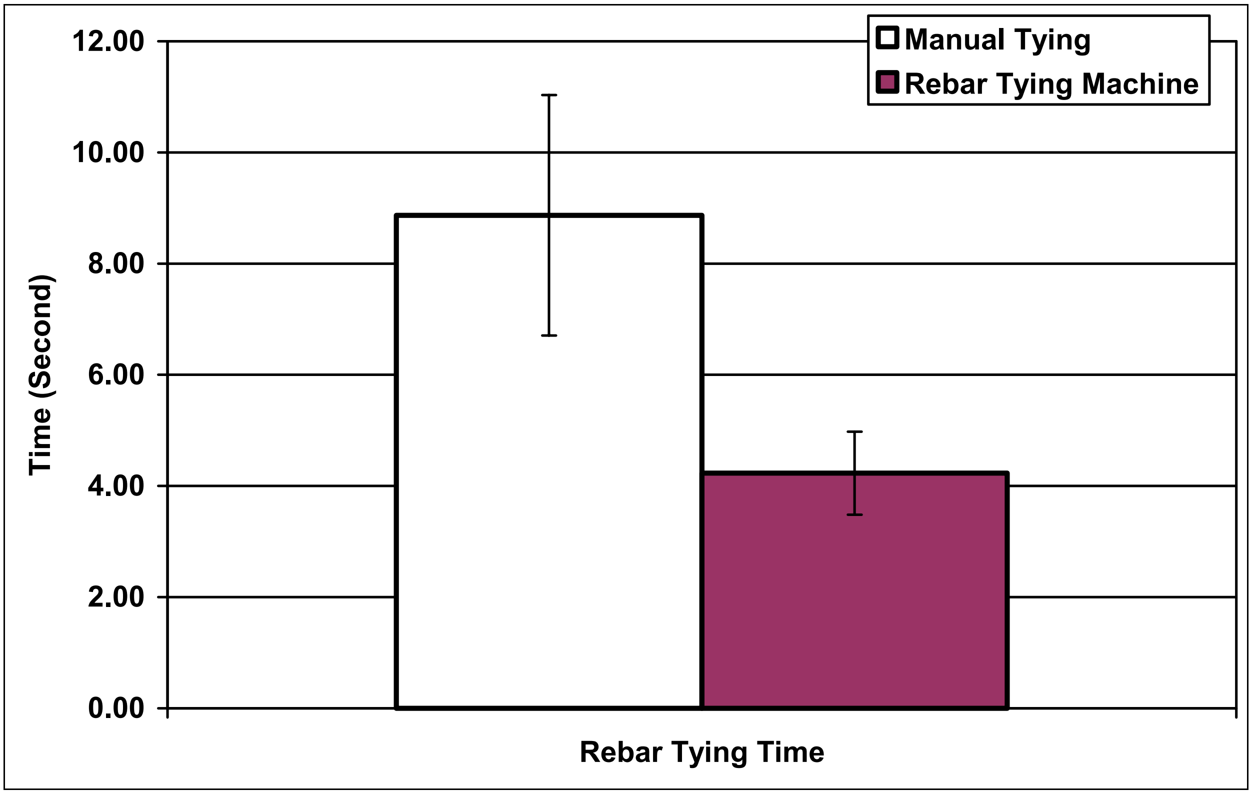

Figure 18: Rebar tying cycle time between the two tying methods. A cycle time is defined as the time required to tie one connection.

Usability Questionnaire

Summaries of the average subjective score for each item on the usability questionnaire are shown in Table 1. Workers' comments on each work method are listed in Appendix 2. The self-report questionnaires identify several user preferences among the tying methods. Generally, working with the rebar tying machine was the preferred work method in several categories on the questionnaire. Users found significantly ($p<0.05$) higher level of comfort, ease of use, and productivity when using the machine. Significantly ($p<0.05$) lower perceived hand force and wrist repetition were found also with the machine. Discomfort in the hands/arms and back area was also found to be significantly ($p<0.05$) lower with the machine. When asked whether they would prefer to work with the rebar tying machine or with traditional pliers, 91% said they would prefer to work with the machine. Only

60% said they would prefer to work with pliers. Participants were also asked whether or not they would recommend a particular tying method. The results revealed that all of the participants would recommend the machine. Only 60% of the respondents would recommend rebar tying with pliers. Please note that these percentages add up to more than 100% because the participants were allowed to choose more than one method as their preferred work procedure.

Table 1: Mean results of self-reports across rebar tying methods. Low score on each item represent favoring for a specific method.

Question	Rebar Tying Machine		Traditional Manual Method		Wilcoxon Signed Ranks Test P-value
	Mean	**SD**	**Mean**	**SD**	
1. Level of comfort	1.91	0.92	4.0	2.10	**0.020**
2. Hand force	2.14	1.76	3.45	1.37	**0.048**
3. Wrist repetition	2.41	2.01	6.54	1.51	**0.003**
4. Hands/arms discomfort	2.64	1.96	4.59	2.18	**0.047**
5. Shoulder discomfort	2.00	1.53	3.64	2.42	0.058
6. Back discomfort	2.77	2.14	6.73	2.94	**0.01**
7. Vibration level	1.73	1.35	1.32	1.23	0.196
8. Ease of use	0.68	0.87	2.04	1.11	**0.016**
9. Productivity	1.27	0.75	3.09	1.81	**0.011**

Scale:
0 ------------ 0.5 ------------ 1 ------------ 2 ------------ 3 ------------ 4 ------------ 5 ------------ 6 ------------ 7 ------------ 8 ----------- 9 ------------ 10
Very good Good Fair Bad Very Bad

Discussion

Trunk Posture Exposure

In a controlled-experimental study, Vi (2003) found significant (<0.01) differences in wrist and arm motions (flexion/extension, radial/ulnar, and pronation/supination) between the rebar tying machine and manual tying methods. For all planes of motion, the rebar tying machine exposed the participants to significantly lower wrist activities (i.e., acceleration of the wrist) than when tying task with pliers. Low-back compression forces were also indirectly measured from electromyography.

Significantly ($p<0.05$) lower low-back compression forces were found when workers used the rebar tying machine.

In the present study, significant differences in the magnitude, frequency and pattern of the trunk posture were also observed between the two tying methods. EVA method demonstrated that rodworkers using pliers (manual method) spent a significantly higher amount of their work time in larger trunk angles in combination with longer time periods than rodworkers using the rebar tying machine. The pattern of exposure revealed a "U" shape relationship between trunk posture and the continuous time period of the exposure level (see Figure 11). EVA and APDF methods also showed that the pattern of the trunk posture in manual tying with pliers differs most strongly for work time in trunk flexion greater than 45° (see Figure 17). With the rebar tying machine, however, the rodworkers' trunk posture was mostly confined between the trunk angles of greater than -10° and less than 40° (see Figure 12).

Long-term exposure to awkward trunk posture while tying rebar can expose workers to a high risk of low-pain back. Evidence from past research indicates the strong association between exposure to awkward trunk posture and risk of low-back pain (LBP). A large case-control study conducted by Norman et al (1998) found a positive relationship between peak trunk flexion and reporting of LBP. The odds ratio (OR) for the risk of LBP between the case and control based on the peak trunk flexion variable was 2.4 (95% CI 1.5-3.8). Similarly Marras et al (1995) observed an OR of 1.6 (95% CI 1.31-1.93). The first evidence of a positive relationship between the percentages of time exposed to non-neutral trunk flexion (>20° flexion) and risk of LBP was found by Punnett et al (1991). In the

Punnett et al (1991) study, multivariate analyses that adjusted for covariates demonstrated that time in non-neutral postures was strongly associated with back disorders (OR 8.09, 95% CI 1.4-44).

As shown in figure 13, working with the rebar tying machine can put workers to risk of LBP due to exposure to non-neutral trunk posture. As indicated from previously, the exposure level is significantly high enough to put workers at risk of injury. For example, Punnett et al (1991) found that any exposure to greater than 10% of the work time in non-neutral trunk posture (>20° flexion) can put workers to five times the risk of LBP when compared with no exposure to any non-neutral posture. The risk of LBP from a relative standpoint, however, is reduced when compared to manual tying. This conclusion was based on the fact that risk of LBP generally increases with the duration of exposure. In a large epidemiology study, Holmstrom (1992) found a positive linear relationship between duration of exposure to stoop trunk posture per day and risk of severe LBP. A prevalence rate ratio of 1.31, 1.88, and 2.61 for risk of severe LBP was observed for construction workers who are exposed to three trunk stoop posture duration categories; <1 hour/day, 1-4 hours/day, and >4 hours/day, respectively. Taking the definition of stoop posture as trunk bending of greater than 45°, workers are exposed to approximately four (4) hours trunk stoop posture when tying rebar with pliers (see Figure 13). With the rebar tying machine, workers are exposed to trunk bending posture for approximately one hour. The reduction in exposure duration will in turn reduce the risk of LBP.

There was large inter-subject variability in trunk posture exposure when participants were asked to tie manually (see Figure 14). With the rebar tying machine however, there was small inter-subject variability (see Figure 15). The large inter-subject differences in the trunk exposure pattern when working with pliers may be due to the differences in workers' anthropometrics. Another factor which may also influence trunk posture exposure is the individual's work pattern. For example, reinforcing steel work consists of two main tasks – rebar placement and rebar tying. Rebar placement involves manual material handing of rebar steel rods from a storage area to a specific location. Throughout the day, workers are required to rotate between tasks of rebar placement and rebar tying. However, there are differences in the preferences between the work tasks among rodworkers. Some workers preferred rebar placement and others prefer rebar tying. As a result of these work preferences, the trunk exposure level and the patterns of exposure will be different among rodworkers. Although there are major differences in the trunk posture exposure level between workers during manual tying, the risk of LBP, however, remains the same (see Figure 13).

Small variability in the trunk posture data was observed when workers used the rebar tying machine (see Figure 14). The small inter-subject variability in trunk posture may be related to the adjustability of the machine's extension handle. The handle was designed to adjust between 7.6 cm and 10.2 cm (3 and 4 feet) in length (see Figure 18). This allows rodworkers of different heights to tie rebar in an upright neutral posture (<20° trunk flexion). The narrow range of work posture (neutral posture) while using the rebar tying machine resulted in a homogenous trunk posture exposure level.

Productivity

As measured by tying time, productivity was very much dependent on the type of tying method. In this study, the rebar tying machine was found to be superior to traditional manual tying. On average, a 52% decrease in the time to tie one rebar was found when using the rebar tying machine (see Figure 18). This increase in productivity is positive because it allows workers to be more productive without increasing the risk of musculoskeletal disorders to the back and upper extremities.

Figure 18: Extension handle on rebar tying machine. Courtesy of MAX USA Corporation (www.maxusacorp.com, New York, USA)

Rodworkers Survey

The majority of responses in the usability questionnaires significantly favored working with the rebar tying machine. Questions relating to level of comfort, ease of use, and productivity were perceived to be in favor of the rebar tying machine. Rodworkers also felt that hand force, wrist and shoulder repetition, and hand/arm and back discomfort were significantly lower when working with the machine. Although most of the workers prefer the machine, many felt that it was only good for ground level rebar construction. Workers recommended that the vertical ties to create columns and walls should be manually tied with pliers because the machine cannot perform saddle-shape ties (see Figure 19).

Comments from the rodworkers also indicated that they do not feel the rebar tying machine will "de-skill" the trade or cause the loss of jobs. Many workers felt that pliers will remain the principal tool regardless of the rebar tying machine (see Appendix 2). Furthermore, working with the machine will still require a competent rodworker who understands the process of placing rebar and the appropriate tying techniques to assemble rebar mesh.

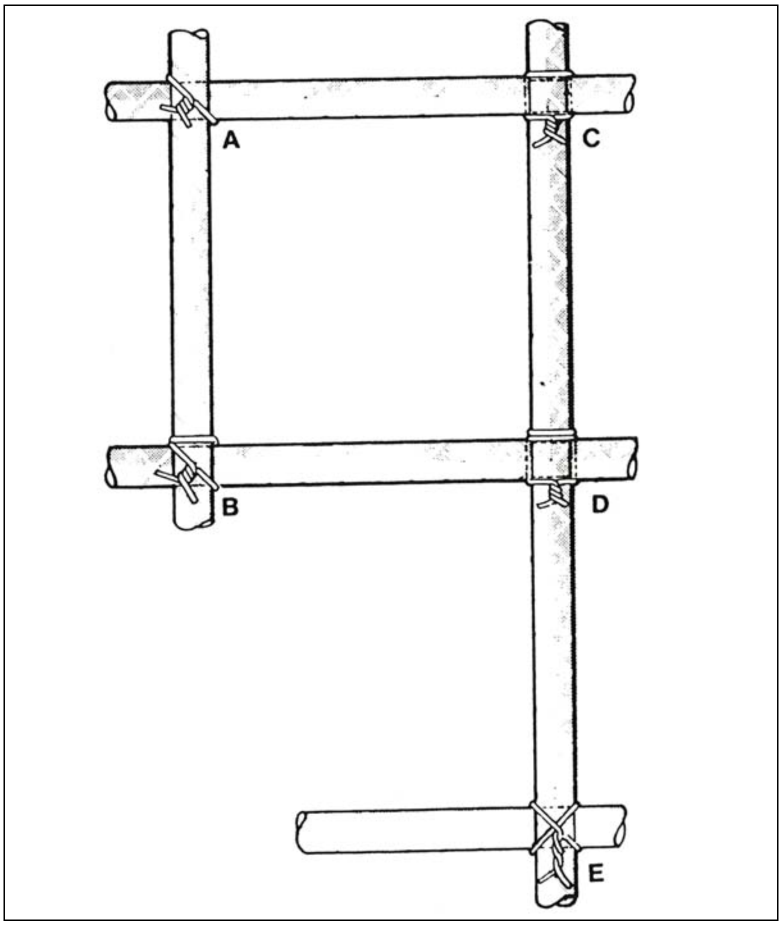

Figure 19: Common rebar ties. (A) Single tie, (B) Wrap and single tie, (C) Saddle tie, (D) Wrap and saddle tie, (E) Figure-eight tie. Courtesy of the Reinforcing Steel Institute of Ontario.

Transferability

During the field study, we discovered the transferability of the rebar tying machine to other trades. Before pouring concrete on top of the rebar mesh, electric conduits are also required to be placed next to the steel rebar rods (see Figure 20). Similar to rodworkers, electricians are required to bend forward and perform manual tying using pliers (see Figure 21). Using the rebar tying machine, however, can allow electricians to tie electrical conduit in a neutral upright trunk posture. Furthermore, repetitive forceful hand exertions while using pliers are also reduced.

Radiant heat tube installation workers can also benefit from the rebar tying machine. Manual tying using pliers can expose the radiant heat installer to awkward trunk posture and repetitive forceful hand exertion. Working with the rebar tying machine, however, can reduce excessive forceful hand exertion and static awkward trunk posture.

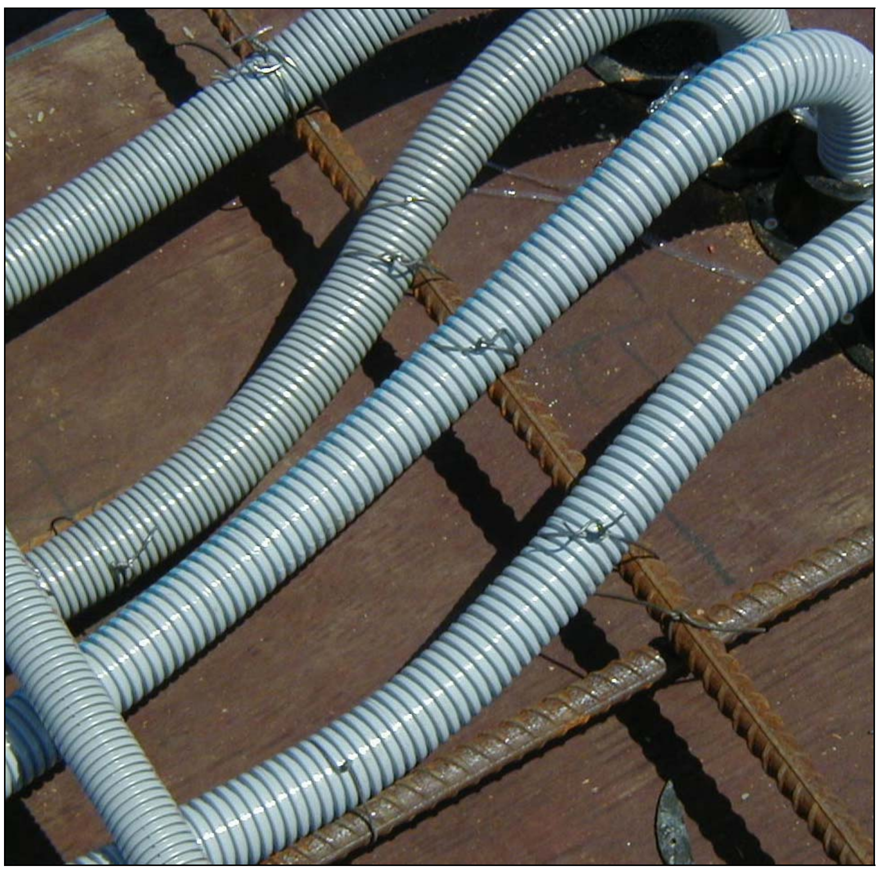

Figure 20: Electrical conduit installed next to rebar steels.

Figure 21: Tying electrical conduit using the rebar tying machine (left) and manual tying with pliers (right).

Limitations

There were several limitations in this field study. A before-and-after study experimental design was used to evaluate the intervention. Although a before-and-after design can be a reasonable method for evaluating intervention effectiveness, the threats to internal validity (i.e., possible alternative explanations for observed results) can exist. Examples of threats to internal validity in a before-and-after design can include changes in historical events, instrumentation/reporting errors, participants dropping out of the study and the Hawthorne effect (Robson et al, 2001). In this study, the effects of changes in historical events (such as legislation, work pace, management-labor relations, etc.), instrumentation/reporting errors, and drop-out rate did not impact the dependent variables. This is due to the fact that no significant changes in the rodworkers' work environment were observed;

except using the rebar tying machine. Research members also made every effort to ensure a consistent process of collecting dependent variables, including the distribution of the usability questionnaire. The consistent application of collecting data ensured that there were no instrument/reporting errors. The Hawthorne effect (i.e., involvement of outsiders can have an effect on the outcome), however, may impact the outcomes of the usability questionnaires. The extent of the Hawthorne or placebo effect on the results of the usability questionnaires cannot be quantified because there was no control group.

Another limitation with this study was the small sample size. Eleven rodworkers participated in this study. This sample size was adequate for a power of 0.8 when observing differences in trunk posture and rebar tying time. However, for many of the observed results in the usability questionnaire, a sample size of approximately 14 participants is required for a study power of 0.8.

Conclusion

A before-and-after experimental design was conducted to evaluate the potential reduction in the risk of musculoskeletal injuries to rodworkers when using an automatic rebar tying machine. Eleven (11) rodworkers participated in this experiment. All dependent variables (trunk posture, rebar tying time, and usability questionnaire) were measured before and after implementing the rebar tying machine. The results of the study indicated that working with a rebar tying machine significantly reduced the magnitude and duration of exposure to awkward trunk posture. Tying time was also faster when participants used the machine. The usability questionnaire indicated that most participants preferred to use the rebar tying machine for ground-level rebar construction. The field study also revealed that the rebar tying machine is not limited to the reinforcing trade. The machine can be transferred and used for other purposes such as tying electrical conduit and attaching radiant heat tube to steel mesh. Based on trunk posture exposure, rebar tying time, usability, and transferability, it is concluded that the rebar tying machine can be an effective tool to reduce risk of musculoskeletal disorders of the upper extremities and low-back.

Recommendations

Based on the findings and experiences gained from this field study, the following issues should be considered when introducing and using the rebar tying machine:

1. Choose a rebar tying machine that allows tying steel rebar at a comfortable back posture. An adjustable extension arm helps to ensure that rodworkers differing in height can tie rebar in a neutral trunk posture.

2. The rebar tying machine should not be limited to rodwork. The machine can be used to tie electrical conduit and radiant heat tubes and decrease the risk of musculoskeletal injuries to electricians and heating tube installers. Furthermore, field experience has shown that the rebar tying machine can significant decrease the time to tie rebar, which in turn can improve productivity. The increase in productivity however, can be more dramatic if used by electrician or radiant heat installer since manual tying with pliers is very slow and awkward when performed by non-rodworkers trade.

3. Select a rebar tying machine that can tie rebar at a variety of rebar sizes.

4. For slab-on-grade rebar, tying rebar with the rebar tying machine will require the use of a lightweight steel hook to lift rebar off the ground (see Figure 6).

5. Many of the rebar tying machines on the market require warm-up during cold weather. Therefore, proper tying tension of the rebar machine should be adjusted during cold days.

6. On very hot summer days, allow the machine to cool down in a shady area during regular breaks and lunch.

7. Working with the rebar tying machine is very productive for a crew of 4-5 workers per site. One worker can use the machine to tie, while two handle and place rods under the direction of the fourth.

8. When purchasing a rebar tying machine, select a vendor that will provide on-going support and can provide regular maintenance.

9. Use the rebar tying machine to assist workers who have an injury of the low-back or hand to return-to-work.

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Appendix 1

Tool Usability Questionnaire – Rebar Tying Machine

Please complete the following questions, trying to represent your true feelings for each topic as best as you can. Circle the number of your best answer; if you are unsure just estimate the level as closely as possible.

1. Rate the **level of comfort** when using the tool on the following scale.

   0 --------- 0.5 --------- 1 --------- 2 --------- 3 --------- 4 --------- 5 --------- 6 --------- 7 --------- 8 --------- 9 --------- 10
   No discomfort | **Fairly comfortable** | **Moderate discomfort** | **Very uncomfortable** | **Extreme discomfort**

2. Rate the level of hand force required to operate the tool on the following scale.

   0 --------- 0.5 --------- 1 --------- 2 --------- 3 --------- 4 --------- 5 --------- 6 --------- 7 --------- 8 --------- 9 --------- 10
   Nothing at all | **Light** | **Heavy** | **Very Heavy** | **Almost Max.**

3. Rate the level of wrist repetition required to operate the tool.

   0 --------- 0.5 --------- 1 --------- 2 --------- 3 --------- 4 --------- 5 --------- 6 --------- 7 --------- 8 --------- 9 --------- 10
   Very slow | **Slow** | **Fair** | **Fast** | **Very Fast**

4. Rate the **level** of **hands or arms** discomfort when using the tool on the following scale.

   0 --------- 0.5 --------- 1 --------- 2 --------- 3 --------- 4 --------- 5 --------- 6 --------- 7 --------- 8 --------- 9 --------- 10
   No discomfort | **Fairly comfortable** | **Moderate discomfort** | **Very uncomfortable** | **Extreme discomfort**

5. Rate the level of **shoulders** discomfort when using the tool on the following scale.

   0 --------- 0.5 --------- 1 --------- 2 --------- 3 --------- 4 --------- 5 --------- 6 --------- 7 --------- 8 --------- 9 --------- 10
   No discomfort | **Fairly comfortable** | **Moderate discomfort** | **Very uncomfortable** | **Extreme discomfort**

6. Rate the level of **back** discomfort when using the tool on the following scale.

   0 --------- 0.5 --------- 1 --------- 2 --------- 3 --------- 4 --------- 5 --------- 6 --------- 7 --------- 8 --------- 9 --------- 10
   No discomfort | **Fairly comfortable** | **Moderate discomfort** | **Very uncomfortable** | **Extreme discomfort**

7. Rate the level of **jerks or shakes** experienced from the tool.

   0 --------- 0.5 --------- 1 --------- 2 --------- 3 --------- 4 --------- 5 --------- 6 --------- 7 --------- 8 --------- 9 --------- 10
   Nothing at all | **Light** | **Heavy** | **Very Heavy** | **Almost Max.**

8. How **easy** was the tool to use?

0 --------- 0.5 --------- 1 --------- 2 --------- 3 --------- 4 --------- 5 --------- 6 --------- 7 --------- 8 --------- 9 --------- 10
Very slow Slow Fair Fast Very Fast

9. How **productive** do you feel using this tool.

0 --------- 0.5 --------- I --------- 2 --------- 3 --------- 4 --------- 5 --------- 6 --------- 7 --------- 8 --------- 9 --------- 10
Very good Good Fair Bad Very Bad

10. Please rate the **suitability** of tool **design** in helping to reduce your manual work load:

0 --------- 0.5 --------- I --------- 2 --------- 3 --------- 4 --------- 5 --------- 6 --------- 7 --------- 8 --------- 9 --------- 10
Very good Good Fair Bad Very Bad

11. Would you prefer to work with or without the tool? (check one) ____With ____Without

12. Would you recommend this tool to others? ____Yes _____No

If no, why?

____
____
____

If yes, why?

____
____
____

13. Please provide any additional comments regarding the use or comfort of this tool:

____
____
____
____
____

Thank you for taking the time to participate in this study and complete this questionnaire.

Appendix 2: Users' Comments

Rebar Tying Machine

Subject	Comments
1	• Good on slab work • Fast and less stress on back • Not good with big crew because each individual ties small sections and it is better to tie by hand
2	• It ties faster and is easy on the back
3	• Easy to use and somewhat faster than the traditional method • Great without the handle and more productive and also more comfortable to use
4	• Fast tying and easy on the body • When tool heats up sometimes it won't tie. If you let it sit for 10-15 seconds it will tie. • Machine works well without handle as well
5	• Good for slab work
6	• Good for someone who has back pain • Good for return to work from injury • Not good for normal production
7	• Good for tying slab only • We use it only on slab on grade • We use a hook with left hand to lift the steel
8	• Good for tying slab only
9	• Good for slab • Quick
10	• Easy to use on slabs • Less wear on wrists and back
11	• Light duty worker can stay on the job • Spool of wire in gun could be bigger

Manual Tying With Pliers (Traditional)

Subject	Comments
1	• Good for every job
2	• I would not recommend tying with pliers because bent over on slab is hard on the back
6	• It is the only way to tie steel
7	• I prefer tying machine on slab • When you use the machine on slab you don't have to bend over
8	• Easy to use
9	• Pliers is the only way to tie on vertical wall
11	• Can by used in any task of the trade

Appendix C:

Promoting Early Return To Pre-injury Job Using A Rebar-Tying Machine

Peter Vi, Construction Safety Association of Ontario

There are numerous risk factors that can influence the duration of work disability after a compensated musculoskeletal injury (MSI). Factors such as age, sex, injury severity, physical demands of job, psychosocial factors, previous MSI injury, employer size, lag time from injury to treatment, industry, occupation, and duration of employment have been found to be significant in influencing the duration of work disability (McIntosh et al., 2000; Dasinger et al., 2000; Infante-Rivard and Lortie, 1996; Oleinic et al, 1996). The relative influence of each factor, however, is dependent on the stage of disability. That is, some factors will have a significant influence on the duration of disability when the injury is in the subacute phase (i.e., <60 days off work) or chronic disability phase (i.e. >60 days off work).

One of the most consistent factors closely associated with duration of disability is the type of industry. Studies have found that injured workers in the construction industry have a significantly longer duration of work disability than other industries such as manufacturing, services or transportation (Oleinick et al., 1996; Dasinger et al., 2000; McIntosh et al., 2000). A recent study on chronic low-back pain in Ontario found that workers in construction have approximately twice the duration of compensated work disability than other industries (McIntosh et al., 2000). Possible factors that prevent injured construction workers from returning to their pre-injury job may be associated with the high physical demands of construction work (Dasinger et al., 2000; Oleinick et al., 1996; Hogg-Johnson and Cole, 1998; Cheadle et al, 1994). In one study, Dasinger et al. (2000) developed a multivariate regression model to describe probability of returning to work and found that, if a construction worker had a severe injury and the job exposed the worker to bending, lifting heavy objects, pushing or pulling heavy objects almost all of the time, the worker would likely have a return-to-work rate that is 20 times lower than office workers with a less severe injury and exposed to less physically demanding jobs.

Positive association between physical factors and length of disability are important because it suggests that lowering the physical demands of a job, such as ergonomic redesign or modifying the job, can promote return to work. Furthermore, by modifying the job, ergonomic risk factors for MSI can also be reduced or eliminated which can further reduce or prevent aggravation of the pre-existing conditions. Evidence to suggest using ergonomic intervention to promote return-to-work can be found in a Quebec study. Loisel et al. (1994) compared how four intervention methods affected time-to-return-to-work. At eight weeks lost time, workers with low-back pain were randomly assigned to receive or not receive a comprehensive occupational medical examination, physiotherapy treatment, and a case review. As well, the firm at which they worked had been randomly assigned to receive or not receive a participatory ergonomic intervention to alter the pre-injury job so as to both maximize injured worker accommodation and prevent recurrence. Thus, some workers received both of these interventions; others only one and the final group had "usual care". The result of the study revealed that the largest effect was from the participatory ergonomic intervention, with the specialist case review contributing minimal additional benefit.

Recently Vi (2004) conducted a before-and-after experimental design to evaluate the potential reduction in the risk of musculoskeletal injuries to rodworkers when using an automatic rebar tying machine. Eleven (11) rodworkers participated in the study. All dependent variables (trunk posture, rebar tying time, and usability) were measured before and three months after implementing the rebar-tying machine. The results of the study indicated that working with a rebar-tying machine significantly reduced the magnitude and duration of exposure to awkward trunk posture. Faster tying time was another benefit when participants used the tying machine for certain applications. The usability questionnaire indicated that most participants preferred to use the rebar machine for ground-level rebar construction. Many participants also indicated that the rebar-tying machine can be a good tool to help injured workers return-to-work.

Using the rebar tying machine as a rehabilitation tool to assist injured workers to return to their pre-injury job has been studied by some researchers (Dababneh and Waters (2000). Qualitative observation on one injured rebar worker found that the rebar-tying machine can enable the worker to continue working productively without the need for wrist twisting or trunk bending, which can aggravate the injury (Dababneh and Waters, 2000). Due to the limited observation made by Dababneh and Waters (2000), the purpose of this study was to further assess the feasibility of the rebar-tying machine to help injured workers return-to-work. An after-only study approach was used.

Method

Participants

Four (4) rodworkers participated in this study. All participants were unionized workers from the International Association of Bridges Structural and Ornamental Iron Workers Local 721. They were of average stature, 173 cm (± 5.5 cm), body weight, 85 kg (± 15 kg), and age, 43 years (± 14 year).

Questionnaire:

A self-report questionnaire was given to all participants four to five weeks after using the rebar-tying tool. The self-report questionnaire used in this study was based on past studies conducted by

Kuorinka et al. (1987), Marley and Kumar (1996), Spielbholz, Bao and Howard (2001) and Punnett L. (1998). Questions in the instrument asked for participants' musculoskeletal health and work condition after returning to their pre-injured job. Participants were also asked for their subjective estimations of overall comfort, hand force, wrist and shoulder repetition, hands/arms discomfort, shoulders discomfort, back discomfort, vibration level, ease of use, productivity, and suitability of the tool design to reduce manual work load. Participants were also asked whether they preferred to work with the tool, would recommend it to others, and to relate any additional comments about the tool. A sample questionnaire is contained in Appendix 1.

Procedure

Two large reinforcing steel construction firms participated in this study. Across an eight-month period, both firms were instructed to offer injured workers, the opportunity to return to their pre-injury job using the rebar-tying machine. The purpose of providing the rebar-tying machine was to accommodate the physical limitations of the injured worker. All participating workers were offered the opportunity to return to work after two weeks from their initial injury date.

The rebar-tying machine used in this study was purchased from MAX Corp USA (New York). It is a battery-powered tool that can be placed around the intersecting segments of rebar rods. When a trigger is depressed, the tool automatically feeds the wire around the bars, twists it and cuts it automatically. The MAX gun is able to tie rebar at a speed of approximately one tie per second. An attachment arm with the ability to adjust between 3' to 4' was also used (see Figure 1).

Figure 1: Rebar-tying machine with (left photo) and without extension arm (right photo).

Before implementing the intervention, all injured workers were trained in the proper use of the machine, including procedures to change the spool wire, trouble shooting, and machine maintenance. After the training session, the injured workers were offered the opportunity to use the tying machine. All injured workers were asked to work for a duration of eight hours per day with two 15 minutes break and a half-hour lunch. They were also allowed to choose either rebar placement or rebar assembly. For rebar assembly, the machine was used instead of the traditional pliers. After four to five weeks of using the rebar-tying machine, all injured workers were asked to fill out a questionnaire (see Appendix 1).

Results

Musculoskeletal Health

Across an eight-month period, four participants agreed to participate in this study. Two of the participants suffered lost-time injuries involving finger fractures. The other two participants had suffered chronic low-back problems but had not taken time off work as a result. Three of the injured workers perceived that their injury was due to "the everyday condition" of their job. Only one worker stated the injury was due to unsafe working conditions.

All participants were experiencing pain in their injured areas at the time of survey. On a 10-point pain scale, a mean of 4.5 was reported by the participants (0 = "No pain", 10 = "As bad as could be"). Although the participants felt pain, two participants felt that their pain/injury problem was getting "somewhat better", whereas the other two participants felt "much better".

Work Task and Work Duration

When asked whether their pain/injury interfered with their daily work activities on a 10-point scale, where 0 is "No interference" and 10 is "Unable to carry on any activities", the participants rated a mean of 6.25. All participants were on modified job duties at the time of the survey.

Detailed inquiries into their ability to carry out manual material handling of rebar steel were conducted. Three of the participants stated that they rebar placement was "somewhat difficult". One participant stated it was "very difficult" to perform manual material handling of rebar. The participants were also asked to estimate the number of hours they were able to handle rebar. The average was 4.9 hours.

Two of the workers who suffered fracture of the finger stated that they were "unable to perform" rebar-tying with pliers. The two chronic low-back pain workers stated that they were performing rebar-tying with pliers with "somewhat difficulty". Both of these workers stated that they were able to perform two (2) hours of rebar-tying with pliers. When asked to estimate the numbers of hours they were able to tie rebar using the rebar tying machine, all four (4) injured workers indicated they could do so for eight hours.

Rebar-Tying Machine Usability Questionnaire

Summaries of the average subjective score for each item on the usability questionnaire are shown in Table 1. All the items in the questionnaire were ranked in the range of "good' to "very good". Reduced wrist repetition, vibration level, and ease of use were ranked at the "very good" level. The level of comfort, hand force, hands/arms discomfort, shoulder discomfort, and back discomfort were ranked in the "fairly comfortable" range. The level of productivity while using the machine was ranked at the "good" level.

Survey results from healthy rodworkers (obtained from Vi, 2004) and injured workers' perception (data from current study) of the rebar-tying machine are also presented in Table 1. No significant ($p>0.05$) differences in opinions between the injured workers and the healthy workers' perception of the rebar-tying machine were found.

When asked whether they would prefer to work with the rebar tying machine, all participants responded positively. Participants were also asked whether or not they would recommend the tying machine to other workers. Again, the response was uniformly positive.

Table 1: Mean results of self-reports across rebar-tying methods. Low score on each item represents favoring for a specific method.

Question	Injured Rodworkers		Healthy Rodworkers		Mann-Whitney Signed Ranks Test P-value
	Mean	**SD**	**Mean**	**SD**	
1. Level of comfort	1.38	0.92	1.91	0.75	0.412
2. Hand force	1.88	1.76	2.14	1.03	0.949
3. Wrist repetition	0.88	2.01	2.41	0.85	0.226
4. Hands/arms discomfort	3.63	1.96	2.64	3.73	0.753
5. Shoulder discomfort	2.75	1.53	2.00	3.77	0.851
6. Back discomfort	1.13	2.14	2.77	1.31	0.226
7. Vibration level	0.98	1.35	1.73	0.85	0.280
8. Ease of use	0.75	0.87	0.68	0.96	0.949
9. Productivity	2.13	0.75	1.27	2.01	0.661

Scale:
0 ------------ 0.5 ------------ 1 ------------ 2 ------------ 3 ------------ 4 ------------ 5 ------------ 6 ------------ 7 ------------ 8 ----------- 9 ------------ 10
Very good Good Fair Bad Very Bad

<u>Discussion</u>

An after-only design approach was used in this study to determine the feasibility of the rebar tying machine to assist injured workers in an early return-to-work program. Due to the nature of the non-experimental design, such as lack of a control group, threats to internal validity can be a major source of flaws in making accurate conclusions. Some sources of threat to internal validity can include history, placebo effect, Hawthorne effect, maturation, and instrumentation or reporting error. Another major source of limitation in this study was the small sample size (i.e., four participants in total).

Despite numerous limitations, the study yields some evidence to suggest that the rebar-tying machine can assist injured workers in an early return-to-work program. Many items on the usability questionnaire suggested that all injured workers were comfortable using the tying machine. Level of hand force, hands/arms discomfort, shoulder discomfort, and back discomfort were ranked in the “fairly comfortable” level. A “good” rating category was reported for ease of use, overall comfort, and productivity level. When comparing perceived comfort levels between injured and healthy workers, the study revealed no significant differences.

The open-ended questionnaires also indicated that the rebar tying machine was favoured as a tool for rehabilitating injured rodworkers. All of the participants surveyed in this study supported the use of the tying machine in accommodating injured workers. Previous studies on healthy rodworkers also found that many rodworkers pointed out the use of the tying machine as a tool for rehabilitating injured workers.

The rebar-tying machine was able to accommodate all four of the participating injured workers in their rebar-tying tasks. The two workers with fractured fingers could not tie rebar, while the two workers with chronic low-back injuries were able to tie rebar only between 3 and 5 hours per shift. Working with the tying machine, however, all of the injured workers indicated that they could work the entire eight hour shift if asked to perform assembly tasks.

The ability of the tying machine to accommodate injured workers was found to be related to the fact that the machine can be used with only one hand and that the extension arm is adjustable. The one-handed feature accommodated the two workers with finger fractures while the adjustable arm accommodated the two workers who could not bend forward because of low-back injuries.

Conclusion

The purpose of this study was to assess the feasibility of the rebar tying machine in helping injured workers back to work. Two large reinforcing steel construction firms participated in this study. Across an eight-month period, both firms were instructed to offer injured workers the opportunity to return to their pre-injury job using the rebar-tying machine. The purpose of providing the tying-machine was to accommodate the physical limitations of the injured workers. After four to five weeks of using the rebar-tying machine, all injured workers were asked to fill out a usability questionnaire. The results of the questionnaire survey revealed that all injured workers were able to use the rebar-tying machine for the assembly task. All the items in the questionnaires were ranked in the range of “good’ to “very good” in terms of comfort, each of use, and productivity. Despite the low sample size, this study found the rebar-tying machine can assist injured rodworkers in an early return-to-work program.

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Appendix 1

Please complete the following questions, trying to represent your true feelings for each topic as best as you can. Circle the number of your best answer; if you are unsure just estimate the level as closely as possible.

A. DESCRIBING YOURSELF

Would you please supply us with the following details:

1. Your age: _______
2. Your sex: Male _______ Female _______
3. Your weight: __________ lbs (or) __________ kg
4. Your height: __________ ft __________ in (or) __________ cm
5. Which hand do you hold your pliers? Right ☐ Left ☐
5. How many hours in total did you work in the last 2 weeks? _________ Hours

B. DESCRIBING YOUR HEALTH

1. Have you, **in the last 12 months**, sought a health care professional's advice about pain/injury in any of these parts of the body?*(Please check all that apply)*

Head	☐	Elbow(s)	☐	Hip(s)/Thigh(s)	☐
Neck	☐	Wrist(s)/Hand(s)	☐	Knee(s)	☐
Shoulder(s)	☐	Back	☐	Ankle(s)/Feet	☐

2. Did you take any time off in **in the last 12 months** because of problems, that you believe to be work related, with any of these areas of the body? *(Please check all that apply)*

Head	☐	Elbow(s)	☐	Hip(s)/Thigh(s)	☐
Neck	☐	Wrist(s)/Hand(s)	☐	Knee(s)	☐
Shoulder(s)	☐	Back	☐	Ankle(s)/Feet	☐

3. About how long ago did you first begin to experience problems with your pain/injury?
   ____

4. Since the start of this recent problem, do you still have pain? Yes ☐ No ☐

5. How would you rate your pain **right now** on a 0-10 scale, where **0** is **No Pain** and **10** is **Pain as bad as could be**?

0 --------- 0.5 --------- 1 --------- 2 --------- 3 --------- 4 --------- 5 --------- 6 --------- 7 --------- 8 --------- 9 --------- 10

No Pain **As bad as could be**

6. How much has your pain/injury interfered with your daily work activities rated on a 0-10 scale, where **0** is **No Interference** and **10** is **Unable to carry on any activities**?

0 --------- 0.5 --------- 1 --------- 2 --------- 3 --------- 4 --------- 5 --------- 6 --------- 7 --------- 8 --------- 9 --------- 10

No Interference | **Unable to carry on any activities**

7. Currently you are on:
   1 Reduced hours
   2 A flexible work schedule
   3 A lighter job
   4 Changes to the layout or equipment in your work area
   5 Special training
   6 Or some other arrangement to help you get back to work – (Please specify) _____________

8. How much difficulty do you currently have when perform rebar tying with pliers?
   0 Unable to perform this task
   1 Very difficult to do
   2 Somewhat difficult
   3 Not difficult

9. If you are able to perform rebar tying with pliers, how long in a regular shift do you able to perform this task? ________________ hours

10. How much difficulty do you currently have when perform manual material handling of rebar steels?
   0 Unable to perform this task
   1 Very difficult to do
   2 Somewhat difficult
   3 Not difficult

11. If you are able to perform manual material handling of rebar steels, how long in a regular shift do you able to perform this task? ________________ hours

12. Overall, is your pain/injury problem is getting better or worse than you expected it to be at this point?
   1 Much better
   2 Somewhat better
   3 What you expected
   4 Somewhat worse
   5 Much worse

13. When you think about the causes of your pain/injury, were any of the following things involved?
   1 The everday conditions of your job
   2 Unsafe working conditions – (Please specify) ______________________________________
   3 Doing a job different from your usual work
   4 Having to do extra work
   5 Having to work too fast
   6 Doing a task unrelated to your job
   7 None of the above – (Please specify) ____
   8 Do not know/cannot remember

C. Rebar Tying Gun

14. Rate the **level of comfort** when using the tool on the following scale.

0 --------- 0.5 --------- 1 --------- 2 --------- 3 --------- 4 --------- 5 --------- 6 --------- 7 --------- 8 --------- 9 --------- 10
No discomfort **Fairly comfortable** **Moderate discomfort** **Very uncomfortable** **Extreme discomfort**

15. Rate the level of hand force required to operate the tool on the following scale.

0 --------- 0.5 --------- 1 --------- 2 --------- 3 --------- 4 --------- 5 --------- 6 --------- 7 --------- 8 --------- 9 --------- 10
Nothing at all **Light** **Heavy** **Very Heavy** **Almost Max.**

16. Rate the speed of wrist repetition required to operate the tool.

0 --------- 0.5 --------- 1 --------- 2 --------- 3 --------- 4 --------- 5 --------- 6 --------- 7 --------- 8 --------- 9 --------- 10
Very slow **Slow** **Fair** **Fast** **Very Fast**

17. Rate the **level** of **hands or arms** discomfort when using the tool on the following scale.

0 --------- 0.5 --------- 1 --------- 2 --------- 3 --------- 4 --------- 5 --------- 6 --------- 7 --------- 8 --------- 9 --------- 10
No discomfort **Fairly comfortable** **Moderate discomfort** **Very uncomfortable** **Extreme discomfort**

18. Rate the level of **shoulders** discomfort when using the tool on the following scale.

0 --------- 0.5 --------- 1 --------- 2 --------- 3 --------- 4 --------- 5 --------- 6 --------- 7 --------- 8 --------- 9 --------- 10
No discomfort **Fairly comfortable** **Moderate discomfort** **Very uncomfortable** **Extreme discomfort**

19. Rate the level of **back** discomfort when using the tool on the following scale.

0 --------- 0.5 --------- 1 --------- 2 --------- 3 --------- 4 --------- 5 --------- 6 --------- 7 --------- 8 --------- 9 --------- 10
No discomfort **Fairly comfortable** **Moderate discomfort** **Very uncomfortable** **Extreme discomfort**

20. Rate the level of **jerks or shakes** experienced from the tool.

0 --------- 0.5 --------- 1 --------- 2 --------- 3 --------- 4 --------- 5 --------- 6 --------- 7 --------- 8 --------- 9 --------- 10
Nothing at all **Light** **Heavy** **Very Heavy** **Almost Max.**

21. How **easy** was the tool to use?

0 --------- 0.5 --------- 1 --------- 2 --------- 3 --------- 4 --------- 5 --------- 6 --------- 7 --------- 8 --------- 9 --------- 10
Very, very easy **Easy** **Difficult** **Very difficult** **Very, very difficult**

22. How **productive** do you feel using this tool.

0 --------- 0.5 --------- I --------- 2 --------- 3 --------- 4 --------- 5 --------- 6 --------- 7 --------- 8 --------- 9 --------- 10
Very good **Good** **Fair** **Bad** **Very Bad**

23. Please rate the **suitability** of tool **design** in helping to reduce your manual work load:

0 --------- 0.5 --------- I --------- 2 --------- 3 --------- 4 --------- 5 --------- 6 --------- 7 --------- 8 --------- 9 --------- 10
Very good **Good** **Fair** **Bad** **Very Bad**

24. If you are ask to use the rebar tying gun, how long in a regular shift do you able to perform this rebar tying? __________ hours

25. Would you prefer to work with or without the tool? (check one) ____With ____Without

26. Would you recommend this type of tool to others? ____Yes _____No
If no, why?
____
____
If yes, why?
____
____

27. Please provide any additional comments regarding the use or comfort of this tool:
____
____
____

Thank you for taking the time to participate in this study and complete this questionnaire