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Biomechanical Assessment of Three Rebar Tying Techniques

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

construction biomechanics reinforcing ironwork

1. BACKGROUND

In the USA, construction ironwork can be divided into four primary specialties: (a) structural ironwork, (b) ornamental ironwork, (c) machinery moving/rigging ironwork, and (d) reinforcing ironwork (also known as rod, rebar, or concrete reinforcement work). This report focuses on the last of these specialties. In reinforcing ironwork, workers place steel rods into concrete forms and tie the rods together using wire prior to filling the forms with concrete. The embedded steel rods provide additional support for the concrete structures being built, including bridge decks and vertical walls.

1.1. Workplace Injuries and Physical Risk Factors

According to the Bureau of Labor Statistics [1], construction workers for the year 2004 suffered work-related nonfatal injuries at a rate of 6.4 per 100 full-time employees compared with 4.8 per 100 full-time employees for all industries. Construction workers specializing in highway, street, and bridge construction had an incidence rate of 6.4 nonfatal injuries per 100 full-time employees, one third higher than the national average.

In a survey of approximately 1 000 construction ironworkers including 250 reinforcing ironworkers (RIWs), respondents were asked if they had ever experienced a musculoskeletal disorder (MSD) over their entire ironworker career [2]. For RIWs, the prevalence of self-reported MSD symptoms

The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health.

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were upper extremities (73%) including wrist/hands/fingers (48%) and shoulders (34%), lower back (52%), and lower extremities (53%) including knees (37%) and ankles/feet (27%). Only 12% of the RIWs reported having experienced no MSD during their career. The respondents were also asked if they had ever received a doctor's diagnosis for a MSD during their career. For RIWs, the prevalence of doctor-diagnosed MSDs were tendonitis (19%), carpal tunnel syndrome (16%), ruptured back disk (14%), and shoulder bursitis (11%). Almost half (49%) of the RIWs reported no doctor-diagnosed MSD during their career.

Ergonomic exposure assessment protocols based on work sampling strategies with observations over extended periods of time were found suitable to accurately estimate exposure to workplace hazards associated with construction work [3]. Forde and Buchholz conducted quantitative exposure assessments for seven construction ironwork tasks, including tying rebar in a highway base layer [4]. Nearly 14 000 observations were made overall. Twelve RIWs were observed over 6 days and over 4 500 separate observations were recorded. These workers, in general, had the worst trunk, arm and leg postures of the seven groups of construction workers. For trunk postures, the RIWs were in neutral posture only 52% of the time, in slight flexion (>20°) 13%, and in severe flexion (>45°) 28% of the workday. For arm postures, the RIWs had one elbow at or above the shoulder 14% of the time and two elbows at or above the shoulder 6%. The RIWs stood on unstable or uneven ground 70% of the time, primarily standing on the rebar mats. It was observed that these workers carried heavy weight (>23 kg) 19% of the workday. For a typical 8-hr shift, this amounted to 1.5 hrs, primarily positioning the rebar into the mat structure. Another 6% of the shift, about 0.5 hrs, the RIWs carried moderate weights of 4.5–23 kg. The RIWs were observed positioning rebar 36% of the time, approximately 3 hrs each shift. The workers spent 29% of the time (2.3 hrs) tying together the rebar mats, typically in a severe trunk flexion posture.

1.2. Work Methods

On this particular project, the RIWs were responsible for placing and tying together the rebar used to reinforce the concrete deck and walls of a highway bridge. The rebar was used to reduce the tensile stresses (i.e., bending and stretching) acting on the concrete deck. The rebar was either No. 10 metric size (10-mm diameter) at 0.56 kg/m, or No. 16 metric size (16-mm diameter) at 1.56 kg/m, and 6.1 m in length. Two rebar mats were placed inside the concrete form over the full length of the bridge. Each mat consisted of rebar placed perpendicular to each other and spaced about 18 cm apart. The mats were supported above the metal decking using wire "chairs" and the chairs were used to separate the top and bottom mats. The specifications for the job, common for highway bridge decks in the USA, required tying 50% of the intersecting rebar on the bottom mat and 100% of the intersections on the top mat. The bridge was approximately 1 600 m long by 18.3 m wide (approximately 30 000 m^2). The contractor estimated 2.2 million wire ties were made on the bridge to secure the rebar. Weather permitting, the ironworkers typically worked a 5-day, 40-hr work week. The amount of rebar placed and tied on any given day depended on several factors, including the number of workers on the job, the environmental conditions, and the pace of the work preceding rebar installation.

The ironworkers typically employed two techniques to tie the intersecting rebar together: (a) pliers and a spool of wire and (b) a battery-operated power tier (Model RB392 rebar tier, MAX USA Corp., USA). Pliers were used to wrap and twist the wire around the rebar when more secure ties were necessary while framing the side walls of the bridge deck or making the first ties for each mat. The power tier (PT) was used most frequently to make the remaining ties. Traditional tying (Figure 1) required the use of two hands—one to use the pliers to pull, wrap, twist, and cut the wire and the other to pull and push the wire. Only one hand was necessary to operate the PT (Figure 2). Both techniques required frequent and sustained deep trunk bending (>60° trunk flexion) to tie the rebar.

Figure 1. Traditional rebar tying with pliers and spool of wire.

Figure 2. Tying rebar with power tier (PT).

The National Institute for Occupational Safety and Health (NIOSH) introduced a commercially available extension handle developed for use with the PT. This was the third rebar tying technique used during the investigation (Figure 3).

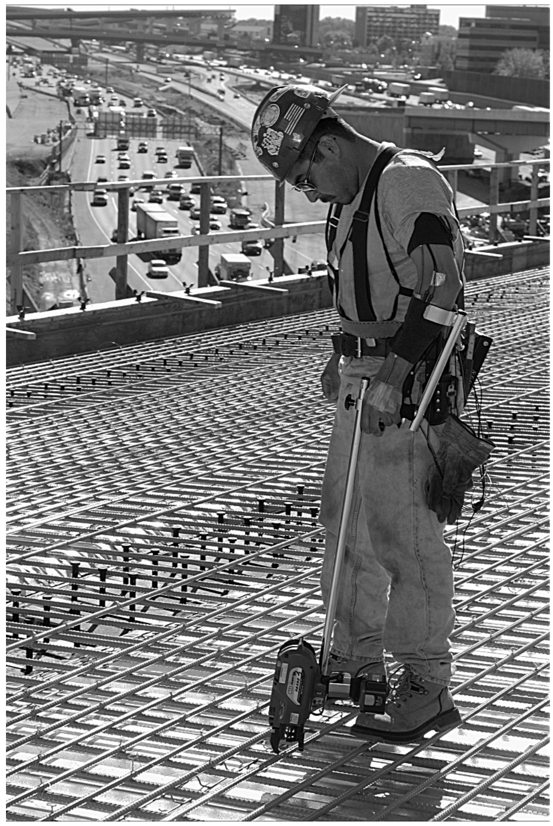

Figure 3. Power tier with extension (PTE).

2. METHODS

NIOSH evaluated ironworkers' exposures to risk factors for developing low-back and hand disorders during hand-tying of reinforcing steel bars (rebar) on concrete bridge decks, and investigated whether the use of rebar power tying tools could be an effective intervention for the prevention of work-related musculoskeletal disorders (WMSDs) of the upper extremities and back.

The investigation was designed as a repeated measures-randomized ordered study. All RIWs working on the study site were enrolled as participants and all were familiar with using the pliers and the PT. The extension handle was brought to the site by NIOSH investigators and none of the employees had previously used the device. Participants were encouraged, but not required, to become familiar with the use of the extension before measurements were made. The order that the three tying techniques were used was randomly assigned to each employee. Independent variables were the three different rebar tying methods. Dependent variables were (a) trunk position, (b) hand–wrist position, (c) hand–wrist movement (e.g., velocity and acceleration), (d) low-back position, and (e) the number of ties per minute.

2.1. Demographics

The construction reinforcing and structural steel contractor that collaborated in the study was a minority-owned business providing structural and reinforcing steel services for new construction projects in a major metropolitan area. At the time of the request, the contractor employed 100 ironworkers. Eight male RIWs participated in the study. Participant mean age was 37 years old (±6) and mean height, weight and body mass index (BMI) were, respectively, 174 cm (±6), 83.5 kg (±9.0), and 27.6 BMI (±1.9). All study participants were members of the International Association of Bridge, Ornamental, and Reinforcing Iron Workers. Subjects reported tying rebar using pliers 8.1 hrs/week (±6.2) and using a battery-powered PT 6.1 hrs/week (±6.9). One worker reported an injury occurring during the previous 12 months that affected his work.

The subjects were directed to tie the rebar placed for the bottom mat using three different tying techniques: (a) pliers and wire spool, (b) the PT, and (c) the PT with an extension handle (PTE).

The contractor had purchased the PTs approximately 2 years prior to the study in part to reduce employees' exposures to biomechanical loading related to tying rebar using pliers. The PT still required deep forward bending when tying at deck level, but workers used one hand to hold the tier tool and the other to support their upper body while tying.

2.2. Data Collection

Each subject tied rebar for about 30 min using (a) pliers, (b) a PT, and (c) a PTE. A twin-axis goniometer (Biometrics SG Series; Biometrics, UK) and a torsiometer (Biometrics Q110) were used to measure the dominant wrist motion and position in the flexion/extension, ulnar/radial, and pronation/supination planes during tying [5]. The goniometers and torsiometer were calibrated on-site using a special fixture to control crosstalk (Figure 4) [6]. The calibration results for the electrogoniometers demonstrated that the wrist position measurements were accurate and consistent.

Observational methods were used to record the position of the trunk during tying and the

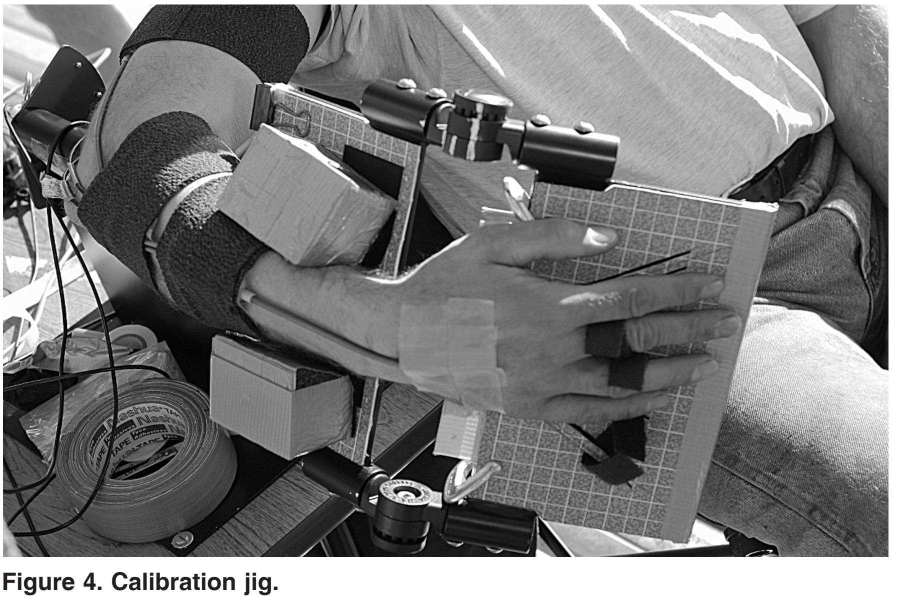

Figure 4. Calibration jig.

number of ties each worker made. This consisted of videotaping each worker from three different angles so that the trunk could be later viewed from both the side and front.

Using the Borg Modified CR-10 scale, each worker was asked to describe the physical effort they used with their hand–wrist and low back on a scale from 0 (*nothing at all*) to 10 (*extremely strong*) when using the three tying methods [7]. Personal information and work history were obtained using self-administered questionnaires.

2.3. Data Analysis Methods

The goniometric data were converted to readable files using proprietary Biometrics Ltd. data management and analysis software. Statistical analysis, including summary and inferential statistics, was conducted using SAS® software version 8, including the MIXED model procedure.

Videotape was analyzed using the Multimedia Video Task Analysis (MVTA™) software program on a computer [8]. This software allows for frame-by-frame analysis of the video of the tying tasks identifying and cataloguing exposure to multiple risk factors, such as trunk and neck postures and wrist deviations. An analyst recorded the frequency and duration of the trunk posture angles and the time required to tie rebar for each of the three tying techniques.

Analysts used the computer-based 3D Static Strength Prediction Program™ (3DSSPP) to estimate the pressure (compressive forces) on the spinal disc between the fifth lumbar vertebrae and the first sacral vertebrae (L5/S1 spinal disc) during rebar tying in stooped postures [9]. Spinal disc pressure is known to vary depending on the amount and type (e.g., forward, sideward, twisting) of bending and external loads [10].

The following methods were used to evaluate the biomechanical loading of the subjects' low back and upper limbs for each rebar tying task of the study (detailed descriptions follow):

1. the American Conference of Governmental Industrial Hygienists (ACGIH™) Hand Activity Level (HAL) Threshold Limit Value (TLV™) [11],
2. guidelines for acceptable hand–wrist motion (e.g., velocity and acceleration) to prevent wrist cumulative trauma disorders (CTD) [12, 13],
3. 3DSSPP™ to estimate the compressive and shear forces on the L5/S1 spinal disc [9], and
4. International Organization for Standardization (ISO) Standard No. 11226:2000 [14].

2.3.1. ACGIH™ HAL TLV™

The ACGIH™ HAL TLV™ uses HAL and peak hand forces to evaluate the risk factors for developing a hand, wrist, and forearm MSD [11]. The HAL is based on the frequency of hand exertions used and the job duty cycle (i.e., distribution of work and recovery periods). Peak force can be measured using a strain gauge or other instrumentation (and normalized on a scale of 0 to 10) or estimated by a trained observer using subjective exertion scales (i.e., Borg Modified CR-10 perceived effort scale) [7]. The total exposure is characterized in terms of average HAL and peak hand force. Scores between 0.56 and 0.77 are at the Action Level and scores above 0.77 exceed the TLV™.

2.3.2. Hand–wrist motion guidelines

Marras and Schoenmarklin studied the relationship between wrist movement, including the angle, repetition, velocity, and acceleration levels, and the risk of developing a CTD [12]. The study found that high wrist and forearm motion (i.e., angular velocity and angular acceleration) during an 8-hr period were significantly associated with risk of developing an upper extremity CTD. Mean wrist acceleration levels associated with high and low CTD risk in the radial/ulnar, flexion/extension, and pronation/supination planes were, respectively, 494 and 301 angular degrees/second^2 (d/s^2), 824 and 494 d/s^2, and 1 824 and 1 222 d/s^2. In follow-up analysis, Marras, Schoenmarklin, and Leurgans [13] reported that wrist acceleration in the flexion/extension plane was the best predictor of a hand/wrist CTD.

2.3.3. 3DSSPP™

The University of Michigan 3DSSPP™ is a computerized model which can be used to evaluate the physical demands of a prescribed job [9]. Inputs to the model are the magnitude and direction of forces at the hands, angles of body segments, and worker characteristics. The model calculates forces (i.e., moments) on the joints of the body and estimates the percentage of the workforce able to sustain the inputted loads. Compressive and shear forces for the L5/S1 disc are calculated. The program allows the analyst to estimate the compressive forces acting on the spine relative to the revised NIOSH lifting equation [15]. In order to prevent low-back disorders, NIOSH recommends L5/S1 disc compression force should not exceed 3 400 Newtons (N) during any single job activity [16] (1 N = 0.225 pound-force).

2.3.4. ISO evaluation of static work postures

The ISO developed the consensus standard No. ISO 11226:2000 [14]. It describes acceptable trunk postures and maximum acceptable holding times for potentially harmful postures. Postures with trunk flexion greater than 60° [6] are not recommended.

3. RESULTS

Manually tying rebar at ground level using pliers and wire involved sustained deep trunk bending and rapid and repetitive hand and wrist movements. Using a PT greatly reduced the rapid and repetitive hand–wrist and forearm movements characteristic of tying with the pliers, and freed one hand to support the weight of the trunk during tying. Adding an extension handle to the PT (PTE) allowed workers to tie rebar standing erect. The results show that manually tying rebar using pliers involves higher exposure to risk factors for developing a low-back WMSD than tying with the PTE. The study indicates that tying with the PT or PTE may lower exposure to risk factors for developing an upper limb WMSD.

3.1. Wrist Kinematics

Wrist mean velocity and wrist mean acceleration were significantly higher during pliers tying than PT or PTE tying (Tables 1–2). Mean wrist velocities measured in the flexion/extension and ulnar/radial planes during pliers tying exceeded velocities associated with high and low risks of developing a CTD [12] (Table 3). The low CTD risk level was exceeded in the ulnar/radial plane using each of the three tying techniques. Operating the PT resulted in a mean wrist velocity in the ulnar/radial plane exceeding the level associated with a high CTD risk.

TABLE 1. Comparison of Mean Wrist Velocity Postures by Rebar Tying Method (Chi-Square Difference of Least Squares Means)

Plane	Pliers vs. PT	Pliers vs. PTE	PT vs. PTE
Flexion/extension	<.0001	<.0001	*ns*
Ulnar/radial	*ns*	<.0500	*ns*
Supination/pronation	<.0001	.0001	*ns*

Notes. PT—MAX RB 392 power tier (MAX USA Corp., USA); PTE—MAX RB 392 power tier plus adjustable extension.

TABLE 2. Comparison of Mean Wrist Acceleration Postures by Rebar Tying Method (Chi-Square Difference of Least Squares Means)

Plane	Pliers vs. PT	Pliers vs. PTE	PT vs. PTE
Flexion/extension	<.0010	<.0010	*ns*
Ulnar/radial	<.0500	<.0009	*ns*
Supination/pronation	<.0001	.0001	*ns*

Notes. PT—MAX RB 392 power tier (MAX USA Corp., USA); PTE—MAX RB 392 power tier plus adjustable extension.

The workers' mean wrist acceleration levels measured during pliers tying exceeded levels found to be associated with (a) high CTD risk in the flexion/extension (i.e., 824 d/s^2) and ulnar/radial (i.e., 494 d/s^2) planes and (b) low CTD risk in the pronation/supination plane (i.e., 1222 d/s^2) (Table 4). Use of the PT exceeded acceleration levels related to low CTD risk level in the ulnar/radial plane (i.e., 301 d/s^2) [12].

TABLE 3. Comparison of Measured Wrist Velocity (degrees/second) to High- and Low-Risk [13] Velocity Rates

Plane	Statistic	Pliers	PT	PTE	Risk	
					High	Low
Flexion/extension	*M*	85[a]	20	21	42	29
	SD	28	6	10	12	8
Ulnar/radial	*M*	56[a]	39	22[b]	26	17
	SD	17	23	14	7	7
Pronation/supination	*M*	114[a]	43	40	91	68
	SD	41	12	9	23	19

Notes. PT—MAX RB 392 power tier (MAX USA Corp., USA); PTE—MAX RB 392 power tier plus adjustable extension; a—exceeds high cumulative trauma disorder (CTD) risk level, b—exceeds low CTD risk level.

TABLE 4. Comparison of Measured Wrist Acceleration (degrees/second^2) to High- and Low-Risk [13] Acceleration Rates

Plane	Statistic	Pliers	PT	PTE	Risk	
					High	Low
Flexion/extension	*M*	961[a]	216	219	824	494
	SD	260	63	98	266	156
Ulnar/radial	*M*	782[a]	454[b]	242	494	301
	SD	205	270	154	142	125
Pronation/supination	*M*	1335[b]	462	452	1824	1222
	SD	377	130	118	533	384

Notes. PT—MAX RB 392 power tier (MAX USA Corp., USA); PTE—MAX RB 392 power tier plus adjustable extension; a—exceeds high cumulative trauma disorder (CTD) risk level, b—exceeds low CTD risk level.

3.2. Self-Reported Data Analyses

Five workers completed the perceived effort questionnaire. Participants reported the lowest low-back effort when using the PTE (1.2 on the 10 point Borg Modified CR-10 scale), followed by 2.8 for the PT and 5.8 for the pliers. The lowest hand–wrist effort was reported for the PT (2.8) and the PTE and pliers were, respectively, 5.0 and 5.2.

3.3. Observational Analyses

ACGIH™ HAL TLV™ scores were calculated using the workers' perceived effort scores [7] (i.e., mean, low, and high) for each tying technique. Using the mean scores, the HAL TLV™ (HAL = 0.78) would be greatly exceeded when pliers were used (2.5) and slightly exceeded when a PTE (HAL = 0.83) was used for 4 hrs or more each day. Use of the PT alone would not exceed the HAL TLV™.

Workers were observed tying rebar with extreme trunk flexion (≥90°) 94% of the time when using the pliers and 93% of the time when using the PT (Table 5). With the PTE workers tied rebar using neutral trunk positions (<15° flexion) 83% of the time and moderate forward flexion (16°–30°) 16% of the tying time.

When using the PT, all workers used their free hand to support the weight of their torso, e.g., resting the hand/forearm on the knee/thigh, 92.4% ±4.0 of the time when they tied rebar at ground level[1].

[1] Workers use two hands to tie using the pliers, while only one hand is necessary using the PT or PTE.

TABLE 5. Time in Trunk Inclination During Rebar Tying

Treatment	Inclination (°)	Time (s) M	SD	Range
PTE	Neutral	124**	35	55–150
	16–30	24*	36	0–95
	31–45	1	3	0–8
	46–60	<1	<1	0–1
	61–75	<1	<1	0–<1
	76–90	0	0	0–0
	>90	0	0	0–0
PT	Neutral	<1	1	0–2
	16–30	<1	<1	0–<1
	31–45	<1	<1	0–<1
	46–60	<1	<1	0–<1
	61–75	<1	<1	0–1
	76–90	5*	7	0–18
	>90	140**	13	110–150
Pliers	Neutral	0	0	0–0
	16–30	0	0	0–0
	31–45	0	0	0–0
	46–60	<1	<1	<1–1
	61–75	<1	1	0–2
	76–90	6*	7	1–23
	>90	141**	9	126–150

Notes. Total sample time = 150 s; PT—MAX RB 392 power tier (MAX USA Corp., USA); PTE—MAX RB 392 power tier plus adjustable extension; $*p < .05$ (comparing differences between PT + PTE and pliers + PTE), $**p < .0001$ (comparing differences between PT + PTE and pliers + PTE).

TABLE 6. Estimated Forces on the L5/S1 During Manual Tying Using the 3DSSPP™ [10]

Trunk	Angle (°)	Total Compression (N)	Total Shear (N)
Flexion	–90		
Rotation	0	2427	306
Lateral	0		
Flexion	–90		
Rotation	0	2857	389
Lateral	±25		
Flexion	–105		
Rotation	0	1864	419
Lateral	0		
Flexion	–105		
Rotation	0	2322	480
Lateral	±25		
Flexion	–115		
Rotation	0	1511	401
Lateral	0		
Flexion	–115		
Rotation	0	1930	501
Lateral	±25		

3.4. Other Analyses

Using 3DSSPP™ [9], compressive and shear forces acting on the L5/S1 disc were estimated to be between 1 511 and 2 857 N during two-hand rebar tying using the pliers without lateral bending or trunk rotation (Table 6). Lateral bending (25° left or right) increased both total and shear compression forces when the trunk inclination did not change. Highest estimated shear forces were 501 N, at the deepest trunk inclination (–15°) and 25° lateral bending.

3.5. Productivity Analyses

Tying with the PT or PTE is faster than using the pliers. The mean number of ties per 2.5 min completed using the pliers, PT, and PTE, respectively, was 42 (±6.8), 84 (±10.3), and 52 (±9.0). Tying times were significantly different for the three techniques.

4. DISCUSSION

4.1. Risks Associated with Pliers Tying

The ACGIH™ HAL TLV™ and the CTD risk estimates developed by Marras and Schoenmarklin [12] assume exposure occurs, respectively, for ≥4 hrs and 8 hrs each day. The RIWs reported tying rebar for about 16 hrs per week using the pliers or PT. Tying rebar using the pliers for 4 or more hours each day exceeded the ACGIH™ HAL TLV™ threefold. Using the

PTE for 4 hrs or more each day slightly exceeded the HAL TLV™.

During pliers tying, wrist motion (i.e., mean velocity and acceleration) in the flexion/extension and ulnar/radial planes was about twice as fast as the motion associated with either low and high CTD risk reported by Marras and Schoenmarklin [12]. The upper limb CTD risk assessment they conducted was for an 8-hr work day. RIWs who do not continuously tie rebar with pliers for 8 hrs may not exceed these parameters.

Tying using pliers requires rapid wrist movement in all three planes of motion in combination with hand forces necessary to pull, twist, and cut the wire. Marras and Schoenmarklin [12] did not describe the combined effect of rapid motion in multiple planes and, therefore, the CTD risk levels reported may underestimate actual risk when rapid motions are required in all three planes. The results of the study show that manually tying rebar using pliers exposes workers to risk factors for developing WMSDs of low back and the upper limbs. Use of the power rebar tier significantly reduced workers' exposure to the risk factors for upper limb CTDs.

Observed trunk postures workers used during pliers and PT rebar tying involved 90° of trunk flexion over 90% of the time which exceeded the ISO standard [14] recommendations. The ISO standard recommends that working trunk postures not exceed 60° of forward bending at any time.

Estimated low-back (L5/S1) compressive forces did not exceed the NIOSH recommended spinal compression force (3 400 N) [16] during pliers tying. These forces, however, are exerted on the low back for several hours each day thereby resulting in high cumulative force over many years of activity, which have been reported to increase the risk of developing a low-back disorder [10]. In addition, a recent experimental study has shown that static lumbar flexion, which occurs during extreme trunk flexion, is a risk factor for developing a low-back disorder [17]. RIWs tying rebar placed at ground level may be at increased risk of developing low-back disorders. Using an extension handle with the power rebar tier whenever RIWs tie rebar placed at ground level, (e.g., bridge and freeway deck, concrete slab) reduces workers' exposures to low-back disorder risk factors.

4.2. Tying Using the PT and PTE

Use of the PT resulted in mean hand-activity level scores below the ACGIH™ HAL TLV™. The PTE resulted in the lowest angular velocity and acceleration rate measured, but also in a mean hand-activity level slightly higher than the TLV™. This difference can be explained by the higher perceived effort scores RIWs gave the PTE on the Borg Modified CR-10 questionnaire [7]. Unlike the PT, workers did not have experience using the extension prior to the study. Use of the extension increases the distance of the hand to the tying location, and possibly reduces control of the tool during placement. Perhaps more importantly, positioning and holding the PTE away from the body results in higher forces on the hand, arm, and shoulder due to the associated larger moment. These factors likely increased the perceived effort scores during PTE use and could be addressed with training. There was no significant difference between the wrist movements (i.e., velocity and acceleration) when comparing the use of the PT and PTE.

In a study to evaluate the potential reduction in the risk of WMSDs to RIWs when using the PTE [18], Vi found that RIWs reported subjective scores in the *very good* to *good* range when using the PTE for the categories of level of comfort, hand force, hand/wrist discomfort, shoulder discomfort, ease of use, and productivity. In Vi's study, where the RIWs had prior experience with using the PTE, they expressed a preference for using the PTE over the pliers method.

In the current study, use of the PTE resulted in nearly eliminating forward bending during rebar tying. If workers receive instruction before using the extension handle, i.e., correct adjustment of the handle height and the advantage of tying close to the body, the additional stress on the upper extremities will be reduced.

Although the PT trunk positions were not very different from the pliers trunk positions, it is reasonable to assume there is less loading on the lumbar spine. The PT only requires the use of one hand to tie rebar and all workers were observed using their free hand to support their upper body weight during the majority of the time spent tying with the PT. The use of the hand or arm to support the upper body should reduce the compressive forces in the lumbar spine. Participants appear to have confirmed this when they reported significantly less perceived effort (Borg CR-10) for the low back using the PT than the pliers (2.8 for the PT and 5.8 for the pliers), despite the similar posture.

4.3. Other Activities

Although RIWs perform additional job activities that require "maximum muscle force to lift, push, pull, or carry objects" [19], NIOSH analyzed only rebar tying during this study due to the nature of the request and time constraints. For example, in addition to lifting and carrying rebar, workers must also separate individual rebar from the bundles transported to the immediate work area. Rebar transported in bundles can become intertwined, which makes the separation of individual rebar lengths difficult. Workers were observed separating rebar using sudden (i.e., jerking) muscle forces—often in stooped and asymmetrical postures—to separate individual rebar from the bundles.

4.4. Study Limitations

There are several limitations of this study. The sample size was small consisting of only 8 subjects. However, this was limited to the available workforce at the participating site. The participants' time using the PTE was extremely short, measured in minutes rather than hours. Subsequently, most, if not all, participants had insufficient time to become accustomed to using the extension. The weight of the PTE (3 kg) was significantly heavier than the pliers (0.5 kg) and so the wrist, elbow, and shoulder may be subjected to larger biomechanical loads when the tool is positioned and held away from the body [20]. Effects for other body parts possibly affected, including the neck, were not evaluated. Inexperience using the extension may also explain some participants higher hand–wrist perceived effort ratings.

The study was not conducted in a manner that could determine the real productivity differences among the three tying techniques. Using the PT nearly doubled the number of ties completed during the analysis periods, while the PTE resulted in a slight increase. The observation time, however, was too short to consider possible nonproductive time related to using the PT, such as the potential productivity loss due to changing batteries and PT mechanical failure (e.g., wire jam). Despite this shortcoming, both RIWs and management representatives expressed confidence that the PT increased workers' productivity.

It would be beneficial if future research were conducted to characterize the following aspects of tying reinforcing steel: (a) the types of reinforced concrete construction that would benefit from the use of PTs; (b) the optimal design of an extension handle for power rebar tiers; and (c) RIWs' biomechanical loading, especially to the back and shoulders, during rebar manual material handling.

5. CONCLUSIONS

The preferred method for preventing and controlling WMSDs is to reduce or eliminate exposure to the risk factors. The most effective way to do this is to design jobs, workstations, tools, and other equipment to match the physiological, anatomical, and psychological characteristics and capabilities of the worker [21]. Under these conditions, exposures to task factors considered potentially hazardous will be reduced or eliminated.

Tying rebar using the PT significantly reduced hand and wrist movements that can contribute to upper limb WMSDs. Deep forward bending was still necessary to tie the rebar, but the free arm was used to support the weight of the trunk, most likely reducing forces on the L5/S1 disc.

Tying rebar using the PTE eliminated the sustained deep forward bending required when tying with the pliers and PT. Wrist movement was significantly lower in all three planes of motion using the PTE. Some participants, however, reported hand–wrist effort similar to using the pliers, resulting in a mean HAL score slightly higher than the ACGIH™ HAL TLV™.

Worker productivity, as measured by the number of ties completed, increased when the PT or PTE were used during the study.

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