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Applied Ergonomics 31 (2000) 507–513

APPLIED ERGONOMICS

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A comparison of different postures for scaffold end-frame disassembly

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Received 15 October 1999; accepted 10 February 2000

Abstract

Overexertion and fall injuries comprise the largest category of nonfatal injuries among scaffold workers. This study was conducted to identify the most favourable scaffold end-frame disassembly techniques and evaluate the associated slip potential by measuring whole-body isometric strength capability and required coefficient of friction (RCOF) to reduce the incidence of injury. Forty-six male construction workers were used to study seven typical postures associated with scaffold end-frame disassembly. An analysis of variance (ANOVA) showed that the isometric forces (334.4–676.3 N) resulting from the seven postures were significantly different ($p < 0.05$). Three of the disassembly postures resulted in considerable biomechanical stress to workers. The symmetric front-lift method with hand locations at knuckle height would be the most favourable posture; at least 93% of the male construction worker population could handle the end frame with minimum overexertion risk. The static RCOF value resulting from this posture during the disassembly phase was less than 0.2, thus the likelihood of a slip should be low. Published by Elsevier Science Ltd.

Keywords: Isometric strength; Scaffold; Shear forces; Required coefficient of friction

1. Introduction

Dismantling and erection of frame scaffolds has been identified as one of the most hazardous tasks for the carpenter trade in the construction industry due to overexertion and fall hazards (The National Constructors Association, 1985). It is suspected that safe job performance in scaffold tasks may be compromised by muscular force insufficiency (i.e., lack of muscular strength) due to scaffold design and work procedures. Human strength capabilities vary considerably between people, and strength requirements vary between tasks. When the job strength demands exceeded the demonstrated isometric strength of workers on the job, the mean injury incident and severity rate increased by a ratio of 3 : 1 (Chaffin et al., 1978). In addition, lifting tasks which required workers to lift greater than 50% of their demonstrated maximum isometric strength seemed to create a greater risk for injury (Chaffin et al., 1978).

Posture is one of the major factors that influence muscular strength (Chaffin and Anderson, 1984; Keyserling et al., 1980). Current muscular strength data were mainly collected from the manufacturing industry for tasks which required postures that consisted of hand separations less than 75 cm, and in most cases, less than shoulder width. However, tasks in the scaffolding industry often differ from this paradigm. A welded-tubular scaffold end frame is typically 1.52 m wide by 2 m in height and requires a hand separation of 90–120 cm. There is a definite need for quantitative research of construction workers' muscular strength capabilities associated with scaffold erection and dismantling.

OSHA has promulgated construction scaffold safety standards to ameliorate the incidence of fall injuries during the erection and dismantling of scaffolds (OSHA, 1991). The overexertion and ergonomic implications of handling scaffold end frame have not been well explored. The need for ergonomic analysis of problematic scaffolding tasks is becoming evident. The objectives of this study were twofold. The first objective was to determine if there was a significant difference in muscle strength between the construction population and the general population. The second objective was to determine which scaffold disassembly postures were the most favourable to reduce

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0003-6870/00/$ - see front matter Published by Elsevier Science Ltd.
PII: S0003-6870(00)00016-8

the overexertion hazard of this task, and to evaluate if the slip potential was high for these postures during the initial phase of end-frame disassembly.

2. Methods

2.1. Subjects

Forty-six male subjects who were experienced in scaffold disassembly were recruited from the local construction industry in Morgantown, WV. Their age ranged from 18 to 49 years. The average height and mass of the subjects were 178.7 cm (SD = 5.5 cm) and 92.2 kg (SD = 16.9 kg), respectively (Table 1). Individuals who volunteered for the study were allowed to participate after passing a physical exam administered by a NIOSH physician.

2.2. Apparatus and procedure

A strength-testing apparatus was designed and fabricated at the NIOSH facility in Morgantown for quantification of isometric strength during simulated scaffold end-frame disassembly. This apparatus consisted of a computer-controlled data acquisition system, Bertec force platforms, and a custom fabricated fixture and scaffold end frame (Fig. 1). The data acquisition system sampled six channels of data from each force platform at a sampling frequency of 100 Hz per channel and displayed isometric force with time on the biofeedback screen while the subject performed an isometric exertion (to help subjects maintain a steady-state maximal exertion). The isometric force was calculated in real time by the data acquisition algorithm by adding the real-time vertical forces from each force plate and then subtracting the subject's total body weight (obtained by the force platforms during a static non-lifting trial). The software was configured to determine in real time if each individual exertion, and set of three exertions, met the project's acceptance criterion. The acceptance criterion was defined by the force deviation being less than 10% of the calculated mean isometric force derived from the intermediate 3 s of the exertion (Caldwell et al., 1974). To determine, if the three "successful" isometric exertions were maximal and consistent in each task, the test–retest coefficient of variation (defined as the standard deviation of the test–retest mean values divided by the mean of the test–retest values) should be no greater than 10% (Chaffin et al., 1978).

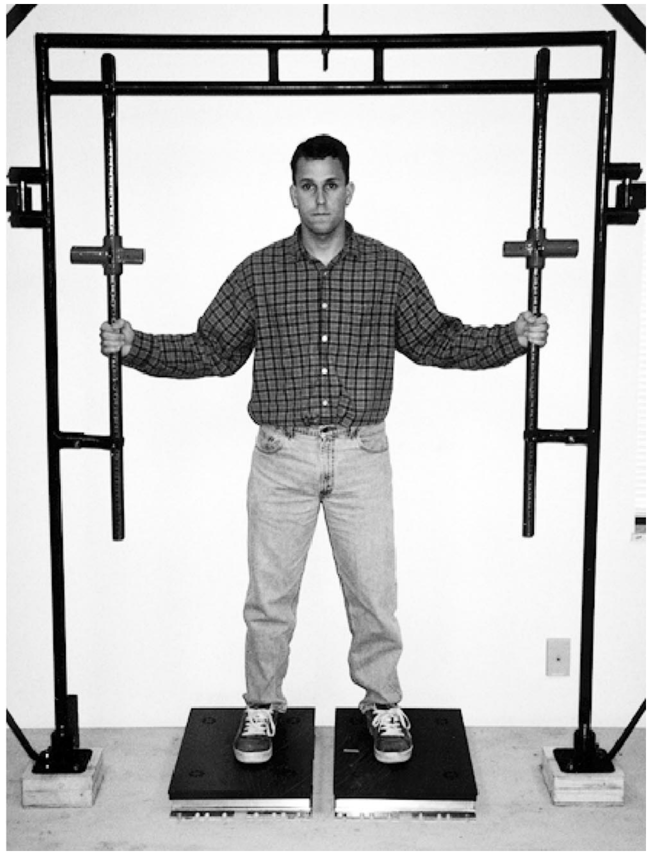

Fig. 1. Isometric strength-testing apparaus.

Table 1
Anthropometric data of the subject population

	Males (N = 46)		
Variable	Mean	Standard deviation	Range
Age (Y)	35.4	8.2	19–49
Height (cm)	178.3	5.3	165.1–190.7
Body mass (kg)	92.2	16.9	65.9–140.0
Acromial height (cm)	147.6	5.2	137.6–160.9
Acromial width (cm)	41.4	2.4	36.0–48.6
Chest height (cm)	131.6	4.7	122.3–141.0
Elbow height (cm)	111.3	4.6	102.6–122.3
Knuckel height (cm)	80.6	4.0	73.4–89.5
Acromium to grip center (cm)	64.8	3.1	57.5–70.9

2.3. Experimental design

The experimental design consisted of two independent experiments. Experiment 1 was a randomized design with four postures (postures 1–4) and three independent observations on each experimental unit (subject). Each of the treatment combinations had seven subjects. Experiment 2 was also a randomized design with three postures (postures 5–7) and three independent observations on each experimental unit (subject). Each of the treatment combinations in experiment 2 had six subjects. Different subjects were randomly assigned to each of the treatment combinations. The seven postures are described in Fig. 2.

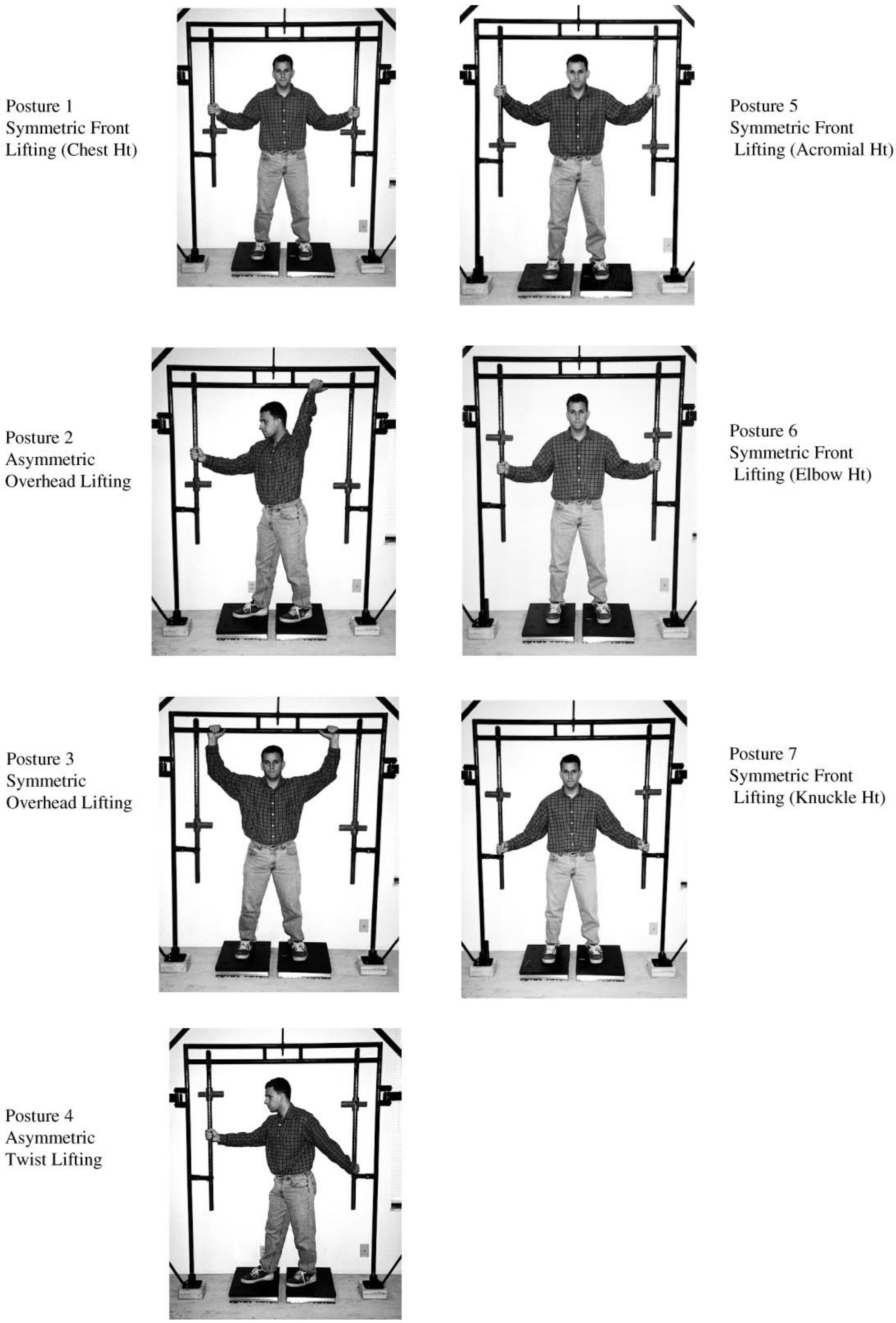

Fig. 2. Scaffold disassembly postures.

Each subject in both the experiments performed three successful isometric exertions in each experiment as well as three successful isometric exertions in a baseline posture (symmetric lift at elbow height, 46 cm hand-separation distance, 90° elbow flexion). Exertions were performed for a duration of 5 s each at 2 min intervals and the subjects were instructed to perform the exertions with the legs straight (no knee flexion). This approach served two purposes: to better assess upper-body strength without the confounding effects of lower-limb muscles. Secondly, to study a worst-case scenario where strength would be assessed without the assistance of lower-limb muscles to determine percentages of strength capables and postures which would allow safe performance of the task to most of the construction population without the use of lower-limb muscles. This strategy was also based on observations of work-sites where workers predominantly used upper-limb muscles during scaffold end-frame disassembly. The postures in which subjects were assigned to tasks was randomized.

The required coefficient of friction (RCOF) was calculated for each disassembly posture based on the vertical force and horizontal shear forces on each force plate during the isometric exertion.

3. Data analysis

Data analyses were preformed by the general linear model (GLM) procedure of the statistical analysis system (SAS, 1991). To estimate the effects of experimental conditions, univariate hierarchieal analyses of variances (ANOVAs) (Winer, 1971) were performed for all three dependent variables: (1) whole-body isometric strength (force), (2) required coefficient of friction 1 (left foot), and (3) required coefficient of friction 2 (right foot). The design had three factors: (1) posture, (2) subject, and (3) trial. Subject was nested under posture and three independent trails were recorded for each subject. Newman–Keuls (Zar, 1996) multiple comparison procedures were performed to investigate pair-wise differences between postures. To investigate the differences between subject groups (that were randomly assigned to different postures), a univariate hierarchieal ANOVA was performed on baseline isometric strength. The groupings for this ANOVA were identical to the ANOVAs described above.

Seven different subjects were randomly assigned to each posture level for postures 1–4 (experiment 1), and six different subjects were randomly assigned to each posture level for postures 5–7 (experiment 2). There were several subjects who participated in both experiments. Therefore, to ensure that samples were independent and uncorrelated, experiments 1 and 2 were analyzed separately.

For each posture level, the estimated percentages of the male construction worker population that have force values greater than 445 N and required coefficients of friction less than 0.5 were calculated (for both coefficients of friction). Percentages were estimated based on 95% one-sided normal distribution tolerance bounds (Hahn and Meeker, 1991). The 445 N value was selected based on the force required to lift a 22.5 kg scaffold end frame (222.5 N) multiplied by a safety index of 2, that is thought to reduce the risk of overexertion injury, since the risk of injury increases as task demands exceed 50% of the maximum isometric strength (Chaffin et al., 1978). Required coefficient of friction values less than 0.5 are generally considered to be safe from slips. To investigate the assumption of normality and homoscedasicity, the standard deviation, skewness, and kurtosis were calculated for all posture levels.

4. Results

ANOVA and multiple comparison results are presented in Table 2. Summary statistics for all dependent variables (given by posture) are presented in Table 3.

4.1. Baseline tests

ANOVA results indicated that no significant differences in baseline isometric strength exist between subject groups for experiment 1 ($p > 0.69$) and 2 ($p > 0.65$). Therefore, no covariance analysis is necessary for the whole-body isometric strength evaluation within the two experiments.

4.2. Interactions

The posture X trial interaction was not significant ($p > 0.16$) for force and required coefficient of friction 1 ($p > 0.26$), but was significant for required coefficient of

Table 2
ANOVA multiple comparison results

	Experiment 1				Experiement 2		
	Posture 3	Posture 4	Posture 2	Posture 1	Posture 5	Posture 6	Posture 7
Population A[a]	A	A	—	—	—	—	—
Population B[a]	—	B	B	B	—	—	—
Population C[a]	—	—	—	—	C	—	—
Population D[a]	—	—	—	—	—	D	D

[a]Similar letters represent similar statistical populations.

Table 3
Summary statistics

Whole body isometric strength	Posture 1	Posture 2	Posture 3	Posture 4	Posture 5	Posture 6	Posture 7
Mean	366.3	466.7	676.3	547.5	334.4	543.7	644.7
SD	91.5	117.6	194.0	136.2	110.4	62.7	71.1
Minimum	212.5	350.3	463.9	341.8	221.9	441.2	540.5
Maximum	543.1	768.6	1088.3	830.7	578.0	628.9	759.8
Skewness	−0.33	1.40	1.16	0.47	1.21	0.05	0.12
Kurtosis	−0.77	1.44	0.45	−0.19	0.39	−1.12	−1.23
Forces above 445 N[ab] (%)	<50	<50	86	63	<50	72	93
Required coefficient of friction 1							
Mean	0.13	0.19	0.13	0.12	0.14	0.12	0.11
SD	0.05	0.10	0.03	0.05	0.04	0.02	0.05
Minimum	0.07	0.08	0.08	0.05	0.09	0.08	0.05
Maximum	0.25	0.43	0.17	0.24	0.24	0.14	0.17
Skewness	0.72	1.29	0.12	0.52	1.37	−0.90	0.12
Kurtosis	−0.49	0.87	−1.11	0.06	1.45	0.03	−1.23
Friction coefficients below 0.50[a,b] (%)	>99	>99	>99	>99	>99	>99	>99
Required coefficient of friction 2							
Mean	0.13	0.14	0.14	0.11	0.13	0.14	0.12
SD	0.03	0.04	0.03	0.03	0.03	0.04	0.05
Minimum	0.09	0.08	0.10	0.03	0.10	0.09	0.04
Maximum	0.22	0.23	0.20	0.16	0.20	0.22	0.21
Skewness	0.90	0.83	0.56	−0.59	1.19	0.77	0.50
Kurtosis	0.00	0.32	−1.12	0.99	0.79	−0.23	−0.80
Friction coefficient below 0.50[a,b] (%)	>99	>99	>99	>99	>99	>99	>99

[a]Values are based on normal distribution one-sided 95% tolerance bounds for population of male construction workers.
[b]Standard deviations were pooled for postures 1–4 and 5–7. Degrees of freedom were 24 for postures 1–4 and 15 for postures 5–7.

friction 2 (in both experiments, $p < 0.05$). Because all the required coefficient of friction 2 measurements were much less than 0.5, the significant posture X trial interaction had no practical importance and was not investigated further.

4.3. Postures

4.3.1. Isometric force for experiment 1

ANOVA results for experiment 1 (Table 2) showed that there was a significant difference in force values between levels ($p < 0.006$). The highest average force of 677 N occurred for posture 3 which was 85% higher than the lowest average force of 336 N that occurred for posture 1 (Table 3). The Newman–Keuls multiple comparison procedure showed that forces were similar between postures 3 and 4 ($p > 0.05$), similar between postures 1, 2, and 4 ($p > 0.05$), and forces under postures 1 and 2 were significantly different from forces under posture 3 ($p < 0.05$) (Table 2).

4.3.2. Isometric force for experiment 2

ANOVA results for experiment 2 indicated that there was a significant difference in force values between posture levels ($p < 0.001$). The highest average force of 645 N occurred for posture 7 which was 93% higher than the lowest average force of 334 N that occurred for posture 5 (Table 3). The Newman–Keuls multiple comparison procedure showed that forces were similar between postures 6 and 7 ($p > 0.05$), and forces under postures 6 and 7 were significantly different from forces under posture 5 ($p < 0.05$) (Table 2).

4.3.3. Force tolerance intervals

Through calculation of one-sided 95% tolerance bounds, the percent of the male construction worker population that have force values above 445 N were estimated for each posture (Table 3). The results showed that at least 86, 63, 72, and 93% of the male construction worker population have force values above 445 N when using postures 3, 4, 6, and 7, respectively. Also, it was found that less than 50% of the male construction worker population have force values above 445 N when using postures 1, 2, and 5 (Table 3).

4.3.4. Required coefficients of friction

For both required coefficient of friction-dependent variables it was found that there was no significant difference between postures ($p > 0.15$). For all postures, it was estimated that at least 99% of the male construction worker population have required coefficient of friction values less than 0.50 (Table 3).

4.3.5. Trials

The ANOVA results showed no significant difference in force values and coefficients of friction between trial times ($p > 0.17$).

4.3.6. Diagnostics

For force measurements at all posture levels, skewness, kurtosis, and standard deviation values ranged from -0.03 to 1.40, -1.23 to 1.44, and 62.7 to 194.0, respectively. For both required coefficient of friction calculations at all posture levels, skewness, kurtosis, and standard deviation values ranged from -0.896 to 1.367, -1.229 to 1.449, and 0.02 to 0.10, respectively (Table 3). Based on these statistics, it was assumed that the deviation from homoscedasicity and/or normality was not severe enough to significantly alter the power and/or significance level of the F tests for all three-dependent variables.

5. Discussion

Whole-body isometric strength values in the baseline posture (457 N mean, Table 3) of the subjects recruited from the construction industry for this study were somewhat higher than those found by Chaffin et al. (1978) in 551 male industrial workers between 20 and 50 years of age (322.6–430.5 N mean). If the study group used in this study is representative of the construction population in the United States, their muscle strength capability is indeed higher than the general population of industrial workers studied by Chaffin et al. (1978).

To reduce the incidence of overexertion injury, Chaffin et al. (1978) recommended that strength should be greater than that required during normal job activities. Also, the maximum lifting strength required by any job should not exceed 50% of maximum isometric strength. Using this paradigm, disassembly postures which resulted in forces exceeding 445 N (based on a 222.5 N scaffold) would be appropriate to use for the disassembly of scaffold end frames. Mean values from postures 3, 4, 6, and 7 resulted in isometric forces in excess of 445 N. The results from the one-sided 95% tolerance bounds calculation indicated that if postures 3, 4, 6, and 7 were used, 86, 63, 72 and 93% the percent of the male construction worker population, respectively, could generate forces in excess of 445 N, assuming the study group was representative of the construction population in the United States. With this in mind, postures 7, 3, and 6 would be the most favourable postures for scaffold workers.

There was a relatively high standard deviation of whole-body isometric strength when posture 3 was employed. Since this exertion was performed with the knees locked, this was representative of the variation in upper-body strength in general, and shoulder strength in particular which is more pronounced when the shoulders are in high angles of abduction. Clearly, repetitive overhead lifting places heavy loads on the shoulders which is particularly conducive to producing acute, chronic, or degenerative tendinitis and rotator cuff pathology (Soderberg, 1996). Postures 7 and 6 would be relatively safe postures for scaffold disassembly; however, the risk of fatigue and injury exists for some individuals (7–28% of the construction population). In addition, because the end-frame center of mass is above shoulder height and the hand locations are low when these postures are assumed, the workers need to be aware of a potential imbalance after the frame is lifted.

A static COF of 0.5 has become commonly accepted as “safe” with values of less than 0.5 becoming increasingly more hazardous (Rosen, 1983). It has been assumed that if the peak RCOF is greater than the COF, a slip will result. The RCOFs measured in this study had a peak value of 0.2. Therefore, with a shoe/scaffold plank COF greater than 0.2, a slip should not result and a worker should be able to perform a safe disassembly of the scaffold end frame. However, one needs to consider the fact that the construction environments are not always contaminant free and, given the variability between testing devices particularly under contaminant conditions (English, 1990), it may not be prudent to assume that the lift can be performed without a slip occurring.

6. Conclusions

Based on the isometric strength data collected in the representative postures, postures 7 and 6 would be the most favourable postures for use in scaffold end-frame disassembly.

However, the likelihood of injury exists for some individuals, even when one of these methods is used, especially if end-frame sections are stuck together which requires a higher disassembly force. Although subjects produced high isometric forces in posture 3, there is a risk of shoulder injury due to repetitive lifting in a overhead lifting posture. Workers also need to be aware of potential postural imbalance after lifting an end frame using posture 7 or 6. Assistive lifting devices may be beneficial in allowing workers to use better-hand placement to reduce postural imbalance and fatigue from repetitive lifting. The slip potential using any of the disassembly postures should be low based on the RCOF findings of approximately 0.2 if the scaffold planks are relatively free of contaminants and properly maintained.

Acknowledgements

The authors wish to acknowledge the efforts of Larry Galloway and James DiPasquale for assistance in the design of the scaffold testing apparatus, Pamela Graydon for recruitment of the subjects and obtaining anthropometric measurements of the study group, Frank Washenitz for assistance in data collection, and Jim Dalton for the fabrication of scaffold frame.

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