

EFFECT OF STEP HEIGHT ON OVERHEAD DRILLING IN CONSTRUCTION

Dan Anton¹, Lee D. Shibley¹, Nathan B. Fethke², Jennifer Hess³,
Thomas M. Cook¹, John Rosecrance¹

¹ Injury Prevention Research Center, The University of Iowa, Iowa City, IA, USA

² Fiskars Inc., Madison, WI, USA

³ Department of Exercise and Movement Science, The University of Oregon, Eugene, OR, USA

Abstract:

The purpose of this study was to determine the effect of moving closer to the work while performing overhead drilling. This task was simulated by twenty subjects while standing on either a lower or a higher step of a stepladder. Shoulder load was estimated by root-mean-square amplitude of electromyographic (EMG) activity and cinematographic analysis to determine shoulder joint moment using static link segment modeling. The results indicated that moving closer to the work surface by moving up a step reduces shoulder joint moment and anterior deltoid EMG. However, biceps brachii EMG increased by moving up a step. There was no significant change noted in EMG median frequencies suggesting that fatigue was not a significant factor. We conclude that while moving up a step reduces the muscular load on some muscles and the shoulder joint, other muscles may work harder. There are also safety considerations regarding moving up a step and alternative methods to move closer to the work surface are suggested.

INTRODUCTION

In the construction trades, it is often necessary to work with the arms in awkward postures such as overhead positions. Awkward postures have been defined as shoulder elevation greater than 60 degrees (National Institute for Occupational Safety and Health [NIOSH], 1997). Additionally, construction workers may be required to use high forces during drilling tasks such as when sheet metal workers drill into concrete ceilings. There is strong evidence that combinations of two or more risk factors, such as force and awkward posture, increase the risk of work-related musculoskeletal disorders (NIOSH, 1997).

Rosecrance, Cook and Zimmermann (1996) reported that 41% of a sample of construction workers in the pipe trades complained of work-related shoulder pain, with tasks performed at differing postures including directly overhead. Several investigators have noted that repeated work in overhead postures may lead to such disorders as rotator cuff tendonitis and shoulder myalgia

(Hagberg & Wegman, 1987; Sakakibara, Miyao, Kondo, & Yamada, 1995). Localized fatigue is also possible from these postures (Kadefors, Petersén, & Herberts, 1976; Malmqvist et al., 1981). Since stepladders are often used in the construction trades, workers frequently move up a step in order to enhance their position. In fact, ergonomists provide the advice, "move closer to the work," in an attempt to minimize overhead work loads.

Although moving up a step seems intuitive, there is little objective evidence that positioning oneself closer to a task reduces shoulder load. The purpose of this study was to quantify the change in shoulder and upper arm load with overhead drilling by moving up a step on a stepladder.

METHODS

Twenty healthy volunteers, without a history of shoulder disorders, participated in this study. Subjects were randomized to stand on one of the lower two steps of an eight foot type IA stepladder, and simulate drilling directly overhead into a

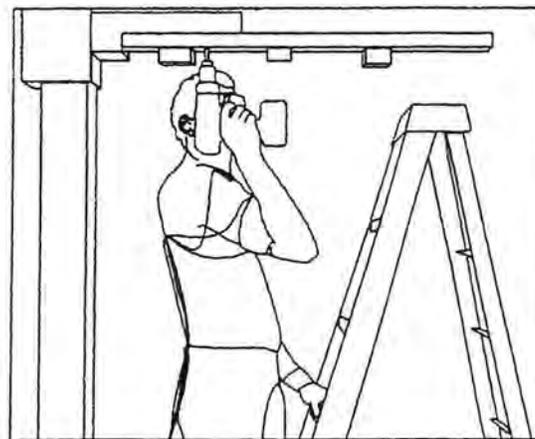
horizontal beam. The beam, which was adjustable up and down according to the subject's reach, had a vertical hole drilled in it that was plumb with the lowest stepladder step to ensure a directly vertical drilling position. A 2.27 kilogram portable drill was fit with a spring loaded bit. When the bit was placed in the vertical hole, an indicator light was triggered when a compression force of 22.3 N was attained.

Myoelectric activity of the right biceps brachii, triceps brachii, and anterior deltoid was recorded using bipolar silver-silver chloride surface electrodes with on-site preamplification. Raw EMG signal was sampled at a rate of 1024 Hz for two seconds. The root-mean-square amplitude (AMP), with an averaging time constant of 50 ms, and median frequency (MDF) from spectral analysis were calculated using a microcomputer data collection system. EMG amplitudes were normalized to the AMP obtained when subjects stood on the lower step prior to the trials.

Shoulder flexion moments were calculated from cinematographic analysis of each trial using a static coplanar link segment analysis of the shoulder, elbow, and wrist joints in the sagittal plane.

Subjects simulated overhead drilling into the three holes while standing on the first and second steps of the ladder (Figure 1). Subjects were instructed to minimize trunk rotation during the experimental procedure. The right arm of each subject served as the test arm. An investigator positioned the drill so the bit entered the hole in the beam. The subjects grasped the drill handle with their right hand and pressed upward until the preset spring tension was achieved. Subjects maintained this position for four seconds with EMG sampling occurring during the middle two seconds. The subjects repeated the same activity for two trials with two-minute rests between trials. Sagittal plane motion was maintained throughout testing.

Statistical analysis included paired t-tests to test for differences between the first and last MDF during the normalization trials. Paired t-tests were also used to determine significant changes in AMP and moment due to the ladder step position variable. An alpha level of .05 was used as the significance level of all analyses.



High Step



Low Step

Figure 1. Posture of the overhead drilling task while standing on the lower and higher step of a stepladder.

RESULTS

The 20 subjects in this study had a mean age of 31 years (SD 8.1) with a range of 22 to 44 years. The subjects' mean height was 173 cm (SD 11.7) and their mean weight was 76 kg (SD 15.5).

The data in Table 1 indicates that moving up a step had the effect of significantly reducing anterior deltoid AMP. Triceps brachii AMP and shoulder joint moment reductions were also noted. In contrast, biceps AMP significantly increased by moving up a step.

Table 1. Mean % normalized RMS amplitudes and shoulder joint moment (Nm) by step ($t = t$ value; SE = standard error).

	Step Height				t
	Low		High		
	Mean	SE	Mean	SE	
Anterior Deltoid EMG	98.91	3.17	30.18	2.41	19.86*
Biceps Brachii EMG	112.98	12.61	379.07	49.82	-5.69*
Triceps Brachii EMG	102.67	4.41	22.93	2.11	16.12*
Shoulder Joint Moment	13.07	0.493	7.03	0.420	20.89*

* $p < 0.0001$

There was no significant difference noted between the first and the last MDF values suggesting that fatigue was not a factor in this study. The t value for the anterior deltoid was -0.20 ($p = 0.8448$), for the biceps brachii was 0.93 ($p = 0.3636$), and for the triceps brachii was -0.65 (0.5223).

DISCUSSION

Fatigue was minimized during this study since all subjects were able to maintain the appropriate force on the spring during each trial. Additionally, there was no significant reduction in MDF from the first to the last trial.

The results of this study indicate that moving up a step during overhead work has the effect of decreasing the load on some muscles while increasing the load on others. Moving up one step on the ladder had the effect of reducing shoulder joint moment 46%, deltoid AMP by 70%, and triceps AMP by 78%. If construction workers use hand tools from a lower step position, muscular load significantly increases and there is potential for causing fatigue or acute strain. If it can be assumed that muscular fatigue is one etiological factor in cumulative trauma disorders, minimizing the vertical reach while using a hand tool is one method of limiting work-related musculoskeletal disorders of the shoulder.

However, biceps AMP increased 235% by moving up a step. It is possible that the constrained posture of the arm while on the second step elicited greater biceps EMG activity. The length-tension relationship of the biceps suggests that there is less ability to generate tension at the extremes of elbow

flexion, such as occurs at the close position. The constrained position of the upper arm may have required greater biceps myoelectric activity to maintain the close posture. On the lower step, the biceps is maintained in a better force generating position since the elbow is flexed around 90 degrees. Thus, although some muscles experience a reduction in loads, others increase their loads. As a consequence, a closer reach while on a higher step may qualify as an "awkward posture" for some muscles even when shoulder flexion is less than 60 degrees.

Regardless, working from the higher step decreased the shoulder flexion angle from an average of 77 degrees to 17 degrees. Since repeated shoulder elevation between 60 and 120 degrees has the potential for creating impingement, it may be beneficial for workers to limit the use of their shoulder in these ranges (Flatow et al., 1994). Moving closer to overhead work in a vertical direction may be a practical method of avoiding rotator cuff or other shoulder disorders.

However, moving up a step or attempting a closer reach while in confined spaces may increase the chance of a fall from the ladder. In the United States, 20% of all construction related disabling falls occur from ladders (Bureau of Labor Statistics, 1993). Although moving up a step on the ladder may reduce the reach and minimize some physical requirements, the raised height of the worker's center of gravity increases the potential that it will fall outside of the ladder's base of support. If the worker is using a drill, the close proximity of the drill bit to the worker's face while on a higher step presents other safety hazards. Reaching sideways on a higher step of a stepladder can also precariously

shift the center of gravity and falls due to this activity are common in industrial settings (Björnstig & Johnsson, 1992). Standing on the top rung of a ladder was found to be another factor in causing falls, often because the ladder was not high enough thus causing an excessive reach. Since falls from ladders account for a significant amount of lost work time in the construction trades, it is important to develop safer work habits when working on ladders (National Safety Council, 1999). The use of an elevated platform or lift at the construction site is one practical solution to reduce the risk of shoulder injury while still maintaining a safe work site.

In conclusion, the findings of this study reinforce that moving closer to the task decreases the load on the shoulder and may decrease the risk of injury. However, shoulder flexion less than 60 degrees is awkward for certain muscles such as the biceps brachii. Constrained postures at lower shoulder elevation could be harmful to such muscles. Also, safety issues exist that make moving closer to the task unfavorable in some circumstances. A universal, optimal position for reducing the load on the shoulder while maintaining safety has yet to be determined for overhead work.

ACKNOWLEDGEMENTS

This project was supported by the National Institute for Occupational Safety and Health cooperative agreement with The Center to Protect Worker's Rights, Washington, DC, USA.

REFERENCES

- Björnstig, U., & Johnsson, J. (1992). Ladder injuries: Mechanisms, injuries, and consequences. *Journal of Safety Research*, *23*, 9-18.
- Bureau of Labor Statistics (BLS). (1993). *Survey of Occupational Injuries and Illnesses*. U.S. Department of Labor.
- Flatow, E.L., Soslowsky, L.J., Ticker, J.B., Pawluk, R.J., Hepler, M., Ark, J., Mow, V.C., & Bigliani, L.U. (1994). Excursion of the rotator cuff under the acromion. Patterns of subacromial contact. *American Journal of Sports Medicine*, *22*, 779-788.
- Hagberg, M., & Wegman, D.H. (1987). Prevalence rates and odds ratios of shoulder-neck diseases in different occupational groups. *British Journal of Industrial Medicine*, *44*, 602-610.
- Kadefors, R., Petersén, I., & Herberts, P. (1976). Muscular reaction to welding work: An electromyographic investigation. *Ergonomics*, *19*, 543-558.
- Malmqvist, R., Ekholm, I., Lindström, L., Petersén, I., Örtengren, R., Bjurö, T., Herberts, P., & Kadefors, R. (1981). Measurement of localized muscle fatigue in building work. *Ergonomics*, *24*, 695-709.
- National Safety Council. (1999). *Injury Facts, 1999 Edition*. Itasca, IL: Author.
- National Institute for Occupational Safety and Health (NIOSH). (1997). *Musculoskeletal disorders and workplace factors: A critical review of epidemiologic evidence for work-related musculoskeletal disorders of the neck, upper extremity, and low back*. (DHHS Publication No. 97-141). Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention.
- Rosecrance, J., Cook, T.M., & Zimmermann, C.L. (1996). Work-related musculoskeletal disorders among construction workers in the pipe trades. *Work*, *7*, 13-20.
- Sakakibara, H., Miyao, M., Kondo, T-A., & Yamada, S. (1995). Overhead work and shoulder-neck pain in orchard farmers harvesting pears and apples. *Ergonomics*, *38*, 700-706.



PROCEEDINGS OF THE
XIVth Triennial Congress of the
International Ergonomics Association
and
44th Annual Meeting of the
Human Factors and Ergonomics Society
"Ergonomics for the New Millennium"

July 29 through August 4, 2000
San Diego, California, USA

Volume 5
Manual Work



Published by the
Human Factors and Ergonomics Society
P.O. Box 1369
Santa Monica, CA 90406-1369 USA
310/394-1811, FAX 310/394-2410
E-mail: info@hfes.org Web: <http://hfes.org>

AF Research
Laboratory Library

PREFACE

In publishing the *Proceedings of the XIVth Triennial Congress of the International Ergonomics Association and 44th Annual Meeting of the Human Factors and Ergonomics Society*, the Human Factors and Ergonomics Society seeks to facilitate an effective and timely dissemination of technical information within its area of concern. The papers contained in this document were printed directly from unedited reproducible copy submitted by the authors, who are solely responsible for their contents.

ISBN 0-945289-13-8

Opinions expressed in proceedings articles are those of the authors and do not necessarily reflect those of the International Ergonomics Association or the Human Factors and Ergonomics Society, nor should they be considered as expressions of official policy by either organization.

Copyright © 2000 by Human Factors and Ergonomics Society. All rights reserved.

Individual readers of these proceedings and nonprofit libraries acting for them are freely permitted to make fair use of the material in the book, such as to make a single copy of an article for use in teaching or research. Permission is granted to quote excerpts from articles in these proceedings in scientific works with the customary acknowledgment of the source, including the author's name and the proceedings name, year, volume, and page. Reproduction of figures and tables is likewise permitted in other articles and books, provided that the same information is printed with them and notification is given to the Human Factors and Ergonomics Society.

Reproduction or systematic or multiple reproduction of any material in these proceedings (including abstracts) is permitted only under license from the Human Factors and Ergonomics Society. In addition, the Society requires that permission be obtained from one of the authors. Address inquiries and notices to the Communications Director, Human Factors and Ergonomics Society, at the address below.

In the case of authors who are employees of the United States government or its contractors or grantees, or of the British Crown, the Human Factors and Ergonomics Society recognizes the right of these governments to retain a nonexclusive, royalty-free license to use the author's copyrighted material for government purposes.



Human Factors and Ergonomics Society
P.O. Box 1369
Santa Monica, CA 90406-1369 USA
310/394-1811, fax 310/394-2410
info@hfes.org
http://hfes.org

Authorization to make a single photocopy of any item in this book for commercial use is granted by the Human Factors and Ergonomics Society, provided that the base fee of \$1.00 plus \$.60 per page is paid directly to Copyright Clearance Center, 27 Congress St., Salem, MA 01970. The fee code for users of the Transactional Reporting Service is 01711813/00 \$1.00 + \$.60.

The HFES annual meeting proceedings are indexed or abstracted in the following publications or services: Applied Mechanics Reviews, Engineering Index Annual, EI Monthly, Cambridge Scientific Abstracts, EI Bioengineering Abstracts, EI Energy Abstracts, EMBASE/Excerpta Medica, Ergonomics Abstracts, ISI Index to Scientific & Technical Proceedings, Transportation Research Information Services (TRIS), and International Aerospace Abstracts. This publication is also available on microfilm from Bell & Howell, 300 N. Zeeb Road, Department P.R., Ann Arbor, MI 48106.

The paper used in this publication meets the minimum requirements of the American National Standard for Information Sciences—Permanence of Paper for Printed Library Materials, ANSI Z39.48-1984.

HFES Annual Meeting Proceedings ISSN 1071-1813