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An Evaluation of Tool Design and Method of Use of Railroad Leverage Tools on Back Stress and Tool Performance

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The effects of railroad claw bar design factors and method of use upon performance and back stress were investigated. Novice and experienced subjects were tested for their ability to use the claw bar to remove track spikes. Two standard claw bar designs were evaluated. The method of tool use was described by body position relative to the claw bar and by body action.

Tool design had no significant effect on either tool-lifting performance or back-stress measures. Body action patterns, but not body position, were found to have significant effects on both performance and back stress. Results support the use of a body action involving the use of the arms only. This method provides the required impulse forces with minimum back stress and also provides proper balance to avoid falls from sudden spike removal.

Proper technique, as opposed to total force application, was found to be the key factor in tool use. Novices attempt to apply a large, sustained force using the whole body, whereas experienced trackmen use a snapping action to generate the required forces. Trackmen generated 50% more lifting force than did the novices.

INTRODUCTION

Leverage tools are common to many occupations involving physical work, such as mining, railroads, heavy machinery maintenance, auto repair, and even gardening. Typical leverage tools found in the rail industry are prybars, wrenches, claw bars, ballast forks, shovels, jacks, lining bars, and "come alongs," which are designed to amplify human forces. Poor design of these tools or improper methods of use can lead to accidents, progressive trauma, and general ineffectiveness of tool use. Injuries can be of three types: (1) slips and falls associated with tool slippage, postural instability, and poor force control; (2) sudden damage to muscles in the back, arms, and shoulders from overexertion; and (3) repetitive trauma due to long-term wear on the human system. Repetitive trauma results from long-term use of the tool and involves progressive damage to muscle ligaments and other soft tissue due to repeated use of improper methods.

Casualty data from the Federal Railroad

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Administration (FRA) showed that for the period 1975 to 1980 (McMahan, 1980), there were 3000 on-the-job injuries annually due to the use of hand tools. Nonpowered hand tools are present in approximately 5% of all injuries reported to the FRA and each year account for more than 20 000 days lost and $28 000 000 in claims. Of these hand-tool injuries, the largest portion (42%) was reported by trackmen. The largest portion of tool injuries (27%) involved torso sprains and strains from overexertion while using hand tools. Such injuries are common to leverage tools.

The railroad environment represents a labor-intensive industry that relies heavily upon the use of hand tools, particularly in track maintenance. Most leverage track tools are nonpowered tools that require the user to exert significant forces upon a tool at a point that is often a considerable distance from the midline of the body. This may cause significant moments to be imposed upon the trunk of the user; however, no evaluations of the magnitude of these moments have been reported.

In interviews, 21 railroad safety officers were asked which track tools they considered to be the most critical in hand-tool injuries. The safety officers believed that the claw bar and spike maul were the two worst tools in terms of injuries and accidents to trackmen. Data from one railroad over a 12-month period revealed claw bars as the tool with the highest (21%) injury frequency (Rockwell, 1982). Together, striking tools (e.g., spike maul) and leverage tools (e.g., claw bar) characterize most track hand tools. This paper focuses on leverage tools, specifically the claw bar. In a companion study to this research, we have described the results of a study of spike mauls (Marras and Rockwell, 1986, this issue).

The claw bar, found in track maintenance, is used both for removing spikes and, with its opposite end, as a leverage bar to lift objects, particularly tie plates and track ties during spiking operations. The bar is 150.2 cm long, weights 12.3 to 13.6 kg, and is used by a single operator. The heel of the bar (see Figure 1), at the forked end, provides the mechanical advantage for spike removal. Downward thrusts of the bar result in some 18 500 kg of lifting force. The bend in the bar at the opposite end of the heel serves to warn users to keep their hands off of this part of the bar, as spike removal on the inside of the rail can cause pinching of the hands at this point on the opposite rail.

In general, the most serious problem in spike removal is one that involves a spike that resists removal and thereby encourages significant exertions by the user. When the spike subsequently comes loose rapidly, the claw bar user often loses balance and falls on the track bed.

Use of the claw bar in spike removal by trackmen from Conrail, Chessie, and Sea-

Figure 1. *Use of the claw bar.*

board Systems railroads was videotaped during track repair. Their methods were categorized in terms of body action pattern and body position. Two body action patterns for producing forces on the bar were recorded: the use of the arms with minimum back involvement and the use of both back and arms. The latter often involves the whole body. When using this method, the trackman's heels are frequently lifted from the ground. Such a body action pattern invites falls when spikes are removed suddenly. The body position noted involved the shoulders either parallel to the bar or angled. Thus, four methods were observed (see Figure 2). Many railroads recommend the shoulders-parallel/arms-only (parallel/arms) method to minimize falls.

Twenty-eight trackmen used the claw bar under controlled conditions in a rail maintenance yard. Video recordings were taken with the subject against a reference background. These tapes were then analyzed using an IBM PC and a sonic digitizer. From the tapes, researchers were able to produce stick figures representing the changes in body positions over time during the cycle of claw bar use (see Figure 3). This study provided quantitative evidence for the method classification presented previously and provided biomechanical documentation of critical limb angles over time.

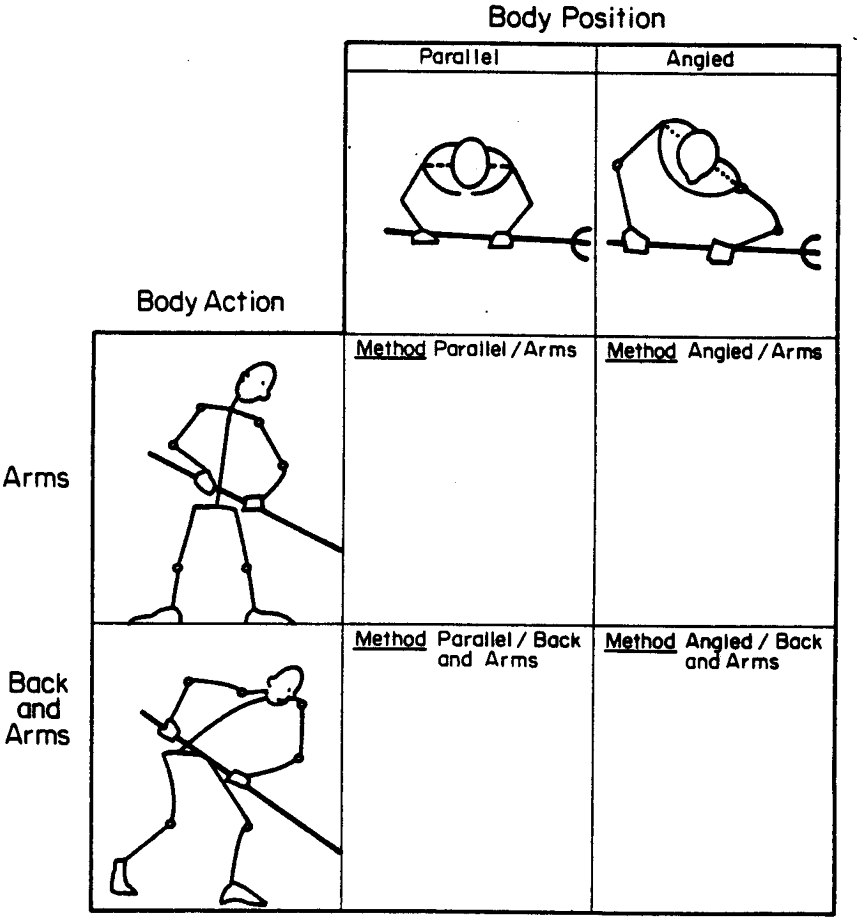
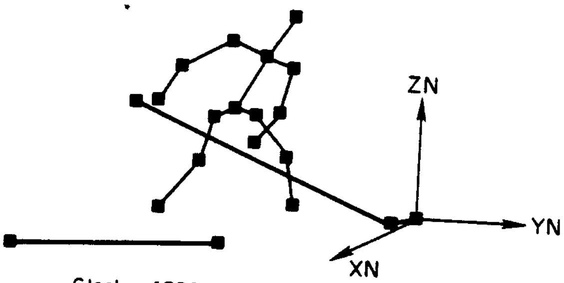


Figure 2. *Depiction of claw bar use methods as a function of body position and body action.*



Clock = 45022 Sequence = 3

Index No.	Description	Angle (Deg)
1	Right Elbow	153
2	Left Elbow	157
3	Right Shoulder	120
4	Left Shoulder	102
5	Clawbar	30

Figure 3. *The digitized representation of body position derived from video analysis in a trackyard.*

We hypothesized that claw design would influence the use of the tool. In particular, we thought that the angle of the claw bar to horizontal at the outset of spike removal might determine the mechanical advantage, and thus necessary force requirements. This angle is determined by heel design. Two claw bars of different heel design are found in use today. Older bars produce an angle of aproximately 66 deg, whereas current designs produce a bar angle of approximately 44 deg. We also hypothesized that the greater the forces applied on the bar, the greater would be the lifting forces at the spike.

Objectives

The basic research question was whether claw bar design (tool angle) and method of use affect tool performance and loads imposed on the back. In another paper in this issue (Marras and Rockwell, 1986) we describe a noninvasive method to evaluate compression, shear, and torsion forces acting on the spine as a function of striking tools. In this study, we used the same methodology to evaluate relative spine forces due to the use of the claw bar.

METHOD

Subjects

Forty male subjects volunteered for participation in this study. Of the 40 subjects, 28 were professional trackmen and 12 were novice subjects who had no track tool experience. Subjects' ages ranged from 18 to 55 years. The mean age of the trackmen was 32 years, whereas the mean age of the novice subjects was 22 years. All subjects were in good health at the time of the testing. The subjects were of varied gross anthropometry. Anthropometric measures were collected on all subjects. Measures of static and dynamic back strength were collected using a Cybex dynamometer.

Apparatus

The configuration of the experimental apparatus is the same as reported in the spike maul study (Marras and Rockwell, 1986, this issue) except that load cell forces measured spike tension forces rather than compression of the spike. Two measurement systems were employed: one to measure the *x*, *y*, and *z* forces of the tool acting on the spike (see force illustration in Figure 3), and the second to estimate spine forces through the use of back muscle electromyography (EMG). These systems are described in detail in the paper in this issue dealing with the spike maul (Marras and Rockwell, 1986).

Procedure

The experimental procedure for the claw bar study mirrored that employed in the spike maul study. The task involved applying a downward force on the claw bar so that a spike could be pried upward with the claw end of the tool. Trackmen were instructed to use the claw bar as they normally would in the field when faced with a resistant spike. Since, experimentally, the spike could not be allowed to be pulled out from the load cell, the users knew the spike would not suddenly come out. This encouraged more lunging and unstable postures for those using back and arm motion patterns, which might suggest greater downward forces and hence greater tool lifting forces for this method. As will be seen later in the results, such lunging methods did not produce significantly greater lifting forces than the use of the arms only.

Initially, subjects were provided background information about the nature of the experiment, its purpose, and the risks associated with participation. Health history and anthropometric data on the subjects were collected. The anthropometric data concerned the lengths and circumferences of the arms, legs, and torso as well as the gross anthropometric measures of stature and weight. Subjects were then questioned about their backgrounds. These questions involved present and past work history, injury history, and experience, as well as repetitive and traumatic disorders that may have developed due to their work.

All subjects were permitted a warm-up period, which allowed them to become familiar with the use of the claw bar. Once the subjects were comfortable and proficient with the task, they were allowed to rest while they were fitted with EMG surface electrodes and preamplifiers using the same procedure reported in the spike maul study. The electrode site was prepared according to standard procedures, and the electrode location was functionally verified via trunk exertion monitored with an oscilloscope.

When the subjects were fully instrumented, a pretest was performed. This pre-

TABLE 1

Summary of Significance Levels for Experimental Factors

Dependent Measures	*Group Significance*		
	Experienced Subjects	*Novice Subjects*	*Experienced-Novice Differences*
Tool performance			
yn forces	BA(0.04), M(0.01)		
zn forces			
Total force (CLWF)			(0.001)
Back stress			(0.001)
Compression index	BA(0.01) M(0.07)	M(0.008) BA(0.002)	
Shear index		M(0.001) BA(0.001)	
Torsion index	M(0.07) BA(0.01)		
Combined Stress Index		M(0.003) BA(0.001)	
Efficiency index			
EFFCLWF (CLWF/combined stress)		M(0.03) BA(0.003)	(0.05)

Note: Only significant levels $p < 0.10$ are reported.
BP = body position (angle vs. parallel)
BA = body action (arms vs. back and arms)
M = method (4 combinations of BP and BA)
See Figures 3 to 9 for mean estimates

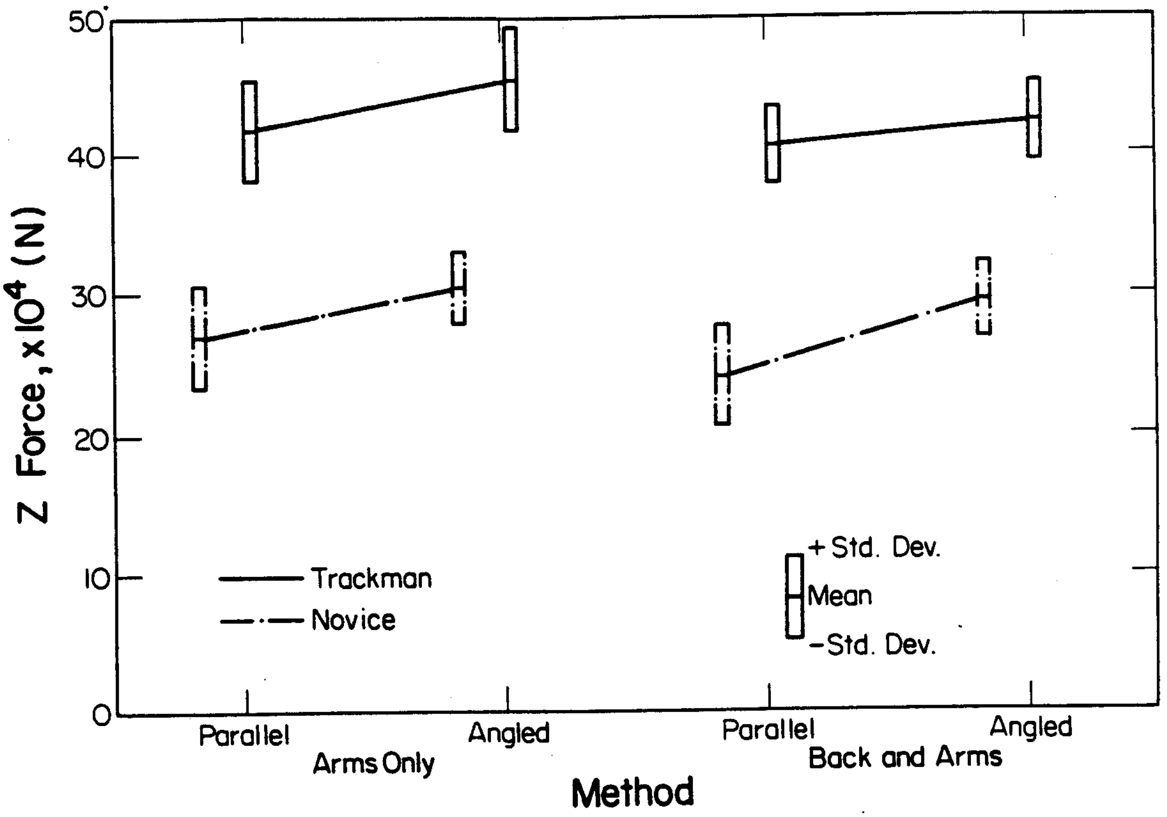


Figure 4. *Vertical lift force, Z, as a function of method and experience.*

test recorded the EMG maximum and minimum muscle activity for comparison purposes. This was necessary because EMG recordings are only comparable between subjects if they are normalized. This pretest evaluated the maximum activity of the muscles under both controlled isometric and isokinetic conditions.

After the pretest, the main experiments began. Subjects were asked to stand on the experimental platform, which housed the spike load cell, ballast, and railroad ties, and perform the experimental task. For each subject, the task consisted of lifting the experimental spike with two different claw bars and two methods: the subject's preferred body action pattern (use of back or use of back and arms) with two body positions (parallel and angled).

After the the experiment, subjects were debriefed and questioned regarding their impressions and preferences of the tools they had used.

Experimental Design

The independent variables in this experiment consisted of (1) horizontal tool angle (tool inserted into spike before activation)—two levels, 66 deg and 44 deg; and (2) method (M)—a variable described by the body action pattern and body position (see Figure 2).

Subject body action and experience were blocking variables in this experiment. Experience refers to novice subjects versus experienced trackmen.

Although all subjects used both claw bars, each subject used his preferred method without any coaching. He was then in-

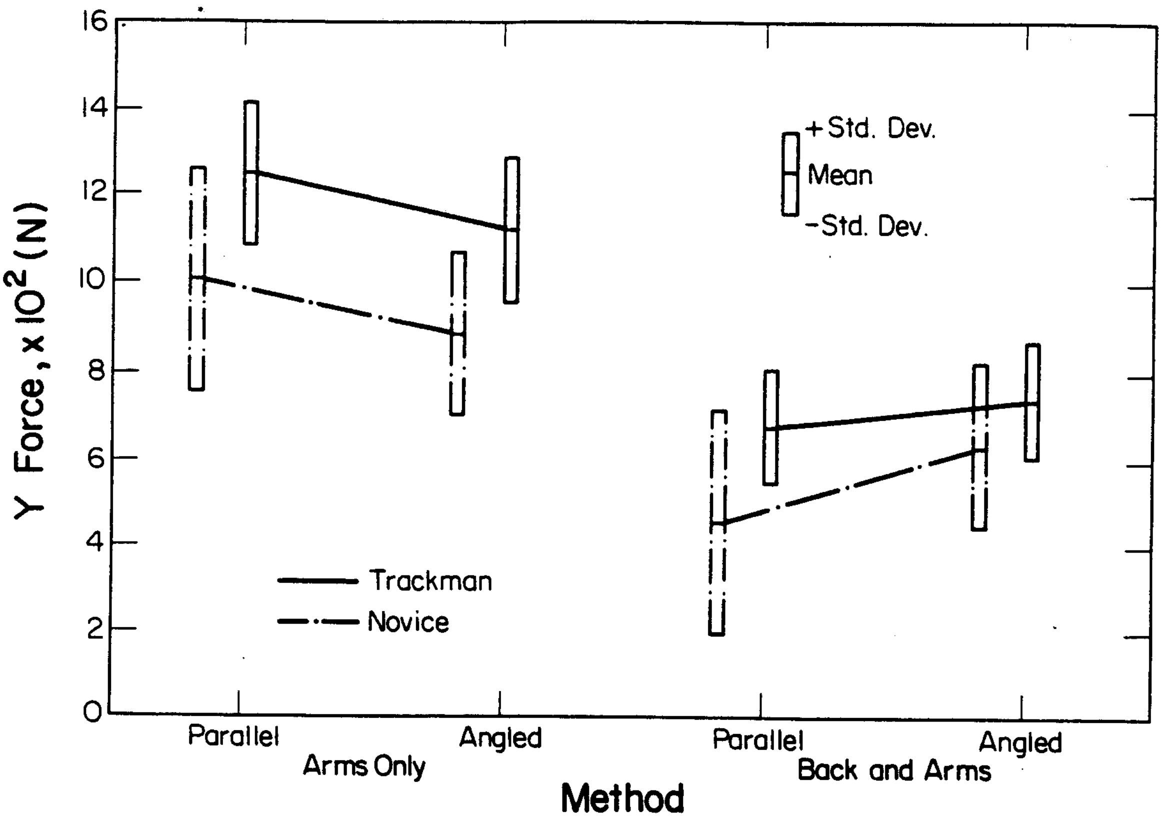


Figure 5. *Transverse force as a function of method and experience.*

structed to change his body position from parallel to angled or vice versa but not to change his body action pattern. It was believed that changing action patterns would entail considerable learning and would therefore contaminate experimental results.

The dependent measures were:

(1) *Tool performance*—peak spike forces in Newtons in the x, y, and z plane (xn, yn, and zn) (see Figure 3) and a total force combination:

$$\text{CLWF} = \sqrt{(\text{xn})^2 + (\text{yn})^2 + (\text{zn})^2} \qquad (1)$$

(2) *Back stress*—integrated EMG activity of the right and left latissimus dorsi and right and left erector spinae muscles. From these EMG activities several dependent measures were derived: compression, shear, and torsion indices and a combined stress (sum of compression, shear, and torsion indices). The use of EMG to develop these indices is discussed by Marras and Rockwell (1986, this issue)

(3) *Efficiency measures* (CLWF/combined stress). This variable related to the efficiency of the method in producing tool forces with minimum back loadings.

RESULTS

Tool Design Effects

Using a two-factor, two-level analysis of variance, the dependent measures (tool performance, back stress, and efficiency) indicated no statistically significant effect of tool design ($p < 0.10$) except for xn, the force orthogonal to the plane of the bar. Unlike yn, which is a force parallel to the bar, the xn force does not contribute to the lifting of the spike. A lower tool angle, by virtue of the heel design, produces greater twisting effects but no differences in the other force planes. The higher-angled tool has been phased out of use

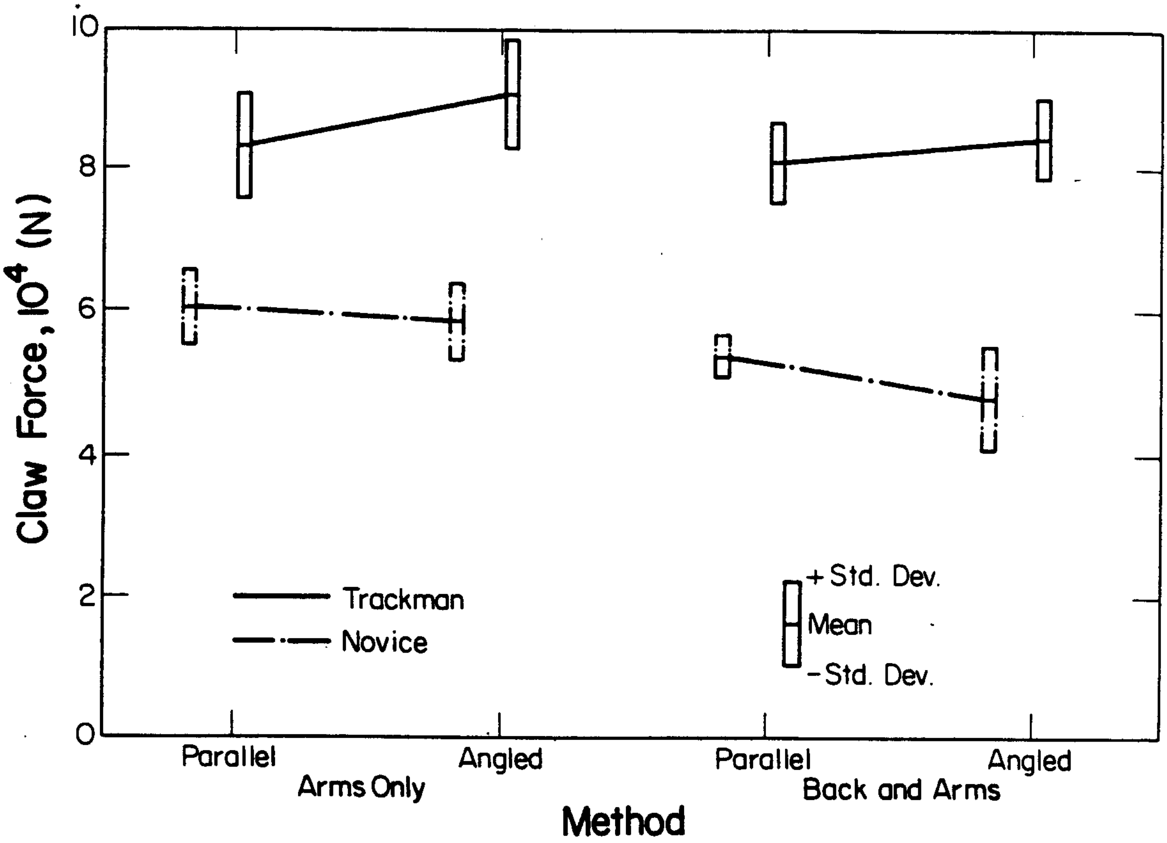


Figure 6. *Total claw force as a function of method and experience.*

by most railroads. It is interesting to note that the high angle discourages back usage, as the bar is chest-high with the spike inserted.

Correlations among Anthropometric Back Strength, Tool Performance, and Back-Stress Variations

Anthropometric and back-strength measures were cross-correlated with tool performance and back-stress measures. Only significant correlations ($p < 0.10$) were noted. Dynamic back-strength measures were positively correlated with lifting forces for novice users, but not for experienced users. Static back-strength measures were not correlated with tool performance for either user group. No anthropometric variables were correlated with lifting forces for either group. These results suggest that brute force is secondary to technique in producing lifting forces for trackmen.

Method, Position, and Body Action Effects

Table 1 depicts the summary of method (position and body action) effects on tool performance, back stress indices, and efficiency as well as differences between experienced subjects and novices. Note that body position (BP) has no statistically significant effect on any performance measures. Body action (BA) and method (M) (because it is derived from body action) both show some effects. As noted in Figures 4, 5, and 6, *zn*, *yn* and CLWF show little difference in tool performance as a function of method except for a significant difference in the case of *yn* (Figure 5).

The nature of the significant effects for the

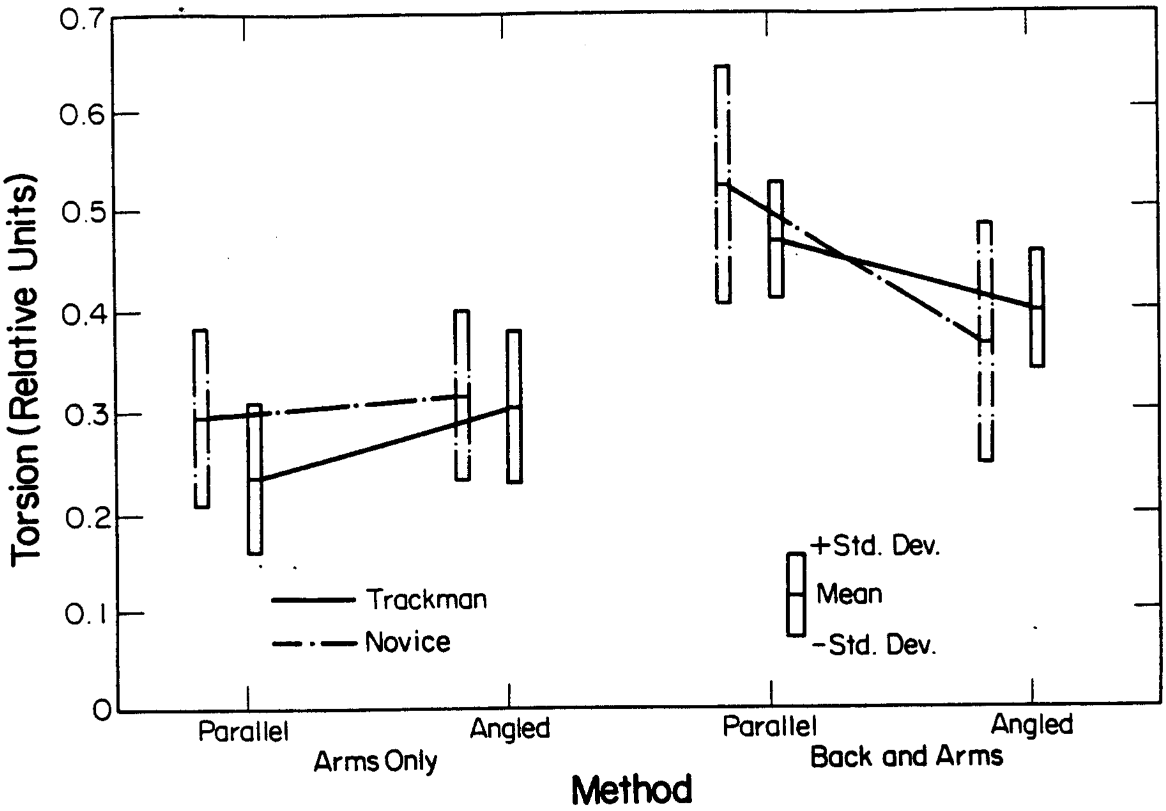


Figure 7. *Torsion index as a function of method and experience.*

back-stress indices are shown in Figures 7, 8, and 9. Novice users are more sensitive to method. They show significant effects in compression, shear, and combined stress indices. Novices show higher shear indices for arm-only use, and significantly higher compression and combined stress indices for back and arm use. Torsion and compression effects are noted for method and body action for trackmen, with higher indices for back and arm action. Torsion effects might be expected from trackmen because of their tendency to use a jerking, twisting motion, especially when using the back and arms.

With regard to compression indices, novices and trackmen show different patterns with respect to body action (see Figure 9). Novices show greater compression values for back and arm use than for arms only, whereas the opposite is true for trackmen. This might be the result of trackworker technique effects.

For the efficiency measure EFFCLWF, novices show a significant body action and method effect (see Figure 10) with arm use providing higher efficiencies. With few exceptions (e.g., shear forces in novice users and the compression index for trackmen), the use of arms only is equal to or superior to use of back and arms in terms of developing lifting forces, minimizing back stress, and providing higher efficiencies. In terms of a single method, parallel/arms is slightly superior to angled/arms in terms of less torsion, higher *yn*, less shear, and less combined stress. This is an important finding because of the stable nature of this method, which results in fewer falling accidents. This conclu-

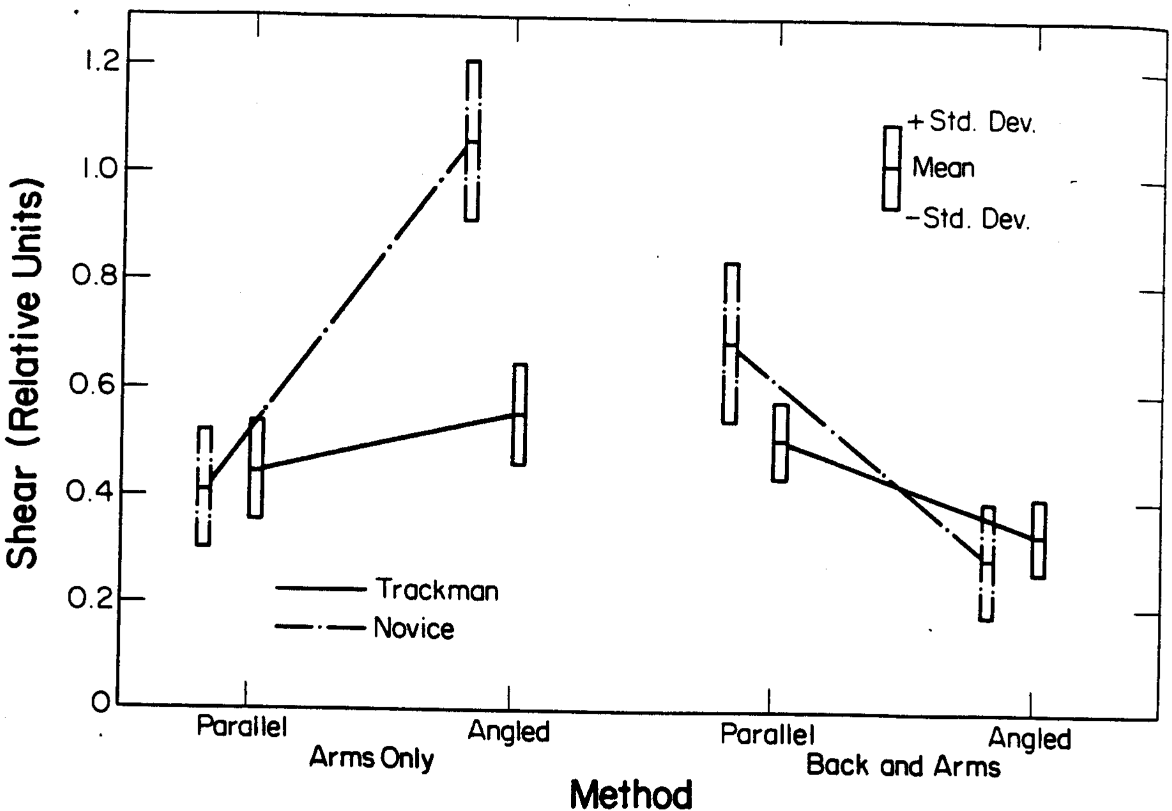


Figure 8. *Shear index as a function of method and experience.*

sion, because it holds for novice users as well as experienced users, offers potential for improved training of new trackmen.

DISCUSSION

Differences between Experienced and Novice Claw Bar Users

It would seem that young, "in shape" college students ought to perform as well as experienced trackmen for a simple leverage task that requires a force on one end of a fulcrum. And yet, spike vertical lifting force, *zn*, shows dramatic differences between novices and experienced claw bar users, with trackmen producing about 50% greater lifting forces (see Figure 4). Total bar forces generated, CLWF, also show dramatic differences between the two groups (see Figure 6). These greater outputs by the trackmen can be explained both by their technique and by the way the lifting forces were measured. In the latter case, peak amplifiers were used to capture the peak impulse force on the spike. The technique of experienced trackmen involved snapping or jerking the bar downward to create a peak force over a short time duration. Their experience with stubborn spikes has alerted them to the fact that the peak impulse force is what frees up the spike, not the total energy (i.e., a high force applied over a longer time). A short impulse force provides less time for bar deflection, a situation common when novices applied large forces over a longer time period. In support of this view are railroad accident data that report instances in which the deflected bar springs back and hits the user in the head. Another advantage of the snap method is better balance, which minimizes falling injuries. Thus, much like the skill requirements in spike

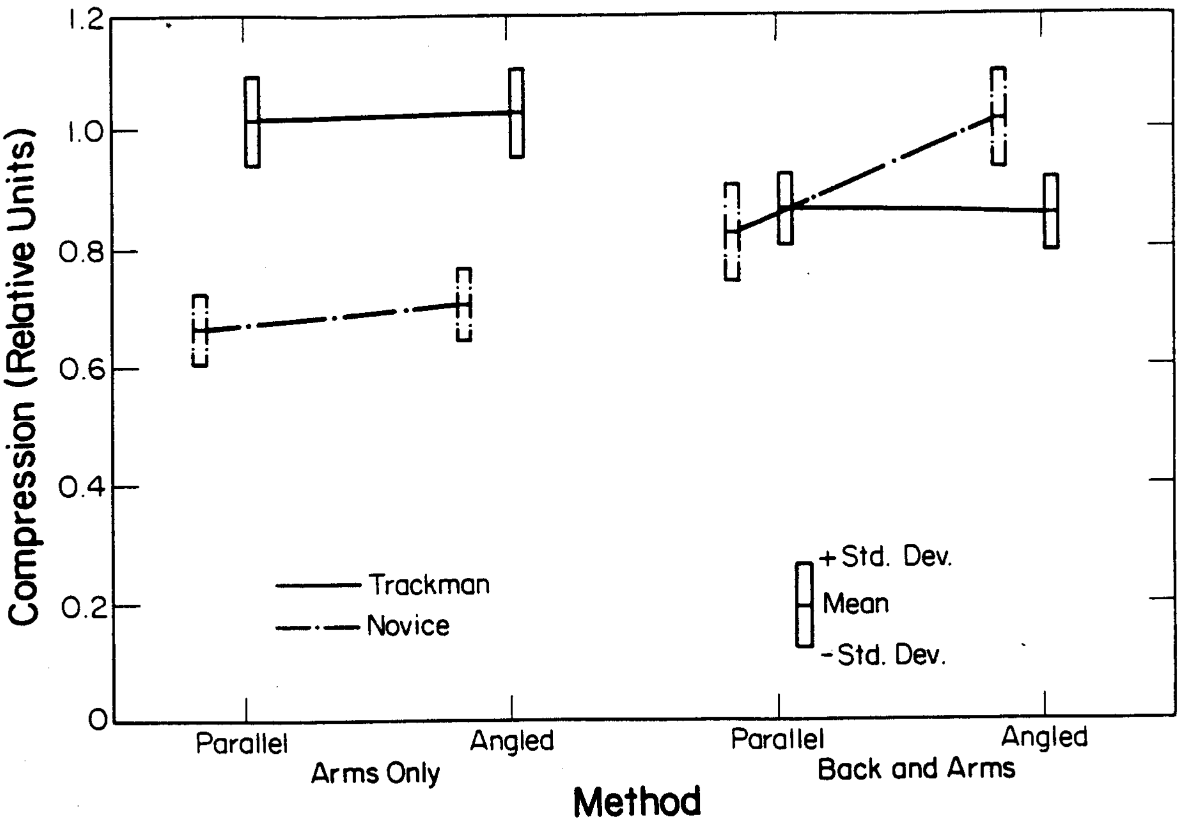


Figure 9. *Compression index as a function of method and experience.*

mauling, good technique, not simple power, plays a key role in effective and safe claw bar usage.

Back Indices and Efficiency

Measures of relative back stress and tool-use efficiency are the factors that determine the risk of traumatic as well as repetitive injuries. This study has shown that all back-stress indices react significantly to changes in tool-use methods. These back-stress patterns would not be obvious from a visual observation of the task.

Torsional loading of the spine is considered to be one of the more hazardous components of work. This analysis (Figure 7) has shown that use of back and arm methods increases the torsion experienced by professional trackmen. Shear forces are greatest when the angle/arm method is used by novice subjects (see Figure 8). This awkward position appears to overload the side of the trunk that is farthest from the bar, thus causing shearing. Compression indices appear to respond quite differently for novices than for professional trackmen (see Figure 9). Compared with trackmen, novice subjects exhibit substantially less compression when the arms alone are used, but somewhat greater compression when using the "back and arm" body action. Many of the differences can be explained by the differences in the amount of force subjects were exerting on the bar (greater forces result in greater back load). A novice subject using the "angled/back and arms" method suggests contraction against antagonist muscles simply to maintain the position. This would result in greater compression.

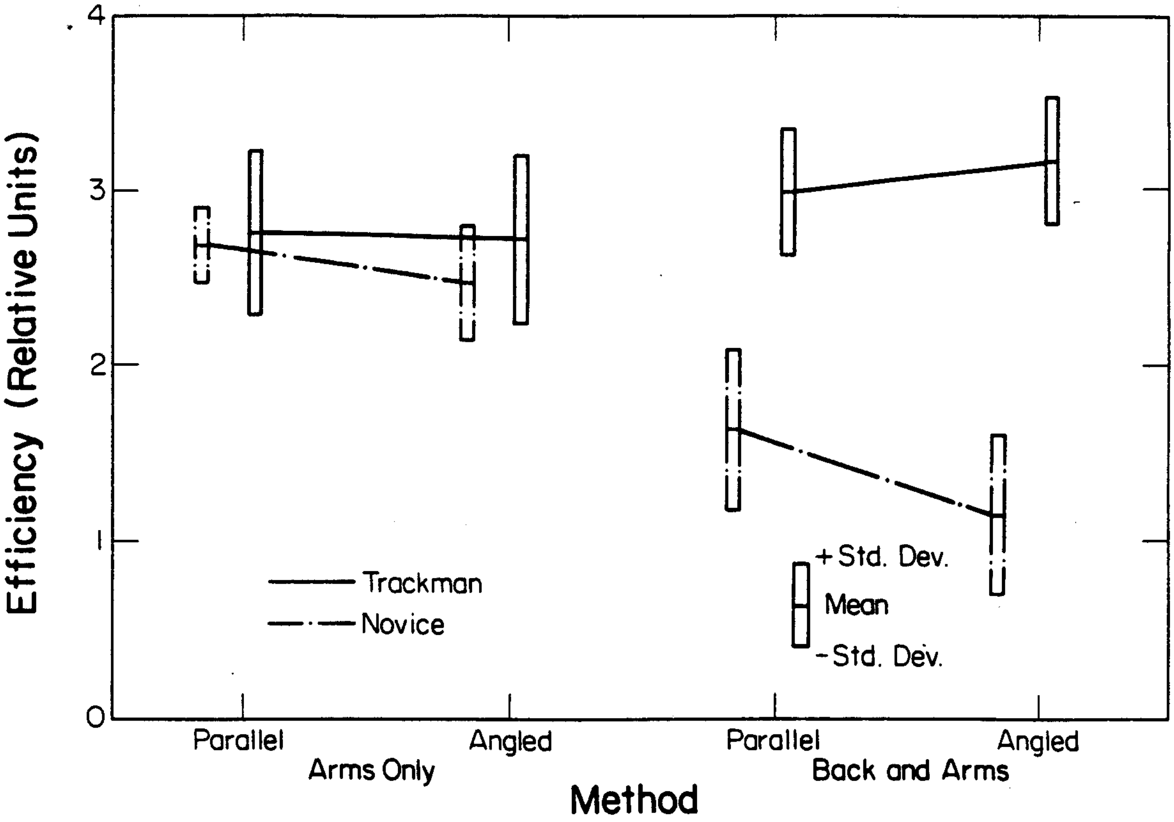


Figure 10. *Claw force efficiency as a function of method and experience.*

Trackmen on the other hand, have learned not to tense all of the antagonistic trunk muscles to produce such motion.

Collectively, these indices indicate that the parallel/arm method creates the least amount of stress on the back. Biomechanically, this position allows the tool user to minimize the moment between the tool and the spine, thus reducing the torque required to operate the tool. Similarly, torsion and shear advantages occur with this method, as tool users can use their arms to adjust for differences in hand levels on the angled tool. If a back and arms body action is used, subjects must compensate for the greater moment they must support due to the weight of the trunk that is further away from the body's midline. This situation would also increase torsion and shear.

The back indices also play a major role in the development of efficiency (Figure 10). However, the efficiency measure must be kept in persective: the repetitive trauma risks must be weighed against the risk of instantaneous trauma so that large, traumatic, yet efficient, exertions are not favored. The "parallel/arms" method results in much less back stress than the other methods, and also results in moderately high spike-lifting forces. Hence, when these factors are considered synergistically, this method is most efficient when trackmen and novice performance are considered collectively. It would also result in the greatest job performance with the least amount of wear on the back, less risk of trauma, and fewer repetitive use injuries over the long term. This is particularly significant when the frequency of claw bar use is considered throughout a trackman's career.

Conclusion

This study demonstrates that technique dominates method and tool-design effects. The research supports industry training recommendations for use of the claw bar; that is, use of the "parallel/arms only" method, which provides stability against falls and is equal or superior to the other methods in maximizing lifting forces and minimizing back-stress indices. Use of arms and back accomplishes no gain in lifting force and produces higher back loadings. During the tests, the experimenters tested the effect of simply dropping the bar quickly in the "parallel/arms only" method. The peak impulse produced from the weight of the bar alone was almost three-quarters of the force produced from the test subjects' heavy downward pressure on the bar. In effect, the tool as designed will do most of the work itself if the impulse force is short in duration. The critical message is that more effort on the bar does not produce comparable lifting forces at the spike, and that excessive force from the use of the back could result in injuries from the deflected bar snapping back into the body and falls resulting from unstable postures and sudden spike removal.

It does not appear that tool design, in terms of heel configuration, has any effect on the performance and back-stress measures. Bar weight and length might be studied in the future. A lighter, longer bar might deliver equivalent performance and yet be easier to carry, provided its design did not produce greater bar deflections.

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