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An Experimental Evaluation of Method and Tool Effects in Spike Maul Use

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An experiment was performed to study the effects of hand-tool design factors and methods of tool use upon tool force generation and loading of the back. Forty novice and experienced subjects were tested on their ability to drive a spike with a railroad spike maul. Method of tool use affected the spike-driving performance of novice subjects, whereas tool striking surface area influenced the ability of experienced trackmen to drive spikes. Method of tool use also affected the components of spine loading. Tool force generation was considered as a function of spine loading indices to create efficiency measures. Efficiency was used to evaluate the cumulative trauma effects of the hand tool.

INTRODUCTION

In recent years, it has become apparent that hand-tool use is becoming an area of increased concern for workers in many industrial environments. Researchers are becoming aware that improper hand-tool design and use can lead to cumulative trauma disorders. Armstrong (1983) and Tichauer and Gage (1978) have pointed out the role of hand-tool design in carpal tunnel syndrome. Much research has examined the effects of tools on localized trauma in the arm and wrist. However, it is also believed that tools that require large loads to be imposed frequently about the trunk may contribute to disorders of the trunk, such as low-back impairments. Unfortunately, very little of the literature has addressed such issues.

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Employee injuries constitute a major problem for the railroad industry. McMahan (1980), of the Association of American Railroads, cited some significant statistics concerning the magnitude of the problem. Using the Federal Railroad Administration (FRA) data, it was noted that between 1975 and 1979, American Railroads reported an average of 32 000 lost-time injuries annually with 470 000 lost worker-days. More than $41 000 000 was required for additional personnel to make up for the lost time, and this does not include the costs of overhead and fringe benefits. In 1979 alone, there was a cost of more than $300 000 000 for litigation and claim settlements for employee casualties within the industry for all causes.

Rockwell (1982) reviewed the FRA casualty data for the period 1975 to 1980. He found that there were 20 357 on-the-job injuries due to the use of hand tools during this period. Of these injuries, the largest portion (more than 42%) was reported by track workers. Similar injury rates were reported by McMahan (1980), who reviewed injury data in the railroad industry from 1975 to 1979. These data represent a loss of more than 23 500 worker-days per year. Hand-tool injuries in the rail industry are exceeded only by slips, falls, and materials handling in causing loss of time.

Further analysis of the data by Rockwell revealed that the largest portion of injuries involved sprains and strains, which suggests a predominance of overexertion injuries. The greatest percentage of injuries was sustained by the torso; sprains to the torso accounted for more than 30% of all hand-tool injuries.

The railroad environment represents a labor-intensive industry that relies heavily upon the use of hand tools. Most of the tools are nonpowered tools that require the user to exert significant forces upon a tool whose center of gravity is often at great distance from the user's trunk. This situation may cause significant moments to be imposed upon the user's trunk during tool use. However, no evaluations of the trunk loadings imposed by these moments have been reported.

Railroad safety officers were interviewed and asked which tools they considered to be the most critical in hand-tool injuries. These interviews revealed that more than 67% of the safety officers thought that the spike maul was a problem tool in track work. The next most hazardous tool was the claw bar.

These tools characterize most track tools that are either leverage or striking tools. This paper focuses on striking tools. Rockwell and Marras (1986), in a companion study to this research also presented in this issue, describe the results of a study of leverage tools.

Much of the literature on low-back disorders has investigated workplace factors that relate to such disorders. Epidemiological studies by Andersson (1981), Davis (1979), Strachan (1979), Strasser (1980), and Manning and Shannon (1981) have demonstrated that bending, twisting, lifting, forceful moments, and repetitive work are all associated with an increased risk of low-back injuries. Mechanically, the forces acting on the spine during these activities are often resolved into compressive, shear, and torsional loading components.

A noninvasive method to evaluate the loading of the spine is through the use of electromyography (EMG). Andersson, Herberts, and Ortengren (1976), Andersson, Ortengren and Nachemson (1976), and Andersson and Schultz (1979) have all demonstrated that trunk-muscle EMG is related to the moment imposed about the trunk in lifting and standing in various postures. When a load in the form of a moment is imposed about the spine, a counteracting moment must be imposed by the back muscles so that the body is in a state of dynamic equilibrium. However, because the back muscles are at a distance very near the spine compared with the source of the load moment, they are at a severe mechanical disadvantage. Substantial muscle forces are therefore required to counterbalance the load, and these muscle forces are generally proportional to the moment imposed on the spine by the load. Hence, these muscle forces supply a major portion of the spine loading during the task performance. Because EMG represents a method to assess the force within muscle, it is believed that monitoring the posture-supporting trunk musculature will provide information about the effects of the load on the components of force acting on the spine.

Further studies by Andersson and Ortengren (1974) and by Ortengren, Andersson, and Nachemson (1978, 1981) have reported significant correlations between back muscle EMG and measured disc pressure within the vertebral column. Later studies (Schultz and Andersson, 1981; Schultz, Andersson, Haderspeck, Ortengren, Nordin, and Bjork, 1982; Schultz, Andersson, Ortengren, Nachemson, and Haderspeck, 1982) have shown that back-muscle electromyography can also be related to predicted compressive, shear, and torsional loading of the spine. Marras, Joynt, and King (1984) have also demonstrated the relationship between trunk loading and EMG under motion conditions.

OBJECTIVES

The spiking task requires workers to swing a 4.5- to 5.5-kg maul about their trunk and hit a spike. This task requires both skill and strength. Skill is required to aim the maul at the spike. The spike surface area is only 3.91 cm^2, and the maul striking surface area is 5.3 cm^2. Strength is required to lift and swing the maul with sufficient force to drive the spike. Observations have revealed that it takes between 6 and 10 swings of the maul to drive a spike. It is evident that this task could conceivably load the spine substantially, especially after repeated exertions over a working career.

It was the objective of this study to evaluate the factors that could effect cumulative trauma to the back during spike-mauling operations. In the present study, back-muscle EMG was used to evaluate the compressive, lateral shear, and torsional components of the spine loading during spike maul use. These components were evaluated as a function of the tool characteristics and the method of tool use. The tool force generation on a spike was also observed. However, because it is well established that low-back disorders are a cumulative disorder, the efficiency of tool use was of interest. This efficiency was defined as the relationship of the back muscles' loading components to the force the tool produces to accomplish the intended task.

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. The 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 from all subjects.

Apparatus

The configuration of the experimental apparatus is shown in Figure 1. Spike force was measured by a three-axis load cell that was attached to a railroad spike. The spike and load cell were mounted on a shock absorber. The shock absorber air pressure was adjusted until the resistance was similar to that encountered when driving a spike into a railroad tie. The load cell signals were amplified by charge amplifiers and the maximum value was recorded with peak meters. This system was designed so that the spike peak force occurred and was recorded before the force was transmitted to the shock absorber.

The muscle activity of the back musculature was recorded with EMG. Recessed surface electrodes were placed over the right and left erector spinae and latissimus dorsi muscles. These electrodes were connected at the muscle site to miniature preamplifiers. This arrangement helps to minimize noise and motion artifacts. The signals were then passed on to main amplifiers, filters, and integrators.

Both spike and muscle signals were monitored by an ISAAC 2000 data acquisition system. This system converted the signals from analog to digital form and stored the data until they were conditioned and formatted by a microcomputer. The data were then stored on disk in final form and were later analyzed with a mainframe computer.

A Schmitt trigger was used to control the data acquisition process. This trigger con-

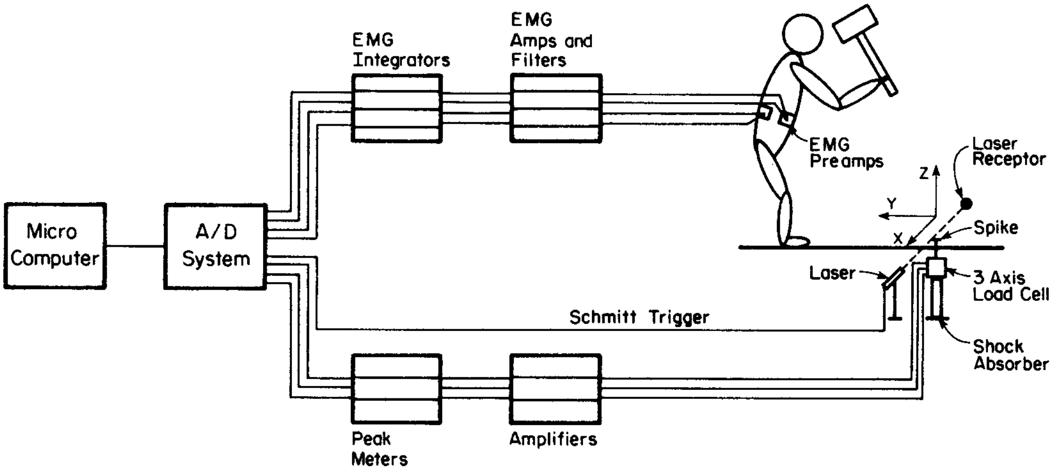

Figure 1. *The experimental apparatus with spike force reference axes.*

sisted of a laser beam that was directed just above the spike. When the subject lifted the spike maul to begin the swing, the beam was allowed to trigger a receptor and the data acquisition was begun. This process facilitated the definition of swing cycles.

Procedure

Initially, subjects were provided with background information on the nature of the experiment, and health histories of the volunteers were collected. Subjects were informed of the experiment's purpose and of the risks associated with participation. Next, anthropometric data on the subjects were collected. These 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 asked a series of questions regarding their backgrounds. These questions involved present and past work history, accident injury history, and experience, as well as progressive and traumatic disorders that may have developed due to their work.

All subjects were permitted a warm-up period. This period allowed the subjects to become familiar with the use of the spike maul. Subjects were allowed to drive spikes into railroad ties during this time. This period also served as a checkpoint for subject task ability. If a novice subject was not able to perform the spike-mauling task, he was eliminated from the experiment.

Once the subjects were comfortable and proficient with the spike-mauling task, they were allowed to rest while they were instrumented with EMG surface electrodes and preamplifiers. The electrode site was prepared according to standard procedures, and the electrode location was functionally verified via trunk exertions monitored with an oscilloscope. Control measures were also taken to minimize the possibility of motion artifacts when preparing the electrode site.

When the subjects were fully instrumented, a pretest was performed. This pretest recorded the EMG maximum and minimum muscle activity for comparison purposes. This was necessary, as EMG recordings are comparable between subjects only if they are normalized. This pretest evaluated the maximum activity of the muscles under both controlled isometric and isokinetic conditions.

Once the pretest was concluded, the handtool experiment began. Subjects were asked to stand on the experimental platform that housed the spike load cell, ballast, and railroad ties and perform the experimental task. A picture of this experimental platform is shown in Figure 2. The task consisted of hitting the experimental spike with various spike mauls. Subjects were asked to drive the experimental spike as they normally would if they were performing the task throughout the workday. They were also asked to rate subjectively the quality (in terms of accuracy and drive force) of their hit after each trial. If the subjective rating indicated that the swing was unacceptable, the trial was repeated.

Pilot tests have indicated that during repetitive use of the spike maul, the spiking forces and accuracy are most stable after the second swing. Therefore, during the experimental portion of this research, subjects were asked to execute three consecutive hits with the spike maul. The experimental apparatus was programmed to collect data after the second swing. This was accomplished by monitoring the status of the laser beam, which was projected just above the spike. In this manner, one complete swing phase was recorded.

When the experiment was concluded, subjects were debriefed and asked questions regarding their impressions of and preferences for the tools that they had used. Once these procedures had been completed, subjects were paid an hourly rate for their efforts.

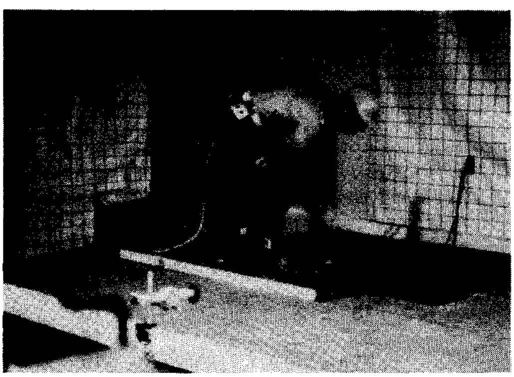

Figure 2. *The experimental platform containing the experimental spike and load cell.*

EXPERIMENTAL DESIGN

The independent variables in this experiment consisted of two tool factors and two blocking variables. The tool factors were fixed and consisted of the following conditions.

(1) Three tool weights (2.7, 4.5, and 5.5 kg) of standard (5.3 cm^2) striking area
(2) Three tool striking surface areas (2.52, 5.33, and 8.97 cm^2) of equal weight (4.5 kg)

All other tool characteristics, such as length, balance, and size, remained unchanged.

The blocking variables in this experiment consisted of subject experience and preferred method of tool use. Subject experience was classified into two levels. One level consisted of professional trackmen who were experienced in the use of the tool. The other level was composed of novice subjects who had never used a spike maul, except during the warm-up period.

The other blocking variable consisted of the method of tool use. Previous micro-motion methods analysis of trackmen performing spiking tasks (Rockwell, 1984) has shown that the method of spike maul use varies according to the combination of source of body motion and position of the hands. The body motion can be subcategorized into two distinctive events. First, the motion of the tool is accompanied by angular rotation of the back around the pelvis (back condition), with the arms relatively in phase with the back during the downward swing of the tool. Second, both the back and arms move at different rates (back and arm condition) during the downward swing of the tool. In this second method, the back and arms move out of phase in relation to each other. These methods have been quantitatively determined using a video system and sonic digitizer (Rockwell, 1984).

The hand position has been classified according to the action of the hands during the downward phase of the swing. Method analyses have shown that the hands are in one of three positions: apart, together, or sliding. It has been hypothesized that the method characteristics may induce different moments about the spine, thus creating potential spine loading of varying intensities.

The methods of tool-use classification were described by combinations of body motion and hand position (i.e., back/apart). The possible body/hand methods are listed in Table 1.

Rockwell (1984) studied the methods of spike maul use employed by professional trackmen. Observations of trackmen and track yard workers indicated the percentages of trackmen who used each combination of motion and hand position. Observed method frequencies, along with the percentages of trackmen who employed each method, are shown in Table 1. This table indicates that, in terms of method, the subject trackmen in this experiment were reasonably representative of railroad workers. It should also be pointed out that because method was a blocking variable, it was difficult to balance the experimental design. In fact, none of the novice subjects was able or elected to use the back/together method. This method is referred to by trackmen as "rolling" the maul.

The dependent variables in this experiment consisted of the following factors.

(1) F_x—Peak force on the spike lateral to the spike maul handle (see Figure 1).
(2) F_y—Peak force on the spike medial to the spike maul handle (see Figure 1).
(3) F_z—Peak force on the spike perpendicular to the ground (see Figure 1).
(4) "Integrated" EMG activity of the right latissimus dorsi muscle.
(5) "Integrated" EMG activity of the left latissimus dorsi muscle.
(6) "Integrated" EMG activity of the right erector spinae muscle.
(7) "Integrated" EMG activity of the left erector spinae muscle.

Along with these direct dependent measures, several derived dependent measures were defined. First, three back-loading indices were derived by evaluating the relative contribution of the four muscle activities. The three spine forces consisted of compression, lateral shear, and torsion indices. The compression index was defined as the sum of the relative (normalized) integrated activities of all four back muscles. The lateral shear index was defined as the difference in relative muscle activities on the right and left sides of the back. The torsion index was defined by timing the sequential order of muscle peaking activity among the latissimus dorsi and erector spinae muscles.

Next, spike performance measures were derived. A spike accuracy performance variable was defined as:

$$\text{Accuracy} = \frac{Fz^2}{Fx^2 + Fy^2 + Fz^2} \quad (1)$$

Accuracy represents the vector of productive force used to drive the spike. The driving

TABLE 1

Frequency of Spiking Method Used by Trackmen

Spiking Method Body Motion/Hand Position	*Rockwell (1984) % Pilot Study*	*Rockwell (1982) % Field Video taping*	*% of Trackmen in This Experiment*
1. Back/apart	13	3	14
2. Back/together	27	27	35
3. Back/sliding	10	3	10
4. Both/apart	14	13	10
5. Both/together	14	33	16
6. Both/sliding	22	21	15
	(n = 28)	(n = 40)	(n = 28)

force of the spike was also evaluated. This force was dependent upon more than just force in the z direction; it was found to depend upon the force in all three directions. The driving force was defined as:

$$(4Fz^2 + Fx^2 + Fy^2)^{1/2} \quad (2)$$

Finally, a measure of work efficiency was defined. Efficiency was generally defined as:

$$\text{efficiency} = \frac{\text{driving force [defined in (2)]}}{\Sigma \text{ back loading indices}} \quad (3)$$

This variable represents the work-producing force of the tool in relation to the relative back loading experienced by the subject. Through the use of this definition, it was possible to evaluate specific efficiencies (i.e., spike-driving force as a function of compression indices) as well as composite efficiency measures (i.e., driving force as a function of total back-loading indices).

RESULTS

Correlation analysis revealed no significant trends between back strength, spike mauling performance, and subject anthropometry. When spike force measurements were compared with subjective evaluation of hit quality, neither experienced nor novice subjects were capable of estimating their performance accurately.

The results indicate that the professional subjects were able to produce significantly greater forces upon the spike than novice subjects: $F_x(1,207) = 9.72$, $p < 0.002$; $F_y(1,207) = 52.66$, $p < 0.0001$; $F_z(1,207) = 124.75$, $p < 0.0001$. Professional subjects averaged 136 846 N of force in the z direction, whereas novice subjects were only able to produce an average of 64 446 N.

Table 2 summarizes the significance levels of tool performance measures, back-loading indices, and efficiency measures as a function of method and tool variables. This table indicates the level at which the dependent variables become significant as a function of the independent variables and their interaction. Values not reported had a significance level greater than 0.12. The results indicate that method effects had a profound effect on the performance measures for both experienced and novice subjects. Tool area also had a significant influence for some of the performance measures (mainly tool performance), but only for experienced trackmen.

DISCUSSION

The most obvious difference observed in this experiment was the contrast in performance between professional and novice subjects. Not only was there a difference in the spike force levels produced by professional and novice subjects, but these force levels also were affected by different factors. Professional subjects were affected by tool factors, whereas novice subjects were affected only by method factors. As shown in Figure 3, the forces the professional subjects exerted on the spike were at least twice those of the novice subjects under the various tool area conditions. In both cases (but particularly in the professional track worker's case), as the tool area increased, the spiking force also increased. This change might have been even more pronounced if a greater range of surface areas had been investigated. It is believed that greater forces are generated as the surface area increases because the increased surface area allows more ballistic swings, which generate greater inertia. When swinging the spike maul, the worker must generate small control motions during the downward swing so that the tool hits the spike. If the tool-striking surface area is small, the worker must exhibit greater control over the tool, which decreases the moment of inertia and thus the impact. However, as the tool striking area increases, the required control motions decrease and more energy is generated due to a more ballistic

TABLE 2

Summary of Significance Levels for the Experimental Factors

	Method		Tool	
	Experienced Subjects	Novice Subjects	Experienced Subjects	Novice Subjects
Tool Performance				
Z Forces		H 0.01 B 0.01 P 0.01	A 0.08	
X Forces	B 0.01			
Y Forces	B 0.01 H 0.08		A. 0.08	
Driving forces		H 0.01 B 0.01 P 0.01	A 0.08	
Accuracy	B 0.06			
Back loads				
Compression	H 0.01 B 0.01	B 0.01		
Shear	B 0.01	H 0.01 B 0.05 P 0.06		
Torsion	H 0.01		A 0.12	
Combined stress	H 0.06	H 0.03 B 0.04		
Efficiency				
Compression efficiency	B 0.01 H 0.07 P 0.01	B 0.01 H 0.01 P 0.01		
Shear efficiency		B 0.08 H 0.02		
Combined efficiency	B 0.01 H 0.07	B 0.01 H 0.01 P 0.01		

B = body position A = tool area
H = hand position W = tool weight
P = hand/body combination T = tool-area/weight combination

swing. The tool area factor was significant only for professional subjects. This would be expected because the degree of available control would be much greater for experienced, professional trackmen. These results may suggest that track workers ought to use sledge hammers with much greater surface areas than spike mauls. However, such a solution would be impractical, as workers are often required to drive spikes while reaching over the rail. Long, narrow heads are thus a necessary feature of spike maul design, but striking surface area could certainly be somewhat expanded.

The method of tool use appeared to play a part in spike force for the novice subjects but not for the professionals. Figure 4 shows the nature of this difference. The experienced trackmen have adapted to their preferred method over the years. Therefore, little difference is seen between methods used by these subjects. Novice subjects, however, exerted greater force on the spike if they used back motion exclusively. This finding may be

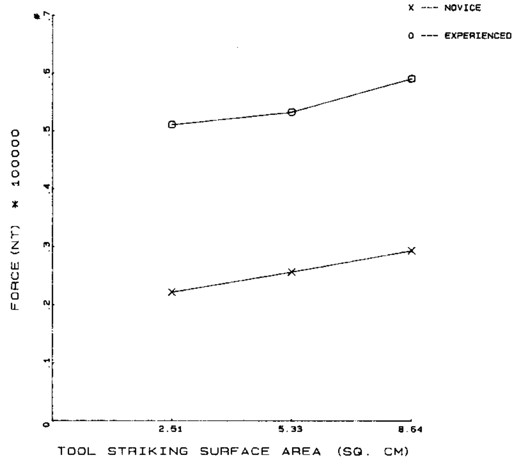

Figure 3. *Tool force as a function of surface area and subject classification.*

due to the fact that increased control was possible because the subject only had to compensate for one axis of rotation (back) as opposed to two (back and arm). This condition would result in a more ballistic swing. When hand position was considered, a similar phenomenon was observed. When subjects used the "slide" technique with their hands along with the back and arm body motion, their performance worsened because more compensation of hand motion was required. When back and arm/together body motion was used, significant increases in spike forces were also observed. In this case, only two body motions require precise control. These findings suggest that the amount of spike force generated may depend on the amount of control that must be achieved by the worker. It appears that the less control that is necessary, the more ballistic is the motion, and thus, the greater the force on the spike. In the back/slide, back/apart, and the back and arm/together positions the operator must compensate for precise motion changes in two body parts. However, in the back and arm/slide or apart position, the worker must compensate for three components of body force or motion, and performance deterio-

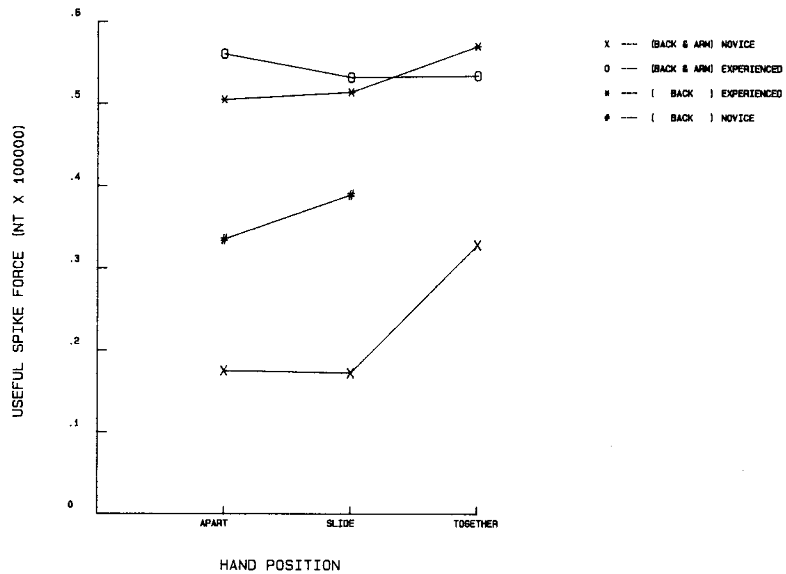

Figure 4. *Tool force as a function of tool use method and subject classification.*

rates. The experienced subjects apparently have sufficiently developed this control process so that spike force production is not affected by method.

Experienced subjects were also observed to "square up" with the spike; that is, the spike was aligned with the sagittal plane of the body. This technique should reduce the amount of body control necessary to hit the spike. When the maul and the spike are both aligned in the same plane of the body, only lateral and "forward-back" control are necessary to hit the spike. However, when the maul is swung over the shoulder it is no longer aligned in the sagittal plane, and additional translational control is required to hit the spike. In this case, the spike can be driven only when the maul crosses the vertical plane of the spike in a specific area. Hence, far more control is required if the user does not "square up."

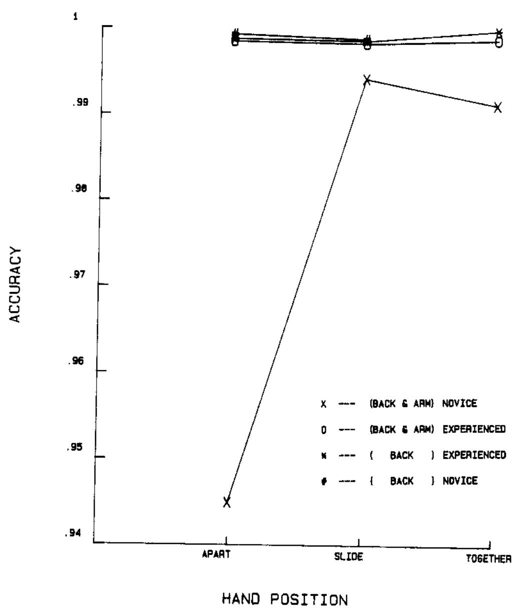

Figure 5. *Spiking accuracy as a function of method of tool use and subject classification.*

This concept of tool control also has an effect on accuracy during spike mauling. Figure 5 presents spiking accuracy as a function of spiking method. This figure indicates that when novice subjects use the back motion method, their accuracy is much greater than it is with the back and arm method, and it is similar to that of professional subjects. This indicates that the amount of control involved in tool use increases dramatically when subjects must only control one body articulation (the back) as opposed to two articulations (back and arms). This results in increased accuracy as well as increased tool force generation.

Tool weight was also examined in this study. Figure 6 shows the spike forces generated in the z direction as a function of the tool weight. Even though the tool weight effect was not statistically significant ($p < 0.10$), a pattern was observed in both novice and professional tool users that may be considered in future studies. The results indicate that the 4.5 kg (10-pound) tool, which is the standard weight used for spiking, produces the least force on the spike. Increasing or decreasing this weight by 0.9 kg resulted in increased z spike forces. This pattern was particularly

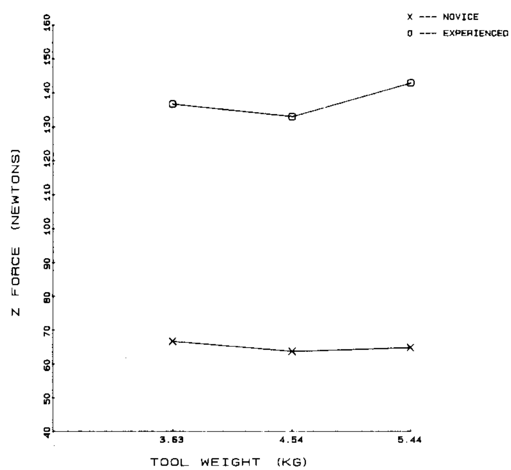

Figure 6. *Spike force in the z direction as a function of tool weight and subject classification.*

apparent for professional track workers. The pattern observed may become more pronounced if a larger weight range is investigated. The present weight range (0.9 kg) represents only a small percentage (2 to 3%) of most subjects' body weight. A greater range of weighted tools may accentuate effects that may be present.

The back-loading variables investigated in this study were derived from myographic recordings of the back muscles. As discussed earlier, the relationship between back loading and EMG has been established under isometric and isotonic conditions at constant velocity. This relationship has also been investigated with success under material-handling conditions. It is generally accepted that the EMG signal represents the muscle activity required to create a countermoment needed to balance a load held in the arms. In the present experiment, the EMG signal was used to define relative back-loading indices. These were used solely for comparison purposes and do not represent a measure of the absolute forces acting on the spine. Pilot tests were performed that indicated that the lateral shear, torsion, and compression indices were obtainable from the EMG signals.

The back-loading indices were primarily affected by the method of tool use. Tool area was the only tool factor that approached significance at generally accepted significance levels when the back-loading factor was considered.

The behavior of the various trunk-loading indices observed in the experiment are shown in Figures 7 and 8. The professional trackmen displayed less spinal stress under the back and arm body-motion conditions than under the back conditions. There seems to be a trade-off between the torsion/shear components of back stress and compression. The conditions that maximize compression for the professional group minimize torsion and shear. The back method produced lower spinal stress in novice subjects. In this case, compression and torsion interacted under the back motion method. Generally, total stress on the spine was seen to decrease when the hands were positioned apart; the moment developed by the tool about the spine is reduced by separating the hands on the tool handle. This brings the tool weight closer to the body. The shear forces also decrease when the hands are placed apart. However, compression usually increases under this condition because the back must be extended farther toward the spike, creating a larger moment.

A cumulative stress index is also shown in Figures 7 and 8. This stress index is derived by averaging the sum of the compression, shear, and torsion components of back stress. Future research in this area may specify how these components of back loading should be rearranged to represent the true risk of injury due to the loading components. The epidemiological studies mentioned earlier indicate that compression, shear, and torsion are all significant factors in the risk of back injury. However, the relative risk of each component is not known. Future research may weigh one, or any combination, of these components differently according to the risk associated with repetitive loading. In this manner, the stress variable can be adjusted to represent the true risk of injury.

In order to consider both the back-loading variables and spike forces, measures of relative efficiencies were needed. Because most back injuries are due to repetitive wear and tear, it was felt that efficiency would reflect the true cost of using the tool. A tool that causes little back stress and little strike-driving power may be undesirable because it may require many more swings to accomplish the task.

As indicated in Table 2, several measures of efficiency were derived. Most measures of efficiency were sensitive to method effects.

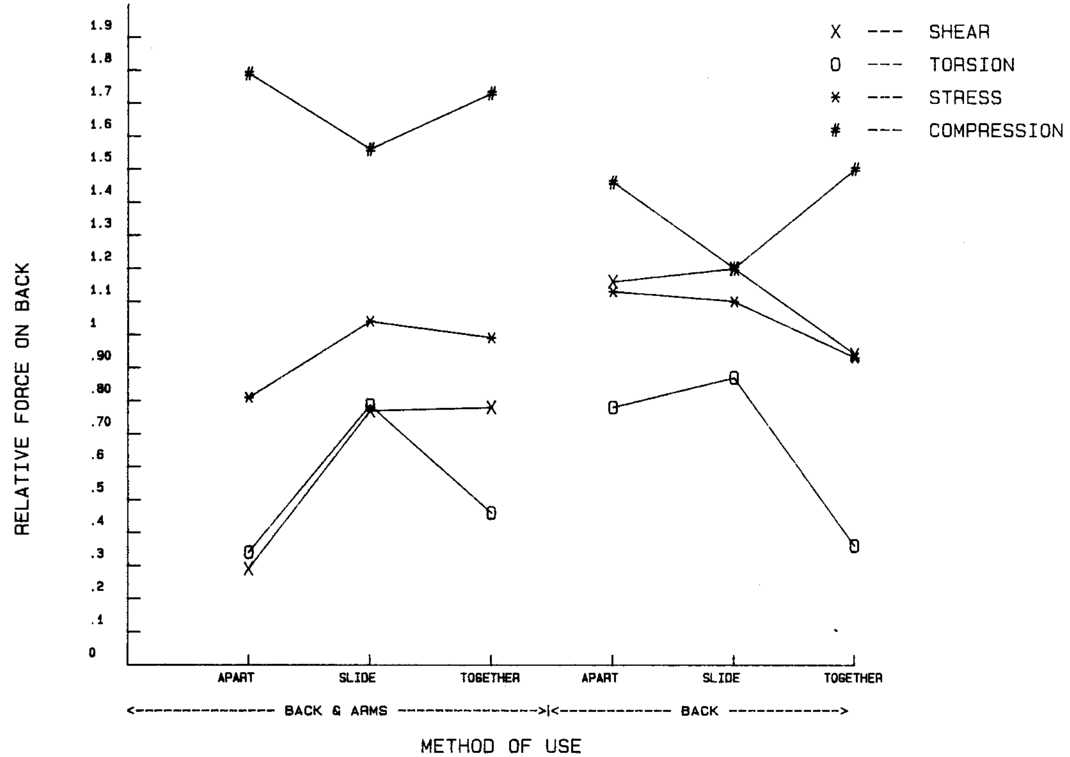

Figure 7. *Back-loading indices as a function of tool use method for experienced subjects.*

Figure 9 shows the behavior of an efficiency measure, which is a collective measure of spike-driving force and cumulative back stress. When novices are compared with professional trackmen, we see that if the novices use the back method of spiking, they approach the efficiency of professionals. The best efficiency produced by trackmen was observed when they used the back and arms/apart method. This efficiency measure was a function of the back stress indices. If this measure had been defined differently, other conditions might have been optimal.

As an example of the sensitivity of such efficiency measures, one could consider the efficiency based on a single back-load measure. Figure 10 shows such an efficiency measure based on spine compression only. As shown in this figure, when novice subjects use the back and arm method, they approach and even exceed the efficiency of professional subjects using the back and arm method. The optimal conditions for professional trackmen also change when different efficiency measures are used. This represents trade-offs between back loading "costs" (i.e., shear versus compression) that are not considered in this measure. If the total efficiency is considered, the back and arms/apart method is optimal. If the compression efficiency is the measure of performance, then the back/slide method becomes optimal. This difference in efficiency may have profound effects on spine degeneration throughout a worker's career. Therefore, it is important that future research considers the relative importance of

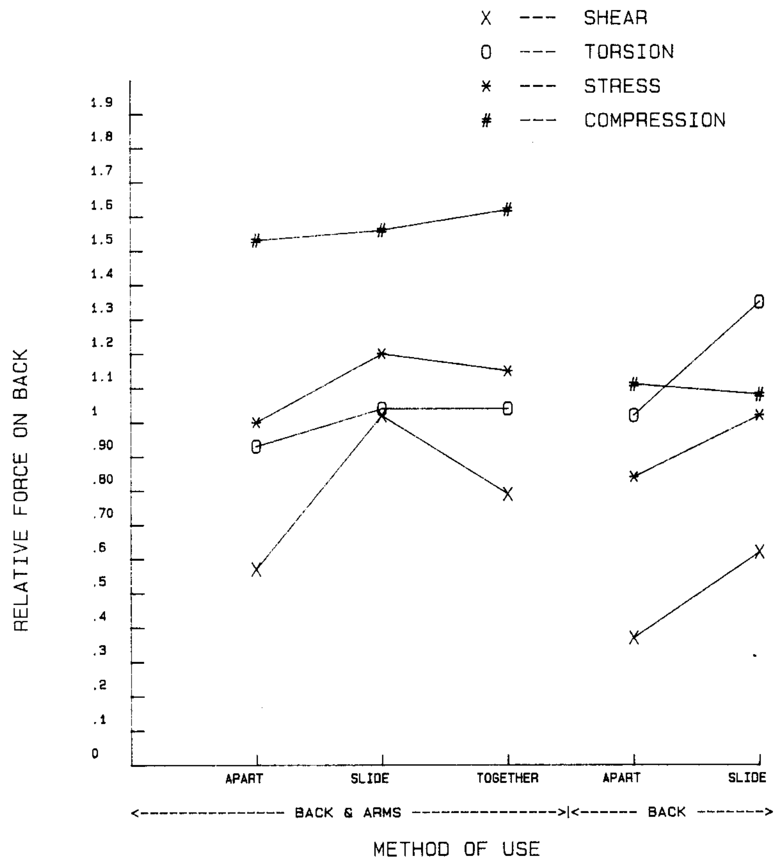

Figure 8. *Back-loading indices as a function of tool use method for novice subjects.*

the back-loading components. A word of caution is also warranted in the use of efficiency measures. Even though a particular method is optimal from the standpoint of efficiency, it may be advisable to occasionally change the method so that the effects of repetitive trauma could be minimized.

Efficiency measure indices must also be considered only within an acceptable range. It is important that the index is used in such a way that a very large exertion, which may be efficient but also may lead to excessive instantaneous or repetitive trauma, will not be feasible. Hence, a range of acceptability must be identified.

The results of this study indicate that the most important factor in spike-driving performance for novice subjects is method of tool use. Professional trackmen, on the other hand, are affected by changes in the tool. As discussed earlier, this may reflect the degree of control that must take place to accomplish the test. It appears that new trackmen could benefit most in spike performance if they limit the motion and adjustment involved in performing the task to two areas of the body. Attempting to control more than two body elements during spiking tends to decrease performance. Experienced trackmen are not affected by such methods in spike perfor-

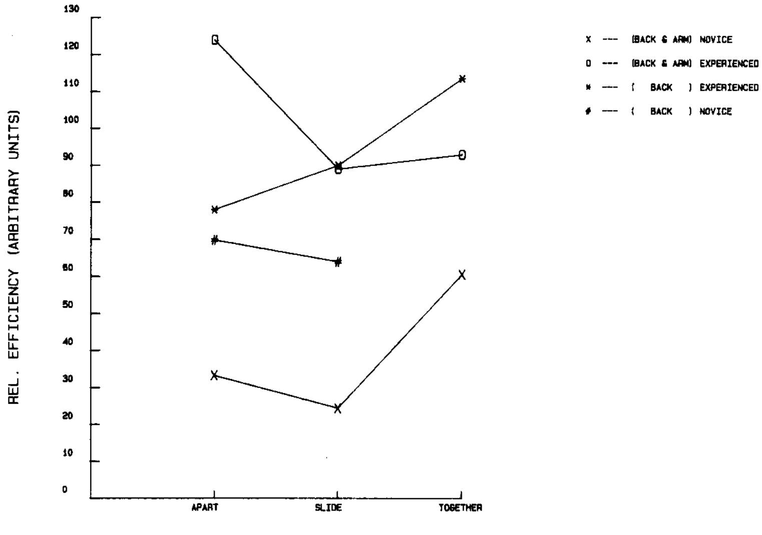

Figure 9. *Relative efficiency as a function of tool use method for novice and experienced subjects.*

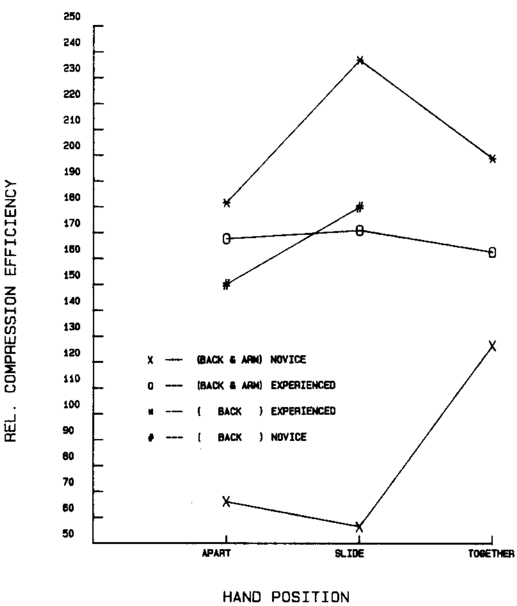

Figure 10. *Relative compression efficiency as a function of tool use method for novice and experienced subjects.*

mance. Thus, method of use seems to be a developmental factor when spike force is considered. When back loading and efficiency are considered, however, both novice subjects and experienced trackmen are affected by method factors. It appears that the back method of spiking is best for new workers. However, after they have developed their spiking coordination, they could realize extra efficiency benefits by using the back and arm method.

CONCLUSION

This effort has been concerned with the development of a quantitative method to assess the impact of tool designs and method of use of large, striking hand tools. We have considered the forces produced by the tool as well as the loading of the back in order to evaluate the tools. A new method was also devised to assess the components of loading on the trunk. It was discovered that when a novice tool user begins to use a tool, the greatest effect on performance and back loading is due to the method of use. Experienced subjects benefit more from the changes in tool design considered in this study. However, experienced subjects' back loading and efficiency were also greatly affected by the method of tool use. This research represents a new method of evaluating the effects of hand-tool use on loading of the spine and the generation of force by the tool. This method is unique because it makes possible the assessment of a tool based on tool user efficiency and provides a means of quantifying the cumulative trauma on the body.

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