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An electromyographic study of strength and upper extremity muscle activity in simulated meat cutting tasks

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Meat cutting has long been associated with a high incidence rate of upper extremity musculoskeletal disorders. This study examined upper extremity muscle activities and force exertion capabilities to identify postures which have potential for causing overexertion injuries. Fifteen subjects exerted force against a handle in postures similar to those observed in the meatpacking industry. Exertion level, direction of exertion, handle height, reach distance and grip type were varied. Activity in the posterior deltoid, biceps brachii, triceps brachii, extensor digitorum and flexor digitorum superficialis was monitored via surface electromyography (EMG). The ratio of normalized EMG activity to force produced during the exertion was computed for each muscle under each condition. The results showed that handle position had a significant effect on force exertion capability and the EMG/force ratio in all muscles. Force exertion capability was maximized, and the EMG/force ratio was generally minimized when participants pulled downward on a handle positioned at full arm's reach above the shoulder. For vertical cuts, force decreased and muscle activity generally increased as the handle height was lowered. For horizontal cuts, the full reach distance tended to allow greater force exertion with lower EMG/force ratios. The stab grip also tended to be associated with higher forces and lower EMG/force ratios than the slice grip. This study supports the premise that musculoskeletal stresses in meatpacking tasks can be altered through tool and workstation redesign. The data provided herein may be useful in selecting design modifications that reduce biomechanical stress on the upper extremities. Published by Elsevier Science Ltd.

Keywords: electromyography (EMG), musculoskeletal disorders, force, posture, meatpacking

Introduction

The meatpacking industry has long been associated with a high rate of accidents, injuries and illnesses. Widespread use of knives, hooks and circular saws in slippery, wet environments has always presented a high risk of cuts and lacerations to workers. More recently, increasing attention has been given to the rise in chronic diseases among workers in this industry, specifically the growing incidence of upper extremity musculoskeletal disorders. In 1993, these disorders afflicted 13 of every 100 workers in the US meatpacking industry, a rate 34 times higher than that observed among workers in general industry (0.38 disorders per 100 workers; Bureau of Labor Statistics, 1995).

Although the precise etiology of upper extremity musculoskeletal disorders is not known, it is well established that sustained or repetitive loading of the muscles and tendons can cause damage to these structures. Prolonged muscle contraction has been linked to chronic muscle pain (van Wely, 1970; Westgaard and Aaras, 1984; Kilbom *et al*, 1986). These contractions may arise from external work demands or from excessive postural requirements (Westgaard, 1988). At the same time, there is evidence that reductions in muscle loading can have positive effects on the incidence of musculoskeletal complaints (Westgaard and Aaras, 1985; Aaras, 1994). In an attempt to identify design factors which will reduce muscular effort during manual pulling and cutting tasks, a number of researchers have measured force exertion capacity under a variety of conditions (Cochran and Riley, 1986; Jorgensen *et al*, 1989; Hallbeck *et al*, 1990; Fothergill *et al*, 1992). The basis for these studies is the recognition that the force produced in an exertion depends not only on the number of contracting motor units within the muscles and the frequency of the contractile stimuli, but also on muscle length and the geometric arrangements of muscles and tendons about the joints (Chaffin and Andersson, 1991). Even subtle changes in posture can affect force exertion capability if the muscles are lengthened or shortened, or if the moment arm of the force about the joints is altered (Tichauer, 1973). It is reasoned that postures which cause force vectors to be transferred from larger, stronger muscle groups to smaller, weaker muscles are more likely to result in overexertion injury.

This approach may be over simplistic for the following reason; most exertions require the coordinated contraction of several muscles acting about multiple joints. While some muscles are engaged directly in force production, other muscles become active to stabilize the body in the required posture. It is not clear that conditions defined as optimal using a force exertion criterion would also be optimal using other criteria, e.g. loads imposed on a specific muscle group. Ultimately, the goal in work design should be to permit postures which maximize force exertion capacity while minimizing overall muscular strain. If engineers know how the involvement of specific muscle groups varies with the configuration of a task, their ability to identify probable injury sites, and formulate task design recommendations to relieve biomechanical stress at a particular anatomical location will be improved.

The purpose of this laboratory study was to measure the activity of upper extremity muscles using electromyography (EMG) while subjects exerted forces in postures similar to those observed in typical meat cutting tasks. The main intent of this research is to provide data to be used by engineers, and other safety and health professionals when evaluating or designing knife cutting tasks similar to those simulated in this experiment. Information on muscle loading can improve the analyst's ability to assess hazards and recommend changes to existing meat cutting tasks, while providing a quantitative basis for establishing the attributes of newly designed cutting tasks.

Materials and methods

Subjects

Fifteen right-handed males between the ages of 20 and 35 years were recruited from a temporary employment agency to participate in this experiment. All participants were free of any known musculoskeletal impairments. At the beginning of each test session, informed consent was obtained, and anthropometric measurements were made. These data are summarized in *Table 1*.

Experimental task

In this study, meat cutting forces were simulated as static forces; although meat cutting is a dynamic task, we assumed that cuts are relatively short (posture does not change dramatically) and are performed slowly (i.e. the meat resists the worker's motion). These motions are probably typical of more difficult and forceful meat cutting tasks. Participants applied force to a straight, cylindrical handle with the right hand in postures similar to those observed during meat cutting tasks (*Figure 1*). The handle was attached to the #50 Linear Motion Device (LMD) of the LIDO WorkSET II work simulator system. Participants performed 16 sets of exertions: in eight of these, participants applied a downward (vertical) force to a handle positioned parallel to the floor. In the other eight, participants applied a horizontal force directed towards the body, to a handle positioned normal to the floor. During vertical exertions, the handle was positioned at one of four heights relative to the participant's body dimensions: (1) at full arms' reach, measured up from the shoulder; (2) at half the distance between (1) and the top of the shoulder when the arm is at rest; (3) at the level of the hand when the arm is at rest and the elbow is fully flexed; and (4) at a level half the distance between (3) and the tip of the elbow (*Figure 2*). Handle height was controlled using an adjustment mechanism on the work simulator. During horizontal exertions, the handle was positioned at one of two heights (shoulder height and elbow height), and at one of two distances from the body (at 50% and 100% of the distance from the shoulder to the hand when the shoulder is flexed 90 degrees and the elbow is fully extended). These distances will be called 'half' and 'full' reach, respectively (*Figure 3*). Exertions in each posture were repeated with both stab and slice grips (*Figure 4*).

Procedure

Each participant performed isometric exertions against the handle at 100%, 75% and 50% of maximum effort using all 16 treatment combinations in random order. Force output was measured and displayed by the LIDO WorkSET II work simulator system. The WorkSET was programmed for isometric exercise to permit assessment of pull force at each test condition. For each trial, participants stood in front of the workstation, with the handle aligned with the right arm. Participants grasped the handle using the designated grip and attempted to move the handle in the specified direction (downward or towards the body). During maximum efforts, participants held the exertion for a 5 s period. Maximum strength measurements were repeated three times for each condition. During submaximal exertions (75% and 50% of maximum), participants applied force to the

Table 1 Anthropometric characteristics of study participants

	Age (years)	Height (cm)	Shoulder height (cm)	Waist height (cm)	Elbow height (cm)	Hand length (cm)	Hand breadth (cm)
Mean	26.1	181.6	149.6	114.0	105.2	19.8	8.6
SD	4.1	6.9	6.4	4.6	7.4	1.3	0.5

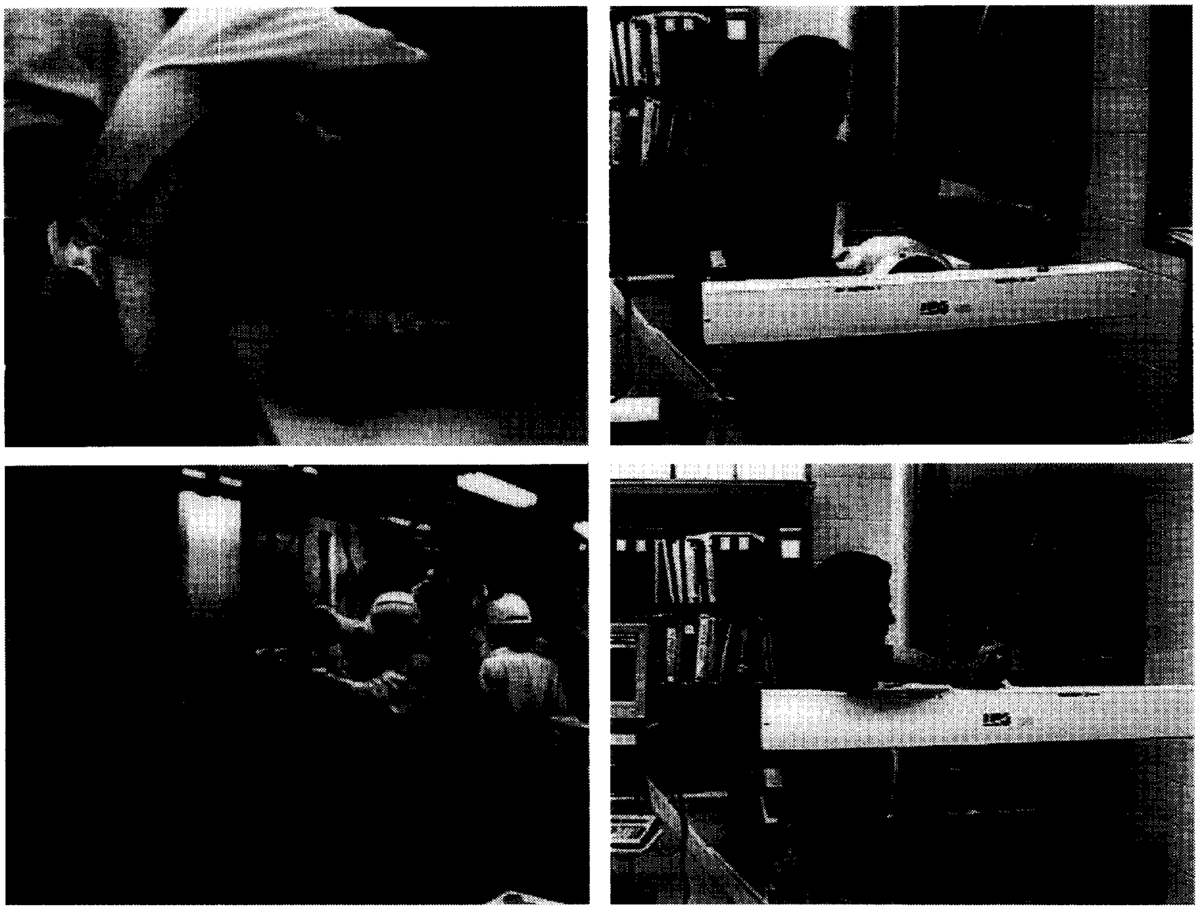

Figure 1 Examples of postures used in actual and simulated meat cutting tasks

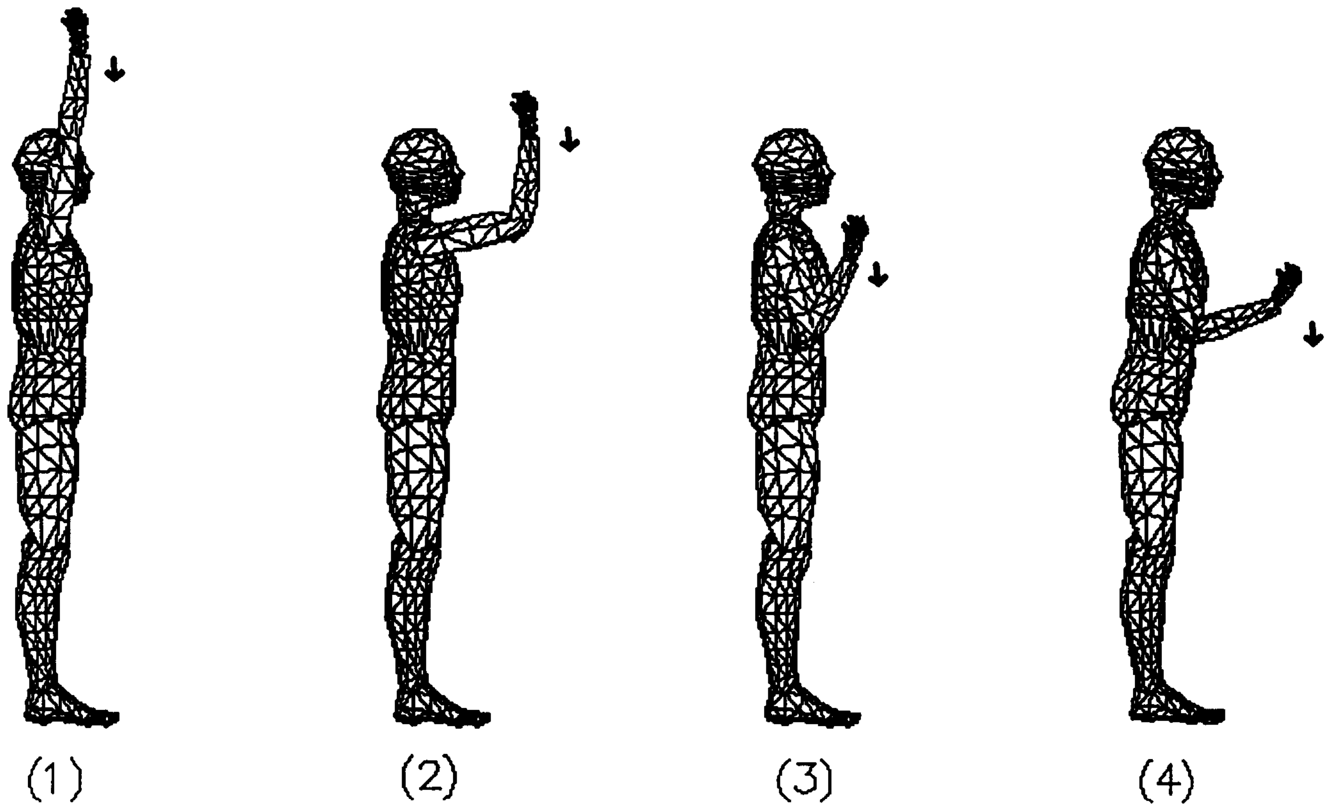

Figure 2 Postures examined during vertical force exertions

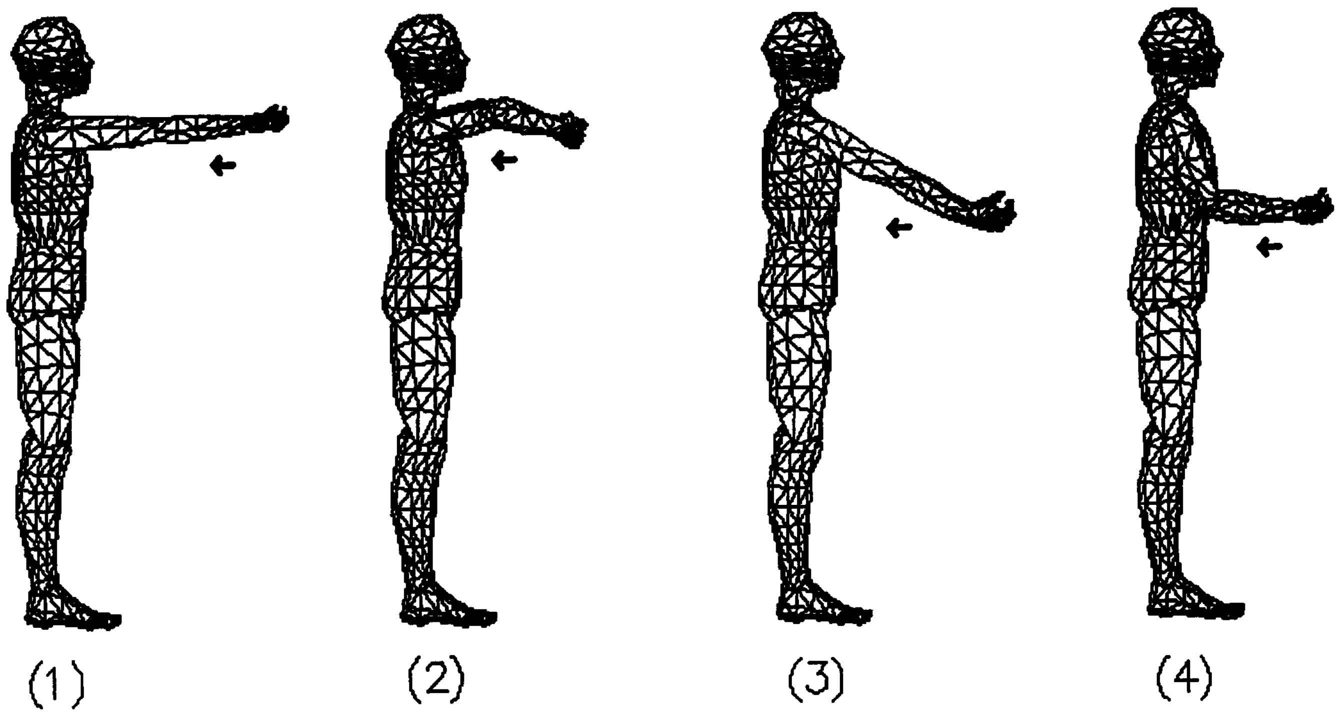

Figure 3 Postures examined during horizontal force exertions

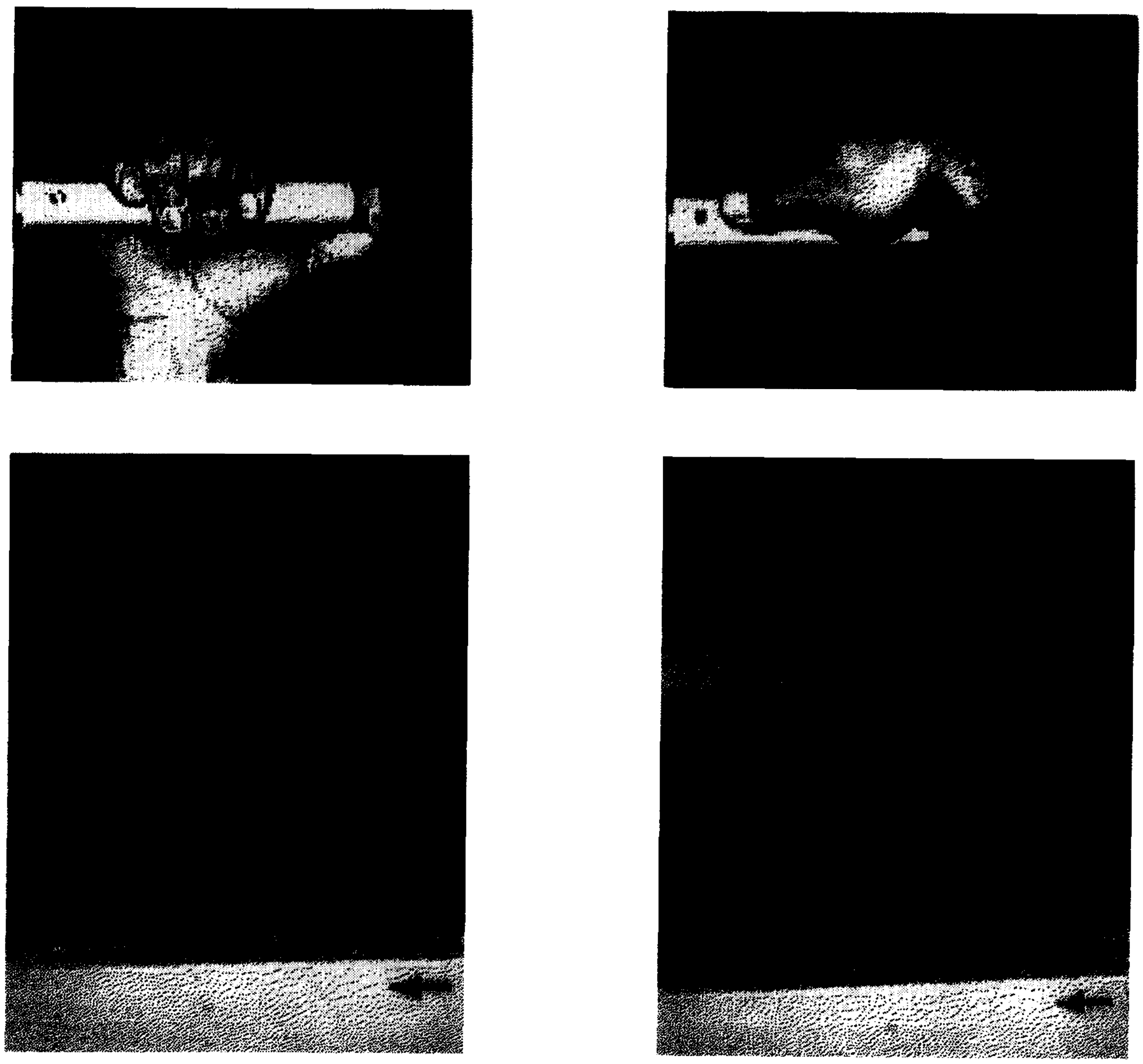

Figure 4 Stab (left) and slice (right) grip postures in vertical (top) and horizontal (bottom) exertions

handle while watching the WorkSET's biofeedback display. The display showed both the desired force level and the force actually exerted. Once the desired and actual force values matched, participants were asked to hold the exertion for a 5 s period. Because the level of force was controlled (reducing potential variability in the measurements), submaximal exertions were repeated only twice. Rest was provided after each set of exertions (between conditions) to avoid fatigue.

Dependent variables

Force output and the root-mean-square (RMS) voltage of surface EMG signals from right arm and shoulder muscles were recorded during each exertion.

Maximum force (i.e. strength) was recorded from the WorkSET's biofeedback display (hidden from the participant's view) after each maximal (100%) effort. During submaximal contractions, the level of force was controlled (set to 75% and 50% of maximum effort), and thus was not recorded.

EMG activity was recorded using surface electrodes positioned over the posterior deltoid, the long head of the biceps brachii, the triceps brachii, the flexor digitorum superficialis, and the extensor digitorum muscles in the configuration recommended by Zipp (1982). The actions of these muscles are described by Kendall and McCreary (1983). These muscles were chosen because of their size, their proximity to the surface of the skin, the likelihood that they would be active during the simulated work tasks, and the susceptibility of their tissues or tendons to overexertion injury. Although other muscles may be active during upper extremity exertions, most are smaller and further from the skin surface. Furthermore, it is expected that EMG activity in smaller, deeper muscles (i.e. the flexor digitorum profundus and the brachialis) would be highly correlated with EMG in the muscle groups we monitored (i.e. the flexor digitorum superficialis and the biceps) since their actions are similar. EMG data were collected using the Therapeutics Unlimited (TU) Model 544 Electromyographic System® during each 5 s exertion. The system features a high-pass filter with a cut-off frequency of 20 Hz to remove low frequency noise from the EMG signals. A 22 ms time constant was selected for purposes of calculating the RMS of the EMG amplitudes. The processed EMG was sampled at 100 Hz and stored by microcomputer using a 12-bit analog-to-digital converter and LabTech Notebook® data acquisition software. The data from the middle 3 s of each 5 s recording were averaged, and the mean was used to represent the RMS EMG amplitude for each muscle under each condition.

Data analysis

Due to technical difficulties, EMG data from two of the 15 participants were not used. EMG amplitudes for each condition were normalized to the highest amplitude observed for each muscle during the experiment. Because the force produced by maximal exertions under different conditions varied, the ratio of the normalized EMG to the force produced during the corresponding exertion (also normalized) was computed and used in subsequent analyses. Relatively high levels of muscle activity associated with relatively low levels of force production will result in ratios > 1.0. Repeated measures ANOVA procedures were used to test the effects of handle height and grip (vertical exertions), and handle height, distance and grip (horizontal exertions) on the maximum force produced under each condition and EMG/force ratio for each muscle group.

Results

Strength

Maximum force exertion capacity (i.e. strength) as a function of treatment combination is shown in *Figure 5*. During vertical exertions, both height and grip had significant effects on force (*Table 2*), with grip having a larger effect on strength at the middle heights. During horizontal exertions, strength was significantly influenced by distance and grip, but not by height.

Muscle EMG/force ratio

The mean EMG/force ratio for each muscle, under each condition, is shown in *Figures 6–10*. Except for the flexor digitorum superficialis, exertion level did not affect the EMG/force ratio (i.e. as force levels declined, muscle activity declined proportionately), nor did it modify the effects of the other independent variables on this relationship (see *Table 2*). Therefore, the results may be considered applicable over the range of exertions examined (50–100% of maximum effort).

Deltoid. For vertical exertions, the ratio of deltoid activity to force produced increased significantly as handle height decreased (*Figure 6*). For horizontal exertions, muscle activity increased relative to force production as the handle was raised and moved closer to the body. The effect of grip was also significant, having a larger influence when the handle was positioned at half reach distance.

Triceps. As shown in *Figure 7*, the ratio of triceps EMG to force production generally decreased as handle height increased. The slice grip produced larger EMG/force ratios during vertical exertions, especially at the two lower heights.

Biceps. The biceps EMG/force ratio increased with handle height, regardless of handle orientation (*Figure 8*). Reach and grip effects were not significant.

Extensor digitorum and flexor digitorum superficialis. EMG activity in the extensor digitorum and the flexor digitorum superficialis was largely unaffected by the variables examined in this study, with the exception of exertion level. Hence, variations in the EMG/force ratio for these two muscles (shown in *Figures 9* and *10*) are primarily the result of changes in force output. Because force output increased, EMG/force ratios decreased with increasing height during vertical exertions, and increasing reach distance during horizontal exertions. Using a slice grip produced increases in the flexor EMG/force ratio, but grip had no effect on the extensor EMG/force ratio. Interestingly, flexor activity did not decline with reductions in exertion level when the slice grip was

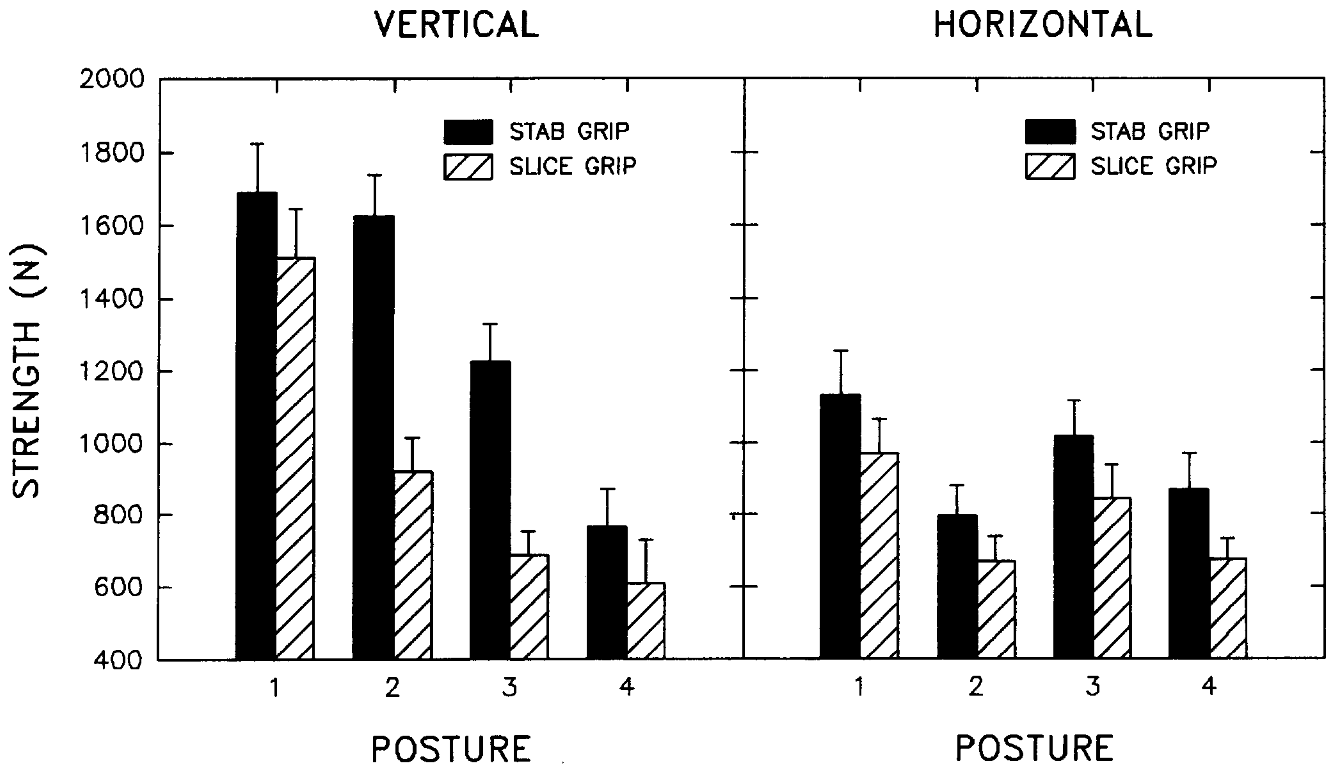

Figure 5 Force exertion capacity as a function of posture. Bars represent standard error about mean over all exertions. (See *Figures 2* and *3* for definitions of postures (1–4) during vertical and horizontal exertions)

Table 2 Repeated measures ANOVA results (top = vertical exertions, bottom = horizontal exertions)

	Strength	Posterior deltoid	Triceps brachii	Biceps brachii	Extensor digitorum	Flexor digitorum superficialis
Exertion	N/A	NS	NS	NS	NS	$p < 0.01$
Height	$p < 0.01$	$p < 0.01$	$p < 0.01$	$p < 0.01$	$p < 0.01$	$p = 0.02$
Grip	$p < 0.01$	NS	$p < 0.01$	NS	NS	$p < 0.01$
Height*Grip	$p < 0.01$	$p = 0.02$	$p = 0.01$	$p = 0.02$	NS	NS
Exertion	N/A	NS	NS	NS	NS	NS
Height	NS	$p = 0.04$	$p < 0.01$	$p < 0.01$	NS	NS
Reach	$p < 0.01$	$p < 0.01$	NS	NS	$p = 0.03$	$p < 0.01$
Grip	$p < 0.01$	$p < 0.01$	NS	NS	NS	$p = 0.01$
Exertion*Grip	N/A	NS	NS	NS	NS	$p < 0.01$
Height*Reach	NS	NS	NS	$p = 0.04$	NS	NS
Height*Grip	NS	NS	NS	NS	NS	NS
Reach*Grip	NS	$p < 0.01$	$p < 0.01$	$p = 0.05$	NS	NS

used, although flexor activity did decline in proportion to force output when the stab grip was used.

Discussion and conclusions

Meat cutting tasks can have high force requirements (Magnusson *et al*, 1987). Hence, allowing workers to adopt postures which maximize their force exertion capacity while minimizing muscular strain may be an important element in avoiding musculoskeletal injuries. In this study, the EMG/force output ratio provides a useful means for identifying tasks and working conditions where high levels of muscle activity are present, but are not effectively translated into force output. Situations where the EMG/force ratio $\leqslant 1$ should be viewed as desirable, whereas conditions where the ratio $\gg 1$ should be avoided. For example, vertical exertions with the hand at or below shoulder height resulted in deltoid, triceps and extensor EMG/force ratios near 2. In these positions, activity in the deltoid and triceps was near maximal, while the forces generated by these exertions were comparatively weak. This was likely because the line of force resulting from the contraction of these muscles was different than the direction of force required by the task (Grieve and Pheasant, 1981). In any case, requiring workers to perform cutting tasks in these positions may increase the risk of shoulder and elbow strain, even if the required forces are relatively low.

A possible use of the data from this study is in assessing the expected benefits resulting from design changes to tools, tasks or workstations. While reducing the force requirements of some meat cutting tasks may be impractical, altering the work to allow workers to exert forces in a more favorable posture may be possible. In some instances, relatively simple changes

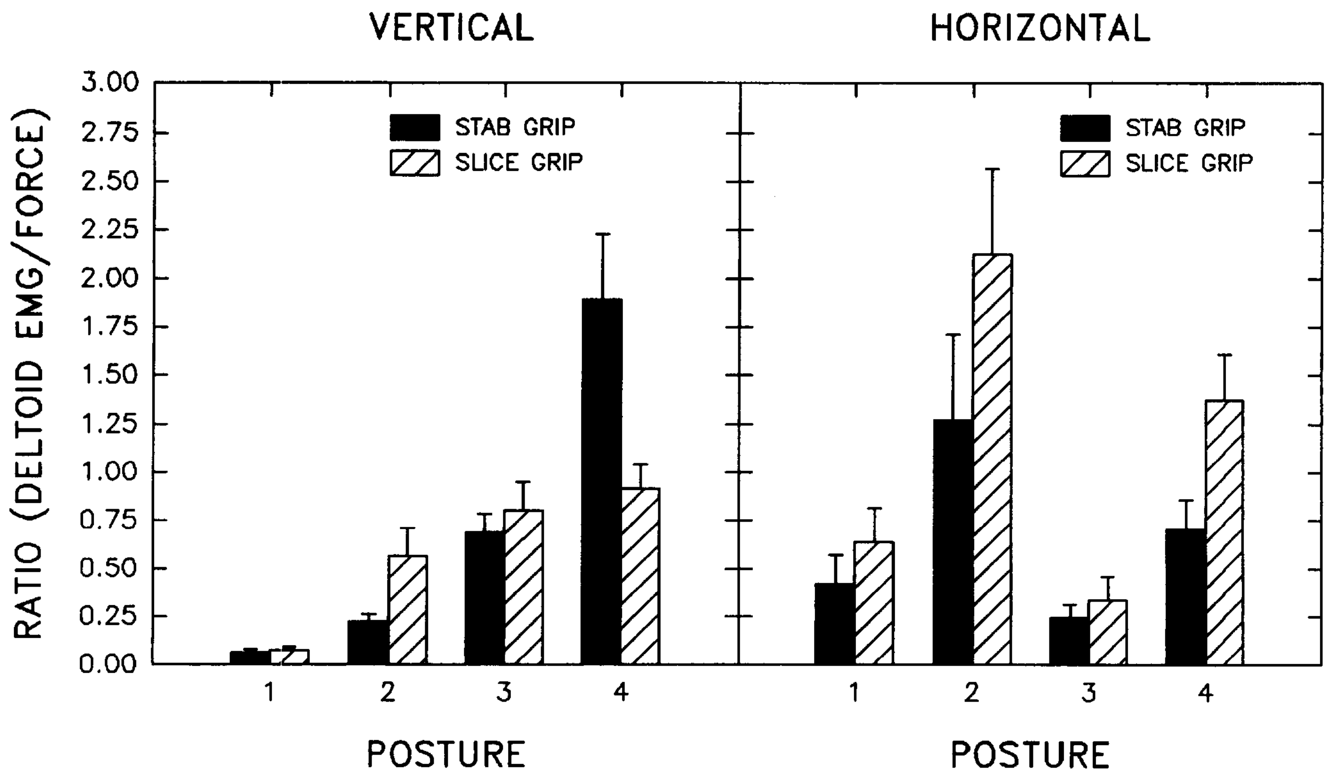

Figure 6 Ratio of posterior deltoid activity to force production at the hand as a function of posture. Bars represent standard error about mean

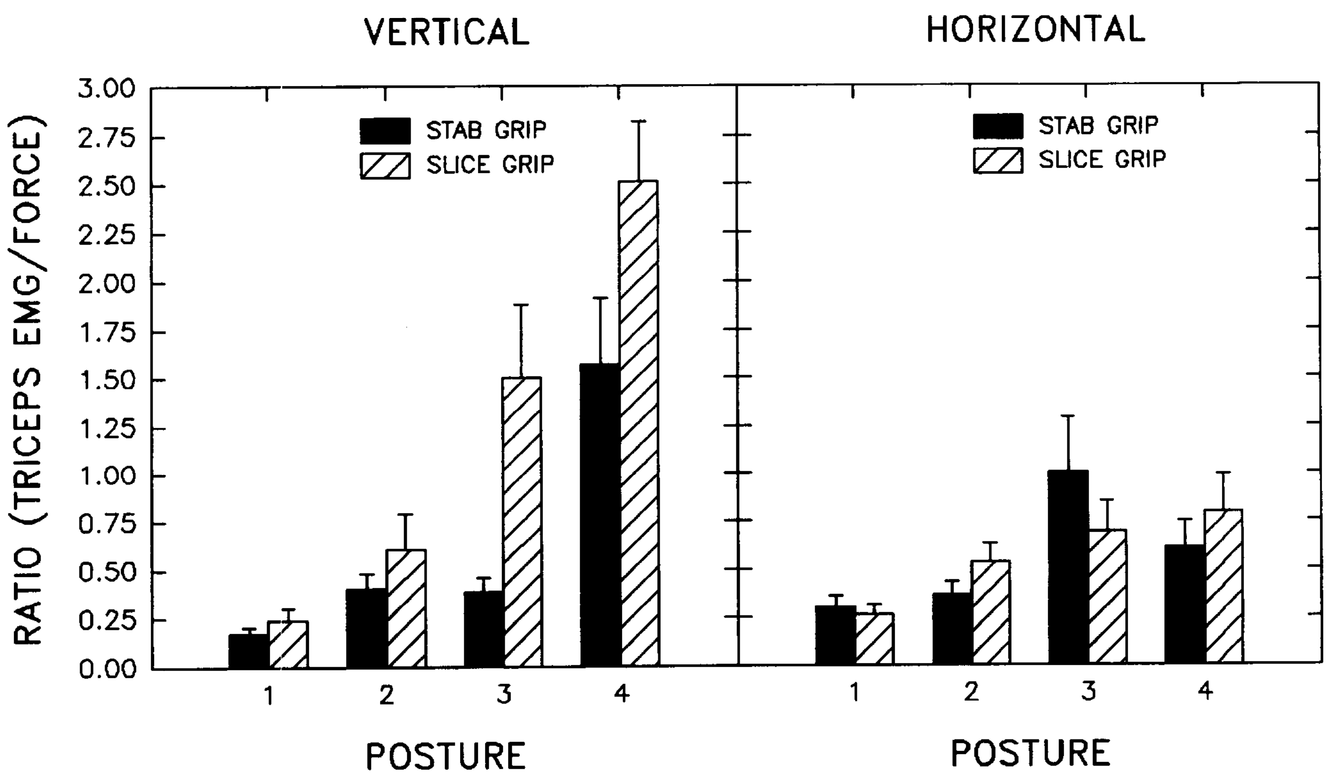

Figure 7 Ratio of triceps activity to force production at the hand as a function of posture. Bars represent standard error about mean over all exertions

such as modifying the knife handle to allow use of a stab grip rather than a slice grip (*Figure 11*) could be expected to double force exertion capacity, while reducing muscle activation by as much as 80%. Positioning work in a manner that allows workers to use their full reach to initiate longer or more difficult cuts may have similar effects. Interestingly, the full reach posture is not the posture which maximizes the strength of the elbow flexors (biceps) or extensors (triceps). However, the full reach position stabilizes the

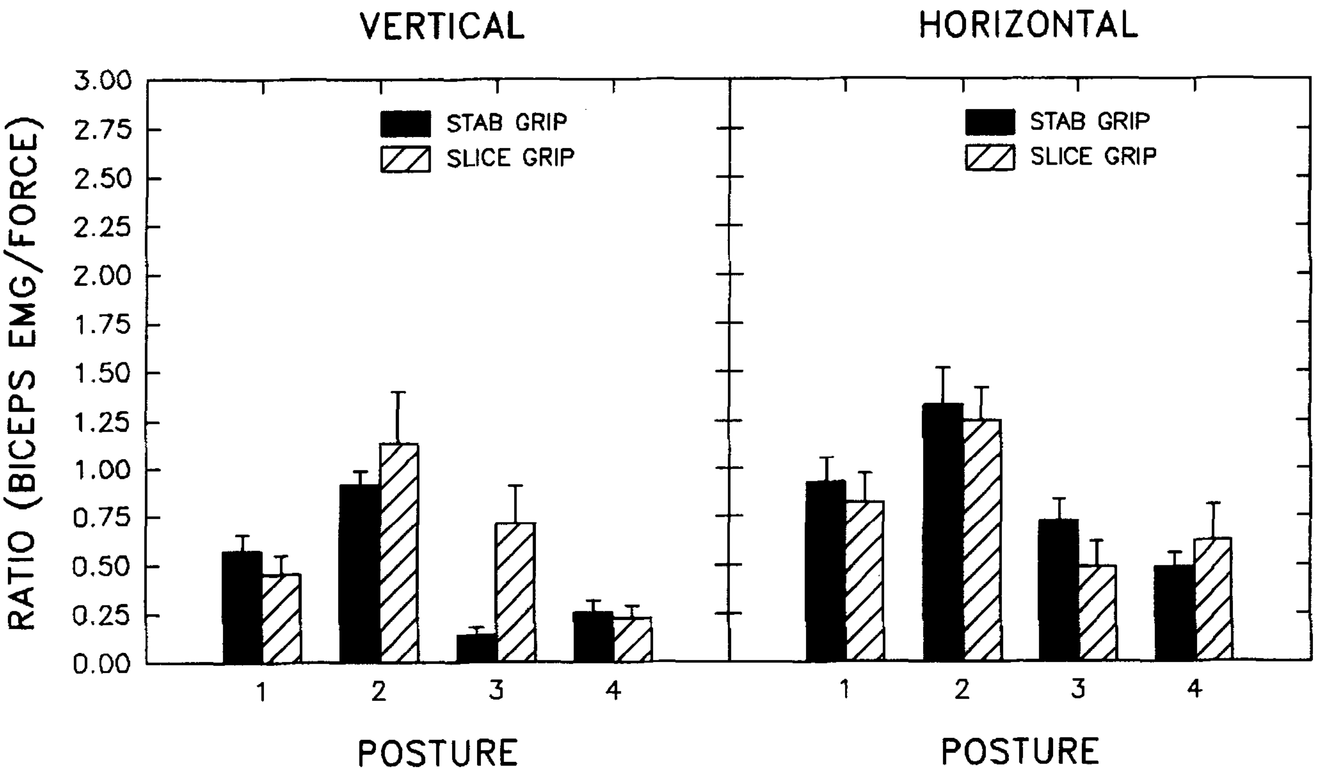

Figure 8 Ratio of biceps activity to force production at the hand as a function of posture. Bars represent standard error about mean over all exertions

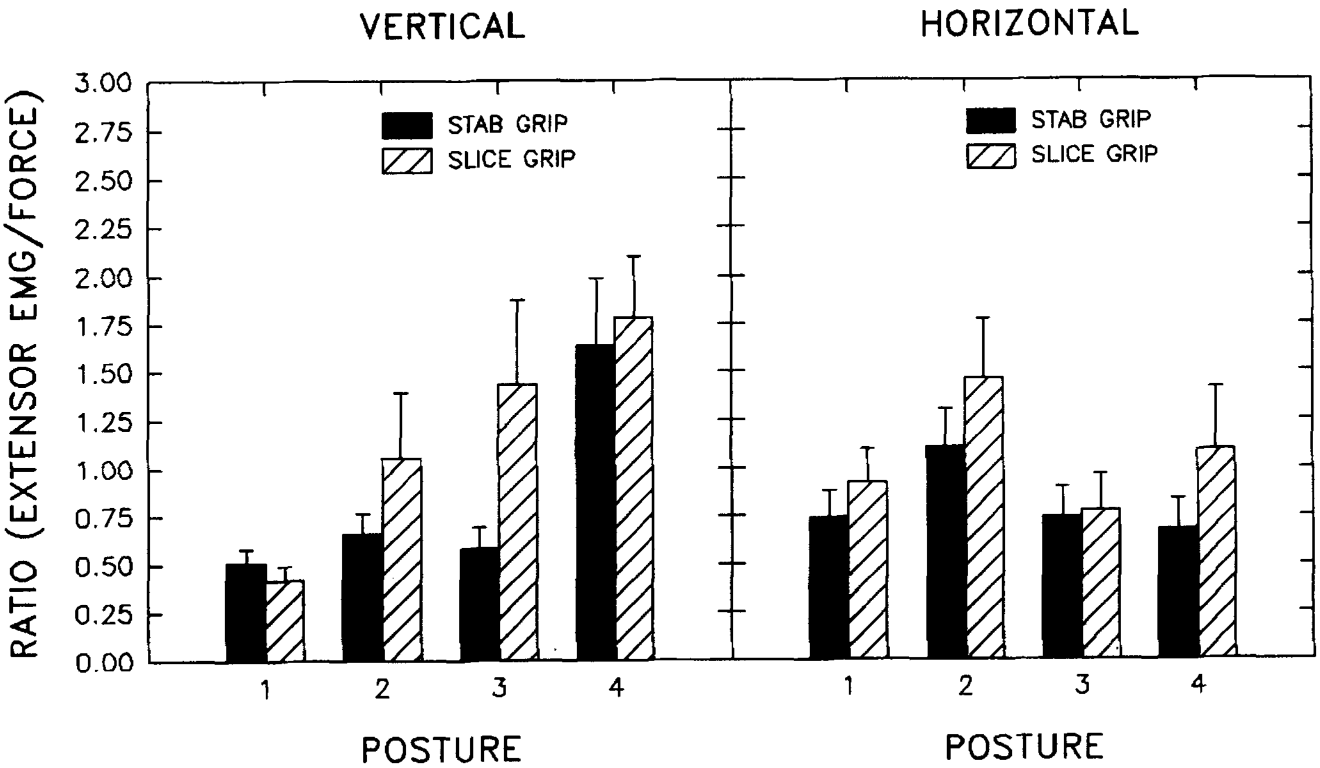

Figure 9 Ratio of extensor digitorum activity to force production at the hand as a function of posture. Bars represent standard error about mean over all exertions

elbow in a position which may allow transmission of higher forces to the hand by stronger shoulder or back muscles (Haslegrave, 1990). In other cases, popular design modifications, such as providing height-adjustable, horizontal work surfaces, may have more modest impact and may be difficult to justify. Using these data, changes to the interface between the human and work task can be examined in light of their potential impact on the musculoskeletal system before they are implemented on a more permanent basis.

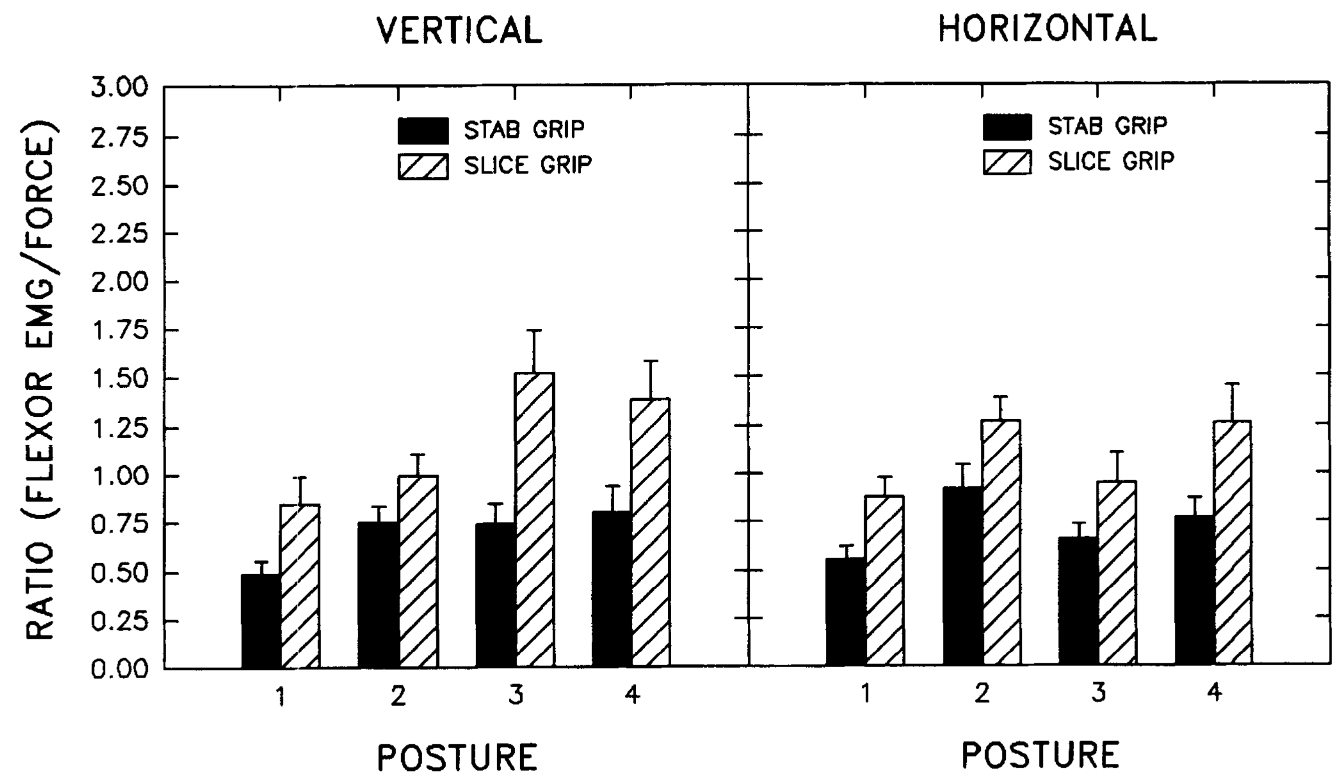

Figure 10 Ratio of flexor digitorum superficialis activity to force production at the hand as a function of posture. Bars represent standard error about mean over all exertions

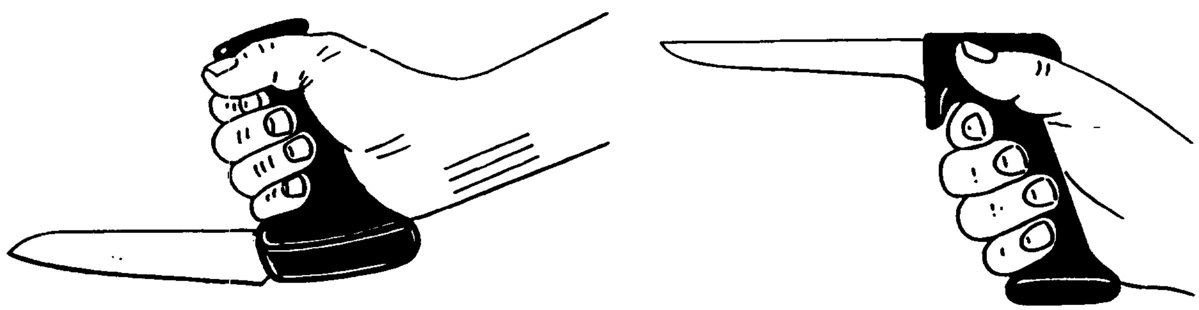

Figure 11 Knife handles designed to promote use of a stab grip

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