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ABSTRACT

A review of the scientific literature reveals little research on the ergonomics of handsaws and no literature on the specific challenges of arborist saws (saws for cutting and pruning living trees). This study was designed to provide some insight into the effects of saw design and height of sawing activity on the biomechanical response of the upper extremity. Eighteen participants performed a simple sawing task at three different heights using six different arborist handsaws. As they performed this task, the electromyographic activity of several muscle groups of the forearm (flexor and extensor digitorum), arm (biceps brachii long and short heads) and shoulder girdle (posterior deltoid, infraspinatus and latissimus dorsi) were sampled. Also gathered were the wrist postures in the radial/ulnar plane at the beginning and ending of the sawing stroke, the time to complete the sawing task and a subjective ranking of the six different saws. The results show an interesting mix of biomechanical and subjective responses that provide insight into handsaw design. First, there were tradeoffs among muscle groups as a function of work height. As work height increased the biceps muscles increased their activation levels (~19%) while the posterior deltoid activity decreased (~17%) with the higher location. The results also showed the benefits of a bent handle design (average 21% reduction in ulnar deviation). The subjective responses of the participants generally supported the productivity data, with the saws demonstrating the shortest task completion time also being the ones most highly ranked.

Relevance to Industry:

Understanding the stresses placed on the upper extremity during sawing activities, and design features that can reduce these stresses, may help saw designers to create products that reduce the risk of injury in workers who use handsaws.

Keywords: handsaws, shoulder, wrist, biomechanics

INTRODUCTION

Research into the area of hand tool design is motivated by the documented relationship between the design characteristics of the tool and the resulting exposure to recognized risk factors for upper extremity cumulative trauma disorders. A review of the epidemiological evidence showed strong evidence of a positive association between exposure to highly repetitive, forceful hand/wrist exertions and the development of carpal tunnel syndrome and hand/wrist tendonitis (NIOSH, 1997). In the shoulder region, this review provided evidence for a positive association between highly repetitive work and awkward shoulder postures and shoulder musculoskeletal disorders. In the elbow, this review showed evidence for a relationship between forceful work and epicondylitis. Hand/wrist risk factors such as high grip forces, exposure to vibration, repetitive hand and/or wrist motions are all factors that may be controlled through engineering design of the hand tool, while exposure to high force and awkward posture exertions of the elbow and upper extremity can often be addressed through workplace design.

A review of the archival literature finds a relatively large number of studies of both manual hand tools and power tools. These include studies on pliers (e.g. You et al., 2005; Duke et al., 2004; Dempsey and Leamon, 1995; Lewis and Narayan, 1993), hammers (Schoenmarklin and Marras, 1989a,b; Konz, 1986; Knowlton and Gilbert, 1983), knives (Claudon and Marsot, 2006; Szabo, Radwin and Henderson, 2001; Fogleman et al., 1993; Armstrong et al., 1982), drills (e.g. Potvin et al., 2004; Bjoring et al., 1999) and sanders (Bovenzi et al., 2005; Mirka et al., 2002). In general, these studies have shown the importance of a neutral wrist posture (midrange of flexion-extension and ulnar-radial deviation), appropriate sizing of the handle of the tool to improve the biomechanics of the hand-handtool interface, and, for powered hand tools, consideration of the frequency of vibration to which the operator is exposed is important.

As compared to these handtools, handsaws are a bit different in that the nature of the typical work task involves not only the hand/wrist and elbow but the shoulder joint as well. Surprisingly little research has been conducted on the ergonomics of the handsaw. Kuijt-Evers et al. (2007) performed a subjective evaluation study that included a screwdriver, a paintbrush and a handsaw. The focus of this study was to explore the underlying factors that led to a subjective assessment of comfort when using hand tools. These investigators found that the best predictor of comfort for the screwdriver was "Has a nice feeling handle"; the best predictor the paintbrush was "Fits the hand"; and, interestingly, the best predictor for the handsaw was "Offers a high task performance". This would indicate that the fit or the ergonomics of the handsaw is secondary in importance to the functionality of the tool. This result, along with the limited research conducted in this area, indicates that further research into the ergonomics of the handsaw is needed.

Arborist handsaws pose a particularly interesting study in that not only are there important issues with regard to the handsaw itself, but the location of the item to be sawn is not fixed relative to the worker, making the proper positioning of the worker relative to the work an interesting challenge. As with many challenges in the agricultural environment, the location of the "work piece" when using an arborist handsaw can vary considerably based on the specific location on the tree where the work is to be performed. This provides another interesting variable to explore in the assessment of arborist handsaws. The objectives of this research were to evaluate the effects of saw design and work height on the biomechanical responses of the user. Specifically, we are interested in their effects on the response of the upper extremity musculature, wrist angle in the radial/ulnar plane and productivity.

METHODS

Participants

Eighteen participants (16 men and two women) from the university community were recruited for this study. The mean (and range) of the age statue and whole body mass of the participant population were 30.2 years (24 – 47years), 175.5cm (166.9 – 186.9cm), 73.9kg (59.1 – 96.8kg), respectively. None of these individuals were professional arborists and history of the use of handsaws varied. None had any current of chronic musculoskeletal pain in the upper extremity. Prior to participation, each provided written informed consent on a form approved by the North Carolina State University Institutional Review Board.

Apparatus

Seven pairs of bipolar Ag–AgCl surface electrodes (Model E22x, In-Vivo Metric, CA, USA) were used to record (Myopac, Run Technologies, CA, USA) the muscle activity from the unilateral (right-side only) flexor digitorum, extensor digitorum, biceps brachialis long head, biceps brachialis short head, posterior deltoid, infraspinatus, and the latissimus dorsi. These data were amplified, A/D converted and collected at 1024 Hz.

The experimental apparatus for this study included a set of six different arborist saws and a structure to secure the wooden dowels for sawing. The arborist saws used in this study varied on a number of dimensions, including teeth per inch (large tooth and fine tooth saws, handle design, and the foldability of the saw (fixed blade vs. folding) (Figure 1). Next, an apparatus was constructed that allowed the positioning of the 5cm diameter wooden dowels in a horizontal orientation at participant-specific heights of “elbow”, “mid chest” and “acromion” (Figure 2). During the sawing task the dowels above the one being cut were retracted while the one immediately below was kept in place for safety reasons. The structure was securely mounted to the floor, but did allow a certain degree of flex, simulating the amount of movement that would be encountered when sawing a limb on a tree. Participants were instructed hold the dowel with their off hand in much the same way that an arborist would hold the limb being removed.

Insert Figures 1 and 2 Here

Independent Variables

The independent variables in this study were SAW (six levels) and HEIGHT (three levels). The six levels of SAW were:

Saw#	Saw Characteristics		
1	large teeth	long, bent handle	fixed blade
2	large teeth	short, bent handle	fixed blade
3	large teeth	long, bent handle	folding saw
4	fine teeth	long, straight handle	folding saw
5	fine teeth	short, bent handle	fixed blade
6	large teeth	long, straight handle	folding saw

The three levels of HEIGHT were participant-specific and were standing elbow height, standing mid chest (xiphoid process) height and standing shoulder (acromion) height.

Dependent Variables

The dependent variables in this study included both objective and subjective responses. Objective measures included the normalized (to maximum) integrated electromyographic (EMG) activity of the flexor digitorum (FD), extensor digitorum (ED), biceps brachii long head (BL), biceps brachii short head (BS), posterior deltoid (DT), infraspinatus (IS) and latissimus dorsi (LD) as well as the ulnar deviation of the right wrist at the beginning of the stroke (WAs) and at the end of the stroke (WAe). In this regard, it should be noted that arborist saws cut on the "pull" stroke and the ending of this stroke is therefore near the tip of the saw. The time to complete the sawing activity was also collected (Time). The subjective assessment of the saws was a simple rank ordering of the six saws (1(worst) – 6(best)).

Experimental Procedures

After providing written informed consent, the participants spent five minutes doing some simple stretching/warm up exercises for the torso and upper extremities. Surface electrodes were then applied to the skin over the muscles of interest using standard preparation procedures (Marras, 1990). The participant then performed a series of maximum voluntary contraction (MVC) exertions each specifically designed to elicit the peak muscle activity for the specified muscles. The MVC exertions for the muscles of the forearm were performed with the participant exerting maximum wrist extension and flexion against manual resistance with the wrist in a neutral posture. The MVC exertions of the biceps muscles arm were performed against the static resistance provided by a Kin/Com isokinetic dynamometer, with the forearm supinated and the elbow flexed to 90 degrees. Finally, MVC exertions for the muscles of the shoulder region were performed with the participant bent at the waist (~60 degrees) and pulling (transverse extension of the shoulder) against the resistance of a handle that was secured via a rope to the floor. Two repetitions of each exertion were performed. A two minute break was provided between MVC exertions.

Upon completion of the maximum voluntary exertions the participants performed a randomized sequence of the 18 sawing tasks (6 saws x 3 heights). Between trials the participants were given a rest period of one minute. The participants were told to complete the task as quickly as possible. After completing the sawing of a dowel, the participant was asked to hold the posture that they used at the beginning of the sawing stroke and at the end of the sawing stroke while a digital picture of that wrist posture was taken. At the completion of the 18 trials the participant was asked to rank order the six different saws in terms of overall performance (comfort, speed, perceived accuracy all considered collectively.)

Data Processing and Statistical Analysis

The unprocessed EMG signals from all trials were filtered (10-500 Hz band pass and 60 Hz notch) and then rectified. For the experimental trials, these data were then averaged over the time period wherein the participant was sawing the wood (i.e. data collected after completion of sawing motion was not included.) For the MVC exertion trials, the data were then partitioned into 1/8th second windows for the three-second duration of each trial. The average voltage was then determined for each of the 24 windows for each muscle in each MVC trial. The highest average value calculated for any 1/8th second window for each muscle was identified. All of the EMG data collected during the experimental trials were then normalized relative to the muscle-specific maximum value. The digital pictures of the wrist angles (radial/ulnar plane) were evaluated by finding the angle between the line segment running from the third metacarpal-phalangeal joint to the center of rotation (radial/ulnar) of the wrist and the line running from the center of rotation of the wrist and point located between the radius and the ulna (Figure 3). This procedure allowed for a relative evaluation across conditions, but does not provide data describing the absolute value of ulnar deviation.

Insert Figure 3 Here

A MANOVA was conducted to examine the effects of SAW, HEIGHT and their interaction on the dependent measures collectively. If statistical significance of the MANOVA ($p<0.05$ for the Wilks' Lambda statistic) was found for a main effect (or interaction), then that effect (or interaction) was tested using individual ANOVA for each measure. A randomized complete block design (RCBD) was used in this statistical analysis with “participant” acting as the blocking variable, thereby controlling for the high levels of inter-individual variability. When significant effects of the technique were detected, a Tukey-Kramer post-hoc analysis was performed to further refine our understanding of the significant effects. Finally, for the subjective assessment of the saws, the non-parametric Kruskal-Wallis test was performed on the rankings.

RESULTS

The MANOVA results for the muscle activation levels showed a significant effect of both SAW and HEIGHT but not their interaction (Table 1). While the univariate analyses did show several significant effects, there were no consistent trends in these muscle activation profiles that would lead one to conclude that one saw was superior to the others (Figures 4-5). It was interesting to note that Saw #3 (long handle) did show a significantly lower activation level of both the flexor digitorum and biceps muscles (Figure 4) but the reduction was rather modest (Figure 5). This lack of consistency in these responses makes it impossible to identify a superior saw in the comparison of muscle activation levels. The effects of HEIGHT, on the other hand, were more pronounced and formed consistent trends (Figure 6). As height increased from elbow to shoulder height, the activation of the extensor digitorum (11%), both biceps (19% and 13%) and infraspinatus (6%) all showed significant increases while the activation of the posterior deltoid showed a significant decrease (17%).

Insert Table 1 and Figures 4-6 Here

In terms of the wrist angles at the beginning and ending of the stroke, there were significant differences (Table 2) as a function of both SAW and HEIGHT and most of these effects followed closely the expectations. Saws that had a significant bend to their handle (Saws #1, #2 and #5) showed less ulnar deviation at all positions than those that did not (Figure 7) while the lower levels of HEIGHT showed reduced ulnar deviation (Figure 8).

Insert Table 2 and Figures 7 and 8 Here

Finally, subjective assessments and time to complete the sawing task showed very similar trends as a function of SAW (Figures 7 and 9). The results of the statistical analysis of these subjective assessments showed that there were significant effects (χ^2=56.1, $p<0.001$) of saw type on the ranking of the saws. From a productivity standpoint Saws #2 and #5 showed the quickest completion times and these were also the ones ranked highest by the participants. Saws #1 and #3 were shown to be the slowest and they were also the ones least preferred by the study participants.

Insert Figure 9 Here

DISCUSSION

A review of the archival literature revealed little quantitative information regarding the ergonomics of handsaws. Arborist handsaws pose a particularly interesting study because of the dynamic nature of the environment in which these activities are performed and the varied heights (and resulting upper extremity postures) that are employed to accomplish the task. Arborist handsaws remove material on the pull stroke of the sawing motion which activates many of the flexor muscles of the upper extremity (e.g. flexor digitorum, biceps brachii) as well as the muscles that perform transverse extension of the shoulder joint (posterior deltoid, latissimus dorsi, infraspinatus). The current study was undertaken to provide quantitative biomechanical data on the effects of saw design and work height.

The evaluation of the effects of specific saw characteristics is challenging in this study because the experiment was not a complete factorial design of the various characteristics of the saws (handle angle, handle length, tooth size, folding vs. non-folding, etc.). The evaluations of the effects of the independent variable "SAW" are limited to the totality of the characteristics of the individual saws. While there were statistically significant effects of SAW, the magnitude of the differences between saws and the inconsistency in the trends as a function of the individual characteristics (Figures 4 and 5) lead us to conclude that there was no superior saw in the group tested. It was our expectation that the inclusion of a finger hook at the base of the saw would provide an opportunity for reduced need for hand grip force (Cacha, 1999), and while one of the saws with such a finger hook (Saw #3) did show a slight reduction in flexor digitorum activity, this characteristic did not produce this effect in all such saws (Saws #1, #2 and #5). Likewise the degree of handle angle did not show a consistent significant effect on the muscle activity profiles. Saws #4 and #6 both had the handles with the least amount of bend and the highest levels of the flexor digitorum activity, but this was not significantly greater that Saw #2, which did have a bent handle. In terms of the wrist angles at the beginning and ending of the stroke, there were significant differences (Table 2) as a function of SAW and most of these effects followed closely the expectations. Saws that had a significant bend to their handle (Saws #1, #2 and #5) showed less ulnar deviation at all positions than those that did not (Figure 7). These results are consistent with the basic premise of the bent handled tools – that, under the correct task conditions, they are able to reduce ulnar deviation (Tichauer, 1973; Schoenmarklin and Marras, 1989a). Further, the relatively simple, single-plane motion of the sawing task does not require significant off-plane motions that have been suggested (e.g. Dempsey and Leamon, 1995; Duke et al., 2004) as reasons why many bent-handled tools have not become the norm in industrial environments. The bent handle on the arborist saw appears to provide nothing but a benefit to this activity.

The effects of sawing height were pronounced but did not always follow initial expectations. Specifically, from a muscle activation perspective there was an interesting tradeoff between the biceps muscles and the posterior deltoid as a function of sawing height. The activation levels of the posterior deltoid were reduced and the activation levels of the biceps muscles were increased at the higher positions (Figure 6). This response can be explained by the fact that the saws were cutting on the pull stroke of the sawing action and the participants were applying a pull down (biceps at the higher locations) vs. a pull back (deltoid at the lower location). The effect of height on wrist angle is not as clear as it often is for other handtools because the orientation of the saw blade does not need to remain horizontal, but can instead be adjusted to be a more vertical orientation without any negative impact on performance. This explains the relatively modest (2-3 degree) differences in wrist angle across these different work heights.

Finally, the relationship between the subjective assessment data and the data describing the time to complete the sawing task provided some interesting insight. Specifically, the saws that performed with the quickest time to complete (Figure 7) were also the ones that were the more highly rated by the participants (Figure 9). These results correspond well with the previously cited work of Kuijt-Evers et al. (2007) that indicated that performance was the most highly valued characteristic of hand saws. It was observed that as the distance between the hand and the blade increased, stability and accuracy of the sawing action decreased and this may be an important source of the more negative subjective response received by Saw #3. Another saw blade characteristic that might have influenced this response is the blade stiffness, but this was not controlled or measured in the current study. It should be noted that the participants in this study were not experienced arborists and this may have influenced the subjective assessment and the techniques employed to perform the task.

CONCLUSIONS

This study has provided some quantitative data describing the effects of arborist handsaw design and sawing height on the biomechanical responses of the upper extremity, on productivity, and on the subjective evaluation of the user. Our results showed only small differences in the biomechanical responses among the saws but showed significant effects on subjective responses and productivity – with those saws that showed high levels of productivity also showing the better subjective assessments. The effects of work height showed an interesting tradeoff between the muscle groups used to perform the sawing task where the biceps muscles showed greater utilization at the shoulder height work positions (20% greater than elbow height) and the deltoid muscles being employed to a greater extent at near elbow height levels (21% greater than shoulder height). Future studies can provide more design-focused information with regard to saw characteristics by employing a full factorial design that will allow for statements to be made about specific saw characteristics and their impact on the biomechanical and subjective variables.

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TABLES

Table 1. Results of the MANOVA and ANOVA for the EMG data

	MANOVA	FD	ED	BL	BS	DT	IS	LD
SAW	F=3.23 p<0.001	F=3.16 p=0.009	F=1.56 p=0.173	F=3.89 p=0.002	F=1.26 p=0.281	F=9.96 p<0.001	F=2.88 p=0.015	F=4.11 p=0.001
HEIGHT	F=8.83 p<0.001	F=0.06 p=0.947	F=12.22 p<0.001	F=13.60 p<0.001	F=4.43 p=0.013	F=25.88 p<0.001	F=3.58 p=0.029	F=4.30 p=0.014
SAW*HEIGHT	F=0.69 p=0.974	*	*	*	*	*	*	*

Table 2. Results of the MANOVA and ANOVA for the ulnar deviation and time to complete data

	MANOVA	WAs	WAe	Time
SAW	F=11.39 p<0.001	F=17.10 p<0.001	F=7.96 p<0.001	F=12.65 p<0.001
HEIGHT	F=4.56 p<0.001	F=3.73 p=0.025	F=6.50 p=0.002	F=6.88 p=0.001
SAW*HEIGHT	F=0.701 p=0.8846	*	*	*

FIGURES

Figure 1. Arborist Saws used in the study.


Figure 2. Experimental apparatus.

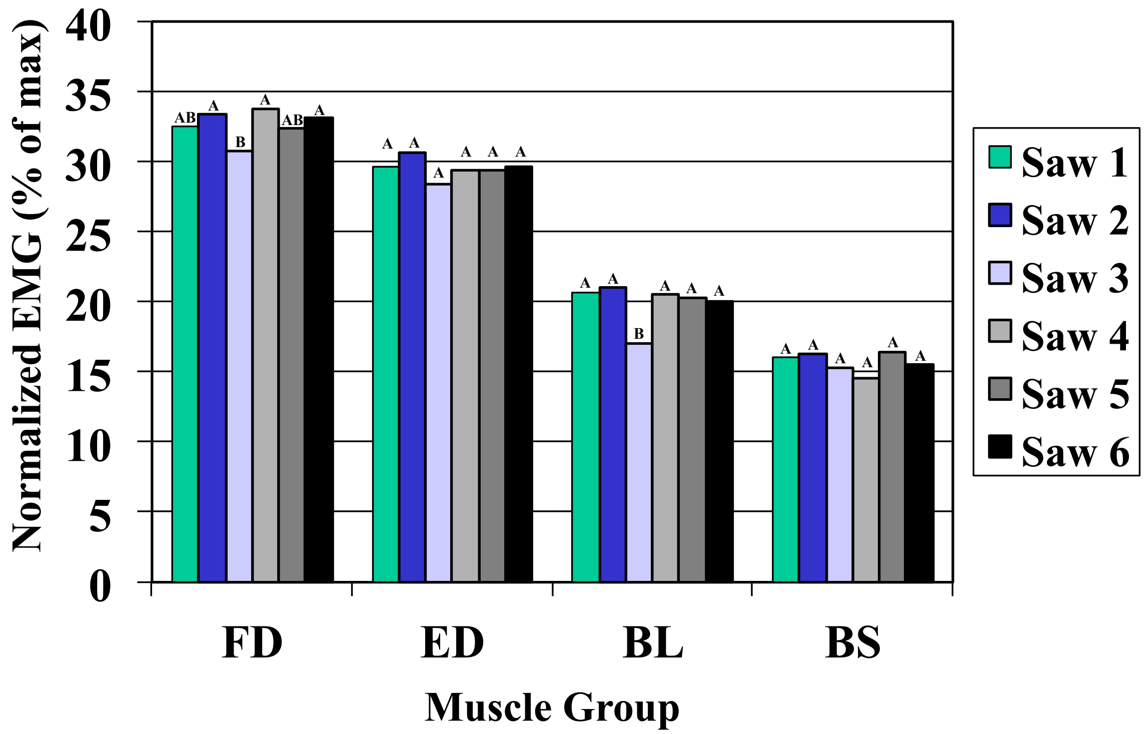

Figure 4. Normalized EMG of the muscles of the arm and forearm as a function of SAW (bars with the same letter are not statistically significantly different).

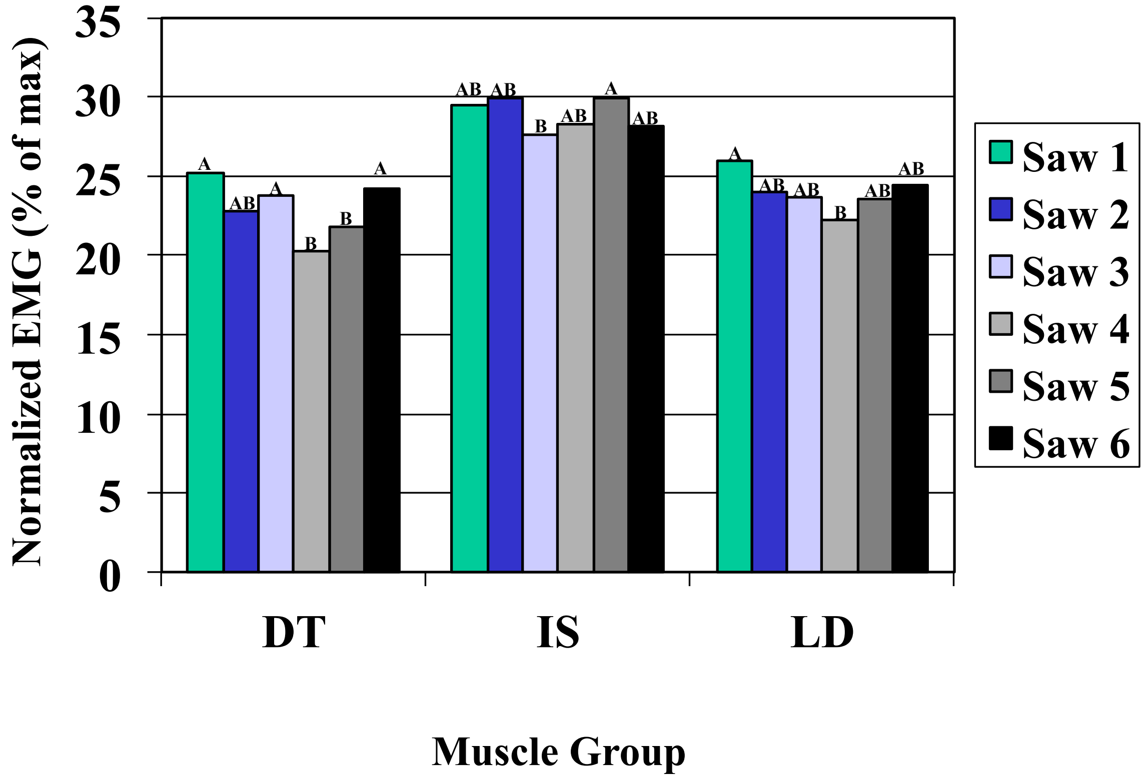

Figure 5. Normalized EMG of the muscles of the shoulder/upper back as a function of SAW (bars with the same letter are not statistically significantly different).

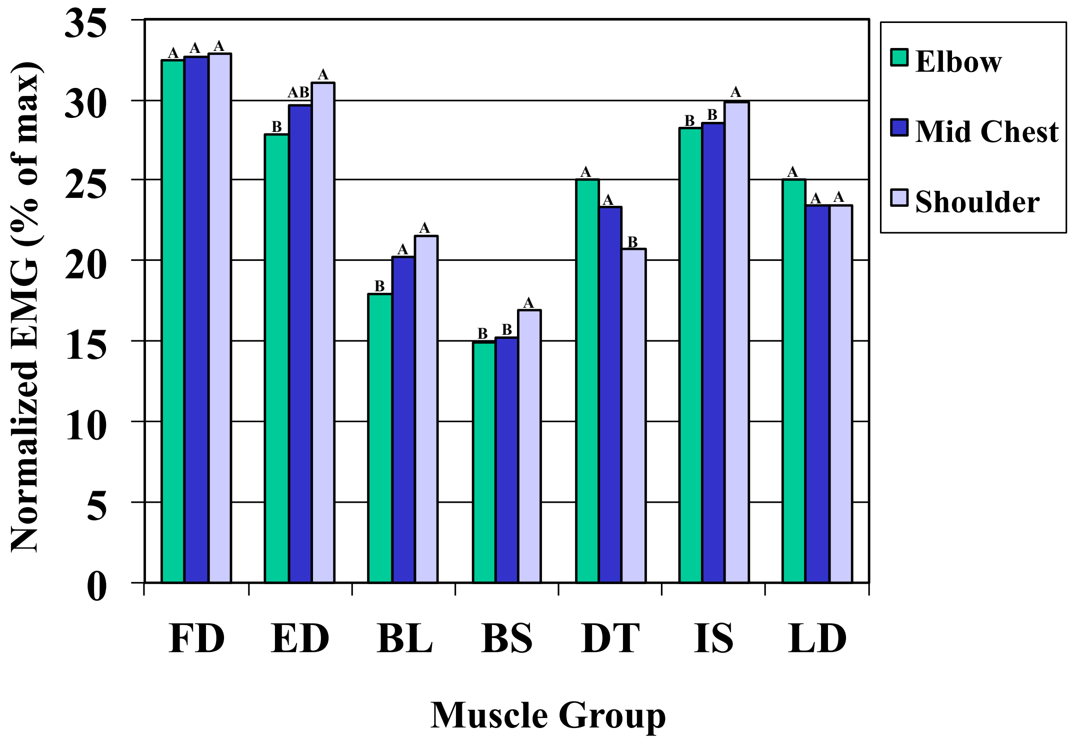

Figure 6. Normalized EMG as a function of HEIGHT (bars with the same letter are not statistically significantly different).

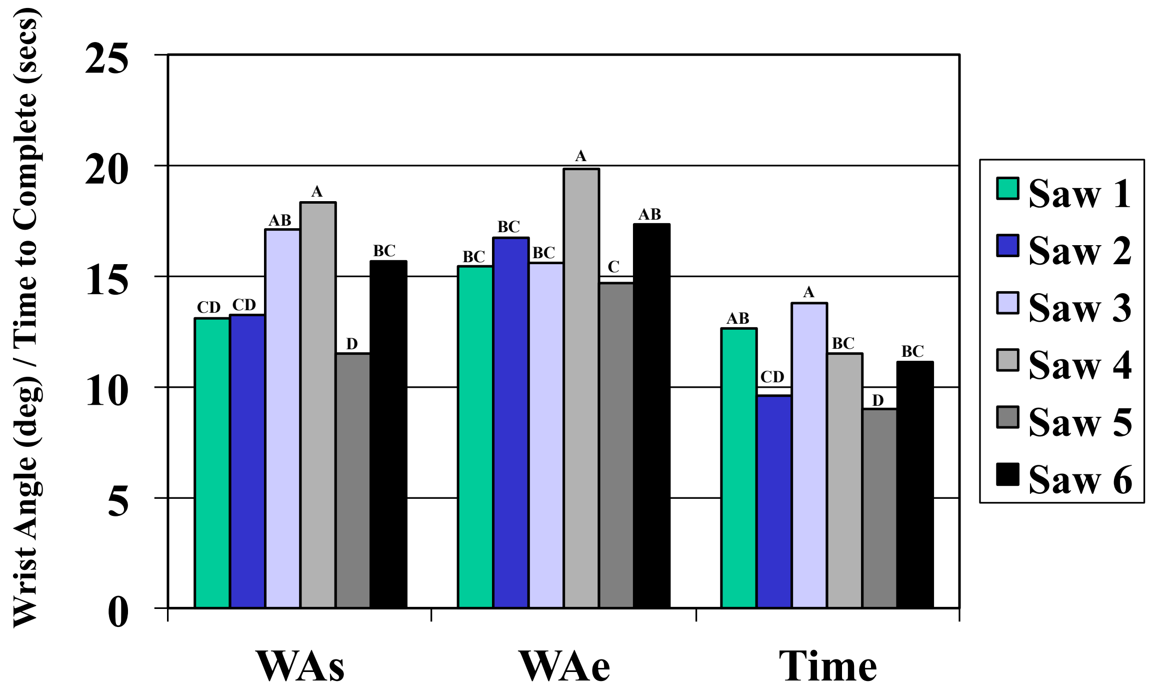

Figure 7. Ulnar deviation and Time to complete as a function of SAW (bars with the same letter are not statistically significantly different).

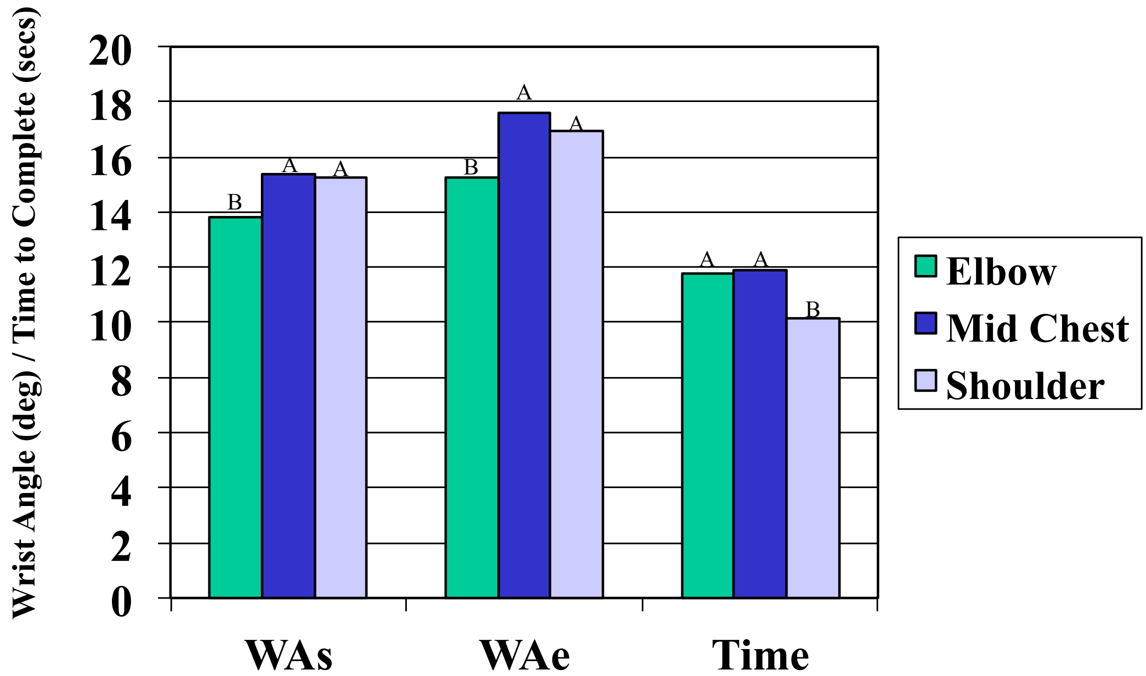

Figure 8 Ulnar deviation and Time to complete as a function of HEIGHT (bars with the same letter are not statistically significantly different).

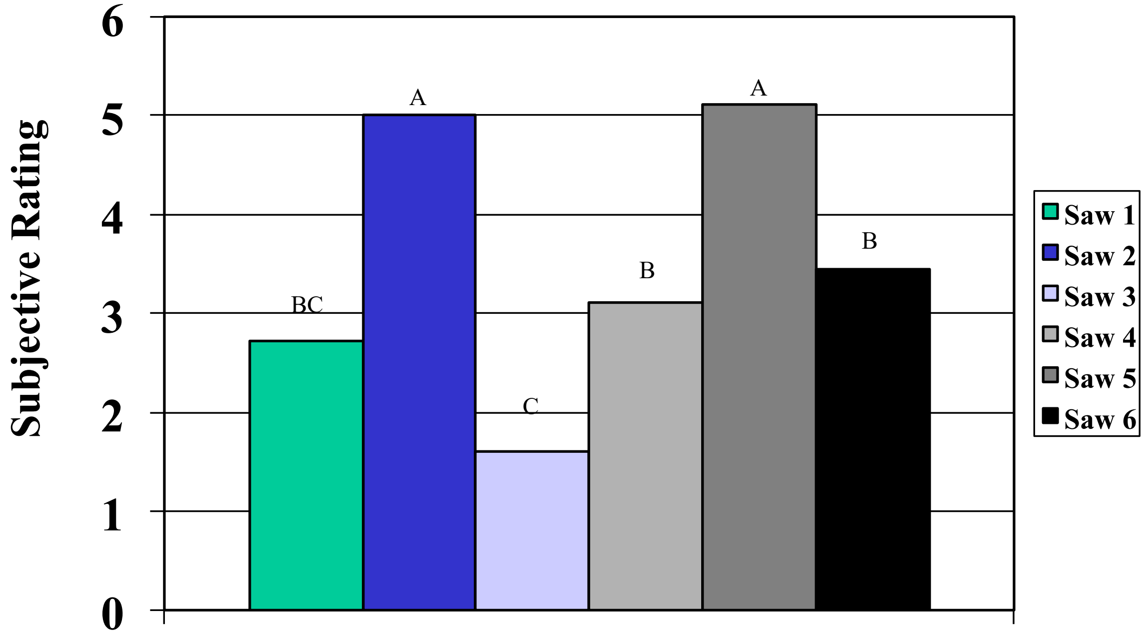

Figure 9 Subjective rank ordering of the saws. Higher number means a more positive assessment (bars with the same letter are not statistically significantly different).