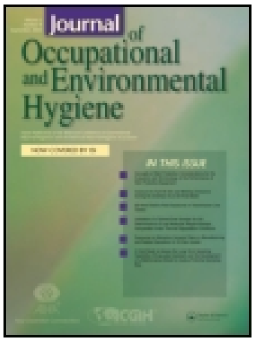

Journal of Occupational and Environmental Hygiene

ISSN: 1545-9624 (Print) 1545-9632 (Online) Journal homepage: http://www.tandfonline.com/loi/uoeh20

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To cite this article: Dan Anton , Fredric Gerr , Alysha Meyers , Thomas M. Cook , John C. Rosecrance & Jonathan Reynolds (2007) Effect of Aviation Snip Design and Task Height on Upper Extremity Muscular Activity and Wrist Posture, Journal of Occupational and Environmental Hygiene, 4:2, 99-113, DOI: 10.1080/15459620601117087

To link to this article: https://doi.org/10.1080/15459620601117087

Published online: 30 Oct 2007.

Journal of Occupational and Environmental Hygiene, 4: 99–113
ISSN: 1545-9624 print / 1545-9632 online

DOI: 10.1080/15459620601117087

Effect of Aviation Snip Design and Task Height on Upper Extremity Muscular Activity and Wrist Posture

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Hand tools described as ergonomic in design are intended to reduce exposure to physical risk factors associated with work-related musculoskeletal disorders. Additionally, using the right tool for the job is believed to reduce exposure and, consequently, risk of disease. Sheet metal workers frequently use a cutting tool called aviation snips when fabricating and installing ductwork. The purpose of this laboratory simulation study was to determine the effect of (1) aviation snip design; and (2) work height on muscle activity, wrist posture, and user satisfaction among sheet metal workers. We hypothesized that specific aviation snips designs would be most appropriate for use at specific heights. Twenty-three sheet metal workers used three different designs of aviation snips to make curved cuts in sheet metal placed both at waist height and shoulder height. Conventional circular snips, straight snips, and an alternate design of offset snips were used. Upper extremity muscle activity was measured with surface electromyography, wrist posture was measured with electrogoniometry, and user satisfaction was rated by the participants on a survey. Statistically significant effects of snip design and task height on muscle activity, wrist posture, and user satisfaction were observed. However, no snip was preferable for all dependent variables. Work height had a greater effect on muscle activity and wrist posture than snip design. Field studies are indicated to determine the long-term effect of snip design on physical risk factors and risk of musculoskeletal disorders.

Keywords construction, ergonomics, hand tools, intervention effectiveness, musculoskeletal disorders

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INTRODUCTION

Forceful exertions, extreme postures, and repetitive use of the hands are known risk factors associated with upper extremity musculoskeletal disorders.(1,2) Use of hand tools in industry may increase exposure to these risk factors, and hand tools have been associated with pain, injury, and disability.(3) For this reason, some manufacturers now describe their hand tools as "ergonomic" in design. Presumably, users of an ergonomic hand tool experience reduced exposure to physical risk factors when compared with users of nonergonomic tools. However, the accuracy of this claim has rarely been tested empirically. In addition to using ergonomic tools, exposure to risk factors may also be reduced by adhering to the maxim "use the right tool for the job." However, few studies have examined the effect of using the supposed "wrong tool" on exposure to physical risk factors.

Among all occupational groups, the construction industry accounts for the fourth highest number of sprains and strains with days away from work.(4) Among construction workers, use of hand tools has been associated with musculoskeletal complaints and disorders. For example, construction workers using hand tools for more than 3 hours per day had five times the prevalence of carpal tunnel syndrome compared with construction workers using hand tools for 1 hour or less.(5) Sheet metal work is a construction trade that is hand intensive and requires frequent use of hand tools, including snips, hammers, and screwdrivers. Approximately 30–50% of sheet metal workers complain of musculoskeletal symptoms of the hand and wrist.(68) Among all construction trades, sheet metal workers are second only to cement masons in complaints involving the hand and wrist.(7)

A frequent field task of sheet metal workers is the fabrication of ductwork at floor and waist height, as well as the installation of ductwork in overhead positions.(9) To accomplish these tasks, workers cut sheet metal with *aviation snips*. Sheet metal workers typically own three pairs of snips: one for cutting curves to the left (used in the right hand), one for cutting curves to the right (used in the left hand), and one for cutting in a straight line (usually used in the right hand). Although three different snip designs are available, sheet metal workers, as

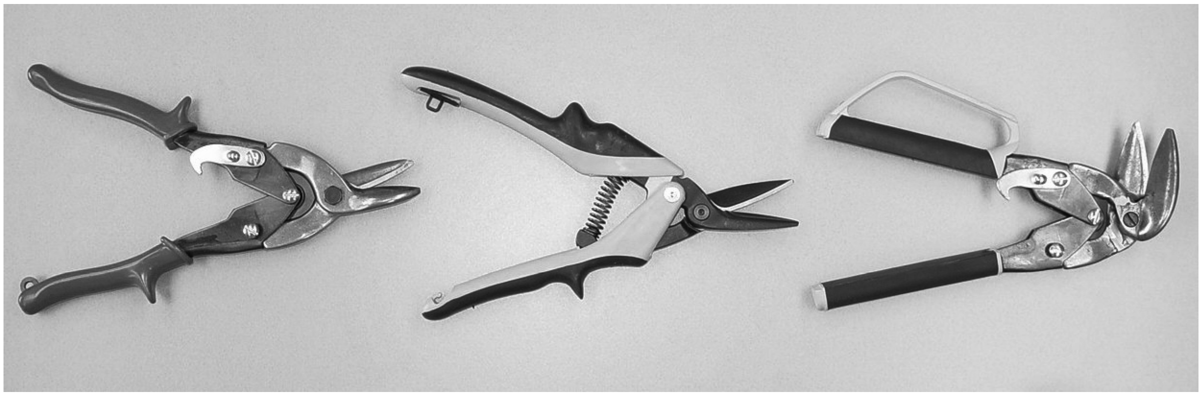

FIGURE 1. Circular, straight, and offset aviation snips (left to right).

well as other construction workers, often use whatever tool is most convenient at that time. For example, sheet metal workers installing or modifying ductwork while on a ladder may use a straight snip to cut curves instead of descending the ladder to obtain a curved snip. Thus, they may use the “wrong tool” in certain circumstances. However, the effect of using the wrong tool has rarely been evaluated, and it is unknown whether changes in exposure to physical risk factors result.

The installation of ductwork often requires sheet metal workers to reach above shoulder height to access the top surface of existing duct. Recently, an alternate design of aviation snip was developed for the stated purpose of making access easier to confined spaces or for other applications in which overhead cutting of sheet metal was necessary. Unlike commonly used snips with the cutting blades offset approximately 45° from the handle, the blades of the recently designed snips are offset 90° from the handle (Figure 1). Although convenience/access was the primary design consideration of the 90° offset snips, they may provide ergonomic benefits as well, including a more neutral wrist posture and concomitant reduction in forceful exertions of the distal upper extremity muscles. Reduction in distal muscle activity may also be associated with reduced activity of the proximal stabilizing muscles of the upper extremity. However, there is no evidence that the snip provides any ergonomic advantage in applications with the shoulder elevated. Indeed, it is unknown whether the offset snip is best used in applications with the shoulder elevated or at other work heights.

The purpose of this laboratory study was to compare muscle activity, wrist posture, and user satisfaction between different designs of aviation snips. Specifically, conventional aviation snips (designed for making circular cuts), straight cutting snips, and the newly designed offset snip were evaluated among sheet metal workers performing circular cutting tasks at shoulder height and at waist height. We hypothesized that, at shoulder height, use of the 90° offset snips would result in a more neutral wrist posture and reduced upper extremity muscle activity than use of the other two snips at shoulder height. We hypothesized that, at waist height, cutting with the circular snips would be preferable to the other snips in terms of a more neutral wrist posture, reduced upper extremity muscle activity, and greater user satisfaction. Finally, we hypothesized the straight snips would clearly be the wrong tool as evidenced with increased upper extremity muscle activity, more extreme postures of the wrist, and lower preference among sheet metal workers.

METHODS

Subjects

Twenty-three male sheet metal workers participated in this intervention effectiveness study. All participants were third or fourth year apprentice-level (or journey-level) sheet metal workers experienced with cutting sheet metal with aviation snips. This sample size provided approximately 80% power of finding a medium effect size of 0.35. A convenience sample of participants was recruited at a local sheet metal worker training center. All interested sheet metal workers were given the opportunity to participate. Although approximately 4% of sheet metal workers are female,[10] none volunteered for this study. The mean age of the sheet metal workers was 30.2 years (SD 6.0), mean height was 1.8 m (SD 0.2), and mean body mass was 89.0 kg (SD 16.8). The sheet metal workers worked an average of 40 hours per week (SD 0.5) and 50.1 weeks per year (SD 3.4). All study participants were right hand dominant.

Exclusion criteria included a history of any musculoskeletal disorder involving the upper extremity during the 2 months prior to participation, any orthopedic surgery of the upper extremity, wrist fracture, or rheumatoid arthritis. The Institutional Review Board at the University of Iowa approved the study and participants provided written consent. Participants were compensated monetarily for participating in the study.

Electromyography and Normalization

Surface electromyography (EMG) was sampled from study participants while cutting sheet metal with aviation snips in a standard manner. Electrodes were placed using standard locations for the dominant-side flexor digitorum superficialis, extensor digitorum, and upper trapezius.[11] Although the forearm electrode locations are specific to these muscles, they are subsequently described as the flexor forearm (flexor digitorum superficialis) and the extensor forearm (extensor digitorum). Excess muscle activity may be in the causal pathway of various musculoskeletal disorders.[12,13] The muscles that were evaluated were chosen for their potential association with disorders such as carpal tunnel syndrome, epicondylitis, and trapezius myalgia, all commonly reported disorders among sheet metal workers.[6,8,14]

The electrodes had dual 8 mm diameter, bipolar, silver-silver chloride surfaces, an interelectrode distance of 22 mm, and on-site preamplification with a gain of 35 (E.Q. Inc., Chalfont, Pa.). The electrodes were attached to a differential amplifier/processor module (EMG-67, Therapeutics Unlimited, Iowa City, Iowa) with a bandwidth of 40 Hz to 4 kHz (two-pole Butterworth filter), common-mode rejection of 87 db at 60 Hz, and 55 m/sec time constant. For each subject, the gain was adjusted between 500 and 10,000 to prevent saturation of the signal. Muscle activity was collected as real-time root-mean-square (RMS) EMG at a 100 Hz sampling rate. The amplifier module was connected to an analog-to-digital data acquisition interface (1401 plus, Spike 2 v. 3.21, Cambridge Electronic Design, Cambridge, England) affixed to a personal computer.

All RMS EMG obtained during the tasks was normalized to the myoelectric activity obtained during submaximal reference voluntary contractions (reference voluntary electrical activity or %RVE).[15] For normalization of the flexor and extensor forearm muscles, participants were instructed to grip a digital hand dynamometer (GripTrack; J-Tech Medical, Salt Lake City, Utah) with a 9.1 kg force (observed on the digital display) with their arm in a standard position.[16] For all participants, the handle of the dynamometer was maintained at grip position 2 (second closest to the fixed handle). For normalization of the upper trapezius muscle, participants abducted their shoulders to 90° in slight horizontal flexion, i.e., abduction in the plane of the scapula.[17] A 2-kg weight was attached to their wrists.[18] Each normalization contraction was held for 15 sec with the middle 10 sec used for analysis. Participants repeated each normalizing contraction three times, with the mean value used for %RVE. To minimize the effects of fatigue, participants rested for 2 min between all normalizing contractions. Resting EMG was recorded and subtracted from myoelectric activity obtained during the normalizing contractions and tasks.

Electrogoniometry and Calibration

A standard, twin-axis wrist electrogoniometer (SG65, Biometrics, Ltd.; Ladysmith, Va.) was used to measure wrist motion during the cutting tasks. Due to an equipment malfunction, wrist motion was measured for only 17 of the 23 participants. The end blocks of the electrogoniometer were affixed to the dorsum of the subject's dominant hand and distal forearm with double-sided medical tape using standard procedures.[19] The leads were connected to a force/pressure module (FPM-544, Therapeutics Unlimited) attached to the same data acquisition interface used for EMG, and the sampling rate was 100 Hz.

There are multiple methods of calibrating electrogoniometers to a study participant, including taking a single measurement while the individual's wrist is maintained in a neutral posture,[20] measuring only maximum active wrist angles,[21,22] or taking multiple measurements in combinations of wrist extension/flexion and radial/ulnar deviation.[23–26] To minimize the time burden on the sheet metal workers in the current study, seven wrist postures were used to calibrate the electrogoniometer separately for each participant. Voltage output was sampled while the participant's wrist was positioned in a jig placed in 0° (neutral), 15° and 45° flexion, and 15° and 45° extension while in neutral radial/ulnar deviation. In a similar manner, the hand was positioned in 15° ulnar and radial deviation while in neutral extension/flexion. Separate linear regression equations were developed to predict wrist angle from voltage output.

Snip Satisfaction Survey

Immediately after the experimental trials, all participants were asked to complete a survey that included a rating of satisfaction with each of the snips based on several characteristics. These characteristics included handle softness, shape, size, grip span, maneuverability of the tool, cutting productivity, and force required to cut. The characteristics were rated on a 0–10 scale (Poor – Excellent). Additionally, the participants reported their preferences among snips and indicated whether they would purchase them.

Aviation Snips

Three designs of aviation snips were used in this study: circular, straight, and 90° offset (Figure 1). These snips met the American Society of Mechanical Engineers standard for shears (ASME B107.16M-1998). The circular snip was designed to cut curves in sheet metal. The straight snip was designed to cut only straight lines and was used as the positive control for trials requiring curved cuts. The offset snip was also designed to cut curves and was originally developed to allow easier access to ductwork at or above shoulder height. The circular snip weighed 419 g, the straight snip 371 g, and the offset snip 506 g. Maximum grip span, measured between the point where the second digit was placed on the snips to the point where the web space of the thumb contacted the snips, was approximately 10 cm for the circular and straight snips, and 9 cm for the offset snips. All snips had a spring-loaded mechanism with similar tension to assist in handle opening.

Circular and offset snips are available in right- or left-handed models. Straight snips are designed only for use in the right hand. Thus, all study participants used right-handed snips.

Experimental Procedure

Participants were instructed to make curved cuts to the left in sheet metal with each of the three aviation snips, at two different work heights. Sections of 22 gauge sheet metal,

FIGURE 2. Sheet metal worker using a circular snip to perform the cutting task with fixture positioned at waist height

measuring 30.5 × 30.5 cm, were scribed with a 15.2 cm diameter circle, and a 2.5-cm hole was predrilled in the center of the circle to allow access for the blade tips. The section of sheet metal was clamped horizontally to a fixture that was adjustable vertically. For each subject, the fixture was placed at the height of the subject's anterior superior iliac spine and separately at the height of the acromioclavicular joint. These placements simulated typical sheet metal cutting tasks conducted in the shop at waist height (Figure 2) and in the field at shoulder height (Figure 3).

After the instrumentation was attached, participants were instructed to practice with each snip at each fixture height until comfortable (self-report) with their use. Using one of the snips, the participant positioned the tips of the snip into the center hole, cut from the center hole to the scribed circle, and then around the scribed circle in a counterclockwise direction. Participants were instructed to perform each trial at a typical work pace and were told that it was not a race. Subsequent cutting trials were performed in a similar manner with a 2 min rest between each trial. Participants performed all six cuts (two work heights × three snip designs) in a counterbalanced order (i.e., no participant performed the six cuts in the same order). For data quality purposes, all trials were videotaped and synchronized with the EMG and electrogoniometer data. After completing all trials, participants completed the satisfaction survey.

The following variables were evaluated to examine the effects of snip design and work height: (1) mean RMS amplitude of EMG (%RVE); (2) mean wrist posture (degrees), (3) maximum wrist flexion and extension (degrees), (4) the percentage of time spent in wrist flexion and extension >45°, and (5) the percentage of time spent in radial and ulnar deviation > 20°. Additionally, the distribution of wrist posture in various posture categories (% time) was determined. For both flexion and extension, five wrist posture categories were defined *a priori*: >45°, >30° to 45°, >15° to 30°, and neutral (15° flexion to 15° extension). For wrist ulnar and radial deviation, two wrist posture categories were defined *a priori*: >20° and neutral (20° radial deviation to 20° ulnar deviation). Comparable postural boundaries have been used by other investigators.[27–29] Because a torsiometer was not used in this study, wrist angles were not corrected for crosstalk.

Mean RMS amplitude of the EMG signal was calculated separately for each muscle group. The EMG and electrogoniometry data used for the analysis was limited to the time period that began when the cut reached the scribed circle and ended when the scribed circle was completely cut.

FIGURE 3. Sheet metal worker using the offset snip to perform the cutting task with fixture positioned at shoulder height

Task time was collected to allow for assessment of learning effects.

Statistical Analysis

Univariate analyses, and tests of assumptions of normality and sphericity, were conducted for the EMG and electrogoniometer data. Extreme outliers in the normalized EMG and electrogoniometer data were defined *a priori* as those with z-scores greater than 2.58 ($p < 0.01$, two-tailed). Outliers were recoded to a value of one unit greater than (or less than) the next most extreme value.[30]

Two-way mixed repeated measures analyses of variance (RANOVA) were used to test for significant changes in mean EMG amplitude for each muscle group separately, and for the electrogoniometer measures separately with fixture height and aviation snip design as independent variables. Height of the fixture was a within-subjects factor with two fixed levels: waist and shoulder. Aviation snip design was also a within-subjects factor with three fixed levels: circular, straight, and offset. The interaction between fixture height and snip design was a fixed factor, and participants was the random effect. The Mauchly test was used to test the sphericity assumption and the Huynh-Feldt epsilon estimate was used if this assumption was violated. Because a circular snip is typically used to cut curves in sheet metal, where appropriate, the offset and straight snips were compared separately with the circular using nonorthogonal contrasts. If the interaction was not statistically significant, nonorthogonal main effects contrasts were used to determine whether the straight snip or the offset snip differed appreciably from the circular snip. The α level was 0.05 for each muscle group and electrogoniometer variable separately, with $p \leq 0.008$ used as the Bonferroni adjustment. Analyses were conducted with SPSS 12.0.1 (SPSS Inc., Chicago).

TABLE I. Means (SD) of the EMG Amplitudes (n = 23) and Wrist Postures (n = 16)

	Circular Snips		Straight Snips		Offset Snips	
Variable	**Waist**	**Shoulder**	**Waist**	**Shoulder**	**Waist**	**Shoulder**
Muscle Activity						
Flexors (%RVE)	176.3 (77.6)	126.0 (55.1)	219.0 (109.0)	169.2 (85.4)	163.6 (91.7)	112.8 (46.9)
Extensors (%RVE)	292.7 (130.2)	289.0 (116.9)	262.1 (115.3)	309.8 (131.6)	257.0 (137.7)	316.4 (178.4)
Trapezius (%RVE)	173.7 (74.7)	215.8 (129.6)	200.0 (85.2)	227.4 (159.1)	51.2 (43.4)	315.4 (179.7)
Wrist Posture						
Extension/flexion ((−/+°)	24.2 (9.8)	–9.6 (21.1)	10.9 (11.5)	–8.2 (18.0)	–5.6 (18.1)	–18.0 (14.3)
Radial/ulnar (−/+°)	11.8 (13.7)	–4.1 (11.4)	11.7 (12.6)	0.8 (13.0)	–16.5 (7.7)	–4.8 (9.4)

Note: Negative values are extension or radial deviation; positive values are flexion or ulnar deviation.

Friedman two-way analysis of variance by ranks was used to test for significant differences in responses on the satisfaction survey for each snip characteristic separately. When statistically different responses were found, multiple comparison procedures were used to test for all pairwise differences with a family-wise α level of 0.05.[31] Descriptive statistics were calculated for the reported preferences among snips and purchase indications. Analyses were conducted with NCSS 2000 (NCSS, Kaysville, Utah).

RESULTS

Based on task time, there was no learning effect, since there was no significant effect of snip design on the time to complete the cutting task (data not shown; ($F\ \{2,46\} = 1.2$; $p = 0.32$). The shortest mean cutting times were for the straight snips at waist height (43.4 sec), and the offset snips at shoulder height (52.2 sec). However, the interaction between snip design and work height was significant ($F\ \{2,46\} = 21.1$; $p < 0.001$), with cuts at shoulder height taking an average of 14 sec longer than at waist height ($F\ \{1,23\} = 83.6$; $p < 0.001$).

Effect of Aviation Snip Design

Electromyography Results

Two EMG values met criteria as extreme outliers, one for the extensor forearm and one for the upper trapezius. Means (SD) of the RMS EMG amplitudes (%RVE) for all muscles tested are listed in Table I.

The two-way interaction between snip design and fixture height was not statistically significant for the amplitude of the dominant flexor forearm (Table II). Amplitude was significantly associated with snip design. Differences between the circular snip and the offset snip were relatively small. Significantly higher amplitudes were observed during use of the straight snip than during use of the circular ($F\ \{1,22\} = 29.0$; $p < 0.001$). Although lower amplitudes were observed while using the offset snip compared with the circular, the difference was not statistically significant ($F\ \{1,22\} = 3.3$; $p = 0.08$).

A statistically significant interaction between snip design and fixture height was observed for EMG amplitude of the extensor forearm (Table II). Because this indicates that the effect of snip on the EMG amplitude of the extensor forearm differed by fixture height, simple effects of snip design were examined for each of the fixture heights separately. No

TABLE II. Repeated Measures Analysis of Variance *F* and *p* Value Results

	Snip Design		Height		Height × Snip Design	
Variable	***F***	***p***	***F***	***p***	***F***	***P***
Muscle Group						
Flexors (%RVE)	22.2	<0.001^{A,B}	20.3	<0.001^{A}	0.002	0.98^{B}
Extensors (%RVE)	0.09	0.871	11.1	0.003^{B}	9.5	0.003^{A,B}
Trapezius (%RVE)	4.6	0.016	16.2	<0.001^{B}	48.5	<0.001^{A,B}
Wrist Posture						
Extension/flexion (−/+°)	36.6	<0.001^{A}	44.5	<0.001^{A}	9.5	0.003^{A,B}
Radial/ulnar (−/+°)	71.7	<0.001^{A}	4.5	0.05	26.9	<0.001^{A,B}

^{A}Statistically significant difference with Bonferroni adjustment (p < 0.008).
^{B}Huynh-Feldt adjusted.

significant differences in amplitudes across snip design were observed while cutting at waist height, (F {1.5,33.5} = 3.2; p =0.07; Huynh-Feldt corrected) or at shoulder height (F {1.4,30.7} = 2.0; $p = 0.17$; Huynh-Feldt corrected). Although the simple effects were not significant, nonorthogonal simple comparisons showed significantly less muscle activity while using the straight snips than the circular snips at waist height (F {1,22} = 9.6; p = 0.005), but the difference was not statistically significant at shoulder height (F {1,22} = 5.9; p = 0.02). Compared with the circular snips, less extensor forearm muscle activity was observed while using the offset snips at waist height and more activity was observed at shoulder height. However, these differences were not statistically significant.

For EMG amplitude of the upper trapezius, a statistically significant interaction between snip design and cutting height was observed (Table II). In contrast to the extensor forearm EMG, there was a significant difference in amplitudes across snip designs while making cuts both at waist height (F {1.6,35.6} = 57.2; $p < 0.001$; Huynh-Feldt corrected), and at shoulder height (F {1.7,37.9} = 16.9; $p < 0.001$; Huynh-Feldt corrected). Compared with the circular snip, significantly less trapezius activity was recorded with use of the offset snip at waist level (F {1,22} = 55.0; $p < 0.001$), whereas significantly more activity was noted when cutting at shoulder level (F {1,22} = 25.0; $p < 0.001$). Slightly more upper trapezius muscle activity was required to cut with the straight snip at waist level compared with the circular snip, though this finding was not statistically significant (F {1,22} = 7.0; $p = 0.01$).

Electrogoniometry Results

Mean (SD) wrist postures (degrees) are provided in Table I. Mean wrist extension was greatest while using the offset snip at shoulder height (18°), and mean wrist flexion was greatest while using the circular snips at waist height (24.2°). For the straight and offset snip designs, the wrist was maintained in the neutral range of extension/flexion for the majority of time at waist height (Figure 4). At shoulder height, all snips were used for the majority of time in a neutral or extended range (Figure 5).

A statistically significant interaction between snip design and fixture height was observed for wrist extension/flexion (Table II). A significant simple effect of snip design was

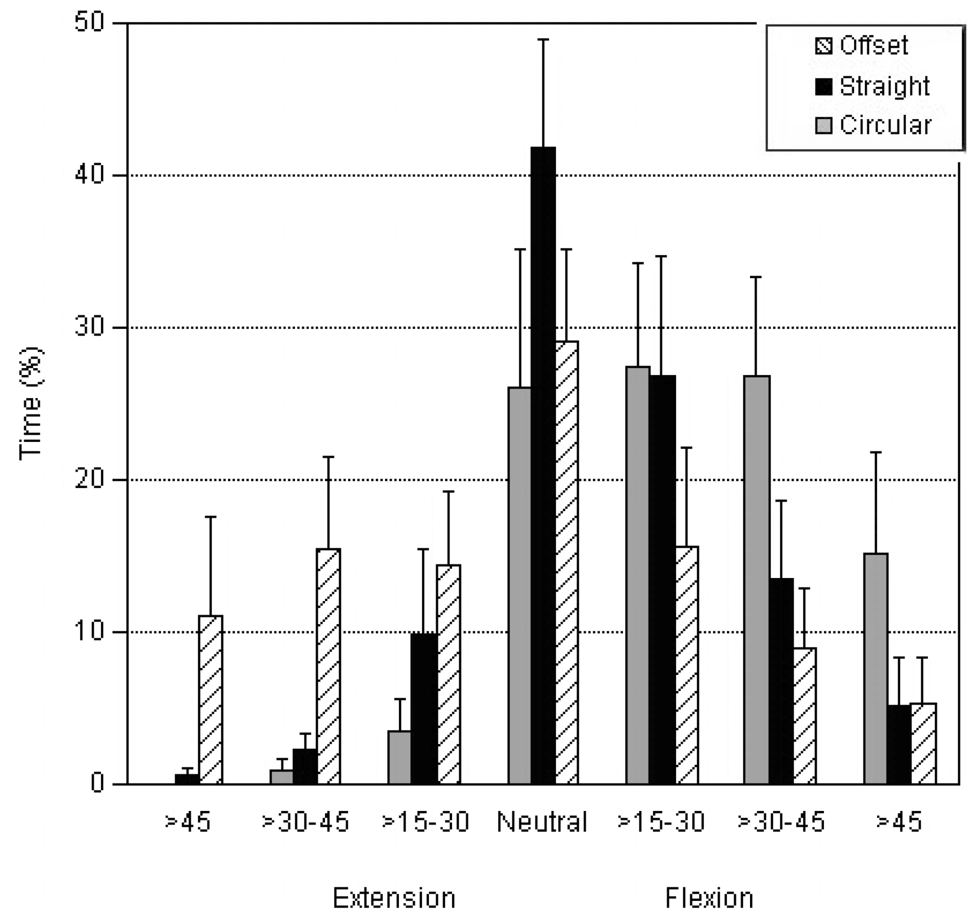

FIGURE 4. At waist height, percent time in various categories of wrist extension/flexion postures (°) across snip designs while cutting sheet metal. Error bars are 1.96 standard error. Neutral is defined as 15° extension to 15° flexion.

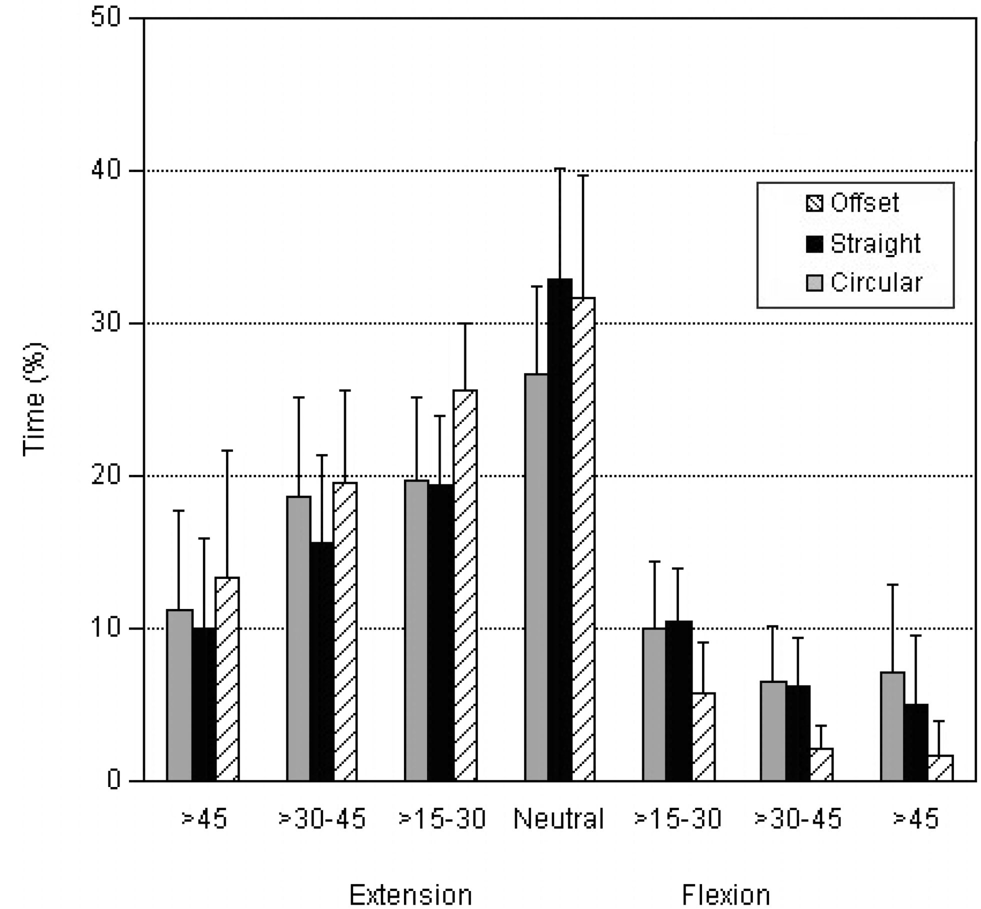

FIGURE 5. At shoulder height, percent time in various categories of wrist extension/flexion postures (°) across snip designs while cutting sheet metal. Error bars are 1.96 standard error. Neutral is defined as 15° extension to 15° flexion.

observed at waist height (F {1.3,18.7} = 34.3; $p < 0.001$, Huynh-Feldt corrected) but not at shoulder height (F {2,28} = 2.3; $p = 0.12$). When compared with use of the circular snips at waist height, a more neutral posture was maintained on average when participants used the straight snips (F {1,14} = 58.0; $p < 0.001$) or the offset snips (F {1,14} = 44.4; $p < 0.001$).

Mean wrist radial deviation was greatest while using the offset snips at waist height (16.5°), and mean wrist ulnar deviation was greatest while using both circular and straight snips at waist height (approximately 11°). For all snip designs, the wrist was maintained in the neutral range of radial/ulnar deviation for the majority of time at waist height (Figure 6) and at shoulder height (Figure 7).

Comparable with wrist flexion and extension, the interaction between snip design and fixture height was significant for ulnar and radial deviation (Table II). The simple effect of snip design was significant while cutting at waist height (F {1.2,16.7} = 88.9; $p < 0.001$; Huynh-Feldt corrected) but was not significant at shoulder height. Nonorthogonal simple comparisons indicated significantly more radial deviation while using the offset snips at waist height than the circular snips (F {1,14} = 79.8; $p < 0.001$).

Effect of Fixture Height

Electromyography Results

A statistically significant interaction between height and snip design was observed for the extensor forearm and upper trapezius EMG. The EMG amplitudes of the flexor forearm were significantly lower while cutting at shoulder height than at waist height (Table II). Simple effect analysis indicated no significant difference in amplitudes due to working height for the circular snip (F {1,22} = 0.1; $p = 0.76$). However, significantly more muscle activity of the extensor forearm was observed when cutting with the straight snip at shoulder height (F {1,22} = 25.4; $p < 0.001$), and when cutting with the offset snip at waist height (F {1,22} = 10.6; $p = 0.004$). For the upper trapezius, the interaction was also significant. More muscle activity was noted only while using the offset snip at shoulder height (F {1,22} = 56.6; $p < 0.001$).

Electrogoniometry Results

Cutting height also influenced wrist posture. When using the circular or the straight snips, there was significantly more wrist flexion at waist height than at shoulder (Circular: F {1,14} = 44.1; $p < 0.001$; Straight: F {1,14} = 22.1; $p < 0.001$;

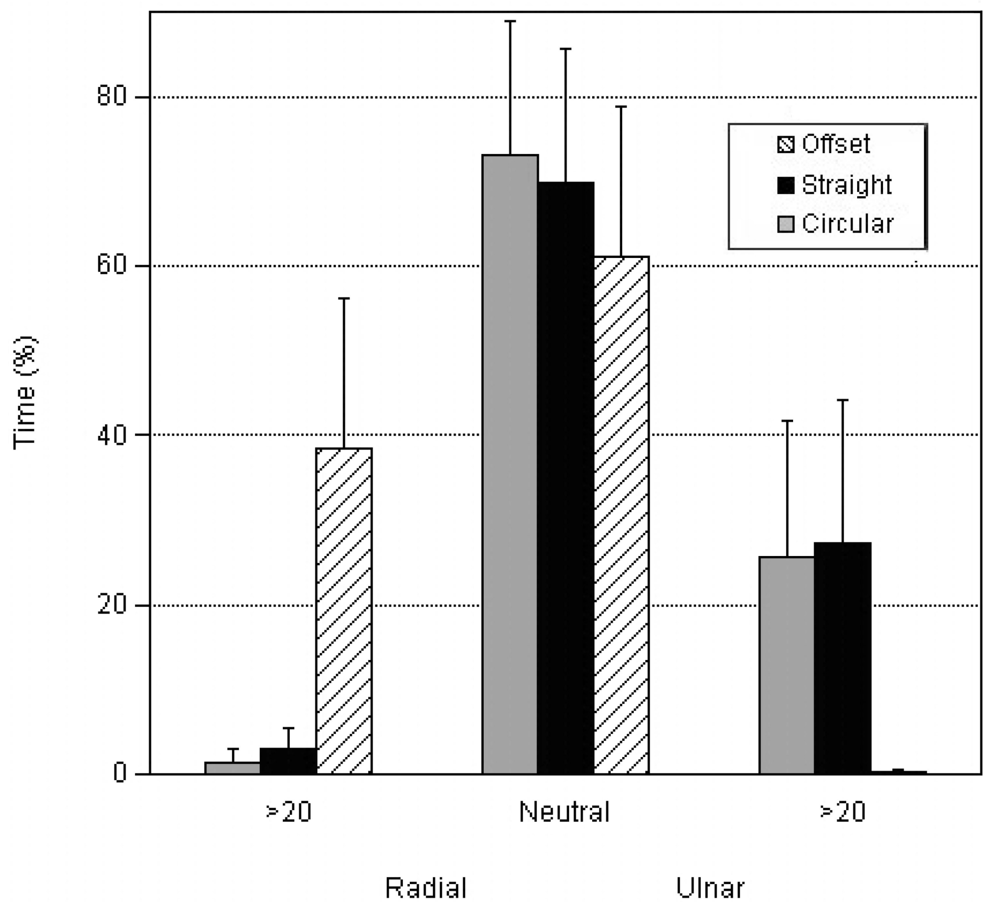

FIGURE 6. At waist height, percent time in various categories of wrist radial/ulnar deviation postures (°) across snip designs while cutting sheet metal. Error bars are 1.96 standard error. Neutral is defined as 20° radial deviation to 20° ulnar deviation.

simple effects). In contrast, more wrist extension was observed while cutting with the offset snip at shoulder height than at waist height (F {1,14} = 10.3; $p = 0.006$). Cutting with the circular or straight snip also required more ulnar deviation at waist height than at shoulder, although the difference was not significant for the straight snip (Circular: F {1,14} = 13.8; $p = 0.002$; Straight: F {1,14} = 9.8; $p = 0.007$). The offset snips once again followed a different pattern with significantly more radial deviation used at waist height than at shoulder height (F {1,14} = 47.7; $p < 0.001$).

Satisfaction Survey

For all snip characteristics, a statistically significant difference in median satisfaction ratings was observed (Figure 8; $p \leq 0.01$). Multiple comparisons indicated that the ratings for the circular and offset snips were similar for all characteristics. Additionally, no statistically significant difference between the circular and the straight snip was observed for the grip span characteristic. In general, the straight snip was consistently rated more poorly than the other two, with cutting productivity as the characteristic responsible for the greatest disparity. The median rating for productivity was 8 for the circular and offset snip, and 1 for the straight snip.

Ratings varied considerably for snip preference depending on work height. For cutting at waist height, 55% of the sheet metal workers preferred the circular snip, 36% the offset, and 9% the straight. For cutting at shoulder height, 94% preferred the offset snip, 6% the circular, and 0% the straight. The favorite snip overall was the offset snip (63%) followed by the circular (37%). In response to the question, "I would buy this snip," 64% responded yes for the circular and 86% for the offset. None of the sheet metal workers would purchase the straight snip.

DISCUSSION

The results of this study lead to the general conclusion that a specific aviation snip design is not indicated for use at waist height and another for use at shoulder height. The results from the EMG, electrogoniometry, and satisfaction survey were not always consistent. Depending on

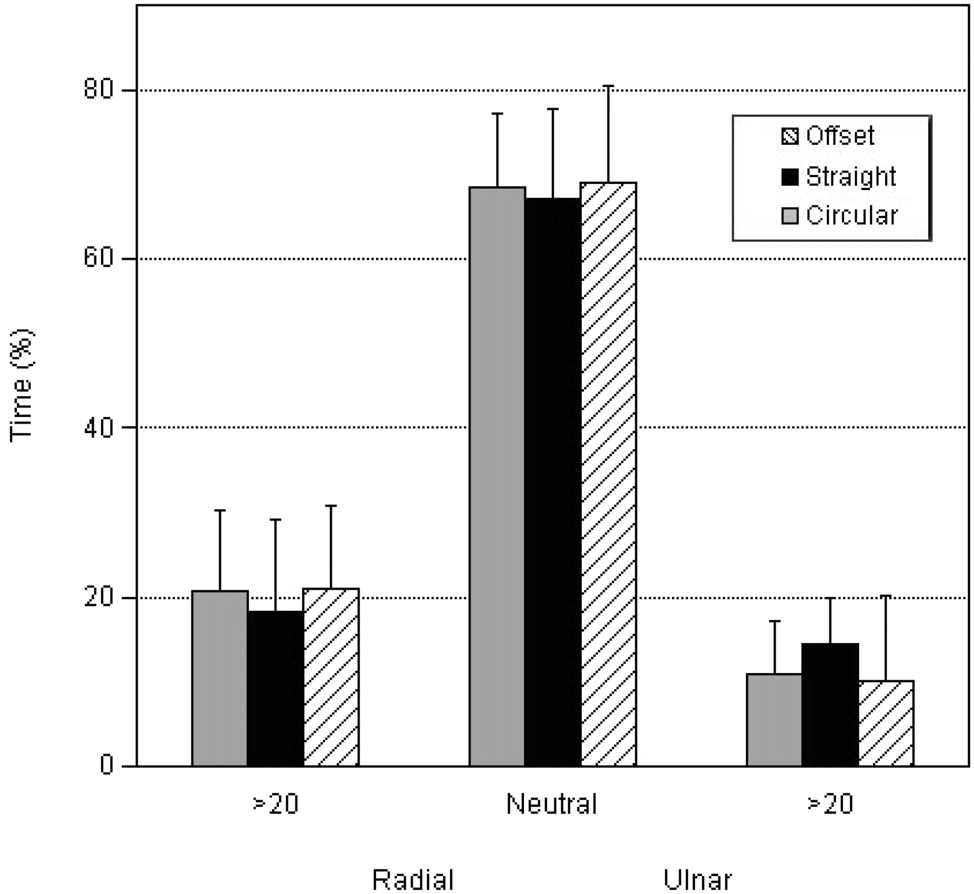

FIGURE 7. At shoulder height, percent time in various categories of wrist radial/ulnar deviation postures (°) across snip designs while cutting sheet metal. Error bars are 1.96 standard error. Neutral is defined as 20° radial deviation to 20° ulnar deviation.

the relative importance placed on the various measures used in this study, a snip could be considered appropriate or not appropriate.

In general, our hypothesis that use of the 90° offset snips would result in reduced exposure to physical risk factors at shoulder height was only partially confirmed. When compared with use at waist height, use of the offset snip at shoulder height resulted in more frequent neutral or minimally extended (15° to 30°) wrist posture (Figure 5), and slightly less EMG amplitude of the flexor forearm, although not statistically significant. If the position of function of the wrist is considered to be in approximately 15° wrist extension,[32] the mean wrist posture at shoulder height (18° extension and 4.8° radial deviation) suggests that the offset snip is appropriate for use at this height. Additionally, the sheet metal workers who participated in this study widely preferred using the offset snip at shoulder height.

Significantly more muscle activity of the extensor forearm and upper trapezius was observed among participants using the offset snip at shoulder height when compared with waist height. The highest mean activity in these two muscle groups was noted while using the offset snips at shoulder height. Thus, the benefit of a neutral wrist posture at shoulder height appears to coincide with an undesirable increase in muscle activity. Although shoulder motion was not measured, the increased upper trapezius activity was most likely due to greater shoulder elevation among participants using the offset snips compared with the other snips. Based solely on upper trapezius EMG, the offset snips may actually be more appropriate for use at waist height than at shoulder height. Upper trapezius muscle activity was significantly lower among participants using the offset snip at waist height than at shoulder height. Upper trapezius activity at waist height was also substantially lower when using the offset snips compared with using the other two snips.

Previous investigators have evaluated the ergonomic benefits of offset or bent-handled tools.[33–35] Recently, Roquelaure and colleagues[34] examined muscle activity, wrist posture, and cutting rates among four winegrowers during a pruning task. Lower mean muscle activity of the flexor forearm was reported with use of offset pruning shears compared with conventional shears, even though the differences were not statistically

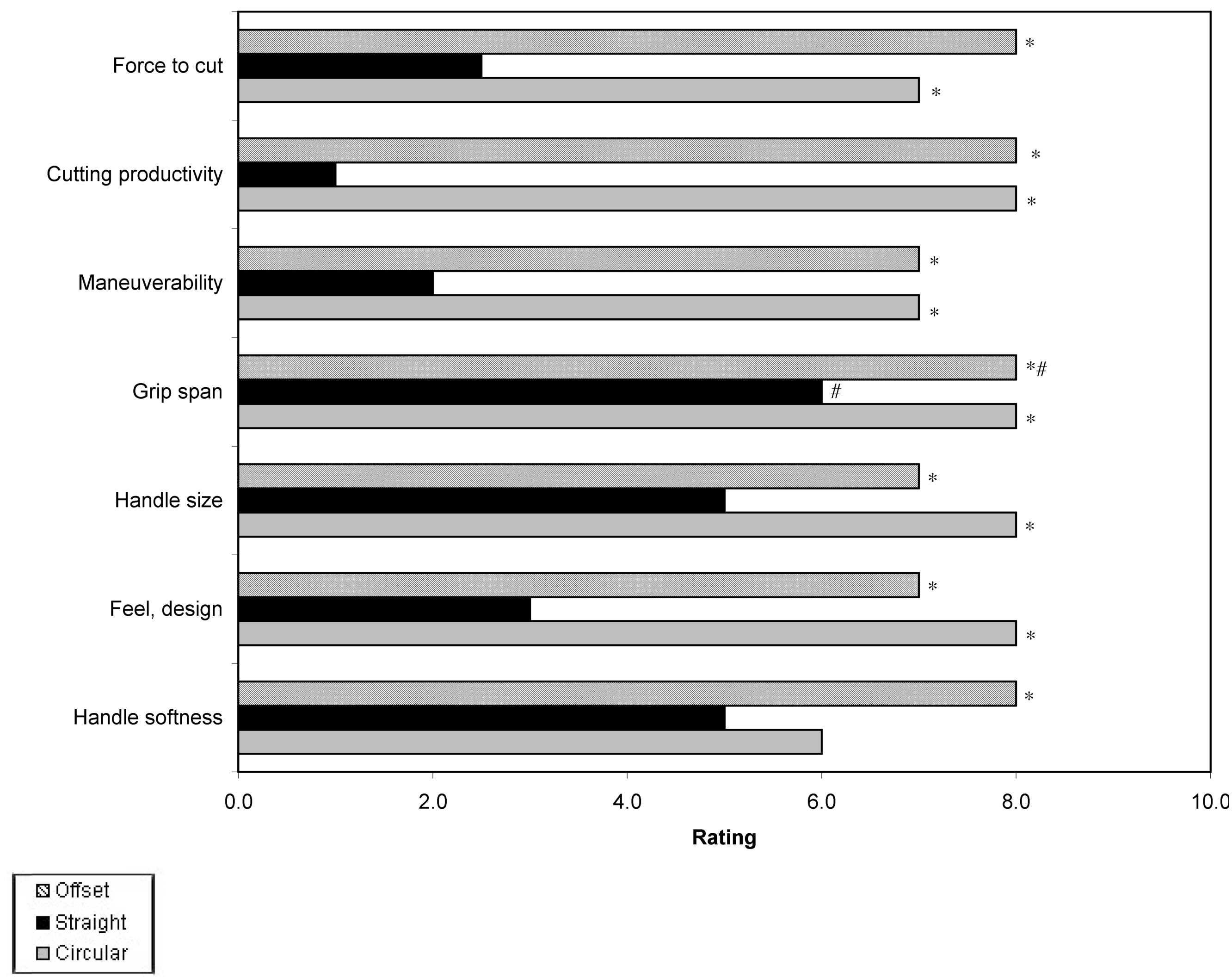

FIGURE 8. Median satisfaction ratings (0-poor, 10 = excellent) after cutting with the aviation snips at waist and shoulder height. Similar sum of ranks from Friedman's multiple comparison procedures are designated with * or #.

significant. Also comparable to results of the current study, wrist posture in the sagittal plane was closer to neutral while using offset shears.

Duke and colleagues[35] examined the effect of bent-handled pliers design and work surface orientation on wrist posture and productivity during manipulation of small parts. Ulnar deviation was reduced 12% with use of bent-handle pliers compared to conventional pliers. In contrast, we observed that the wrist was radially deviated while using the offset snips, especially while cutting at waist height (Figure 6). This apparent inconsistency is most likely due to differences in positioning of the working end of the tool. Bent-handle pliers would typically be used with the working end of the tool up, while the offset snips are used with the working end down, leading to more radial deviation if used at waist height.

The sheet metal workers preferred cutting at waist height with the circular snip compared with the other snips. However, our hypothesis was not entirely supported that use of the circular snips at waist height would result in the lowest muscle activity and most neutral wrist posture among all snip designs. While using the circular snip at waist height, flexor forearm EMG was lower than while using the straight snips. However, there was no significant difference in extensor forearm activity among the snips, despite the highest mean flexed wrist posture (24.2°) while using circular snips at waist height. It would seem that a flexed wrist posture would be associated with increased flexor forearm activity and reduced extensor forearm activity. This apparently inconsistent relationship between wrist posture and forearm muscle activity suggests that extensor forearm muscles may work as wrist stabilizers rather than primary movers during these cutting tasks, a role reported by other investigators during gripping tasks.[21] Li and colleagues[36] compared tools with substantially different designs for tying wire and, similar to the current study, found no difference in extensor forearm muscle activity.

Based on muscle activity at the two work heights and satisfaction ratings, the straight snip was generally the "wrong tool" for the job. The exception was at waist height where muscle activity of the extensor forearm was slightly lower while using the straight snips than the circular snips. Additionally, participants used a neutral posture of the wrist more frequently at waist level with the straight snip than the other snips (Figure 4). The straighter blade of the straight snips may have allowed the worker to maintain this neutral posture for a longer duration while cutting at waist height.

Parenthetically, study participants commented frequently about the difficulty cutting the curves with the straight snip, especially at shoulder height. This difficulty was evident with the significantly greater EMG amplitude of the extensor forearm while using the straight snip at shoulder height when compared with waist height. At shoulder height, it was apparent from the video that participants performed a lifting motion of the straight snips by extending their wrists to adequately separate the edges of the cut sheet metal. Qualitatively, the edges of the cut circle were more jagged for the straight snips, especially at shoulder height, as compared with the other two snips. Although experienced sheet metal workers would typically avoid using straight snips for cutting curves, inexperienced users may be unaware of the limitations of the tool and increase their susceptibility to a cut hazard from the jagged edges of sheet metal.

Cutting height had a greater effect on muscle activity and wrist extension/flexion posture than snips design. Other investigators have reported that working height has more of an effect on posture than tool design. Dempsey and colleagues[37] evaluated wrist posture and productivity of a wire-twisting task by comparing conventional pliers and bent-handle pliers used at different work heights. Work height and the interaction between work height and orientation of the work surface influenced wrist posture more than pliers design. In the current study, wrist radial/ulnar deviation posture was more affected by snips design than cutting height.

Consistent with biomechanical principles and other investigations, results from the current study indicate substantially greater muscle activity in the upper trapezius while working with the shoulder elevated. Muscle activity increased from 13% to over 500% when performing the cuts at shoulder height compared with waist height. Thorn and colleagues[38] reported increases in upper trapezius activity as high as 250% with use of a pneumatic nut-runner at shoulder height compared to hip height (90 cm from the floor). Similarly, Örtengren and colleagues[39] found greater upper trapezius muscle activity while using a power screwdriver at eye level compared with hip level. Other investigators have reported the deleterious effects of work with the arms elevated above shoulder level.[40–43]

It was somewhat surprising that mean RMS amplitude of the forearm flexor muscles was higher at waist height than at shoulder height, regardless of snip design. This relationship can be partially explained by wrist posture. The wrist was more likely to be flexed while cutting at waist height (Figure 4), a position in which grip strength is reduced.[32] It is possible that more muscle activity would have been required of the flexor forearm muscles to accomplish the same cutting task in a flexed wrist posture than with the wrist extended. Additionally, the flexor forearm muscles would have been shortened at waist height compared with shoulder height. Similarly, extensor forearm muscle activity was greater using the offset snips at shoulder height than waist height. Use of the upright snips at shoulder height resulted in greater mean wrist extension than all other conditions, which would shorten wrist extensor muscles. In general, as muscle length decreases, muscle activity increases.[44–48] However, other investigators have reported decreased muscle activity as muscle length decreases,[49] and the length of the moment arm also influences EMG amplitude.[48]

It is generally recommended that a neutral wrist position be adopted when using tools.[50] Work in a neutral position may promote the length-tension relationship of muscles and may affect other physiological variables such as carpal tunnel pressure.[51,52] In the current study, the wrist was maintained in a neutral range most often while cutting with the offset snip at waist height, compared with shoulder height. Additionally, muscle activity of the trapezius and extensor forearm muscles was lower at waist height than at shoulder height. In contrast, muscle activity of the flexor forearm was greater at waist height compared with shoulder height while using the offset snip. Study participants greatly preferred the offset snip for use at shoulder height compared with the other two snips. These findings suggest that the role of the primary activators of the cutting motion (i.e., flexor forearm muscles) may have a greater effect on tool preference than the synergistic role of stabilizers (i.e., extensor forearm muscles) or transient increases in extreme wrist posture.

In the current study, participants were instructed to work at a pace typical of usual work and were told that the task was not a race. It took longer to cut with the straight snips at shoulder height and the offset snips at waist height, than the other snips. However, the difference in task time due to snips design was not statistically significant. Additionally, participants rated "cutting productivity" of the offset and circular snips similarly. Other investigators have reported minimal differences in productivity due to changes in tool design. Roquelaure and colleagues[34] found that the rate of vine pruning was similar for two different pruning shear designs. Dempsey and colleagues,[37] in a study comparing bent-handle pliers with conventional pliers, noted no difference in overall productivity between the two tools. In contrast, Duke and colleagues[35] reported that tool design had a small but statistically significant effect on productivity (task time). Tasks took approximately 5% more time to complete when using bent-handle pliers than while using conventional pliers.

Conflicting results between direct measurements of biomechanical exposure and self-report preferences have been reported by other investigators. For example, Spielholz and colleagues[53] evaluated the effect of three random orbital sanders on flexor forearm activity. The static, median, and peak levels of flexor forearm EMG were similar for the three sander designs, yet study participants largely preferred the standard sander. Regardless, the inconsistent results found in the current study emphasize the need to evaluate several measures of exposure to physical risk factors at several body sites in laboratory and field studies. Typical bench testing methods such as load cutting tests conducted by a machine, fail to account for the various effects of the tool on a human operator.

Limitations

This study had limitations that may have influenced the results. First, we simulated only one aspect of work typical for sheet metal workers: cutting with shoulders elevated. In addition to the use of aviation snips, sheet metal workers also perform drilling and hammering activities overhead. Overhead use of aviation snips is often required in residential construction when a new section of duct must be added to existing ductwork running between floor joists. To reach the top of the ductwork, workers must stand on a ladder and reach into the confined space between the joists. In the current study, the confined space was not simulated. Thus, upper extremity postures in the field could be different.

A second limitation was that we considered only the effect of snip design and work height on muscle activity and wrist posture. Other physical risk factors, such as extreme postures of the shoulder or repetitive activities, could be associated more with work-related musculoskeletal disorders among sheet metal workers. Because most construction workers are under substantial time pressure, the role of repetition as a risk factor could be considerable. Additionally, force requirements of the aviation snips may be more effectively assessed with bench tests of the tools. Indeed, bench tests are routinely conducted on tools primarily to determine whether they meet specifications. However, bench tests evaluate only the external exposure from the tool.[54] In contrast, field trials or laboratory studies such as the current one would be necessary to determine the internal exposure or the muscular response of the operator during use of tools.

There were also potential methodological limitations in this study. Normalization of the EMG was conducted in a single posture whereas the cutting tasks were dynamic. Thus, the estimates of RMS amplitude could be erroneous due to the effect of muscle length and dynamic activity on EMG amplitude. However, there was no correlation between wrist posture and EMG amplitude. Crosstalk between the electrogoniometer extension/flexion and radial/ulnar deviation channels could also have produced erroneous data. Crosstalk error increases as the wrist motion becomes $>45^\circ$,[24] although recent evidence suggests that crosstalk error is $<2^\circ$ for wrist posture.[26] Regardless, the percent of time spent in wrist extension/flexion $>45^\circ$ (Figures 4 and 5) should be interpreted with caution. An additional issue related to the electrogoniometry was that, due to an equipment malfunction, fewer electrogoniometric than EMG measurements were included in the statistical analysis. Thus, it is possible that the results from the electrogoniometry lacked statistical power. However, only one test was not statistically significant (simple effect of snip design on wrist posture at shoulder height).

Generalizability of the findings is limited to the muscles that were evaluated. It is probable that other muscles could have a significant impact on use of aviation snips. For example, forceful pinch grips of the nondominant hand are necessary when cutting sheet metal to keep the metal edges separated. The relationship between hand dominance and musculoskeletal disorders among sheet metal workers has not been previously considered.

Another possible limitation was that there could have been an effect of snip blade sharpness on the EMG results. New snips were not used for each study participant and a common degree of sharpness was not maintained during the experiment. Because the offset snips were a prototype, only a few copies were available for testing. Consistent blade sharpness during the study would have been difficult to maintain and confirm.

The effect of a reduction in sharpness of the blades would most likely be exhibited as an average increase in mean flexor forearm muscle amplitude as the study progressed. To test for this effect, we regressed mean EMG amplitude (%RVE) of the flexor forearm on subject sequence number. There was no evidence of this effect in the data ($R^2 = 0.02$). Thus, we feel that there was no systematic error due to the sharpness of the snips.

The consistently lower ratings on the satisfaction survey for the straight snips may have been evidence of bias due to the participants' previous experience with aviation snips. For example, "grip span" was rated lower for the straight snips than the circular, yet the actual span was similar for both. Freund and colleagues[55] suggested that having end-users of a tool as study participants could bias results due to previous experience with the tool. However, the sheet metal workers in the current study consistently preferred the new offset snip for use at shoulder level and the circular snip for use at waist height, suggesting that they did not have a preconceived bias against new snip designs. Experienced sheet metal workers participated in the study because cutting sheet metal poses a definite risk of injury to inexperienced users.

It is possible that survey ratings were heavily weighted by one specific characteristic of the tool. In the current study, "cutting productivity" was rated substantially lower for the straight snips than the other two. Thus, it is possible that this characteristic influenced ratings of the other characteristics. Finally, it should be noted that this study evaluated only the effect of cutting circles in sheet metal. Alternate results may be expected if aviation snips are used to cut straight lines.

CONCLUSIONS

Choice of hand tools may have a substantial impact on the risk of work-related musculoskeletal disorders. It is preferable to use hand tools that may reduce exposure to physical risk factors associated with these disorders. In general, none of the aviation snips evaluated in this study performed best in all circumstances, making hand tool selection more difficult.

The offset snip was widely preferred by the participants at shoulder height, yet had the greatest impact on reducing physical factors at waist height. Except for flexor forearm activity, muscle activity was lowest and wrist posture was closest to the neutral range when using offset snips at waist height. Many of the sheet metal workers considered the offset snip a tool to be used for special situations when working overhead. Thus, workers would likely tolerate the intermittent exposure to higher muscle activity or non-neutral postures for the convenience of the tool. Use of the straight snip also resulted in somewhat conflicting findings. We cannot definitively describe the straight snip as the wrong tool for the job, since some physical factors were worse and some better while using this snip. However, cutting curves with a straight snip resulted in jagged edges of the sheet metal and cuts/lacerations are the second most frequent type of injury among sheet metal workers.[56]

In general, an adverse effect of work at shoulder height was observed for muscle activity of the upper trapezius. Other physical factors were not as influenced by work with the shoulder elevated. Indeed, wrist posture was more often non-neutral while cutting with aviation snips at waist height. Field studies are indicated to determine the long-term effect of snip design on physical risk factors and risk of musculoskeletal disorders.

ACKNOWLEDGMENTS

This study was supported by the Center to Protect Workers' Rights using funding from the National Institute for Occupational Safety and Health. The contents are solely the responsibility of the authors and not necessarily the official views of the funding agencies. The authors would like to thank the sheet metal workers who participated from Sheet Metal Workers Local 91, Rock Island, Illinois. Additional thanks to Robert Frick and John Churuvia of Local 91.

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