An Analysis of Grip Design for Manual Hammer Stapling Tool

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ABSTRACT

Three hammer stapling tools with distinctly different handle designs were evaluated in terms of comfort, safety and hand-arm stress. Sixteen male participants used each tool on two simulated roofs with 4:12 and 6:12 pitches, and stapled roofing underlayment at a frequency of 1 staple per second for two minutes. Tools with smooth, rounded and compressible grips, received significantly better ratings ($p<.05$) in grip comfort and ease of use, than the tool with rectangular grip cross-section employing a hard and serrated grip surface. Tools with grip features that provided protection from unintentional finger pinching received higher safety rating ($p<.05$). The tool with a 10 degree bent handle reduced ($p<.05$) the wrist angle at tool strike. The bent handle tool reduced the wrist flexor muscle activity, but increased the wrist extensor muscle activity. The findings of this study suggest that the hammer stapling tool with smooth and rounded grip cross-section, with a bent handle, improves grip comfort, usability and tool safety, and reduces the risk of repetitive strain injury of the wrist joint.

Keywords: hand tool, grip design, hammer, bent handle

1 INTRODUCTION

Typically a roofer uses a hammer stapling tool (Figure 1) to staple several hundred staples on the paper underlayment to attach it to the plywood roof decking. Since the roofer's hand-arm system experiences repeated impacts from the tool use, the grip design plays an important role in providing of grip comfort and protection from acute trauma and repetitive strain injury. Poor hand tool design is associated with risk of both acute and chronic disorders of hand, wrist and forearm (Aghazadeh and Mital, 1987). Design deficiency of tool or improper selection of tool can generate excessive biomechanical stresses (Chaffin, Anderson and Martin, 1999).

Scientific studies on grip comfort of similar types of tools suggest that, foam rubber grips provides more even distribution of contact pressure than hard unyielding grips (Fellows and Freivalds, 1991), the palmer side of hand is sensitive to serrated grip surface (Fransson and Kilbom, 1991), and grip cross-sections with rounded corners improves grip comfort and functional grip strength compared to grips with less rounded corners (Page and Chaffin, 1999).

The ergonomic principle of "bending to tool, not the wrist" has been studied for hammer. For horizontal and vertical working surfaces, a bent handle hammer reduced the wrist angle at impact (Knowlton and Gilbert, 1983; Schoenmarklin and Marras, 1989), and caused less strength decrement (Knowlton and Gilbert, 1983) compared to a straight handle hammer. A hammer with 10 degree bent handle was preferred than a straight handle hammer by users without any decrement of nailing productivity (Konz and Streets, 1984). Although the action of the hammer stapling tool is similar to an ordinary hammer, the former is associated with an additional risk of inadvertent finger injury by getting pinched against the roof surface. Striking on a slanted roof and guarding against finger pinching might have a different influence on wrist joint than that found in previous studies on hammering task.

The objective of this study is to evaluate the grip design features of hammer stapling tools available in the retail market in terms of grip comfort, safety, usability, wrist angle and muscle activity. Three tool models with distinctly different grip design were selected (Figure 1) for the evaluation. Essentially the three models were comparable in terms of size, weight, magazine capacity and staple size but differed in grip shape, grip material and handle angle.

2 METHOD

2.1 Hand tools

The model HT50 (Figure 1a) and HTX50 (Figure 1b) were manufactured by Arrow Corporation, and the model PC2K (Figure 1c) was manufactured by Bostitch Corporation. Henceforth these tool models will be referred to as Tool#1, Tool#2 and Tool#3, respectively. Tool#1 and Tool#2 had identical length and weight, 28 cm and 0.95 kg, respectively. Tool#3 had slightly longer overall length of 36 cm and weighed 1.0 kg.

Tool#1 grip design was basic, incorporating a straight handle with rectangular grip cross-section, rigid plastic surface with crosswise serrations. The shape of the section along grip axis was uniform, and the serrations were provided to improve gripping friction.

Tool#2 grip had a similar straight handle and rectangular grip cross-section but with more rounded corners. The finger side of grip surface was made of smooth and non-resilient rubber material. The two grip ends had raised sections that acted as shields against unintentional finger pinching during tool strike. The raised sections would also prevent slippage of the tool within the grasp.

The cross-section of Tool#3 grip was oval, and grip surface was smooth and was covered with resilient foam rubber. The thickness along the length of the grip was wedge shaped with a flared section at the end. This shape meant to prevent slippage of the tool along the grip axis within the grasp. This tool had employed a 10 degree upward bend of the handle. The upward bend had provided a clearance from the roof surface, and reduced the risk of finger pinching. Also, the bent handle might possibly promote a more neutral wrist posture during the tool strike.

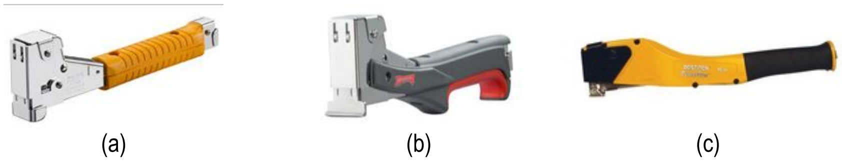
(a) (b) (c)

Figure 1 Hammer stapling tools evaluated in the study

2.2 Participants

Sixteen male university students participated in the study. All participants were in good physical health with no history of musculoskeletal problems and were paid volunteers for this study. Their average (standard deviation) height, weight, and age were 177(8.4) cm, 80(20.0) kg and 22(3.4) years, respectively. The study received approval from the institutional review board.

2.3 Experimental Design

A 6x4-foot wide platform was fabricated with 5/8th inch roofing grade plywood with a pitch of 4 inch rise to 1 foot run (Figure 2). A removable base insert was used to increase the roof pitch to 6-inch rise for 1 foot run. These two pitches are commonly found in residential pitched roofs. The participants stood on the platform facing the roofing underlayment and stapled it onto the plywood.

Each participant completed six separate experimental trials involving the combinations of three different tools and two roof pitches in a randomized order. Participants practiced with the hammer staplers before the experimental session. Five minutes rest break was provided between two experimental trials, to avoid fatigue. Each experimental trial consisted of stapling at a frequency of 1 staple per second for two minutes. The stapling pace was maintained by following an audible metronome. The stapling was done in a pattern following the three rows marked by pre-printed lines on the roofing paper. The pattern consisted of striking on the top, middle and bottom row and repeating this sequence while moving laterally from one side to the other. During stapling operation, the participants were instructed to apply enough force to insert the staples correctly flushed with the paper. Stapling with the hammer stapling tool was a comparatively easy task to accomplish and mistakes were rare.

Figure 2 Test Platform (4:12 Pitch - Left, 6:12 Pitch - Right)

Electromyographic (EMG) activity was monitored for the Flexor Carpi Ulnaris (FCU) and the Extensor Carpi Radialis (ECR) muscles of the forearm, and the Biceps Brachii (BB) muscle of the upper arm (Figure 3). The two forearm muscles, FCU and ECR, have insertion points on the metacarpal bones of wrist joint, and they resist wrist motion from the tool action in the ulnar-radial plane. BB was selected as the main forearm flexor muscle. The skin surface was cleaned and abraded and conductive gel was applied prior to applying the surface electrodes. The surface electrodes (Biometrics Ltd., Model SX 230W) employed a preamplifier (gain 1000), and high pass and low pass filter circuitry to reduce external interference. Two end terminals of an electrogoniometer (Biometrics Ltd. Model SG 110) were affixed to the dorsal skin surface of the forearm and hand by double sided adhesive tape, and the goniometer reading was set to zero while the subject maintained a neutral wrist posture. The EMG and goniometer signals were captured at 1000Hz and were transmitted via a remote patient data acquisition unit attached to the participant's belt to a Biometrics Datalink DLK800 base unit and stored in a personal computer operating Biometrics Datalink software, for further processing.

Prior to the experimental task, EMG for the maximum voluntary contraction (MVC) was recorded. Participants were instructed to hold Tool#3 with the elbow flexed at 90 degree and wrist at the neutral posture so that the tool was in a vertical position. They were then instructed to restrain the tool with their free hand while performing a maximum contraction of their FCU muscle by attempting to rotate the tool away from them (the direction of ulnar deviation of the wrist). They held the maximum contraction for a count of six followed by a rest. The MVC of the ECR muscle was obtained by repeating the same procedure in the opposite direction (the direction of radial deviation of the wrist). The MVC for the BB was measured by having the participant sit in a chair with their elbow flexed 90 degrees. With their fist placed underneath the edge of the desk surface, they performed a maximum contraction of the BB. The MVC efforts were repeated three times for each muscle.

Participants rated their perceived level of discomfort, on a 0-10 scale, in ten key areas of the body, immediately after each trial. The participants also rated each tool in terms of ease of use, grip comfort, and protection from injury potential after each experimental trial, on a 0 -10 scale.

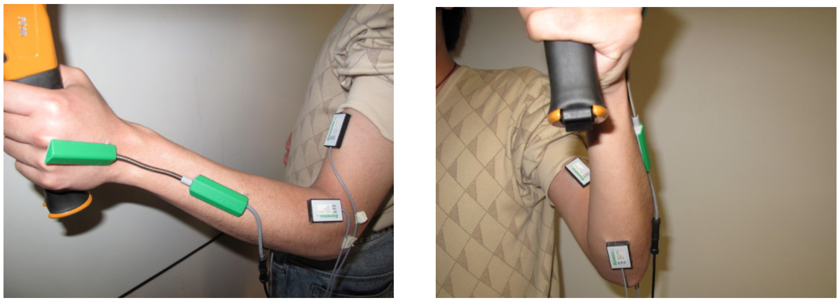

Figure 3 Placement of surface electrodes and goniometer

2.4 Data Analysis

Raw EMG data of task and MVC were first transformed by applying a root-mean-square (RMS) filter with a time constant of 200 millisecond and then were averaged. The maximum of the average RMS of the three MVC data for each muscle was used for normalization. The normalized EMG in percent (%MVC) represented muscle activity.

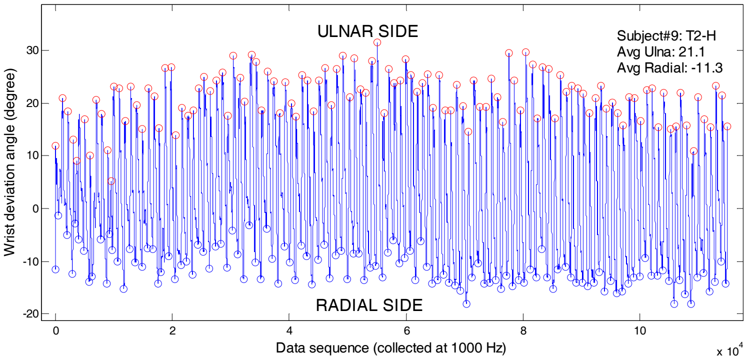

Figure 4 The typical wrist angle variation registered by the goniometer over an experimental trial; the circles at the peaks and valleys represent the wrist angle at impact and windup, respectively.

Figure 4 shows the typical variation of wrist angle in the ulnar/radial plane as registered by the goniometer over an experimental trial. A customized Matlab program pin pointed the impact (ulnar) and windup (radial) wrist angles of each strike. Means of impact wrist angles and windup wrist angles were calculated for each condition, and later used for statistical analysis. The data set from one participant was discarded, because of the detachment of the goniometer during an experimental trial.

All response variables were statistically analyzed using a two-factor (tool and pitch) analysis of variance (ANOVA) model with participant as a blocking factor. Significant differences in the factor level means were determined from Tukey's test of joint confidence interval.

3 RESULTS

No interaction between tool and pitch factors was significant for any of the response variables. Also, the pitch factor was not significant for any response variable, except for the radial deviation angle of the wrist joint.

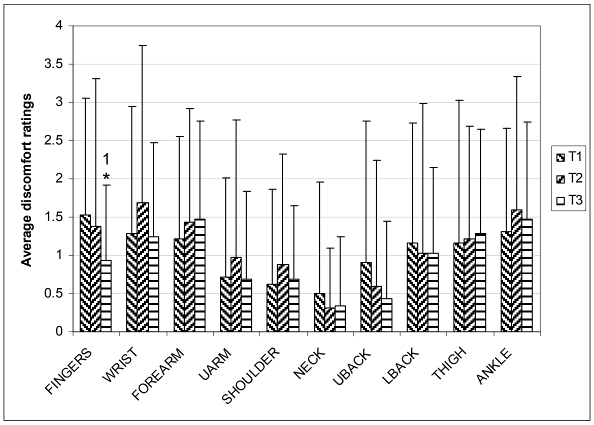

Figure 5 Mean and standard deviation (n=16) of discomfort ratings on a scale 0 to 10; asterisk and the number on the bar represent a significant difference in mean ($p<.05$) with tool number.

3.1 Discomfort Ratings

The mean and standard deviation of body part discomfort ratings for all participants are illustrated in Figure 5. Although the mean discomfort scores in all body regions were less than 2, the individual ratings varied from 0 to 9. The mean discomfort score for Tool#3 was significantly lower than for Tool#1 in fingers ($p=0.03$), but no other contrasts of means were statistically significant at $\alpha=.05$.

3.2 Subjective Perception of Tool Characteristics

The mean and standard deviation of tool characteristics ratings for all participants are illustrated in Figure 6. In terms of ease of use, Tool#3 received significantly better ratings ($p=.01$) than Tool#2 and Tool#1. In terms of grip comfort, Tool#2 and Tool#3 were not different, but Tool#1 was rated significantly inferior than Tool#2 (p=0.01) and Tool#3 (p=0.00). Similar statistical results were found for perception of protection of injury, ie., no significant difference between Tool#2 and 3, but Tool#1 was rated significantly inferior compared to Tool#2 (p=0.00) and Tool#3 (p=0.00).

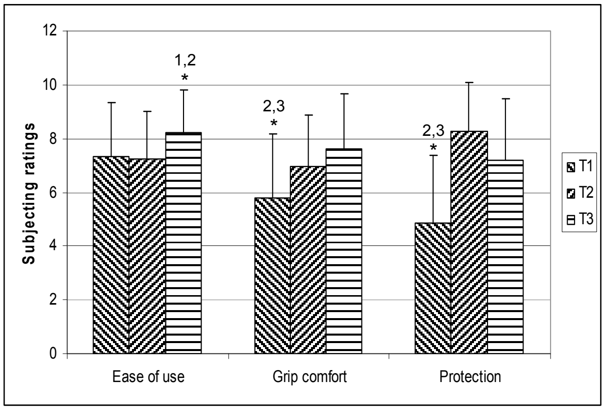

Figure 6 Mean and standard deviation (n=16) of tool characteristics ratings on a scale 0 to 10; asterisk and numbers on a bar represent a significant difference in mean (p<.05) with tool numbers, respectively.

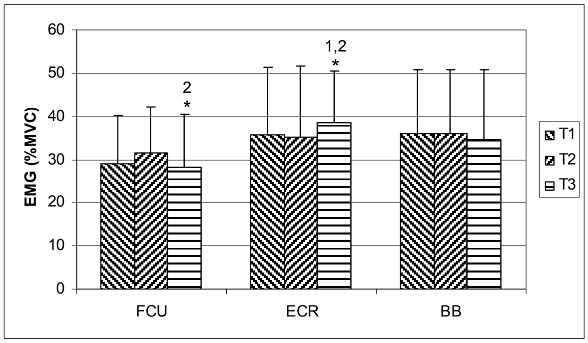

Figure 7 Mean and standard deviation (n=16) of normalized muscle activities; ECR-Extensor Carpi Radialis; FCU-Flexor Carpi Ulnaris; BB-Biceps Brachii; asterisk and the number(s) on a bar represent a significant difference in mean (p<.05) with tool number(s), respectively.

3.3 Muscle Activity (%MVC)

The mean and standard deviation of muscle activity in terms of %MVC are shown in Figure 7. The mean muscle activity of the FCU was lesser for Tool#3 than for Tool#2 (p=.02). The mean muscle activity of the ECR was significantly higher for Tool#3 than for Tool#1 (p=.02) and Tool#2 (p=.00). None of the other contrast of means was significant.

3.4 Wrist Angles at Impact and Windup

The mean and standard deviation of the wrist angle at impact (ulnar deviation) and windup (radial deviation) are plotted against each tool in Figure 8. Tool#3 produced significantly less ulnar deviation as compared to Tool#1 (p=.04) and Tool#2 (p=.00). The radial deviation was not affected by the tool factor.

The wrist angle at windup (radial deviation) was the only variable that showed a significant increase (p=.01) from low pitch to high pitch roof, with means of 17.3 to 19.5 degree, respectively.

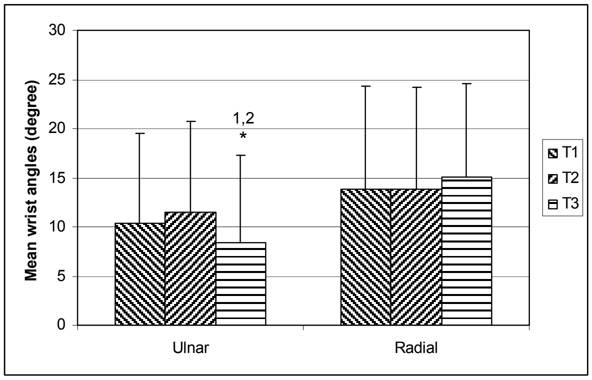

Figure 8 Mean and standard deviation (n=15) of radial and ulnar deviation of wrist; Asterisk and numbers represent a significant difference in mean (p<.05) with tool numbers, respectively.

4 DISCUSSION AND CONCLUSION

Tool#1, with hard serrated plastic grip and less rounded cross-section received significantly inferior mean rating on grip comfort (5.8) as compared to Tool#2 (7.2) and Tool#3 (7.6) that employed smooth, well rounded grip cross-section. This result supports similar findings from the previous studies on grip design (Fransson and Kilbom, 1991; Page and Chaffin, 1999). Tool#1 also produced 60% more mean discomfort at finger region (1.5) as compared to Tool#3 (0.9). Tool#3's oval and compressive foam rubber grip, as opposed to Tool#1's hard serrated plastic grip with less rounded cross-section, should be responsible for such increase in discomfort (Fellows and Freivalds, 1991). However, the mean finger discomfort of Tool#2 (1.4), which also had smooth grip surface, did not reach statistical significance as compared to Tool#1.

The mean rating on protection from injury of Tool#2 (8.2) and Tool#3 (7.2) were significantly higher that Tool#1 (4.9). Safeguards against pinching injury during tool strike is an important tool design aspect (Konz and Johnson, 2008), and Tool#2 and Tool#3 designs incorporated protection strategies from such mishaps. The absence of such a feature in Tool#1 was clearly perceived by the participants as hazardous. In terms of ease of use, Tool#3 was rated (8.3) to be significantly superior to Tool#1 (7.3) and Tool#2 (7.2). In addition to the grip features, the bent handle construction of the tool could also have contributed to this result.

The mean FCU muscle activity from using the bent handle Tool#3 (28% of MVC) was significantly less than that of Tool#2 (32% of MVC). The mean FCU activity of Tool#3 was less than that of Tool#1 (29% of MVC), but the difference did not reach statistical significance. The FCU muscle is the prime mover for resisting the inward rotation of wrist (radial direction) that tends to occur at the time of the tool strike. This reduction in FCU muscle activity, coupled with reduction in the ulnar deviation of wrist (as explained later) from the use of Tool#3, would act synergistically in protecting the soft tissue injury in wrist.

The mean activity of ECU muscle was significantly greater for Tool#3 (38% of MVC) than that of Tool#2 (35% of MVC) and Tool#1 (36% of MVC). Fellows and Freivalds (1991) reported similar increase in EMG of hand flexor muscle from tool grips made from compressible foam rubber. They attributed the increase in EMG from the increased grasping force necessary due to deformation of the foam and a 'loss of control' feeling of the subjects. The compressible foam grip of Tool#3 exhibited a similar trend. Fellows and Freivalds (1991) recommended reduction the thickness of the foam layer on tool grip to reduce the higher grasping force.

The mean ulnar deviation of the bent handle Tool#3 (8.4^o) was significantly less than that of Tool#2 (11.4^o) and tool#1 (10.4^o). Reduction of ulnar deviation is an important factor in reducing the soft tissue injury potential, since the wrist joint is maximally deviated in the ulnar side at the instant of tool strike (Knowlton and Gilbert, 1983; Schenmarklin and Marras, 1989). Most of the muscle tendons develop highest tension at the tool impact, and the wrist joint is most susceptible to soft tissue injury when it is more deviated (Chaffin, Anderson and Martin, 1999). The roof pitch 6:12 produced increased mean radial deviation of wrist (19.5^o) than 4:12 pitch (17.4^o). The increased radial deviation can be attributed to the higher windup angle of wrist for higher pitched roofs.

In summary, this study concluded that for a hammer stapling tool:

1. Smooth and rounded shaped grip would improve grip comfort than hard, serrated less rounded shaped grip.
2. An upward 10 degree bent handle was proved to be a better approach in protecting inadvertent finger pinching than the raised sections at the grip ends.
3. The bent handle promoted better wrist posture and lesser FCU muscle activity at tool impact, which potentially would reduce the risk of soft tissue injury in the wrist joint.
4. The compressible foam rubber grip, although found preferable in terms of grip comfort and usability, but it was associated with increased ECR muscle activities. Reducing the thickness of the foam layer might

reduce the necessity of higher grasping force and consequently the muscle activity.

The findings of this study are applicable in the design and selection of hammer stapling tools.

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