Productivity and Ergonomic Investigation of Bent-Handle Pliers

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Awkward wrist posture is generally considered an occupational risk factor for hand/wrist disorders, leading to the ergonomic design principle of "bend the tool, not the wrist." Sixteen participants performed a computer jumper installation task and a simple assembly task while productivity, wrist posture, and shoulder posture were measured. The work surface orientation (vertical and 45°) and the level of constraint placed on the user (constrained grip and unconstrained grip) were also varied. The results indicate that the beneficial effects of the bent-handle pliers are task dependent. In the computer jumper task the bent-handle pliers resulted in 5.3% faster task performance, whereas in the assembly task performance was 4.9% faster with the straight-handle pliers. The bent-handle pliers reduced shoulder deviations by 50% in the jumper installation task, and ulnar deviation was reduced by 12% and 22% for the jumper installation task and the assembly task, respectively (all significant at $p < .05$). However, allowing participants to hold the pliers in a grip configuration of their choosing (unconstrained technique) often reduced these postural benefits. In applying these results to workplace design activities, one should recognize that the ergonomic utility of bent-handle pliers can be considerable but that the 3-D kinematics characteristics of the task must be considered.

INTRODUCTION

The development of work-related musculoskeletal disorders (MSDs) represents a complex interaction among an individual's psychological characteristics, the individual's physiological characteristics, and the mechanical/physical factors of the job or task (National Research Council and Institute of Medicine, 2001). The mechanical/physical factors represent the job or task characteristics that affect the physical loads experienced by the various body tissues. One of these physical risk factors, awkward postures, has been the focus of much research. A 1997 National Institute for Occupational Safety and Health review (Bernard, 1997) concluded that there is epidemiological evidence for an association between posture and some MSDs, including those of the low back, the neck, and shoulder, as well as tendinitis of the hand and/or wrist; in many cases, the strength of association is higher when awkward posture is combined with other risk factors. To be more specific, though there is insufficient evidence of posture alone being causally related to carpal tunnel syndrome, if it is combined with other risk factors (particularly force and repetition) there is strong evidence for this association.

In an attempt to address the impact of awkward postures on MSDs, a common hand tool design recommendation has been proposed: "Bend the tool, not the wrist." This design tenet can be found in many contemporary ergonomics textbooks (Bridger, 1995; Chaffin, Andersson, & Martin, 1999; Kroemer, Kroemer, & Kroemer-Elbert, 1994; Pulat, 1997). The rationale behind this recommendation is sound in that the conventional in-line design of tool handles may require users to adopt awkward postures (typically ulnar deviations) under certain conditions of use and that it is preferable to alter the tool design to maintain more neutral wrist (and often

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shoulder) posture. A number of empirical studies have explored this tool design recommendation for various hand tools, such as hammers (Granada & Konz, 1981; Krohn & Konz, 1982; Schoenmarklin & Marras, 1989a, 1989b), files (e.g., Hsu & Chen, 1999), and knives (e.g., Armstrong, Foulke, Joseph, & Goldstein, 1982; Fogleman, Freivalds, & Goldberg, 1993); of particular relevance to the current study are the investigations related to bent-handled pliers use (Dempsey & Leamon, 1995; Dempsey, McGorry, Leamon, & O'Brien, 2002; Tichauer, 1973).

A visual inspection of the static images in Figure 1 intuitively suggests that the bent-handle design would allow work to be performed in more neutral postures in the radial/ulnar plane. This notion is based on the assumption that the tool is to be used with the jaws aligned with the long axis of the forearm (as suggested by the images); this may not always be the case, however, and this assumption cannot be made without a thorough understanding of the particular task for which the pliers are to be used. If, for example, the task requires the worker to manipulate a piece or part in a number of different orientations and/or along different axes, then the bent-handle design may lose its postural advantage. Similarly, the specificity of the bent-handle design may constrain the user's coupling with the tool to a power grip or an oblique grip. (With the power grip, all four fingers are wrapped around the handle and are opposed by the thumb, and often the handle is perpendicular to the forearm axis. An oblique grip is a modified power grip in which the thumb is aligned with the axis of the tool; Konz & Johnson, 2000). Additionally, the lack of symmetry along the long axis of the tool (the pincer axis) may reduce the worker's options for manipulating the pliers, leading to productivity decrements.

Tichauer (1973) presented the results of a field study in which two groups of trainees in an electronics assembly job took part in a 12-week training program. One group of 40 trainees used conventional straight-handle pliers, and another group of 40 used the bent-handle pliers. The author reported that at the end of the 12-week period, 25 of the 40 participants using straight pliers suffered from injuries classified as either tenosynovitis, epicondylitis, or carpal tunnel syndrome, compared with only 4 of the 40 employees who used pistol-grip pliers for the same task. This would seem to provide a compelling motivation for adopting the bent-handle pliers in similar industrial environments.

More recent works, by Dempsey and Leamon (1995) and Dempsey et al. (2002), have shed additional light on the utility of bent-handled pliers by providing additional empirical data with regard to the effects of the bent-handle design on productivity and ergonomics. Dempsey and Leamon conducted a laboratory investigation that involved a simulated wire-twisting task designed to evaluate the effects of the type of pliers (straight handle vs. bent handle) and also explored the effect of working height. Their results showed that the participants were 8.25% less productive with the bent-handle pliers than with the straight-handle pliers and that this effect

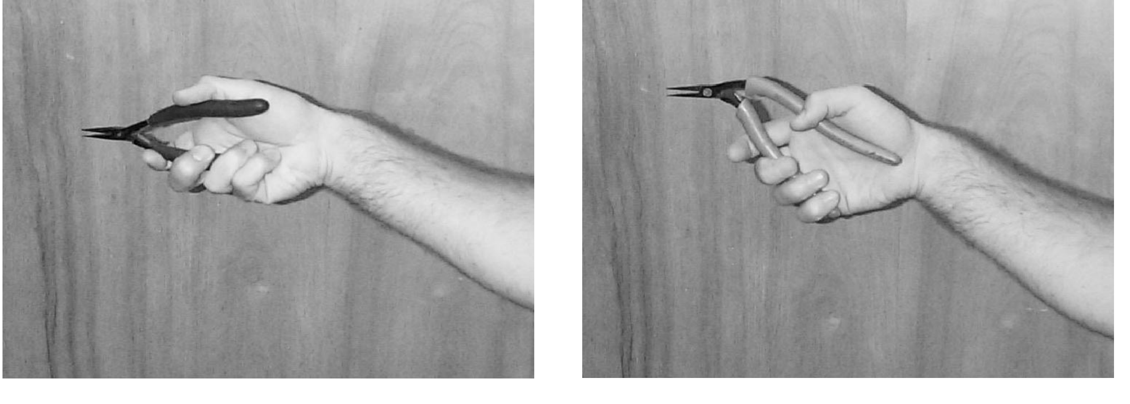

Figure 1. Sagittal view of straight-handle pliers (left) and bent-handle pliers (right).

was particularly pronounced when work was performed at elbow height. Subjective assessments by the participants showed a preference for the straight-handle pliers even though the bent pliers were found to be more comfortable to use, indicating an overriding concern about productivity when using the bent-handle pliers.

In a follow-up study, Dempsey et al. (2002) considered the angular orientation of the work piece in the sagittal plane and measured the wrist postures assumed during this same wire-twisting task. They found improvements in wrist posture but no changes in productivity as a function type of pliers. These studies emphasize the importance of the interaction between type of pliers and other workplace configuration parameters, such as the work height and sagittal plane orientation of the work piece. These studies provide a motivation for the consideration of tasks that require more complicated manipulation of the tool (3-D translations and rotations) that may lead the user to adopt unconventional coupling strategies. Specifically, the wire-twisting task employed in the previous studies required a single-plane motion, and that plane of motion was perpendicular to the long axis of the pincers of the pliers. Many tasks requiring the use of pliers involve more complex 3-D translations and rotations, and the investigation of these activities may provide deeper insight into the ergonomic and productivity effects of bent-handle pliers. Further, the characteristics of these wire-twisting tasks (required grip forces, repetition rates, etc.) may not be conducive to the use of alternative coupling strategies that may be adopted by workers in other industrial work scenarios.

The specific aim of this research is to evaluate the ergonomic and productivity effects of bent-handle pliers in a series of tasks specifically designed to expand the experimental test bed in an effort to further explore the strengths and weaknesses of the bent-handle design. The specific hypotheses to be tested are as follows:

1. There is a significant productivity disadvantage with the bent-handle pliers.
2. The ergonomic benefits (reduced wrist and shoulder deviations from neutral) of the bent-handled pliers are limited to those work tasks involving simple, single-plane motions.
3. When users are allowed to grasp the pliers using alternative coupling strategies, the ergonomic benefits (reduced wrist and shoulder deviations from neutral) of the bent-handle pliers relative to the straight-handle pliers are lost.

METHODS

Experimental Tasks

The experiment consisted of two separate tasks that were designed to represent industrial applications for which bent-handle pliers may be recommended for neutral posture promotion. Both tasks (which will be described in detail) involved parts manipulation in a relatively small work area directly in front of the participant (Figure 2). One of the tasks (jumper: Figure 3, left panel) required small sagittal and lateral movements of the pliers, with essentially no tool rotation, whereas the other task (spring: Figure 2 and right panel of Figure 3) required similar

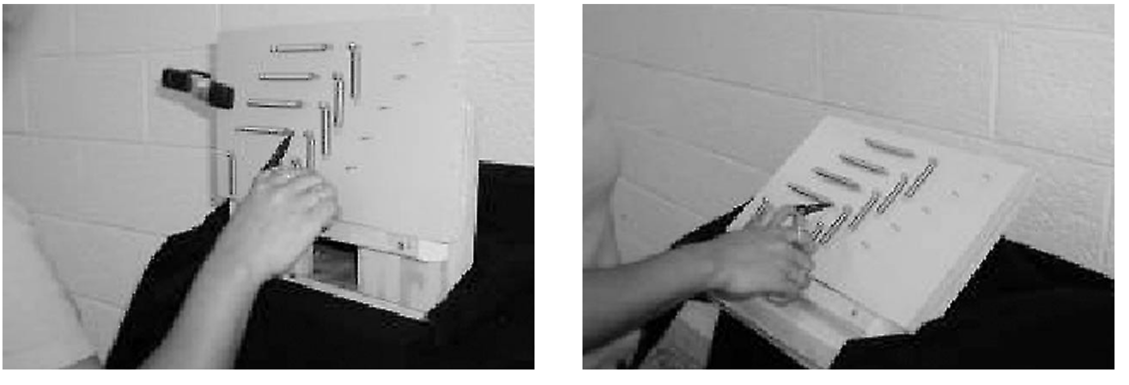

Figure 2. Orientation of the participant relative to the work piece: vertical orientation (left) and 45° orientation (right).

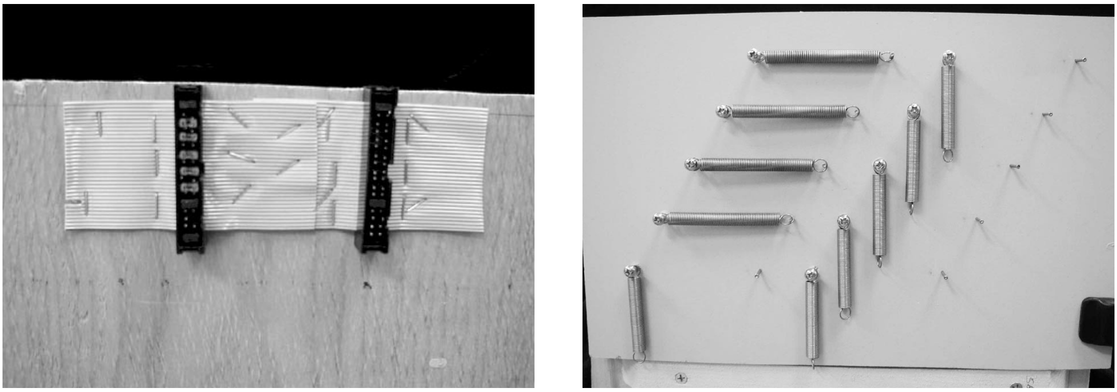

Figure 3. Initial starting arrangement for jumper task (left) and spring task with first four springs connected (right).

sagittal and lateral movements as well as rotational manipulation of the tool.

The first task required participants to move five computer jumpers laterally between two sets of standard 36-pin motherboard computer connectors that were placed 5.6 cm apart. These jumpers were placed on alternate pin pairs (Figure 3, left panel) such that there was always an empty pair of pins above and below each jumper to prevent interference between jumpers. The jumpers themselves were standard 0.1– × 0.3-inch (0.254 × 0.762 cm) computer pin jumpers. The initial condition had the five jumpers in position on the left connector. A cycle consisted of grasping the jumpers, one at a time, and moving them all from their initial pin positions on the left connector to the same pin positions on the right connector, followed by moving them all back to their initial starting position on the left connector. When moving the jumpers from one connector to the other, the participants always started by moving the top jumper first and then worked down.

The other task required participants to use the pliers to connect extension springs to a post. Ten stainless steel extension springs (6.35 cm long; spring rate = 0.96 N/cm; maximum deflection = 10.8 cm) were fastened at one end to a board, as shown in the right panel of Figure 3. A finishing nail was placed 7.7 cm to the right of the spring mounting point to serve as the post. Participants were instructed to use the pliers to grasp the free-end loop of the spring and (pulling against the spring tension) attach it to the post. Participants started at the top left and attached the springs sequentially by working down the column. Once all 10 springs were attached, the participants reversed their work by individually removing the springs from the posts. (Participants had to use the pliers to grasp the spring loop and were not allowed to "flick" the spring free of the post.) In order to avoid interference from adjacent springs, we instructed all participants to unfasten the springs starting at the bottom of the left column. One cycle consisted of attaching all 10 springs, followed by unfastening all 10 springs. Note that because of the two different orientations of the work surface (vertical and slanted, described in the Independent Variables section), the springs always hung down when unattached; however, the orientation of the loop was variable, requiring participants to variably manipulate the pliers in rotation to grab the loop.

Apparatus

Time to complete each trial (productivity) was measured using a handheld stopwatch. The wrist flexion/extension angle and angle of radial/ulnar deviation were measured with two wrist electrogoniometers (Marras & Schoenmarklin, 1993). The 3-D shoulder posture data (measured as the angular deviation of the upper arm from the vertical) were captured by the Ascension Flock of Birds magnetic tracking system (Ascension Technology©, Burlington, VT) and recorded with Innovative Sports Training Motion Monitor© software (Version 4.10). Figure 4 displays the Flock of Birds magnetic sensors and wrist monitors on a participant.

Figure 4. Participant instrumented with wrist goniometers and magnetic sensors.

Independent Variables

There were three independent variables in this study. First, there were two levels of pliers design: straight handle (Swanstrom Model S325E; Figure 1, left panel) and bent handle (Swanstrom Model S325EPR; Figure 1, right panel; Swanstrom Tools USA, Superior, WI). Both pliers had the same jaw characteristics and dimensions. The second independent variable was the degree of constraint placed on the coupling (i.e., grasping) strategy adopted by the participant. In the constrained condition, participants were required to hold the pliers within the palm of the hand using either a power grip or an oblique grip with the pincers extending from the radial aspect of the hand. In the unconstrained condition, participants were allowed to hold the pliers in any manner they desired. Finally, two different work surface orientations were used: vertical and slanted at a 45° angle in the sagittal plane (Figure 2).

Dependent Variables

There were two principal performance measures employed in this study: posture and productivity. Postural data were collected for the right wrist and right shoulder. Angular wrist posture in the flexion/extension and radial/ulnar planes were collected at 300 Hz and measured as angular deviation from neutral about the centers of joint rotation (a local coordinate system) in both the flexion/extension plane and radial/ulnar plane (Marras & Schoenmarklin, 1993). Mean flexion/extension of the wrist and radial/ulnar deviation postural data were determined for the third cycle of task completion for all conditions. Shoulder posture was measured as the angular deviation of the upper arm from the vertical (using a global reference system). This angular deviation could have been abduction, flexion, or a combination of the two, and these data were collected at 60 Hz. Mean shoulder posture data were determined for the third cycle of task completion for all conditions. Productivity was measured simply as the time taken to complete the three cycles of the task.

Working Height

An important determinant of wrist and shoulder posture when using pliers (whether conventional or bent handled) is the height at which the work is to be performed (Dempsey & Leamon, 1995). In this experiment the potential bias that would result from setting the work height at the "best" height for one or the other pliers design was of great concern. Further, it was important to place the work at a position relative to standardized anatomical landmarks on each participant, thereby eliminating the nuisance variance of participant stature. (It is recognized that this limits the generalizability of these results to those work activities that are performed on a static workstation, but it was an important variable to control in order to allow us to make statements about the specific effects that were the focus of this research.)

Therefore, an algorithm was developed for positioning the work piece relative to the midpoint of the participant's upper arm (this midpoint is defined as the point midway between the acromion process of the shoulder and the lateral epicondyle of the elbow). This algorithm was derived from pilot work and equally weighted the preferred location of the work piece when using the conventional and bent-handle pliers. In the full study this algorithm was used to locate the work piece for each participant in each condition, rendering an unbiased, participant-specific positioning of the work piece. In the vertical orientation condition, the work piece was centered at the height of the midpoint of the upper arm for both tasks. In the 45° orientation condition, the work piece was located 17 cm below the upper arm midpoint for the jumper task and 10 cm below the upper arm midpoint for the spring tasks.

Participants

Sixteen participants (8 men, 8 women) were recruited from the general university population. Participants ranged in age from 22 to 38 years, with a mean of 28 years. All participants were right-handed and had normal or corrected-to-normal vision. Participant stature ranged from 156 to 196 cm, with a mean of 173 cm.

Experimental Procedures

Participants were given a brief description of the purpose of the study and the protocol to be followed, after which the participant signed an informed consent form. Anthropometric data (stature, height to right acromion process and lateral epicondyle of the right humerus) were collected, and the height of the midpoint of the upper arm was calculated to determine the appropriate working heights.

The wrist electrogoniometers were positioned and secured to the right wrist following the procedures described by Marras and Schoenmarklin (1993). Two magnetic sensors were affixed to the right arm with adhesive tape. One sensor was positioned on the lateral aspect of the upper arm, just proximal to the elbow, and the other was positioned on the lateral aspect of the upper arm, nearer the shoulder. The sensors were positioned so that they would not interfere with arm motion.

After the instrumentation was applied, the participant was seated with her or his right elbow flexed to 90° and shoulder abducted 90° to a horizontal position while the wrist was held in a neutral position (both flexion/extension and radial/ulnar deviation). Data were collected in this posture to establish reference postures for the subsequent calibration of the experimental data.

Prior to data collection, the experimental task was explained to the participants. The participants were told that they were free to position themselves in a standing position in front of the work surface however they felt comfortable. The investigator demonstrated the task, and the participant was told that the objective was to perform the task as quickly as possible under all conditions. Participants performed two practice cycles of each condition as the last activity before data collection.

All participants performed all eight conditions (two pliers × two orientations × two levels of constraint) for the spring task followed by all eight conditions for the jumper task. Within each task, the order of performance of the four conditions determined by orientation and pliers was randomized. Within this randomization, all participants first performed the constrained condition followed by the unconstrained condition. After each constrained condition, participants were asked to take some time to explore other manners for holding the pliers to determine if there was an alternate way they would prefer to hold them (dagger grip, reduced number of fingers, etc.). During this time the participant was able to try the task with any grip she or he wanted. Once the participant determined the grip that she or he preferred, the unconstrained trial was conducted. (Note that the participant was not obligated to adopt an alternate grip if she or he preferred the power grip.) Under all conditions, three cycles of each condition were performed.

Data Processing

The wrist electrogoniometer data were converted to angular position data relative to the neutral posture through a simple linear calibration equation (Marras & Schoenmarklin, 1993). The data for each trial were then averaged to produce one value of wrist position in the flexion/extension plane and one value of wrist position in the radial/ulnar plane over the course of the third cycle of each condition. (Additional data analysis [root mean square analysis] revealed that because the wrist postures did not vary significantly during a given trial, this averaging process did not result in artificially low average values.) The 3-D position data collected from each of the sensors on the arm were converted, using trigonometric calculations, to an instantaneous value of arm deviation from vertical. The data for each trial were then averaged to produce one value for arm elevation over the course of the third cycle of each condition.

Data Analysis

An analysis of variance (ANOVA) was performed on a randomized complete block model (Kolarik, 1995) to test the effects of the independent variables on the dependent variables and their interactions. The basic assumptions of the ANOVA procedure (homogeneity of variances and normality of residuals) were assessed before attempting the ANOVA.

RESULTS AND DISCUSSION

Our approach to presenting the results of this study is to place the greatest emphasis on those results that had a direct bearing on the original hypotheses (complete results can be found in Duke, 2002). As another introductory point, we note that interpretation of a statistically significant main effect of an independent variable involved in a significant interaction effect was attempted only after a formal simple effects analysis revealed that this was appropriate.

The first issue to be addressed is the nature of the unconstrained postures utilized by the participants. These can be broken down into "major" and "minor" changes to the hand-pliers coupling interface. The typical minor coupling change was to use a "fingertip" coupling with the pliers for greater control and perceived precision (Figure 5, left panel), whereas the typical major coupling change was to use a dagger grip on the pliers (Figure 5, right panel). The type of pliers had an impact on the utilization of these alternative coupling strategies. For the straight-handle pliers, 42% of the unconstrained trials were performed with minor coupling changes and 20% of the trials were performed with major coupling changes. For the bent-handle pliers, 19% of the trials were performed with minor coupling changes and only 9% resulted in major coupling changes. It is believed that these strategic differences between the straight and bent-handled pliers are the result of both a perceived improvement that came from the bent-handled pliers (indicating a reduced need for changes in the coupling) as well as a perception of a reduced "flexibility" of the bent-handled pliers for alternative coupling approaches.

Statistical analysis of the productivity data revealed that pliers type had a significant effect for both tasks (jumper and spring). The results for the spring task ($p < .05$) demonstrated a productivity decrement when participants used the bent-handle pliers; on average, time to complete the task was 4.9% greater (Figure 6), supporting Hypothesis 1. For the jumper task, however, the bent-handle pliers resulted in 5.3% faster task performance ($p < .05$; Figure 6), not supporting Hypothesis 1.

Our suspicion is that because the jumper task requires no rotation of the pliers, the lack of

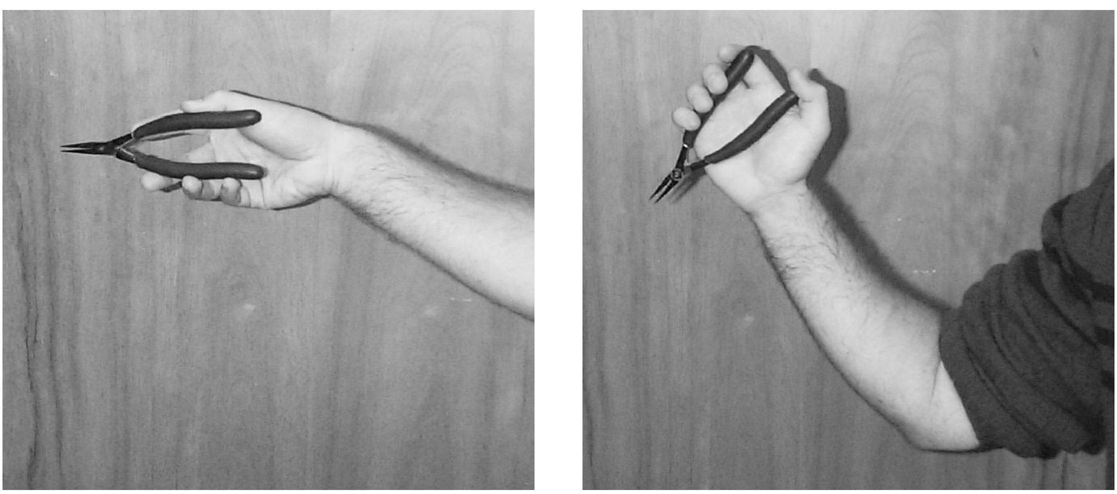

Figure 5. Sagittal view of straight-handle pliers employing minor (left) and major (right) alternative coupling strategies.

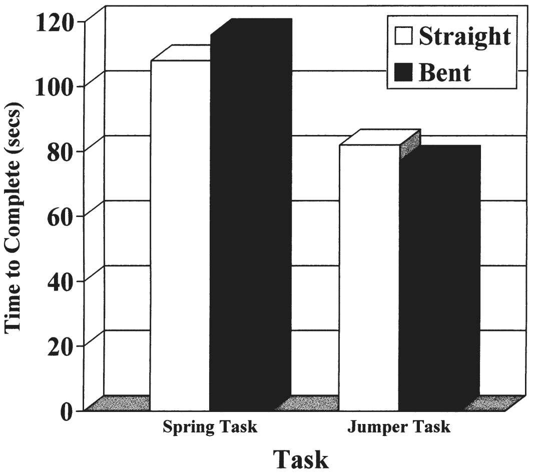

Figure 6. Main effect of pliers on productivity (spring task).

long-axis symmetry of the bent-handle pliers has no detrimental effect on productivity, and in fact there appears to be a productivity advantage for these pliers in this case. A plausible explanation for this advantage is that there is less visual obstruction of the important task characteristics (the interaction between the pliers jaws and the jumper, and the view of the connector pins) with the bent-handle pliers than with the straight-handle pliers. Another possibility is that with the jumper task there were postural benefits of the bent-handle pliers, and the more awkward postures required by the straight-handle pliers could result in a loss of accuracy or a fatiguing effect that reduces productivity. Therefore, as stated, Hypothesis 1 must be rejected. However, the results suggest that the productivity effect of the bent-handle pliers is task specific: A task that requires 3-D manipulation of the tool demonstrates a productivity loss with the bent-handle design, whereas a task requiring simpler, single-plane translations demonstrates a productivity improvement.

The results with regard to the postural benefits of the bent-handle pliers revealed improved postures in both tasks (spring and jumper), thereby rejecting the hypothesis that the benefits would be limited to those tasks with relatively simple kinematic requirements. The data for the constrained trials alone revealed that with the bent-handle pliers, the average arm elevation was reduced by 50% (37°–18°) and the ulnar deviation was reduced by 12% (33°–30°; $p < .05$) in the jumper task (Figure 7), supporting Hypothesis 2. However, there was also a significant ($p < .05$) 22% (27°–21°) reduction in ulnar deviation during the constrained trials of the spring task, indicating that the benefit was seen in this condition as well, thereby contradicting the task-specificity hypothesis. Pliers type did not, however, have a significant effect on arm elevation during the constrained trials of the spring task. Therefore, Hypothesis 2 is rejected because ergonomic benefits of the bent-handle pliers (reduced ulnar deviation) were found in both tasks under these constrained conditions. However, because pliers type did not have a significant effect on arm elevation, the general theme of this hypothesis does appear to have validity and highlights the importance of considering the specific task requirements and ancillary effects on other body parts.

Task specificity also appears to play an important role in the effectiveness of alternative hand-tool coupling strategies. It was hypothesized that an ergonomic benefit would be realized when the pliers were held with a conventional power grip (related to Hypothesis 2) but that this benefit would be eliminated if users were given the opportunity to choose an alternative coupling strategy. The results of this analysis revealed that there was a significant interaction

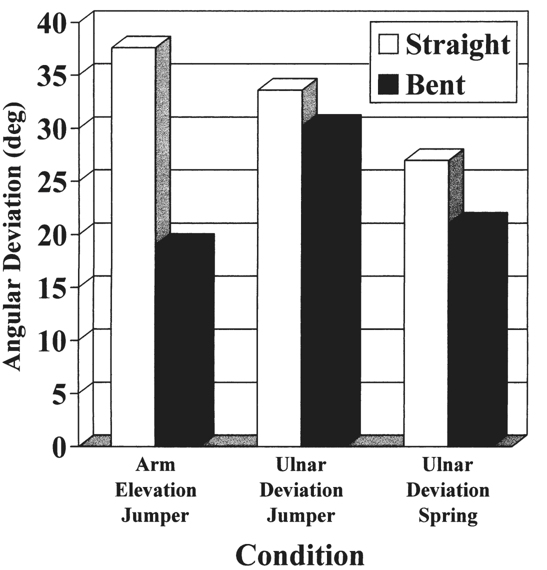

Figure 7. Main effect of pliers type on wrist and shoulder posture under the constrained conditions.

effect ($p < .05$) of Pliers × Constraint on arm elevation for the jumper task (Figure 8), demonstrating a significant reduction consistent with the hypothesis. The significant Pliers × Constraint interaction ($p < .05$) on radial/ulnar deviation for the jumper task (Figure 9) showed an even more profound support for this hypothesis. In the case of the spring task, however, there were no significant effects for the Pliers × Constraint interaction on any of the postural measures of interest, and it appears that the specific requirements of the task dictated whether the alternative coupling techniques elicited positive postural responses.

Work piece orientation is one independent variable that is not directly addressed in the original three hypotheses, but there were some interesting results with this variable that need to be presented. First, productivity was significantly ($p < .05$) greater in the 45° condition in both work tasks (average 6% greater). The improved vision afforded by this slanted orientation is a likely contributor to this response. The productivity benefit, however, came at a postural cost, particularly in the constrained conditions. In the spring task, arm elevation increased by 15% in going from the vertical to the slanted work surface orientation. In contrast, during the jumper task, the slanted work surface afforded the opportunity for the participants to employ the unconventional method of holding the pliers (with the jaws exiting the ulnar aspect of the hand). This had the effect of reducing the average ulnar deviation in this condition, further emphasizing the complex interactions among tool, task, environment, and worker that were revealed in this study.

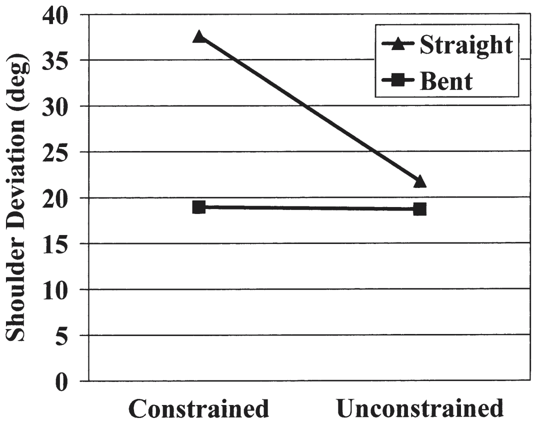

Figure 8. Pliers × Constraint interaction effect on shoulder deviation (jumper task).

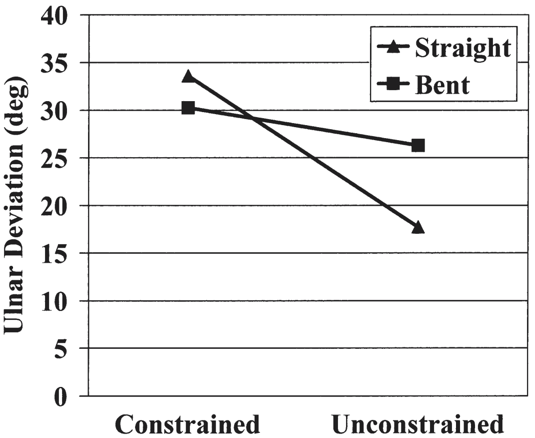

Figure 9. Pliers × Constraint effect on ulnar deviation (jumper task).

The task specificity alluded to throughout this manuscript reveals the major limitation of the current work. Although the tasks performed did expand the test bed created by Dempsey et al. (2002), these tasks still do not encompass the much larger breadth of tasks requiring the use of pliers. Interpretation of these results to a specific task should be done carefully. It is believed that future research in this area should develop a structured characterization of the diverse kinematics involved in industrial uses of pliers and then systematically test the effectiveness of the bent-handle design in these diverse circumstances. Only then can the question of the utility of the bent-handle design be completely answered.

CONCLUSIONS

This study investigated both the ergonomic impact (via posture) and the productivity impact of the two different designs of pliers during simulated work activities. The results of this study indicate the importance of task characteristics as well as the human performance response (in terms of how the user actually uses the tool) and emphasize the need for a clear and complete understanding of the task requirements, the user population behavior, and the environmental conditions before hand tool recommendations are made. Further, the lack of agreement between the original hypotheses and the empirical data indicates that these responses do not always follow conventional logic and, in many cases, may require that empirical data be collected to establish the appropriate hand tool for a given case.

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Date received: February 3, 2003
Date accepted: November 20, 2003