ANALYSIS OF AIMING WITH TOOLS: PROPRIOCEPTION

Nagasridhar Chintapalli[1], Xuedong Ding[1], Shinya Takahashi[2], M. Susan Hallbeck[1]

1) Industrial Engineering Department, 181 Nebraska Hall, University of Nebraska, Lincoln, NE 68588
2) Strength and Conditioning Coordinator, 55 Campus Recreation Center, University of Nebraska, Lincoln, NE 68588

Abstract

One of the major areas of interest in the field of ergonomics is the design of hand tools. Though considerable research has produced more user-friendly tools, there has been some reluctance to use them for some tasks. It is hypothesized that this reluctance on the part of the user may be partly due to the reduction of accuracy while using those handles. A pilot study employing twenty subjects (10 males, 10 females) was undertaken to evaluate three different grip angles, between the tool and handle axis, combined with four visual availability of the target conditions. Each subject was asked to aim at the center of the target under all the twelve test scenarios, with each subject performing ten trials in each scenario. The target was a touch screen monitor. The interface was a black screen background with the center indicated by a red cross-hair. The results of this study showed that the dependent variable, accuracy, was primarily effected by the angle of the of the handle grip with respect to the tool axis and by the visual availability of the target in a manual-aiming task. The tool with the least ergonomically correct wrist position yielded the best accuracy. As expected, the blind condition was the worst, but seeing the points that had been previously hit as additional visual feedback did not improve performance. The overall implication being that the most ergonomically correct tool might not lead to the best performance unless proprioception or feedback is taken into consideration. This has direct implications for tasks such as laparoscopic surgery where a long shafted tool is used with little visual feedback.

Introduction

The emphasis on design of ergonomic tools has been on a rise in the industry. This is mainly due to an increased focus on improving the productivity and efficiency of the worker in relationship to the machine by improving the design of hand tools determining the effect of preferred tool shapes with different grip angles (Ulin, Snook, Armstrong and Herrin, 1992). However it has been found that the end user does not always adopt these human friendly tools. Lack of proper training and resistance to change might be the plausible reasons for this behavior. However one prominent reason that might explain the lack of willingness to use the ergonomic designs might be the problems faced in the user-tool interaction. This is particularly evident among the users working with the hand tools. Of late a lot of research has gone into the design of ergonomic hand tools and new designs have been proposed. Of greater prominence is the problems faced by the end users interacting with such tools while performing the specialized tasks.
These problems might be due to bad proprioception or the feel of the tool, ultimately resulting in a reduced performance (Hägg and Hallbeck, 2001). Proprioception is a sense that lets humans perceive movements and position of the body segments without the aid of vision. These sensations stem from signals arising in mechanoceptors within muscles, joints and skin. Proprioception plays a prominent role in the evaluation and investigation of the sensorimotor processes.
It was felt that manual pointing (aiming) tasks using tools as screwdrivers, drills, were one of the most common tasks performed in an industrial set up. They are also present in laparoscopic surgery where there are tools with long shafts that must be aimed accurately and quickly. The objective of a pointing (aiming) task is accuracy. The hand tools involve an extensive use of the distal upper limb. Kaminski and Gentile (1986) determined that a pointing task comprises of a multi-joint pointing movements. It has also been shown that longer, faster, and more spatially variable initial movements result in increased variability (Worringham, 1987). Thus, a study of a pointing task was performed to evaluate the effect of proprioception in the use of hand tools. Anecdotal evidence showed that the wrist position based on the angle of the grip is an important

consideration with respect to proprioception. The preferred tool shapes for hand tools were inline grips and angled grips (angled at 180 degrees and 135 degrees) (Ulin, et al., 1992). There is a need to understand whether inline grip offers a better ease of use to the end user compared to an angled grip even in situations where, ergonomically, the angled grip would be preferred.

In a general industrial set-up while using the hand tools the level of visual availability with reference to the target is not always the same for different applications. The visual availability of the target is particularly important with respect to the pointing task since it has a marked effect on the accuracy (Elliot, Chua Pollock, Lyons 1995; Elliot, Carson, Goodman, Romeo, 1991; Elliot and Madalena, 1987). There is a need to understand whether the visual availability of the target has any effect on the performance and if there is an interactive effect with respect to the tool or subject gender. One condition to be tested is complete absence of any visual signal or feedback to assess the magnitude of the accuracy decrement. No gender effect is expected, but previous studies were on males only; thus, a balance of males and females will be tested to assess any potential gender effects. The possible interaction among gender, visual availability, and the tool handle angle effects on the accuracy also needs to be evaluated. Thus, this study was designed to investigate how tool angles and visual feedback affect the accuracy of a manual-pointing task for both males and females, and how proprioception plays a role in the pointing task. There are many industrial and medical applications for tools with long shafts where visual availability of the target is limited, such as when a worker is separated from the work piece by another material or working inside a darkened workspace.

Method

Apparatus

A hand tool meant for manual pointing tasks was designed and fabricated as shown in Figure 1. The hand tool had a cylindrical grip. The tool was designed such that the tool stylus could be changed to a desired grip angle with respect to the handle. The pointing tool had a stylus of approximately twenty-five centimeters (25cm) in length. The tool was made of aluminum owing to its lightweight properties. The tool weighed half a pound (0.5 lb) and was fairly well balanced. It was not meant to replicate the weight of a specific hand tool, nor was it meant to simulate a powered hand tool. The grip had a rubber cover over the metal handle to provide cushioning and heat retention for the hand while holding the tool. The circumference of the ovoid handle cross-section was 2.5cm. When the rubber bicycle handle was placed over it, the circumference was 3cm, as shown in Figure 1. A seventeen-inch (17') ELO flat panel LCD touch screen was connected to a personal computer (PC) to analyze the accuracy of the aiming task. A visual interface using Visual Basic 6.0 software was created which also allowed the data to be collected for each scenario, presented in random order. The interface was developed to provide various levels of visual availability of the target to the subjects. The target was the LCD touch screen monitor where a horizontal and a vertical line intersected at the center.

The four different visual availability levels that were tested were: blank screen, feedback, no-feedback and blindfolded. For the blank screen visual availability condition, the subject was asked to hit the center of the blank LCD screen. This point was then taken as the target for all 10 subsequent aiming tasks for that combination of handle and visual scenario trials. For the feedback and no-feedback trials, there was a red target on the screen with 3 concentric circles around it at radii of 8.83 mm, 14.13 mm, 19.43 mm, and 24.7 mm respectively from the center of the target. The difference between the feedback and no-feedback conditions was that in the feedback condition, the point of contact with the screen lit up in green for the duration of the handle angle-visual scenario trial. A fabric mask was used for testing the subjects during the non-sighted or blindfolded scenario. Also the interface provided an audio signal output that would provide the pace for the experiment (80 beats per minute or 40 hits per minute). The screen background was entirely black (blank LCD) while the target was visible as a red cross-hair (+). The experiment was performed in a laboratory with a reasonably good illumination level.

Subjects

A total of twenty healthy university students (10 men and 10 women) with normal corrected vision ranging in ages from nineteen to twenty-five were recruited as subjects for this study. All subjects stated they were right-handed and had no previous experience in manual aiming tasks. In addition, the subjects had no previous injury or illness in their upper limb.

Experimental Design

The dependent variable in the Analysis of Variance (ANOVA) was accuracy. Accuracy was measured as the mean vector distance from the center of the ten-point cluster in a scenario. There were three independent variables analyzed: grip angle, visual availability, and gender. There were three different grip angles of the handle with respect to the axis of the tool: inline (180 degrees between tool and handle axis), right-angle (90 degrees), and pistol grip (135 degrees). Each of these angles was used for four different visual availability conditions *viz.* blank screen, feedback, no-feedback and blindfolded. Thus, each of the three angles was used for all four visual availability levels. Hence the total number of test scenarios developed was twelve. Each of the twenty subjects (10 men and 10 women) was asked to perform the aiming task ten times in each of these twelve test scenarios. All the subjects performed all twelve scenarios leading to a total of one hundred and twenty (120) hits on the target for each subject. The resulting design is a 3(grip angle) X 4(visual availability) X 2(gender) mixed- factor, full-factorial design. The dependent variable of accuracy was analyzed using SAS (V. 8.0). The experimental order of the scenarios presented was completely randomized.

Procedure

Each subject was asked to hold the cylindrical handle and aim at the center of the target. The height of the target was fixed such that the stylus hit the center when the upper arm was adducted and was at right angle to the floor, the elbow had a ninety degree (90) included angle. A physical stop was placed behind the elbow such that the distance from the center of the target screen to the tip of the stylus was exactly equal to the length of the stylus *viz.* twenty-five centimeters (25 cm). The subject sat on an armless chair in an upright position. The body motion of the subject was constrained only to the movement of the upper limb. This was achieved by strapping the subjects to the chair with Velcro, as shown in Figure 2. The pace of the aiming task was set to eighty beats per minute (80 beats /min) to allow the subject to hit the target forty times per minute and the elbow stop forty times per minute. The subjects were given an audio signal in the form of a beep to adjust their pace. A randomized set of the twelve task scenarios were presented before the subject with instructions. The instructions were both explained by the experimenter and also were presented in the interface developed. Each scenario commenced with the subject holding the tip of the stylus onto the screen. The subject was then instructed to move the elbow backwards until he or she hit a physical elbow stop and then move the arm forward and aim at the target on the screen. This oscillatory movement was continued for ten successful trials of aiming at the center of the target. In the blindfolded condition the subject's eyes were blindfolded using a fabric eye mask. The subject was then asked to approximate the center of target, based on the initial placement by the experimenter, and then aim at it. This was continued for all twelve test scenarios. The subjects were allowed to practice initially for some time until they felt comfortable with the handle and the test procedure.

Results

The Analysis of Variance (ANOVA) on the mean vector distance from the center for the ten vector distances taken from the center of the target showed that the significant main effects were the grip angles (p<0.001) and the visual availability (p<0.001), as shown in Table 1, the ANOVA summary table. Post-hoc tests (Student-Newman-Keuls, SNK) were performed on the significant main-effects and the results are shown below in Table 2 for the grip angle and Table 3 for effect of visual availability. The ANOVA revealed a statistically significant grip angle versus visual availability interaction. The interaction graph is shown in Figure 3.

Table 1. ANOVA summary table for the dependent variable accuracy

Factor	**Degrees of freedom**	**Sum of squares**	**Mean of Squares**	**F-value**	*p*
Gender = (G)	1	125494.2	125494.2	5.25	0.022
Subject (G)= S (G)	18	26259470.4	---	---	---
Tool	2	8045077.3	4022538.6	22.1	<.0001
Tool X G	2	449578.6	224789.3	1.23	0.291
Tool X S (G)	36	13227261.4	---	---	---
Sight	3	327439600	109146533.3	599.64	<.0001
Sight X G	3	281581.9	93860.6	0.52	0.6715
Sight X S (G)	54	13227261.4	---	---	---
Tool X Sight	6	7066354	1177725.7	6.47	<.0001
Tool X Sight X G	6	192837597	32139599	73.22	<.0001
Tool X Sight X S(G)	108	57932903.5	---	---	---
Total, Corrected	2399	880871439.6	---	---	---

Table 2. Post- hoc test performed on the grip angles

Types of Grip Angles	Mean (mm)	SNK Grouping
Inline (180^0)	10.95	A
Pistol (135^0)	11.96	B
Right angle (90^0)	13.44	C

Table 3. Post-hoc test performed by visual availability scenario.

Visual Availability Scenario	Mean (mm)	SNK Grouping
Blank Target (BT)	8.92	A
No-Feedback (NF)	8.11	A
Feedback (F)	8.05	A
Blindfolded (BF)	23.41	B

Table 4. Mean vector for each visual availability scenario and grip angle.

Types of Grip Angles	Blank Target (BT) (mm)	No Feedback (NF) (mm)	Feedback (F) (mm)	Blind Folded (BF) (mm)
Inline (180^0)	8.77	7.36	7.34	20.34
Pistol (135^0)	8.29	7.8	8.55	23.22
Right angle (90^0)	9.69	9.17	8.26	26.65

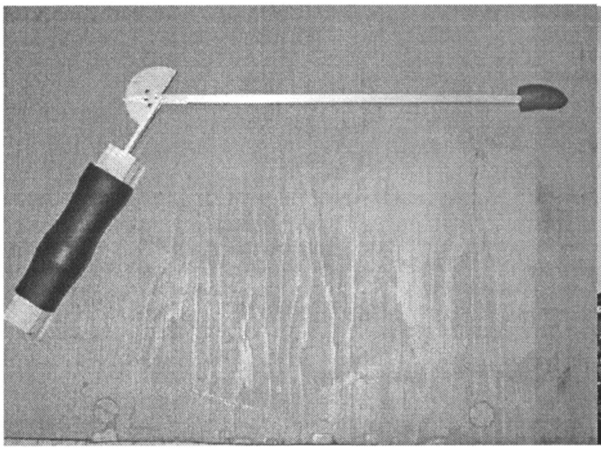

Figure 1. Aiming tool in the pistol configuration

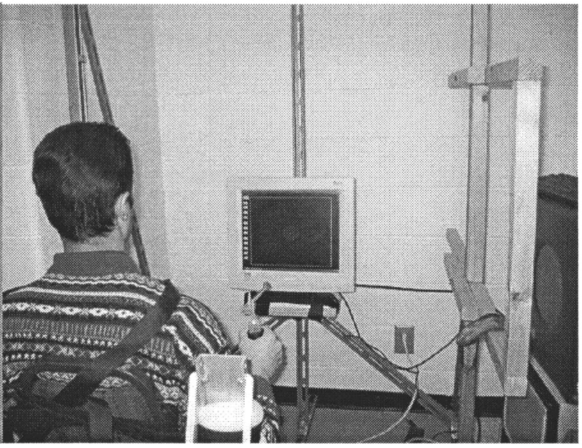

Figure 2. Subject performing task

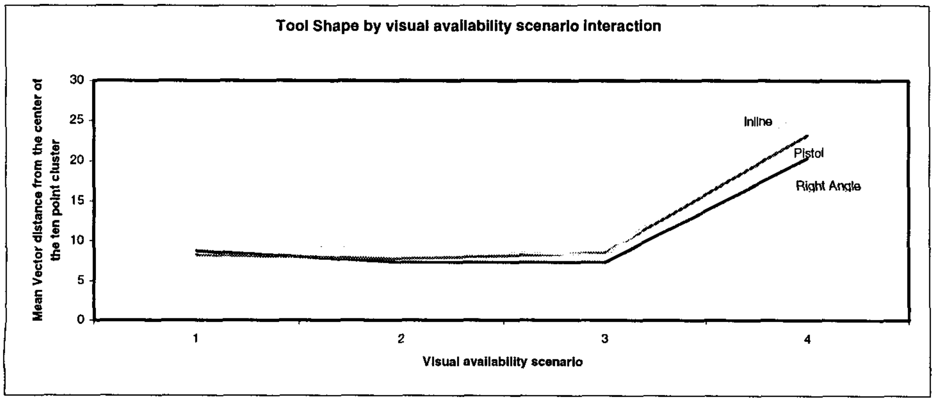

Figure 3. Graph depicting the Tool angle Versus the Visual Availability Scenario Interaction.

Discussion and Conclusions

This study shows that the inline orientation of the handle produced significantly better accuracy when compared with the pistol angled grip (135 degrees) or the right-angled grip (90 degrees). This agrees with the findings of Hägg and Hallbeck (2001). The mean vector distance from the midpoint of the cluster of the ten vectors decreased by 18.53 percent (18.53 %) in the case of inline tool as compared to the pistol angled tool. Also there was an 8 percent (8%) decrease in the vector distance when the inline-angled tool was compared to that of the pistol-angled tool. As expected, the blindfolded condition produced the worst results in that the mean vector distance from the center of the ten-point cluster was significant and was, on average, more than 100% higher than the average of the other visual feedback conditions, as shown in Figure 3.. The visual feedback condition produced the highest average accuracy in that there was a 65 percent (65%) decrease in the mean vector distance from the center of the ten-point cluster compared to the non sighted or blindfolded condition. One interesting result was that there was not a significant difference between the feedback (F) and no feedback (NF) conditions. Hence, knowledge of the position in the previous trial did not aid the subjects in improving the accuracy in this study. There was no gender effect meaning that neither males nor females were significantly more accurate compared to the other gender. However, one interesting outcome of the experiment was the presence of a significant interaction between the grip angle and visual availability condition. The visual feedback combined with the inline tool grip angle produced the smallest average vector distance indicating highest level of accuracy. On the other hand, the right-angled tool shape combined with the blindfolded visual scenario produced the maximum mean vector distances indicating a very low level of accuracy and precision.

The present research findings, particularly those of grip angle, strengthen the initial premise that the ergonomic tools may result in a decreased accuracy. The grip angles are more ergonomically correct when they reduce the wrist deviations and tend to keep the wrist straight. However these angles also resulted in a reduced performance in this study. On the other hand, the inline (180^0) tool grip angle resulted in the best accuracy, while performing the task. This task caused pronounced ulnar deviation.

The study also indicated that visual availability is a significant factor affecting the performance of an aiming task. Though this is fairly obvious, the study indicates that the feedback has no effect on the performance measure. A further study to ascertain this is intended.

Practical Implications

The present experiment is extremely useful in the case of surgical tools. Anecdotal evidence suggested that the surgeons (users) were uncomfortable in using the ergonomic hand tools to perform laparoscopic surgeries. This discomfort in using the tool was more evident with the lack of training. The surgeons were to reach a target inside the body of the patient and perform a task. This is a particular case where users have to perform a task when few or no visual cues are available. The tools used had similar design as the tool that was designed for this experiment.

Future Study

A further study on how wrist deviation for a given grip angle would influence the accuracy of the aiming task is currently being performed. It is also necessary to ascertain if the multi-joint movement of the shoulder and the wrist, for a given grip angle, has any influence on the performance (accuracy). As a part of further research it is also intended to measure the performance in terms of precision as well as accuracy of the aiming task and compare the findings. Precision will be defined as the vector distance from the mean of the 10 trials for each grip angle- visual availability scenario.

Thus, the overall results of the pilot study show that the inline grip angle may give rise to better accuracy in manual aiming tasks. Also the visual availability of the target plays a significant role in the performance of the task while using the hand tools, but the feedback with knowledge of results may not improve performance as was expected.

References

Elliot, D., Chua R., Pollock, B. J., Lyons, J. (1995). Optimizing the Use of Vision in manual Aiming: The Role of practice. *The Quarterly Journal of Experimental Psychology, 48A (1)*, 72-83.

Elliot, D., Carson, R. G., Goodman, D., Chua, R. (1991). *Human Movement Science 10*, 393-418.

Elliot, D., Madalena, J. (1987). The Influence of pre-movement Visual Information on Manual Aiming. *The Quarterly journal of Experimental Psychology, 39A*, 541.559.

Hägg, G. M., Hallbeck, M. S. (2001). Do handle Design and hand Posture Affect Pointing Accuracy? *Proceedings of the Human Factors and Ergonomics Society, 45th Annual Meeting*, 731-735

Kaminski, T., Gentile A.M. (1986). Joint Control Strategies and Hand trajectories in Multi-Joint Pointing Movements. *Journal of Motor behavior, 18 (3)*, 261-278.

Worringham, C. J. (1991). Variability Effects of the Internal Structure of Rapid Aiming Movements. *Journal of Motor Behavior, 23 (1)*, 75-8