Ergonomic Efficiency Testing
Two-Handed vs. One-Handed
CAD Working Styles

Abstract

Ergonomics Technologies Corporation, a leading independent ergonomics consulting firm, specializing in the use of objective measurement systems to analyze human interactive systems, analyzed two contrasting human computer interfaces at a Fortune 100 company.

In physical measurements and user perceptions of 20 CAD subjects, using a two-handed working style (3D motion controller and mouse) vs. a one-handed working style (mouse) yielded the following results:

Physical Measurements:

- Left hand motions were **reduced 67%**
- Right hand motions were **reduced 64%**
- Average muscle activity was **33% less**
- Peak levels of muscle activity were **35% less**
- Average and peak flexion/extension wrist deviation were **reduced 57% and 34%** respectively

Perceptions:

- **All nine** body comfort metrics were rated better
- **90%** of the subjects would prefer to have a 3D motion controller available for their CAD use

1.0 INTRODUCTION

The goal of this project was to assess the efficiency and the user preference of two CAD input styles.

1) The conventional one-handed style of using a mouse, augmented by keyboard function keys (Figure 1)
2) A two-handed style, using a mouse in one hand and a 3D motion controller in the other (Figure 2)

Figure 1: One-handed style (mouse)

Figure 2: Two-handed style (3D motion controller & mouse)

Twenty CAD designers were selected from a Fortune 100 manufacturing company, including 17 males and 3 females, and ranging from 23 to 57 years of age.

Local muscle activity, wrist posture, finger/hand motions, mouse clicks, as well as perceived comfort ratings and working style preference were collected from the 20 subjects performing four design tasks using both input methods.

Subjects performed four design-related tasks including (1) Assembly, (2) Colors, (3) Fillet and (4) Sectioning.

2.0 MEASUREMENTS

2.1 Local Muscle Activity

Local muscle activity associated with the use of both input methods was measured using a computer based analog-to-digital data collection system. Myoelectric signals from two muscle groups of each arm were measured at 500 Hz through the duration of each task. These muscle groups (Figures 3 & 4) included the extrinsic hand and wrist flexors and extensors which flex and extend the fingers and wrist.

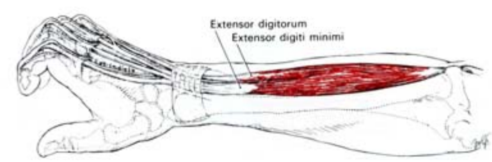


Figure 3: Wrist and finger extensors

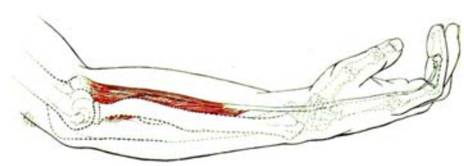
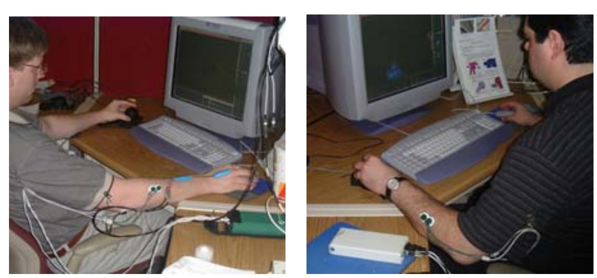


Figure 4: Wrist and finger flexor

After prepping the skin with alcohol, electrodes spaced at 2.0 cm were placed over the muscle bellies. Electrode placement on both arms is illustrated below (Figures 5 & 6).



Figures 5 & 6: Electrode placement

Muscle activity data were normalized as a percent of a maximal voluntary contraction (% MVC) recorded for each subject. Maximum contractions were elicited for each arm and method by squeezing the mouse and 3D device, and pushing down on the keyboard near the function keys. Average and maximum (peak) muscle activity data were thus expressed as a percent of MVC to enable comparison between input methods.

2.2 Wrist Posture

An electrogoniometer was used to measure (500 Hz) continuous real-time wrist posture during performance of the four tasks. This device, which consists of two plastic triangular shaped end blocks separated by a flexible spring-covered wire (strain gauges), is able to yield biaxial postural data. The electrogoniometer was fixed across the wrist joint of the hand operating the mouse. The goniometer was zeroed subsequent to being attached across the wrist. Figures 7-9 illustrate the postures recorded as well as the position of the device on the subjects.

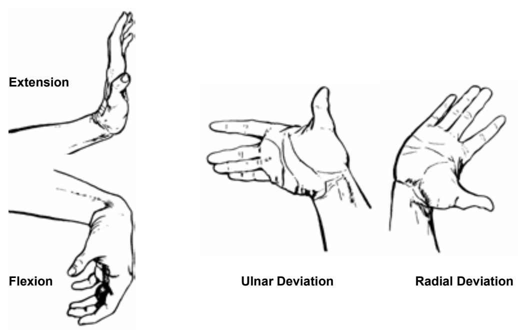


Figure 7: Biaxial wrist postures

Figure 8: Wrist extension

Figure 9: Wrist ulnar deviation

2.3 Finger/Hand Motions & Mouse Clicks

Finger/hand motions and mouse clicks were identified from videotape collected throughout each task for each subject. For the mouse and function key method, a motion was counted as any function key depression and movement of the mouse. Unidirectional mouse rolling was considered one motion. Mouse movement in one direction but then changed to another was considered two separate motions.

Motions for the 3D device were counted when directional changes from an initial axis of movement were made—zooming in and rotating was counted as one motion until the initial motion stopped or was suspended.

2.4 Perceived Comfort

Comfort ratings or the absence of discomfort was queried for both left and right fingers and hands, wrists, forearms/elbows, shoulders/upper back, as well as for the overall upper extremities. Ratings from all subjects for all tasks were averaged per input method.

3.0 RESULTS

3.1 Local Muscle Activity

Local muscle activity of the extrinsic flexor and extensor muscle groups of both arms were collected and processed to yield measures of the overall physical demand per input method. Figure 10 illustrates the overall average, peak or maximum, as a percent of the maximum voluntary contraction (% MVC).

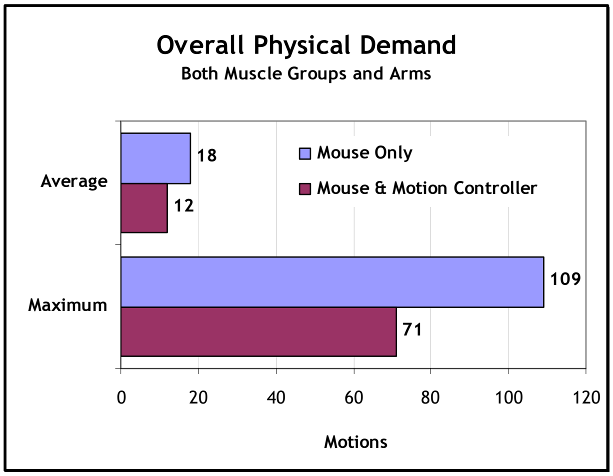


Figure 10: Overall physical demand

When considering that both input methods require use of both arms, the overall physical demand was lower (12% MVC) for the 3D motion control method compared to the conventional mouse and function key method (18% MVC). This 33% reduction in average muscle activity was significant. Further, peak levels of effort were 35% less for the 3D device method (71% MVC vs. 109% MVC) as expressed by the maximum data columns. The relative magnitude of the peak or maximum data may be explained by motion artifacts, especially since the mouse and function key method requires continuous finger movements to toggle between function keys as well as hand/arm motions to roll the mouse.

3.2 Wrist Posture

Direct measurement of wrist posture during mouse use for each input method was analyzed to reveal differences in average and peak postural demands (Figure 11 and 12) for each plane of wrist motion.

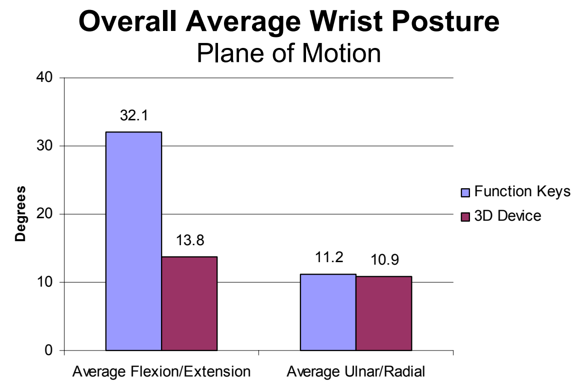


Figure 11: Average Wrist Posture

As indicated in Figure 11 the 3D motion control method resulted in an overall average of 13.8 degrees of deviation within the flexion/extension plane versus 32.1 degrees of deviation using the function key method; a 57% reduction. This difference is likely due to the reduction or relative elimination of mouse rolling with the 3D method. Average wrist deviation within the ulnar/radial plane of motion was reduced slightly during task performance with the 3D input method (10.9^{o} vs. 11.2^{o}).

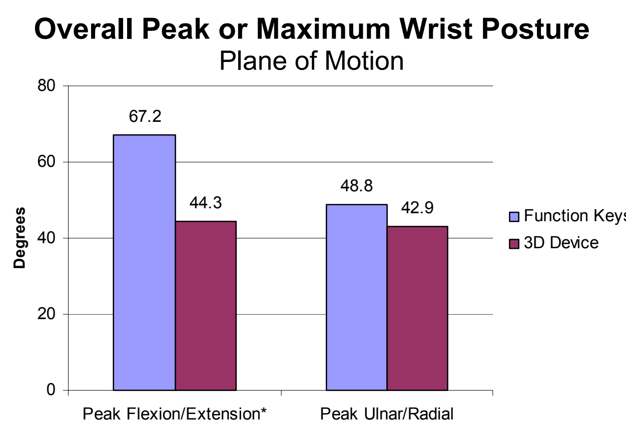


Figure 12: Maximum wrist posture

Postural peak deviations were 34% lower within the flexion/extension plane and 12% lower within the ulnar/radial plane of motion when using the 3D device method. The flexion/extension postural reduction was statistically significant. Again, reductions in peak postural data are likely due to the elimination of frequent right hand motions with the 3D input method.

3.3 Finger/Hand Motions & Mouse Clicks

The average number of motions for each hand per input method as identified from videotape analysis is presented in Figures 13 and 14.

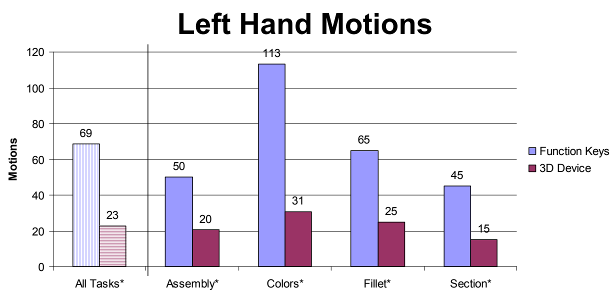


Figure 13: Left hand motions

From the video of all 20 subjects, it was clear that the number of distinct motions or movements made by the left hand/fingers while toggling function keys or manipulating the 3D device was lower with the 3D method. The processed data supported this general observation as the percent reduction in left hand motions for the 3D method ranged from 59% for the Assembly task to 73% for the Colors task. Significant reductions were identified for the average of all tasks as well as for each task. These identified reductions are due to the 3D device's capability of rotating about more than one axis at a time (degrees of freedom).

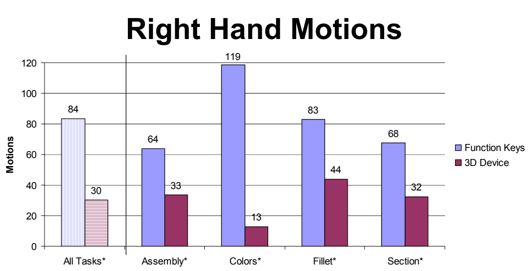


Figure 14: Right hand motions

As indicated in Figure 14, the average number of right hand motions or movements was again lower for the 3D motion control method; a reduction of 64% when considering all four tasks. Right hand motions were 47% to 89% lower for the individual tasks for this method as well. All motion reductions were statistically significant.

3.4 Perceived Comfort

Perceived comfort levels of the upper extremities are provided in the graph below.

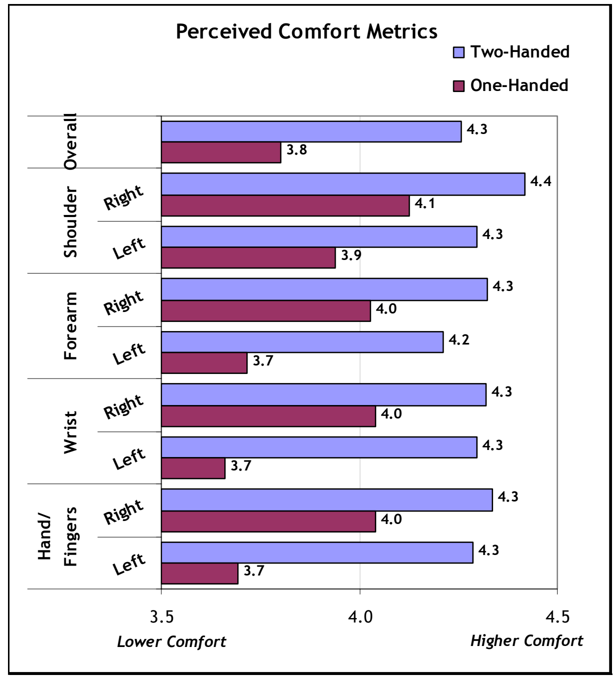


Figure 16: Perceived Bodily Comfort

As indicated, all nine body comfort metrics were higher for the two-handed style than when using the one-handed style. Significant differences were found for the left fingers/hand (toggling function keys vs. 3D device manipulation) and right forearm/elbow (possible rolling requirements of the mouse with the function key method).

From the test group of 20 subjects, 18 of the preferred to use the two-handed method, either exclusively or in conjunction with the mouse and function keys.

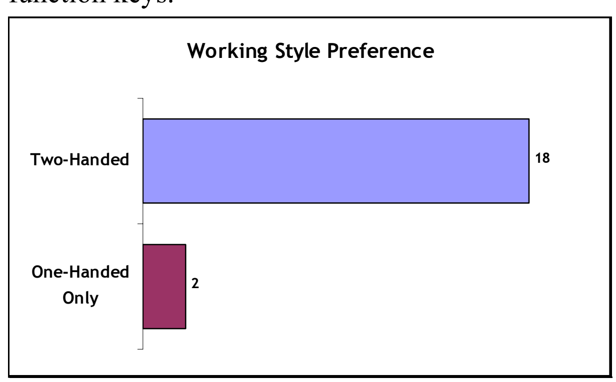


Figure16: Working style preference

4.0 SUMMARY

In summary, an extensive assessment or test battery was conducted between two CAD input methods using designers at a Fortune 100 Manufacturing company. The two input methods assessed - the conventional one-handed method using a mouse, augmented by keyboard function keys versus a two-handed method using a 3D motion control device and mouse. Each input method was used to complete four tasks which named (1) Assembly, (2) Colors, (3) Fillet, and (4) Sectioning.

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