# An Integrated Bimanual Computer Input Station: the Command Chair

## ABSTRACT

A new computer input device, the Command Chair, has been developed to provide bimanual (or, two-handed) input while also addressing several additional ergonomic issues. In particular, the Command Chair integrates an office chair, keyboard input, bimanual pointer input, and forearm support into a single system. This allows a designer to consider the input system as a whole, rather than as a collection of individual devices. In turn, this allows for better control of body activities and postures, with the goal of providing user comfort over a full workday. This system uses the location of the keyboard to position the mouse, removing the need to switch between devices. Preliminary testing indicates that the Command Chair reduces wrist fatigue relative to a traditional input station, but also provides slower pointing speed - partially attributable to higher system inertia.

### Author Keywords

Bimanual input, two-handed interfaces, ergonomics, Video Display Terminal (VDT) design, Musculoskelatal Disorders (MSD), workstation integration

### ACM Classification Keywords

H.5.2 User Interfaces — Input devices and strategies; H.5.2 User Interfaces — Ergonomics

## INTRODUCTION

Bimanual computer interfaces have been shown to offer many potential advantages over conventional one-handed interfaces [2]. These benefits can include increased speed, more intuitive interfaces, and reduced loading on a single arm (by splitting input motions between two arms). To enable and explore work in this field, a new bimanual input device, the "Command Chair" has been developed.

## THE COMMAND CHAIR: DESCRIPTION

The Command Chair is a novel device that provides a two degree-of-freedom input for each arm (Figure 1). This device consists of two articulating armrests with a half-keyboard at the end of each linkage. Mouse buttons are integrated into the keyboards. The armatures are attached to an office chair, thereby allowing keyboard height to be adjusted relative to chair height. The planar motion of the keyboard-halves is used as the pointer input into the computer. Coupling the location of the pointer to the keyboard position obviates the need to switch between input devices. In this way, the Command Chair integrates keyboard and pointer input into a single device. In addition, the design of this device attempts to address several other common computer input problems:

- Reduce the time required to switch between input devices
- Improve comfort and reduce risk of Musculoskelatal Disorders (MSDs) relative to a standard workstation
- Integrate devices to relieve crowding of the ideal working space – providing input devices within comfortable reach
- Improve workstation adjustability by the eliminating the disconnect between a user's chair and working surface
- Maintain a natural mapping between physical and virtual space by mapping input position to output position
- Provide continuous bimanual pointer input

Consideration of ergonomic concepts, such as these, in the design phase of new input devices can lead to more comfortable and usable systems. These considerations

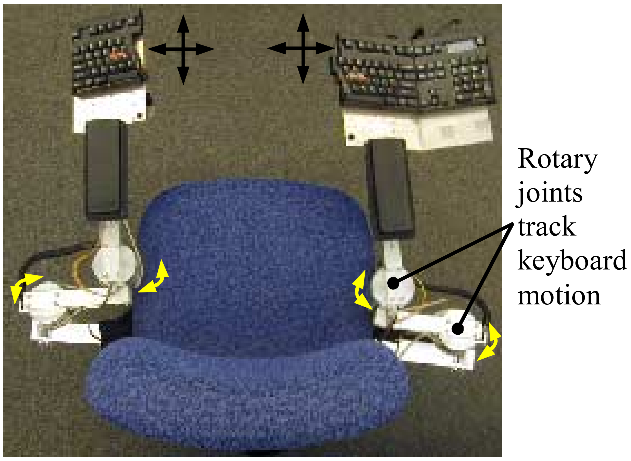

**Figure 1: Command Chair – Top View**

become even more important when considering the high risk of work related musculoskeletal disorders (MSDs) among computer workers [6]. Figure 2 shows several ergonomic heuristics as they were incorporated into the Command Chair [5,6]. More importantly, the approach of the Command Chair provides a workstation designer a higher level of control over the complete workstation than was previously possible. This allows for more control of the body's activities and postures during use, with the goal of making the workstation comfortable to use for a full eight-hour workday, and reducing MSD risk.

In addition, the Command Chair addresses a problem specific to bimanual computer interfacing – the loss of hotkey input for command selection. Or, as Balakrishnan states in his paper addressing this problem, "I've got two hands, but lost my hotkeys!" [1]. This is because the use of two pointing devices simultaneously typically precludes the use of hotkeys, since both hands are on pointing devices, and neither on the keyboard. This diminishes the value of the bimanual system. The Command Chair provides both hotkey input and bimanual pointer input.

## HARDWARE IMPLEMENTATION

The Command Chair consists of four articulating rotary joints (two for each arm), coupled by connecting links. The joints contain encoders that sense the rotation of the joint, as well as thrust bearings to provide a smooth motion. Encoder signals are interpreted by a series of digital boards, which compute the position of the armatures (using two distinct mappings), and relay these positions to the computer's pointer input via a standard PS/2 or serial port.

The two mapping of the command chair are the *kinematic* and *direct* mappings. The kinematic model represents the precise mathematical relation to calculate the position of the end of the armature based on the rotation of the joints.

The direct mapping treats the angular displacement of the two joints as the horizontal and vertical displacements of the pointer, directly. Essentially, this mapping uses the small angle approximation for 'sin' and 'cosine' functions. In the direct mapping case, a rotation of the second joint will cause the output pointer motion to follow a straight path (rather than an arc).

## EXPERIMENTAL DESIGN

To evaluate the Command Chair, a preliminary study was run in order to quantify pointing performance, and gather participant's opinions on the device relative to a standard workstation. Ten right-handed volunteer engineering students participated in a one-dimensional Fitts' tapping test to compare the pointing properties of the two mappings of the Command Chair with a traditional mouse configuration. All participants had extensive computer experience, and used a mouse on a daily basis. Device control:display gain was set to roughly 3.5:1 for all devices.

Testing was performed using the freely available GFLMB software [8], and followed the current version of the testing standard ISO 9241-9 [7]. The task began on a mouse click, and required a user to move the cursor in the horizontal direction from the starting point to the center of a rectangular target. The height of the target was almost equal to the screen height, as the target width was the test condition of interest. A variety of target widths (4,8,16 mm) and distances (80,160,320 mm) were used, with four repetitions of each condition for each. Ten blocks of twenty four trials were run sequentially for each device to track learning effects – for a total of 240 trials per device condition (mouse and 2 Command Chairs). Device presentation and trial order within blocks were randomized.

For each trial, the software measured pointing time, error state, and tap location. From this data, the three devices were compared with respect to input speed, error rate, and learning rate. Subjects completed qualitative questionnaires at the end of each testing session.

**Figure 2: Some Ergonomic Concepts Integrated into the Command Chair**

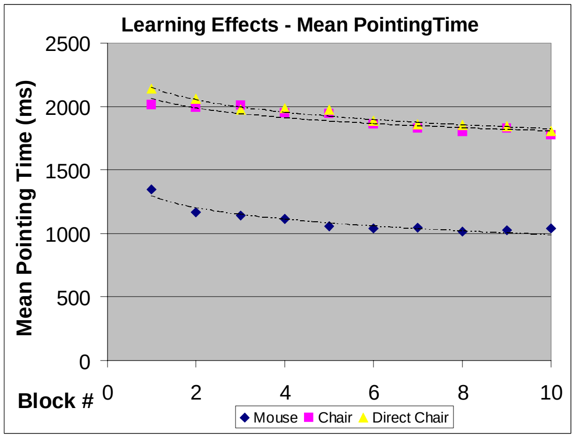

**Figure 3: Pointing Time versus Repetition**

### RESULTS

Trials in which the targets were not correctly selected on the first attempt were registered as errors, and those error times were excluded from mean time values. Mean movement times are plotted as a function of repetition in Figure 3. Learning curve slope similarities can be seen between the devices in this figure, as well as the performance gap between the devices. Results are shown in Table 1 for improvement as well as practiced performance (data from blocks 8-10). Improvement is calculated as the difference between the mean movement time of the first two blocks (novice performance), and the mean movement time of the final three blocks (practiced performance). Throughput is a combined metric of speed and accuracy, and is given by the ISO 9241-9 standard [7].

One-way ANOVA tests were performed to determine the significance of the results, with follow-up Bonferroni t-tests. All tests used a critical cut-off value of $p_{critical} = .05$. Movement time and throughput differences were both found to have significant performance differences between the three devices ($F_{2,807}>100$, $p<.0001$ for both time and throughput). Device improvement values were not found to be significantly different ($F_{2,27}=.19$, $p=.83$), indicating that learning rates were similar between the devices. Device error rates differed significantly ($F_{2,87}=7.17$, $p=.0013$). For mean movement time, throughput, and error rate, follow-up Bonferroni t-tests indicated that both of the Command Chair mappings performed similarly, while both mappings performed significantly differently from the mouse.

| PROPERTY | MOUSE | COMMAND CHAIR |
|---|---|---|
| Mental Effort * | **1.8** (.92) | **3.0** (1.33) |
| Physical Effort * | **2.2** (.92) | **3.6** (.97) |
| Accurate Pointing * | **3.6** (.51) | **1.3** (.67) |
| Device Speed * | **3.7** (1.16) | **2.6** (.84) |
| Wrist Fatigue* | **3.4** (1.32) | **1.6** (1.03) |
| Shoulder Fatigue * | **1.5** (.71) | **3.1** (1.60) |
| General Comfort | **3.8** (1.23) | **3.1** (1.10) |
| Ease of use | **4.8** (.97) | **3.4** (.84) |

1='low', 5='high', *indicates significant difference (p<.05)
(Standard Deviations appear in parenthesis)

**Table 2: Questionnaire Findings**

Additionally, subjective measures of the Command Chair were taken relative to a conventional mouse. Subjects were asked to rank various properties of the two workstations (mouse versus Command Chair) on a scale of one (representing 'low') to five (representing 'high'). Results were analyzed for significance with the Wilcoxon method, for non-parametric data. These results are shown in Table 2.

### DISCUSSION

As expected, the Command Chair was found to be a slower pointing device than a conventional mouse. This finding was expected as the Command Chair has much higher inertia and friction than a mouse. In addition, the Command Chair demonstrated an unanticipated behavior that contributed to its reduced pointing performance. As both rotary joints were coupled in the same horizontal plane, linkage motion caused the moment arms of the joints to vary. This means that the force required to actuate the joints slightly changed as the armature position changed – resulting in more awkward pointing. The presence of armature centering springs may have also had an effect in making pointing more difficult with the Command Chair.

The increased difficulty in pointing also likely contributed to the increased error rate demonstrated by the Command Chair. Similarly, the combination of pointing speed and accuracy (throughput) was found to be significantly slower for the Command Chair than for the conventional mouse.

| Device | **Mean Time (ms)** | **Throughput (bits/s)** | **Error Rate (%)** | **Improvement (Δs)** |
|---|---|---|---|---|
| **Command Chair** | 1812$^{a}$ | 2.56$^{c}$ | 3.80%$^{e}$ | 240.9 |
| Standard Deviation | 501 | .64 | 3.68% | 199.0 |
| **Direct Command Chair** | 1845$^{b}$ | 2.54$^{d}$ | 3.43%$^{f}$ | 288.9 |
| Standard Deviation | 476 | .46 | 3.40% | 147.3 |
| **Mouse** | 1026$^{a,b}$ | 5.10$^{c,d}$ | 1.11%$^{e,f}$ | 250.3 |
| Standard Deviation | 260 | 1.08 | 1.56% | 206.0 |

*Letter pairs indicate significant differences (p<.05)*

**Table 1: Device Performance**

Observed learning rates were similar between the conventional mouse and both mappings of the Command Chair. It was expected that the Direct Command Chair mapping would exhibit higher learning rates due to its approximation of pointer output motion relative to input motion. However, test participants seemed to be able to compensate for these approximations – resulting in similar overall performance for both Command Chair mappings. This is good news because it implies that humans can quickly grasp slightly mismatched input:output mappings.

The similar learning rates observed between all devices are likely to be partially due to the intuitive position-to-position input:output mapping used in all of the studied devices. The shared input:output mapping seems to be more important to learning rate than the arm musculature used to actuate the device. Of course, the actuating musculature selection also affects other important parameters, such as input speed and risk of musculoskeletal disorders.

The subjective questionnaire findings reinforce the quantitative performance measures found in this study. The device was measured to be slower and less accurate than a conventional mouse, and users were able to perceive the difference. Users were also able to perceive that the Command Chair shifts input loads from the user's wrists to their shoulders, as intended. The problems with the Command Chair's high inertia and static friction were also perceived by the users, in the form of low scores for the Command Chair for required effort and shoulder fatigue. While the subjective feedback was not as favorable to the Command Chair as was hoped, it provides a clear path for effecting future device improvements.

Finally, the expected Command Chair benefit of reduced homing time wasn't measured by this study. Typical homing times are in the range of 350-700 ms [3,4]. Of course, total homing time savings will be task dependent (based on the number of device changes that are required for a task). But, when compared with typical pointing and button press times (1.1 s., and .2 s., respectively in Card's Keystroke Level Model [3]), we can see that a homing time reduction could lead to substantial overall time savings for a task that requires many input device changes. However, simply reducing homing time does not necessarily translate to faster overall input [4].

## CONCLUSIONS

The Command Chair approach shows great potential in integrating ergonomics concepts and bimanual input into a single workstation. This includes both potential physical benefits (such as improved body posture), as well as performance benefits (such as reduced homing time, and the benefits of bimanual interfaces).

Users demonstrated similar performance with both mappings of the Command Chair; which indicates that users can compensate for small approximations between input and display motions.

Learning rates were similar for all three devices, indicating that input:output mapping (position:position in the case of this study) may be more important for learning rate than the specific arm musculature used to actuate the device.

The first prototype of the Command Chair demonstrated inferior pointing performance to a conventional mouse. However, relative performance may improve when total workstation throughput (i.e. combined typing and pointing performance) is considered, and device inertia is reduced.

## FUTURE DIRECTION

Future work will include redesigning the Command Chair to improve pointing performance. The new design should reduce both inertia and static friction. Future versions should also provide smoother, less constrained motion. Once the new design is complete, more rigorous testing needs to be performed. Future tests should include body posture measures, 2D Fitts' tapping, and full workstation throughput measures (including typing and pointing tasks).

## ACKNOWLEDGEMENTS

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