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William J. Hughes Technical Center
Atlantic City International Airport, NJ 08405

Human Factors Evaluation of Pointing Devices Used by Air Traffic Controllers: Changes in Physical Workload and Behavior

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16. Abstract

Objective: To ensure that air traffic controller interactions with present systems and the future Next Generation Transportation System (NextGen) are efficient and accurate, as well as without health detriments (e.g., musculoskeletal disorders), as possible, we conducted a simulation to explore the introduction of new pointing devices to air traffic controllers. **Background**: The current en route trackball is inherently limited as to what kind of interactions it allows. However, switching to a new pointing device has risks—different pointing devices have different speed, accuracy, interaction capabilities, and ergonomic features. **Method**: Ten current or recently retired en route Certified Professional Controllers participated in the simulation. Participants controlled traffic in a Data Communications environment while using one of four pointing devices (en route trackball, alternative trackball, hand-shake mouse, and a standard mouse). During the simulations, we recorded the participants' subjective reports, performance, behavior, and muscle activity. **Results**: We found that participants preferred the mouse and current trackball over all other devices and were as successful controlling traffic (e.g., no losses of separation with the same number of aircraft under active control). We found no statistically significant physiological indications that any of the devices under evaluation had the potential to result in musculoskeletal disorders during regular use. We also found that participants were more accurate and significantly faster using the mouse than using other devices. **Conclusions**: Considering the above issues, and the wider variety of possible interactions, the mouse appears to be a pointing device better suited for future air traffic control systems than the legacy trackball.

17. Key Words
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Executive Summary

The Federal Aviation Administration (FAA) predicts that the number of flights in the National Airspace System (NAS) will, potentially, triple by 2025 (FAA, 2008; 2009). In addition to an increase in air traffic, the Next Generation Air Transportation System (NextGen) will introduce many new technologies, including data communications, Automatic Dependent Surveillance-Broadcast (ADS-B), and enhanced user interfaces (e.g., ERAM) with which air traffic controllers will interact. These changes in air traffic and technologies require controllers to interact with an array of computing and communications systems in new and more complex ways than previously possible.

The current en route trackball has been in use in the field for many years and, overall, has been an effective pointing device. However, with the new air traffic control (ATC) systems being introduced, the en route trackball may not be flexible enough to provide controllers with interaction capabilities needed for the new systems. Most modern computing environments use the traditional mouse (or an *ergonomic* variant) as a pointing device. However, there are concerns that switching to a mouse, in addition to impacting a controller's ability to control air traffic, will lead to an increase of Musculoskeletal Disorders (MSDs). In fact, this is what happened when the Swedish Civil Aviation Authority introduced new computer systems to air traffic controllers (Arvidsson et. al, 2008). This increase of reported MSDs was not necessarily due to switching away from a small trackball to a mouse but, instead, it was due to a complete reconfiguration of the workstation itself.

The current study explored the viability of changing pointing devices in the en route environment. We invited current and recently retired controllers to participate in a simulation at the FAA Research Development and Human Factors Laboratory (RDHFL) at the FAA William J. Hughes Technical Center (WJHTC). We monitored the controllers' behavior, ATC performance, and, most important, physical workload through electromyographic (EMG) equipment, as they gained operational experience with the current en route trackball, an alternative trackball, an ergonomic "handshake" mouse, and a standard mouse in a data communications only environment.

We found that participants preferred the mouse and current trackball to all other devices, and that they controlled traffic successfully (e.g., no losses of separation with the same number of aircraft under active control). We found that there were no statistically significant physiological indications that—during regular use—any of the devices under evaluation had the potential to result in musculoskeletal disorders in air traffic controllers. We also found that participants were more accurate and significantly faster using the mouse than using other devices. Considering these factors, and the possibility of a wider variety of possible interactions, the mouse appears to be a more appropriate pointing device for future ACT systems than the legacy trackball.

We recommend that the en route system switch to a standard mouse for the above reasons. However, if a switch is made, a number of factors may need further evaluation. First, it is not entirely clear whether en route trackball logic or traditional mouse logic should be adopted; this could be evaluated in a later study. In open-ended questions, many participants noted that using the center scroll-wheel button as a center click (a cornerstone of the trackball logic) was problematic. The use of a scroll-wheel would provide an opportunity for new types of interactions, such as scrolling through altitude or heading choices quickly.

If a switch is made to a mouse-based en route system, it is imperative that its operational impact is evaluated at a later date. We recommend collection and evaluation of safety, performance, and survey data, as well as musculoskeletal recordings and workers compensation claim rates at the facilities six months or one year after implementation.

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1. INTRODUCTION

Air traffic control (ATC) has undergone many advances since the development of radar. Each major transformation has brought large mental and physical changes in the way air traffic controllers perform their job. In early radar-based ATC, controlling traffic required watching a radarscope while mentally and physically translating that information onto physical representations of the planes (e.g., paper flight strips, shrimp boats). The job of the air traffic controller was a very mentally demanding and physically variable task. As computers have become more capable, controllers have bridged the gap between physical representations of the aircraft to virtual, computer-based representations that integrate flight data with radar data on a single display. For example, the Display System Replacement (DSR) and En Route Automation Modernization (ERAM) systems allow controllers to interact with representations of flight data (data blocks) and aircraft positions (target and position symbols) on a computer monitor as well as allow controllers to input changes and issue clearances (altitude, heading, etc.) with either a keyboard or trackball.

Although the job of an en route air traffic controller is still extremely mentally demanding, the physical variability has all but disappeared. This has made en route controllers more sedentary and restricted in the kinds of postures and movements involved at work. As with most computer work, these changes have led to a concern that controllers may be at an increased risk of developing musculoskeletal disorders (MSDs). Presently, there is no compelling evidence that MSDS are a prevalent problem in ATC in the United States. There are, however, a number of significant upcoming changes in ATC. The limited set of interactions currently available to controllers will increase considerably. There are many new alerting, planning, and clearance issuing tools under development or being deployed to the field. These changes will provide controllers with many more interaction, automation, and communication options. The user-interface changes that accompany these new tools and technologies will require more interaction with pointing devices. Because of its limited interaction capabilities, it is not clear whether the legacy trackball is appropriate for the future ATC tasks. We therefore need to determine whether different pointing devices (a) would provide better interaction capability or (b) would potentially increase the risk to develop MSDs for those who work with them.

1.1 Background

There is epidemiological evidence that computer work, including both keyboard and mouse use, may result in a higher incidence of hand and wrist disorders as well as shoulder and neck disorders (Punnett & Bergquist, 1997). However, development of MSDs in the workplace has been a difficult problem to predict on an individual level. The impact of computer use may interact with physical, psychological, social, and cultural factors to contribute to disorders of the musculoskeletal system. Some researchers have even called this set of related disorders idiopathic since no "smoking gun" is apparent in many cases (Sommerich, McGlothlin, & Marras, 1993). Despite these limitations, the behavioral and physiological responses that occur during computer tasks can provide significant aid for predicting what changes in a workstation configuration may lead to potential MSDs.

To determine what physiological and behavioral markers may predict MSDs, researchers have focused on three related types of analyses: average body positions and muscle activity, variability in posture and muscle activity, and, finally, the frequency of short periods of time that the electromyographic (EMG) signal is under 0.5% of the Maximum Voluntary Contractions (MVC).

The first analysis, and perhaps the most common, evaluates average body positions and muscle activity (see also Harvey & Peper, 1997; Lauresen, Jensen, Garde, & Jørgensen, 2002). These measures have included mean static muscular activity for commonly involved arm and shoulder muscles, including forearm extensors, flexors, and trapezius.

A second analysis, explores variability in posture, movement, and muscle activity during various tasks (Jensen 2006). For example, Jensen et al. (1998) found that mean wrist extensions and EMG levels of Computer Assisted Design (CAD) operators were either the same or only slightly different from the side of the body operating the pointing device and the side of the body not performing any activity relating to the pointing device. However, the overall range of motion of the inactive side of the body had often doubled. EMG activity also showed a similar pattern: The overall activity pattern was less variable, and the proportion of "rest" time was much lower on the side of the body using a pointing device. This is particularly telling because in this same study, three times as many participants reported arm and shoulder problems with the side of the body using the pointing device.

Finally, a third analysis provides evidence that just having higher variability or lower average muscle activity levels may not be the only thing that successfully predicts MSDs. Some researchers have found evidence that the frequency of "silent" rest gaps—less than 0.5% of the maximum muscle activity values—can predict the development of neck and shoulder disorders (Veiersted, Westgaard, & Andersen, 1990). There is also evidence that people with preexisting neck and shoulder disorders demonstrated less frequent rest gaps (Hägg & Åström, 1997). We therefore should consider average activation level, variability, and rest gaps when determining whether a work environment or task could lead to an increase in the rate of MSDs among workers.

Most important to our current study are investigations into MSDs and physical workload in air traffic controllers in Sweden. This set of studies examined a number of aspects related to MSDs as the Swedish Civil Aviation Authority transitioned from its legacy ATC system to a newer system that emphasized the use of a mouse. With the legacy system (Arvidsson, Hansson, Mathiassen, & Skerfving, 2006) controllers sat in front of circular radar screens. When planes entered the controller's sector, a printer dispensed strips with the flight data corresponding to the planes represented on the radar screen. The controllers then placed the strips into holders on their desks, and as they issued clearances to the planes via microphones, they noted changes on the paper strips. Each controller was responsible for using a small trackball (vertically mounted next to the radarscope) and a customized ATC keyboard (mounted in the workstation). Although controllers using the legacy system rarely complained of or were diagnosed with MSDs of the elbows or hands, there was a higher incidence of shoulder, neck, and upper back MSDs among female controllers than in other groups of participants performing "varied office work" (Arvidsson, Arvidsson et al., 2006; Arvidsson, Axmon, & Skerfving, 2008).

The new Swedish ATC system was appreciably different from the legacy system (Arvidsson, Hansson et al., 2006). Not only was the entire workstation configuration changed, but the computer interactions required to control traffic were entirely different. A mouse, a square radarscope, a different keyboard, and a smaller monitor replaced paper strips, the circular radar screen, the trackball, and the custom keyboard. These changes resulted in the display of the many pieces of required information on fewer surfaces, and the controller interacted with the system through the mouse most of the time with very little required keyboard input.

Before deployment of the new ATC system across the Swedish national airspace, Arvidsson, Hansson et al. (2006) compared physical workload using the legacy system during actual ATC as well as during a simulation using similar traffic levels with the new system. They found that the new ATC system caused the controllers to change their physical work styles substantially. Controllers using the new system had lower movement velocities, less variable postures, and, most important, less muscular rest in the right forearm extensors. Not only did the new system lead to these problematic changes, but the predictors of MSDs were amplified at higher work intensities. Not surprisingly, when Arvidsson et al. (2008) returned to the ATC facilities 20 months after national deployment of the new system, there was a higher incidence of right-arm disorders and—among the younger controllers—higher rates of disorders in the neck, shoulder, or back. Senior controllers did not display an increase in neck, shoulder, or back disorders, but it is important to note that these were already quite high. At best, the new ATC system let an ongoing problem with neck, shoulder, and back MSDs continue, and at worst, it increased the number of MSDs in controllers' arms.

The problems that occurred after the Swedish ATC system changed the workstations are particularly useful in considering the potential issues that face the United States ATC system when switching to a different pointing device. There are, however, a number of important differences that necessitate performing our own investigation. The system currently in use in the en route centers in the United States is already quite similar to the new Swedish system. Both systems require interacting with a primary square radarscope and a smaller standard Liquid Crystal Display (LCD) monitor with keyboards and pointing devices. Controllers in the United States use a large trackball and perform significant amounts of data entry with a keyboard, whereas the Swedish system is reliant on command inputs via the mouse (Arvidsson, Hansson et al., 2006). In the United States, for every command that controllers can enter with a pointing device, they can enter the same command with the keyboard (or a combination of the two). This may be a reason why there has not been evidence to suggest that MSDs are currently a problem within the United States ATC system.

To determine whether switching to a different pointing device could potentially lead to MSDs among controllers, we invited current and recently retired controllers to participate in a simulation at the Research Development and Human Factors Laboratory (RDHFL) at the Federal Aviation Administration (FAA) William J. Hughes Technical Center (WJHTC). We monitored controller behavior, ATC performance, and, most important, physical workload as they gained operational experience with four types of standard and ergonomic pointing devices.

1.2 Purpose

We conducted this research to explore the viability of changing pointing devices in the en route environment. We measured controller musculoskeletal activity to determine whether an alternative trackball, an ergonomic handshake mouse, or a standard mouse could be suitable alternatives to the current en route trackball.

2. METHOD

2.1 Participants

Four current and six retired Certified Professional Controllers from en route facilities participated in the study. The participants (1 woman, 9 men, M_{age} = 48.2 years; age range: 28-59 years) had from 5.2 to 31.4 (M_{years} = 23.2) years of experience controlling traffic.

Participants were part of a larger simulation and spent two weeks at the RDHFL. They spent part of their time controlling traffic and using different pointing devices in a data-communication-only ATC environment (no voice communication with pilots). Each participant read and signed an informed consent statement (see Appendix A) approved by the FAA Institutional Review Board before taking part in the experiment.

2.2 Equipment

2.2.1 Air Traffic Controller Pointing Devices

We tested five experimental conditions to investigate four different pointing devices: an En route ATC trackball ("trackball"), a Microsoft® standard mouse ("mouse"), a Logitech® T-BC21 trackball ("alternative trackball"), and an Evoluent, Inc. handshake mouse ("handshake mouse"). Four of the devices used the same button mapping and interactions as the standard ATC trackball. For the standard mouse, there was an additional condition in which the mouse behavior was more similar to a standard mouse (i.e., with click, drag, and release logic—instead of the ATC trackball logic, for which the left button is pressed and released to pick up an object, and the middle button is released to drop the object). In all, the conditions were Alternative Trackball, Handshake Mouse, Mouse-in-Mouse mode, Mouse-in-Trackball mode, and Trackball.

2.2.2 Simulation and Software Systems

We conducted the ATC simulation in a simulated En route facility at the RDHFL. Video and audio equipment recorded the participants' communications and actions during the simulation. We also recorded the radarscopes and all of the participants' interactions (i.e., keyboard and pointing device inputs) with the system.

Workstations consisted of high-resolution (2,048 x 2,048 pixels) 2K 29" LCD radarscopes, keyboard, AIK (a small supplementary keypad), and a pointing device. The console table (see Figure 1) was 36" wide, 24" deep, and 27.5" from floor to tabletop. The participants could freely move the keyboard and pointing devices around. The participants were able to adjust their chairs to comfortable heights at the beginning of the simulation and then kept chairs at the same height throughout the experiment.

Figure 1. Simulated en route workstation with each of the pointing devices.

We used the Distributed Environment for Simulation, Rapid Engineering, and Experimentation (DESIREE) ATC simulator and the Target Generation Facility (TGF) to run the air traffic simulations. The FAA WJHTC developed these two software systems in-house.

DESIREE simulates en route and Terminal Radar Approach Control (TRACON), and Tower functionality, allowing researchers to rapidly prototype changes to the display of information and automation capabilities on the ATC workstations and to evaluate new concepts and procedures. The TGF uses flight plans to generate track data and provides it to DESIREE, which displays information on the controller displays, including radar tracks, data blocks, sector maps, and conflict probe results and conflict alerts.

We used a generic high-altitude sector in Genera developed at the RDHFL. Researchers and Subject Matter Experts (SMEs) designed Genera center (ZGN) to ensure that all controllers participating in simulations would have the same amount of experience with the airspace (Guttman & Stein, 1997). SMEs generated traffic patterns with the goal of making them challenging, yet realistic. All scenarios were 45 minutes in duration.

2.2.3 Transmission Systems

We measured musculoskeletal activity with a wireless Telemyo Direct Transmission System (DTS) from Noraxon USA, Inc. The Telemyo DTS sampled data at 1,500 Hz, had a 500 Hz low-pass filter, no notch filters, a 1st order high-pass filter set to 10 Hz ±10% cutoff, baseline noise < 1 uV RMS, input impedance > 100 MΩ, and an input range of ±3.5 mV. The DTS 2D goniometers had a nominal output range of ±180°, sensitivity of ±mV/degree, accuracy of ±2°, and X-Y crosstalk of less than ±5% for deflection under 60°. The DTS 2D inclinometer had a range of 90° in the X and Y directions, a sensitivity of 25 mV/degree, and an accuracy of ±2°.

2.2.4 Electromyographic Systems

We took EMG recordings with 2.0 cm center-to-center dual, disposable, self-adhesive, Ag/AgCl gel electrodes placed above the right extensor carpi radialis, the right flexor carpi radialis, and the right upper trapezius. We placed goniometers across the wrist and elbow, and one inclinometer on the upper arm immediately below the shoulder.

Prior to analysis, we filtered EMG signals with a band pass filter (10-300 Hz), and we calculated root mean square (RMS) values over consecutive time-windows (100 ms). We calculated the RMS (noise) value for each recording run as the mean of the lowest contiguous 500 ms of EMG value for each sensor. We subtracted the RMS(noise) in a power-sense from the overall RMS signal and normalized to the MVC collected before and after each run. We calculated the corrected RMS value as follows:

$$RMS(corrected)\ as\ \%\ of\ MVC = \frac{\sqrt{RMS(uncorrected)^2 - RMS(noise)^2}}{RMS(MVC)}$$

To evaluate differences in musculoskeletal activity, we analyzed the data as percentiles of the cumulative distribution during the simulation. We evaluated extreme muscle activity and posture (10th and 90th percentiles), median posture and activity (50th percentile), and the range of body postures (95th – 5th percentiles); see Arvidsson, Arvidsson et al., 2006. We also examined the proportion of time spent during the simulation "resting." We defined resting as periods of EMG recording where the amplitude of the signal of a muscle was less than 0.5% MVC for at least 100 ms (Delisle, Lariviere, Imbeau, & Durand, 2005; Delisle, Lariviere, Plamodon, & Salazar, 2009; Thorn et al., 2007).

2.3 Materials

2.3.1 Background Questionnaire

Prior to the experiment, each participant completed a Background Questionnaire (see Appendix B), with questions regarding age, gender, level of ATC experience, current use and experience with different computer pointing devices, and any associated muscle strain or discomfort associated with their use.

2.3.2 Post-Scenario Questionnaire

After completing each scenario, the participants completed a Post-Scenario Questionnaire (see Appendix C). The questionnaire contained items that asked the participants to provide ratings (ranging from 1 to 10) about their performance, workload, situation awareness, and multiple aspects about the pointing devices (comfort, accuracy, etc.). The participants also had the opportunity to provide responses to open-ended questions and to include other comments about the scenario that they considered relevant in each section.

2.3.3 Exit Questionnaire

After the final simulation, participants filled out an Exit Questionnaire (see Appendix D) containing items that allow them to rank the pointing devices from 1 (*best*) to 4 (*worst*) on several dimensions of comfort and effectiveness. The participants also had the opportunity to provide responses to open-ended questions and to include other comments about the simulation.

2.4 Procedure

At the beginning of each recording phase, after we attached the measurement devices, we took a number of baseline measurements. These included resting state, MVC, and measurements of arm positions (straight arm by side of body, lifted straight arm pointing forward, lifted arm with a bent elbow, and elbow bent with arm by side of body).

We then instructed participants to use the pointing device to click once on each of 17 small orange (RGB: 255,165,0) circles, which had a diameter of ~1° of visual angle arranged around the screen (see Figure 2). We measured speed and accuracy (selection distance from the middle of the circle). After completing the "pointing at circles" task, we began the air traffic simulation, which lasted for 45 minutes. After the ATC task, participants completed another pointing at circles task, a resting period, and an MVC session.

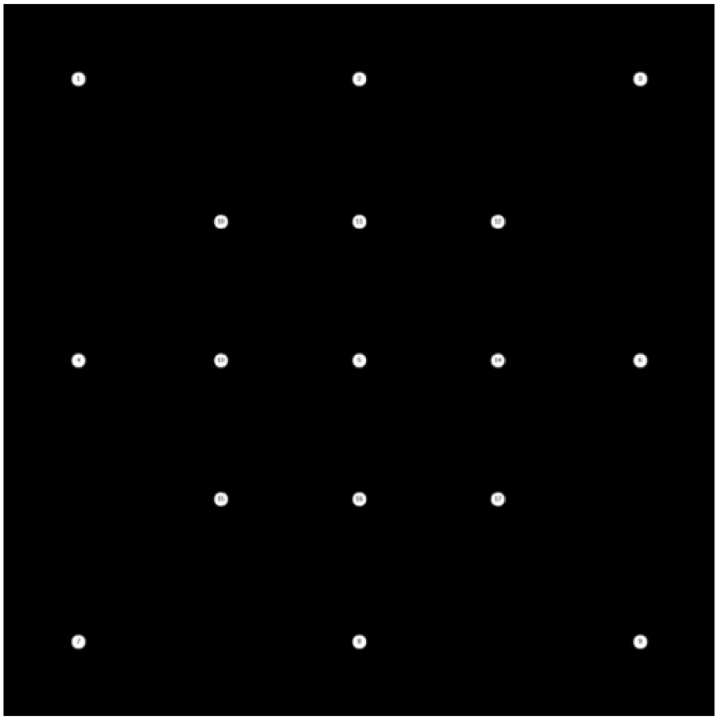

Figure 2. Screen shot of target locations for pointing task.

For each pointing device, participants repeated this procedure multiple times. For the standard En route trackball, participants performed only a single practice session—due to familiarity with the device because they had worked with it every day—before completing a test session. When participants used the other pointing devices (alternate trackball, handshake mouse, mouse with mouse logic, and mouse with trackball logic), they performed three practice sessions before the test session. Participants completed all practice and test sessions for each pointing device in sequence before continuing to the next device. We partially counterbalanced the order of the conditions between participant pairs.

3. RESULTS

3.1 Subjective Data

We used a Friedman test to determine whether participants rated devices similarly for each survey question. For each question that reached significance, we used a post-hoc Wilcoxon matched-pairs tests to determine which specific devices controllers rated significantly different from the other devices. Tables 1, 2, and 3, present individual items for the Post-Scenario and Exit Questionnaires, with their associate descriptive statistics, respectively.

Table 1. Post-Scenario Questionnaire: ATC Questions

	Alternative Trackball	Handshake Mouse	Mouse with mouse logic	Mouse with trackball logic	Trackball
	Mean (StDev)	Mean (StDev)	Mean (StDev)	Mean (StDev)	Mean (StDev)
Scenario Difficulty	5.5 (2.8)	6.9 (2.3)	5.4 (1.9)	6.4 (2.6)	7.0 (2.4)
Overall ATC Performance	9.0 (0.7)	9.1 (0.8)	8.9 (0.9)	8.7 (1.8)	8.9 (1.4)
Overall Workload	6.6 (2.0)	6.7 (2.6)	6.0 (1.7)	5.5 (2.0)	6.8 (2.3)
Overall Situation Awareness (SA)	9.0 (1.1)	9.1 (0.7)	8.7 (0.9)	8.7 (1.5)	9.0 (1.0)
SA for aircraft locations	8.8 (1.1)	9.1 (0.9)	8.9 (0.9)	8.6 (1.6)	9.0 (0.9)
SA for projected aircraft locations	8.7 (1.1)	8.9 (1.2)	8.2 (1.5)	8.2 (2.2)	8.7 (1.2)
SA for potential loss-of-separation	9.2 (0.6)	9.1 (0.9)	9.1 (0.9)	8.9 (1.0)	9.3 (0.7)
SA of potential handoff/airspace violations	8.4 (1.6)	8.7 (2.1)	8.9 (1.5)	8.4 (1.8)	9.1 (0.9)

Table 2. Post-Scenario Questionnaire: Pointing Device Questions

	Alternative Trackball	Handshake Mouse	Mouse with mouse logic	Mouse with Trackball Logic	Trackball
	Mean (StDev)	Mean (StDev)	Mean (StDev)	Mean (StDev)	Mean (StDev)
Comfort	6.4 (3.0)	7.3 (1.4)	9.2 (1.1)	9.1 (0.9)	7.9 (1.3)
Effectivness	5.0 (2.6)	6.5 (1.4)	8.2 (2.0)	8.1 (2.4)	8.1 (1.4)
Accuracy	4.0 (2.8)	5.9 (1.5)	7.3 (3.1)	8.7 (1.1)	8.0 (1.3)
Speed	3.8 (2.8)	6.2 (2.0)	8.1 (2.3)	8.7 (1.0)	7.0 (2.4)
Interaction with toolbars & macros	6.2 (2.8)	7.4 (1.8)	8.3 (1.3)	8.5 (2.1)	7.8 (1.7)
Interaction with data blocks	4.6 (3.0)	6.5 (2.0)	7.8 (2.7)	7.8 (2.4)	7.6 (1.4)
Mistake Prone?	3.6 (3.1)	4.5 (1.4)	6.5 (3.1)	7.3 (2.5)	7.2 (2.0)
Button Position	3.3 (2.8)	6.1 (2.9)	7.8 (1.6)	7.8 (2.6)	8.9 (1.3)
Level of muscle strain	4.4 (2.9)	3.2 (2.7)	2.4 (1.3)	2.9 (2.6)	2.5 (1.8)

Table 3. Exit Questionnaire: Pointing Device Questions

	Alternative Trackball	Handshake Mouse	Mouse	Trackball
	Mean Rank (StDev)	Mean Rank (StDev)	Mean Rank (StDev)	Mean Rank (StDev)
Comfort	3.1 (1.1)	3.1 (0.7)	1.5 (0.8)	2.3 (1.1)
Accuracy	3.2 (1.0)	3.5 (0.5)	1.2 (0.4)	2.1 (0.6)
Speed	3.2 (0.9)	3.2 (0.8)	1.5 (0.7)	3.2 (1.1)
Sensitivity	3.2 (0.8)	2.1 (0.9)	1.5 (0.7)	3.2 (1.1)
Interaction with data blocks	3.2 (1.0)	3.3 (0.8)	1.4 (0.7)	2.1 (0.9)
Interaction with toolbars & macros	3.3 (0.9)	3.2 (0.79)	1.2 (0.6)	2.3 (0.67)
Button Position	3.3 (0.9)	3.5 (0.5)	1.6 (0.5)	1.6 (0.7)

We took the grand mean of the results from each of the pointing device specific questions (e.g., comfort, effectiveness, accuracy, speed, interaction with toolbars & macros, interaction with data blocks, mistake prone, button positions, and level of muscle strain) for the post-scenario and post-experiment questionnaires. We found agreement across participants and surveys about what kind of devices controllers preferred. In the Post-Scenario Questionnaire, participants ranked the devices, in overall order of mean rank, mouse-in-mouse mode (*M* = 4.1), mouse-in-trackball mode (*M* = 3.6), trackball (*M* = 3.4), handshake mouse (*M* = 2.4), and, finally, the alternative trackball (*M* = 1.6). There was a significant effect of rank order between participants, $\chi^2(4, N = 10) = 16.38$, *p* = .003. The only matched-pair that reached significance in the Wilcoxon post-hoc test, after Bonferroni correction for multiple comparisons, was the highest ranked device (mouse-in-mouse mode) vs. the lowest ranked device (alternative trackball), *p* = .005. Other select pairs were significant without correction, mouse-in-trackball mode vs. alternative trackball (*p* = .007), trackball vs. alternative trackball (*p* = .021), mouse-in-mouse mode vs. handshake mouse (*p* = .033), and mouse-in-trackball mode vs. handshake mouse (*p* = .022).

The Post-Experiment Questionnaire showed a similar pattern of results as the Post-Scenario Questionnaire, but with two differences—the alternative trackball and the handshake mouse switched positions as the least preferred device, and the mouse conditions were collapsed into a device-only consideration, ignoring the device interaction type (mouse vs. trackball logic). In overall order of mean rank, across the items that asked about pointing device comfort, accuracy, speed, sensitivity, interactions, and button positions, the mouse was preferred the most (*M* = 1.2), followed by the trackball (*M* = 2.3), then the alternative trackball (*M* = 3.2), and finally the handshake mouse (*M* = 3.4). A number of post-hoc analyses were also significant after correction: mouse vs. alternative trackball (*p* = .007), mouse vs. handshake mouse (*p* = .005), and mouse vs. trackball (*p* = .007). The trackball vs. alternative trackball comparison was significant without correction (*p* = .05).

3.2 Point-and-Click Task

We used a one-way repeated measures Analysis of Variance (ANOVA) to analyze the response time and pointing accuracy. We measured pointing time beginning when the participant clicked on the first dot and ending when the participant pressed the clear button on the keyboard. We measured accuracy in number of pixels from the center pixel of the target circle. For each participant, we averaged the pointing device task before the ATC simulation with the one presented post simulation (see Figure 3).

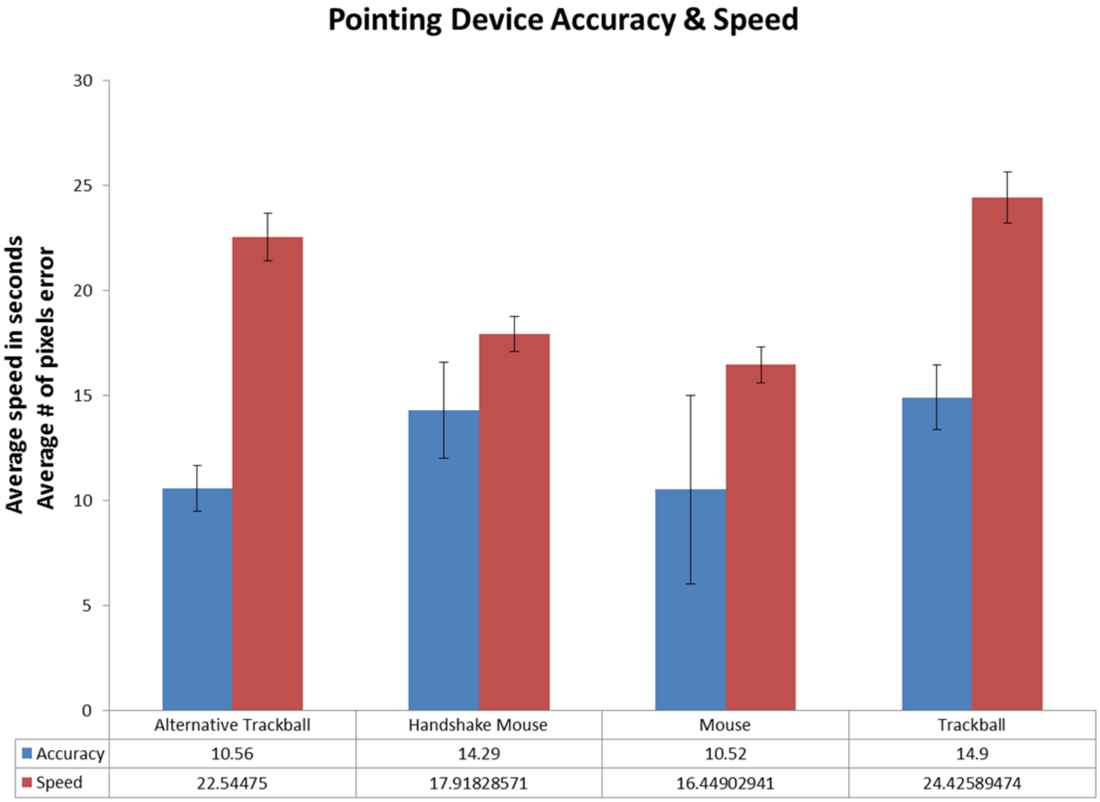

Figure 3. Speed and error of the tested pointing devices. Note that the lower the score for speed and error, the better the controllers performed with the device.

There was a statistically significant difference in time to complete the point-and-click tasks, $F(3, 27) = 41.1$, $p < .001$. Participants were fastest with the mouse ($M = 16.5$ seconds, $SD = 2.7$), followed by the handshake mouse ($M = 17.9$, $SD = 2.7$), followed by the alternative trackball ($M = 22.5$, $SD = 3.6$), and slowest with the trackball ($M = 24.5$, $SD = 3.8$). Post-hoc pairwise comparisons, Bonferroni corrected for multiple comparisons, showed significance between a number of pairs: alternative trackball vs. handshake mouse ($p = .002$), alternative trackball vs. mouse ($p < 0.001$), handshake mouse vs. trackball ($p = 0.001$), and mouse vs. trackball ($p < 0.001$). However, participants were not more accurate in pointing when using the mouse ($M = 10.6$ pixels, $SD = 4.9$) and alternative trackball ($M = 10.7$, $SD = 3.4$) compared to when using the handshake mouse ($M = 14.2$, $SD = 7.2$) or trackball ($M = 14.6$, $SD = 14.2$). These differences did not reach significance ($p < 0.1$).

3.3 Air Traffic Controller Performance

There were no apparent differences between controllers' performance when using the different pointing devices. Controllers, regardless of pointing device, were able to perform their ATC duties successfully, safely, and efficiently when separating aircraft. Controllers controlled a mean of 22.0 planes ($SD = 6.8$) in the first third of the simulation, 22.6 planes ($SD = 1.4$) in the middle third of the simulation, and 28.6 planes ($SD = 1.9$) in the final third of the simulation. There were no significant differences between any conditions in a repeated measures ANOVA for each of the simulation time periods. In addition, controllers managed the traffic equally efficiently across the pointing device conditions. There were no significant differences between conditions with respect to the average distance aircraft traveled in the sector ($M = 84.69$, $SD = 3.11$) and the average time aircraft spent in the sector ($M = 697.16$ s, $SD = 26.25$ s).

3.4 Air Traffic Controller Pointing Device Behavior

Each time controllers opened a fly-out menu to send an altitude, heading, or speed clearance, we calculated the total time to complete the action. There was no significant difference in mean response time across the fly-out menus in a repeated measures ANOVA for mouse-in-mouse mode ($M = 4.6$ seconds, $SD = 1.8$), alternative trackball ($M = 4.8$, $SD = 2.3$), mouse-in-trackball mode ($M = 5.0$, $SD = 2.5$), handshake mouse ($M = 5.5$, $SD = 2.1$), or trackball ($M = 6.3$, $SD = 2.9$).

In addition to measuring controllers' speed at issuing commands with the pointing devices, we measured their overall preference in the use of input devices. Controllers can access many of the functions on the radarscope through the keyboard alone, the keyboard and pointing device in conjunction, or the pointing device alone. If controllers prefer to use a particular pointing device, one would expect them to use that pointing device significantly more than the keyboard for the command entries (in this case, altitude, heading, speed, leader-line position, and handoff acceptances) that are possible from either device. Figure 4 demonstrates this case.

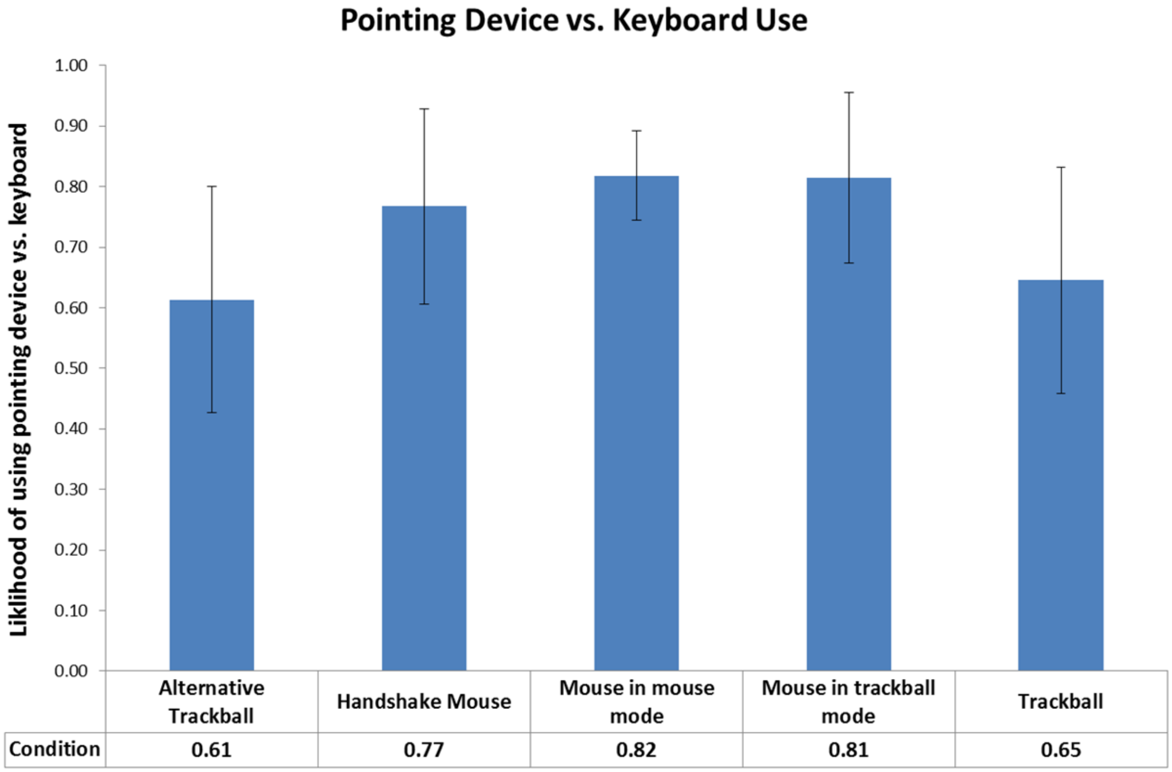

Figure 4. Controllers used the mouse significantly more than the keyboard. Other devices were not used significantly more than the keyboard.

Paired *t*-tests, Bonferroni corrected for multiple comparisons, demonstrated that participants significantly preferred using the mouse-in-mouse mode ($M = 105.1$ issued commands, $SD = 56.9$) over the keyboard ($M = 17.8$, $SD = 29.7$), $t(9) = 8.7$, $p < .001$, as well as the mouse-in-trackball mode ($M = 102.4$, $SD = 33.3$) over the keyboard ($M = 21.2$, $SD = 56.7$), $t(9) = 3.5$, $p < .007$. We ran a 2 x 5 repeated measures ANOVA with command entry modality (keyboard vs. pointing device) and condition (alternative trackball, handshake mouse, mouse-in-mouse mode, mouse-in-trackball mode, and trackball) in addition to the *t*-tests. We transformed all data into proportion of total entries to take into account different total numbers of entries across conditions. We then transformed the proportion data using a arcsin to take into account the non-normal distribution.[1] There was a main effect of command entry modality, $F(1, 9) = 8.8$, $p < 0.016$, indicating that controllers preferred using the pointing device over the keyboard, overall, for command entries. There was no significant main effect of condition or interaction between condition and command entry modality.

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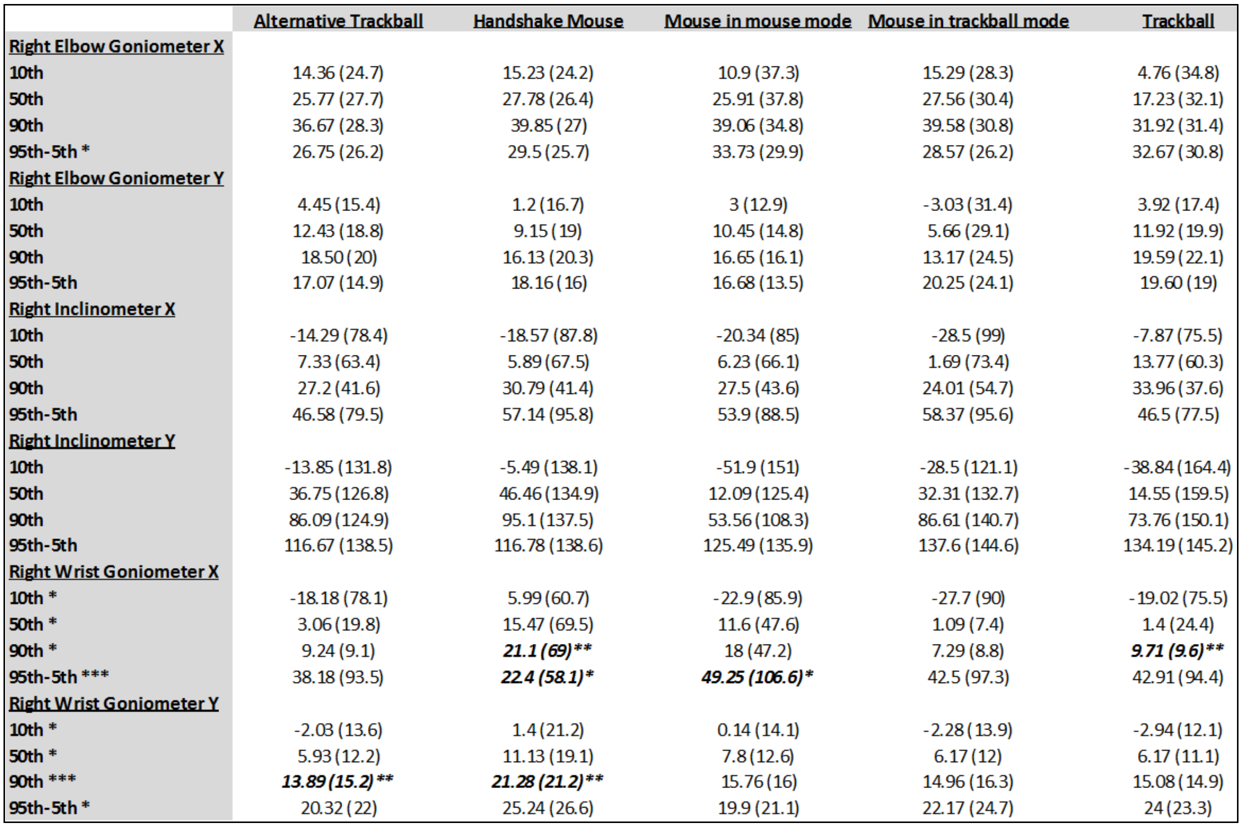
[1] The data were analyzed without transformations as well as with other common transforms for non-normally distributed data (log, etc.). The same pattern of results was present regardless of type or lack of transformation.

3.5 Body Position Measurements

In general, there were not many significant differences between the physical positions of the body, most likely, because the workspace was identical across conditions. There were a handful of interesting differences in body positions across conditions. There was a significant difference in the range (95th-5th percentile) of the right elbow across conditions in the X direction. We found multiple statistically significant differences in the angular measurements of the wrist. Table 4 shows all of the means, standard deviations, and relevant statistics.

Table 4. Post-Mean Arm Positions



	Alternative Trackball	Handshake Mouse	Mouse in mouse mode	Mouse in trackball mode	Trackball
Right Elbow Goniometer X					
10th	14.36 (24.7)	15.23 (24.2)	10.9 (37.3)	15.29 (28.3)	4.76 (34.8)
50th	25.77 (27.7)	27.78 (26.4)	25.91 (37.8)	27.56 (30.4)	17.23 (32.1)
90th	36.67 (28.3)	39.85 (27)	39.06 (34.8)	39.58 (30.8)	31.92 (31.4)
95th-5th *	26.75 (26.2)	29.5 (25.7)	33.73 (29.9)	28.57 (26.2)	32.67 (30.8)
Right Elbow Goniometer Y					
10th	4.45 (15.4)	1.2 (16.7)	3 (12.9)	-3.03 (31.4)	3.92 (17.4)
50th	12.43 (18.8)	9.15 (19)	10.45 (14.8)	5.66 (29.1)	11.92 (19.9)
90th	18.50 (20)	16.13 (20.3)	16.65 (16.1)	13.17 (24.5)	19.59 (22.1)
95th-5th	17.07 (14.9)	18.16 (16)	16.68 (13.5)	20.25 (24.1)	19.60 (19)
Right Inclinometer X					
10th	-14.29 (78.4)	-18.57 (87.8)	-20.34 (85)	-28.5 (99)	-7.87 (75.5)
50th	7.33 (63.4)	5.89 (67.5)	6.23 (66.1)	1.69 (73.4)	13.77 (60.3)
90th	27.2 (41.6)	30.79 (41.4)	27.5 (43.6)	24.01 (54.7)	33.96 (37.6)
95th-5th	46.58 (79.5)	57.14 (95.8)	53.9 (88.5)	58.37 (95.6)	46.5 (77.5)
Right Inclinometer Y					
10th	-13.85 (131.8)	-5.49 (138.1)	-51.9 (151)	-28.5 (121.1)	-38.84 (164.4)
50th	36.75 (126.8)	46.46 (134.9)	12.09 (125.4)	32.31 (132.7)	14.55 (159.5)
90th	86.09 (124.9)	95.1 (137.5)	53.56 (108.3)	86.61 (140.7)	73.76 (150.1)
95th-5th	116.67 (138.5)	116.78 (138.6)	125.49 (135.9)	137.6 (144.6)	134.19 (145.2)
Right Wrist Goniometer X					
10th *	-18.18 (78.1)	5.99 (60.7)	-22.9 (85.9)	-27.7 (90)	-19.02 (75.5)
50th *	3.06 (19.8)	15.47 (69.5)	11.6 (47.6)	1.09 (7.4)	1.4 (24.4)
90th *	9.24 (9.1)	21.1 (69)**	18 (47.2)	7.29 (8.8)	9.71 (9.6)**
95th-5th ***	38.18 (93.5)	22.4 (58.1)*	49.25 (106.6)*	42.5 (97.3)	42.91 (94.4)
Right Wrist Goniometer Y					
10th *	-2.03 (13.6)	1.4 (21.2)	0.14 (14.1)	-2.28 (13.9)	-2.94 (12.1)
50th *	5.93 (12.2)	11.13 (19.1)	7.8 (12.6)	6.17 (12)	6.17 (11.1)
90th ***	13.89 (15.2)**	21.28 (21.2)**	15.76 (16)	14.96 (16.3)	15.08 (14.9)
95th-5th *	20.32 (22)	25.24 (26.6)	19.9 (21.1)	22.17 (24.7)	24 (23.3)

Note. Mean and standard deviation of elbow and wrist angles, and elevations of the arm during test scenarios. Asterisks denote statistically significant differences between pointing devices within rows.

3.6 Electromyographic Measurements

We used a 3 x 5 x 3 (Muscle type x Condition x Percentile) repeated measures ANOVA to examine the effect of muscle type (flexor, extensor, or trapezius), condition (trackball, handshake mouse, mouse-in-mouse mode, mouse-in-trackball mode, and alternative trackball), and percentile (10th, 50th, 90th) to determine whether there were any significant effect on overall muscle activity. We report all results with Greenhouse-Geisser corrections to account for any problems with sphericity. There was a significant main effect of muscle type, $F(2, 16) = 18.15, p < 0.001$, indicating that the muscles are contributing different amounts of activity. There was a significant main effect of percentile, $F(2, 16) = 37.39, p < 0.001$, demonstrating 10th, 50th, and 90th percentiles are significantly separated. There was a significant interaction between muscle type and percentile, $F(4, 32) = 9.01, p < 0.004$, showing a variable response pattern of muscles to pointing device related activities. Most important, however, there was no significant main effect of condition, interaction between muscle type and condition, nor an interaction between muscle type, condition, and percentile. Although the effect of condition and percentile did not reach statistical significance, this interaction may deserve further exploration in the future when more participants are available.

We explored the muscular rest time between conditions in two ways: (a) the total time spent under 0.5% of MVC and (b) the total number of rest breaks per minute (refer to the Methods section for details on what constitutes a "rest"). We used a 3 x 5 (Muscle type x Condition) repeated measures Greenhouse-Geisser corrected ANOVA for both rest time analyses.

In the analysis of total rest time (see Figure 5), there was a significant main effect of muscle type, $F(2, 18) = 5.37$, $p = .018$, indicating that some muscle groups are generally more active than others during ATC activities—it appears that the trapezius is, generally, more active throughout. There was no main effect of condition, and there was no significant interaction between muscle type and condition.

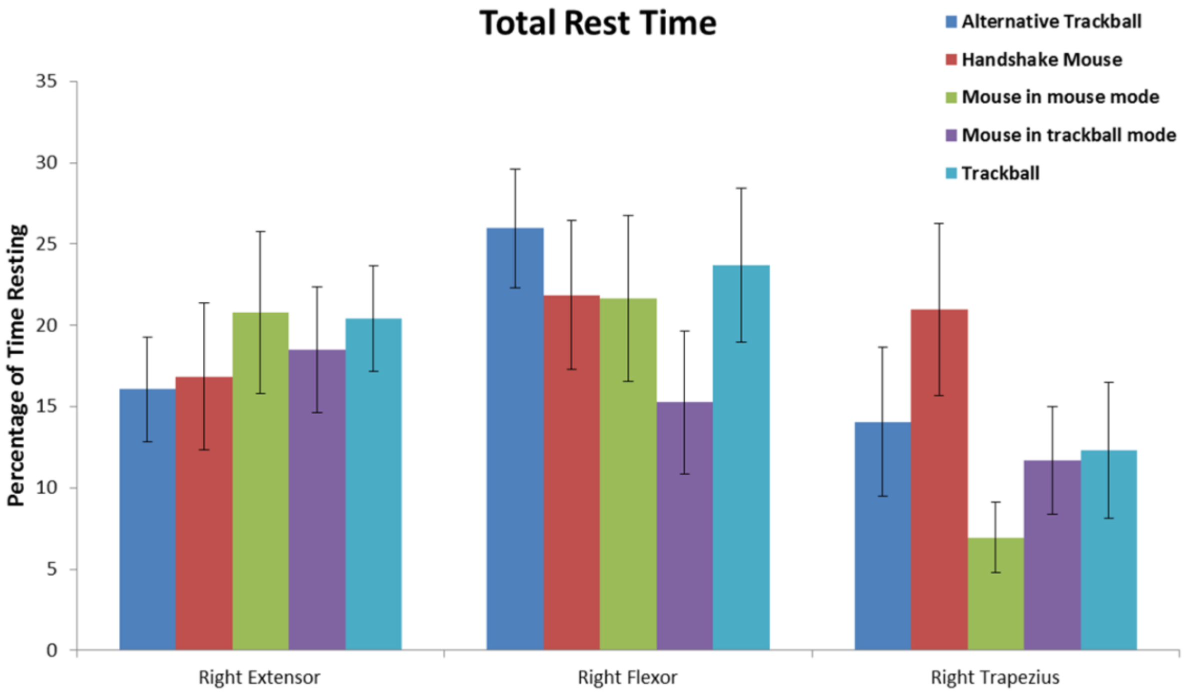


Figure 5. Total amount of muscular rest (< 0.5% MVC) during a test scenario.

The analysis of rest breaks per minute showed a different pattern of results (see Figure 6). There was no main effect of muscle type or condition. There was, however, a significant interaction between muscle type and condition, $F(8, 72) = 2.73$, $p = 0.036$. This effect was driven primarily by the unexpectedly high activation value of the flexor muscle in the alternative trackball condition.

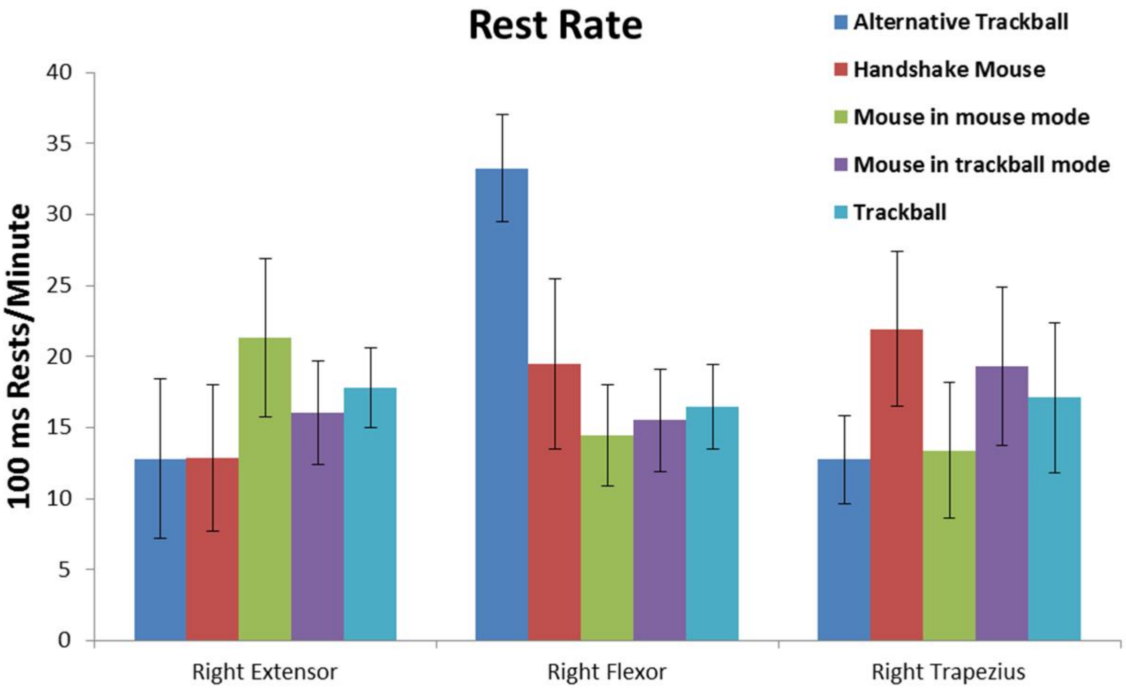


Figure 6. Total number of rest breaks of at least 100 ms per minute during a test scenario.

4. DISCUSSION

When evaluating whether to switch from a device with a long-standing history of use in a safety critical application, such as ATC, it is important to explore different dimensions that could cause harm. The present study has demonstrated through subjective data, behavioral tasks, ATC performance and behavior, and musculoskeletal activity that there will likely be few, if any, issues associated with switching to a mouse-based control system. This recommendation is made with some caution, because the study had limited statistical power due to the small number of controllers who participated.

4.1 Subjective Data

Data from the Post-Scenario Questionnaire and Exit Questionnaire supported the conclusion that participants preferred the mouse and the legacy en route trackball over the other devices. In the Post-Scenario Questionnaire, the participants ranked the input devices in overall order of mean rank: Mouse-in-Mouse mode, Mouse-in-Trackball mode, Trackball, Handshake Mouse, and Alternative Trackball, respectively. Preference for the mouse vs. the trackball was statistically indistinguishable, even though both were rated significantly higher than the other devices. At the conclusion of the study—after participants had many hours of active control experience with each input device—the participants ranked and preferred the mouse and trackball devices over the other devices. The mouse was ranked higher than any other device, including the trackball.

The mouse was widely seen as the most effective and comfortable device across many hours of ATC entry-level air traffic controllers, very experienced air traffic controllers, and retired controllers. Very experienced and retired controllers had used the legacy trackball for well over 15 years. Subjective data are very important when considering not only the likelihood of stakeholder support in implementation but also the likelihood of developing MSDs. There is evidence suggesting that mental attitudes and demands can greatly influence activity in the musculoskeletal system and by extension the development of MSDs (Jensen, 2006; Lauresen et al., 2002).

4.2 Speed and Accuracy in a Non-ATC Task

To evaluate baseline speed and accuracy for each of the pointing devices, we asked participants to use the devices to point-and-click 17 small circles as quickly and accurately as possible. The resulting data supported the findings of the subjective data—using the mouse was faster and more accurate (though not statistically so) than any of the other devices. With the projected increase in traffic, controllers will need to separate more aircraft per sector, with greater computer interaction requirements and capabilities. It is imperative that they use the quickest and most accurate device to update the automation about their intent to make the system more predictable. The mouse satisfies this requirement.

4.3 Air Traffic Controller Performance and Behavior

If we can improve the speed and accuracy of computer inputs in an operational setting by switching from the current en route trackball to an alternative pointing device, there will be a clear benefit to ATC. New devices have a potential to decrease the workload of controllers, but, by extension, increase the capacity and safety of the National Airspace System. We analyzed numerous factors to determine whether the devices could cause a decrement in ATC performance compared to the trackball. The scenarios had the same levels of traffic and controllers separated the same number of aircraft across conditions. Controllers were also not likely to have an operational error and were equally efficient at moving aircraft through the sector across conditions.

There are two caveats with the ATC Performance data. First, the scenario was very familiar to the controllers and contained manageable traffic levels with an all data-communication environment, causing a ceiling effect where the controllers essentially performed the best they could possibly perform. If there were a mixed equipage environment (some voice and some data communications) or there were many more aircraft, the results could have been different. If the non-ATC speed and accuracy task is any indication of performance, the mouse would outperform the other pointing devices in challenging and time critical ATC situations. Second, controllers were able to choose how to interact with the system. Some controllers chose to issue clearances and other interactions primarily with the keyboard, whereas other controllers used the pointing devices. Controllers used the mouse significantly more than the keyboard with commands that could be issued by either input device, whereas the other pointing device entries were not significantly different from the keyboard entries. If we had required participants to use only the pointing devices, the less efficient devices could have led to decrements in performance.

4.4 Musculoskeletal Data

There were no statistically significant findings within any of the musculoskeletal data sets (including body position or variability, overall muscle activity, or time spent resting). There were a few statistically significant findings (e.g., wrist position was more variable in a mouse condition), but none of these led to any obvious concern that the devices were significantly better or worse than the current trackball. We should be careful when drawing this conclusion, because there are a number of important considerations with the musculoskeletal data. EMG data are inherently noisy, and the number of controllers evaluated was very low. To make stronger claims and to detect subtle differences, many more controllers will have to participate. Even if the data suggested that there were different activity patterns between pointing devices that does not predict accurately who will develop MSDs on an individual basis—there are many factors to consider, including, but not limited to, work environment, culture, gender, body type, or anything else that could lead to stress.

5. CONCLUSION AND RECOMMENDATIONS

All of the data—including surveys, non-ATC tasks, ATC performance and behavior, and musculoskeletal data—support or are neutral to switching to the mouse over the trackball in En route ATC. If the agency decides to make the switch, it is not entirely clear whether we should adopt the trackball logic or traditional mouse logic. In open-ended questions, many participants noted that using the center scroll-wheel button as a center click (a cornerstone of the trackball logic) was problematic. However, there is potential use for the scroll-wheel for interactions such as scrolling through altitude or heading choices.

If the agency decides to switch to a mouse-based en route system, it is imperative that we introduce it slowly to a few facilities and reevaluate ATC performance and MSD issues before national implementation. For facilities selected to use a mouse, we recommend collecting safety, performance, musculoskeletal recordings, workers' compensation claim rates, and survey data at the facilities after six months or a year.

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Acronyms

AIK	A small supplementary keypad
ATC	Air Traffic Control
CAD	Computer Assisted Design
DESIREE	Distributed Environment for Simulation, Rapid Engineering, and Experimentation
DTS	Direct Transmission System
EMG	Electromyographic
ERAM	En Route Automation Modernization
FAA	Federal Aviation Administration
LCD	Liquid Crystal Display
MSD	Musculoskeletal Disorders
MVC	Maximum Voluntary Contractions
NextGen	Next Generation Air Transportation System
RDHFL	Research Development and Human Factors Laboratory
RMS	Root Mean Square
SME	Subject Matter Expert
TGF	Target Generation Facility
WJHTC	William J. Hughes Technical Center

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Appendix A: Informed Consent Statement

Informed Consent Statement

I, ____________________________, understand that this simulation, entitled "Separation Management (Sep Man) II: Evaluations of conflict probe location and format, display monitors, and pointing devices:" is sponsored by the Federal Aviation Administration (FAA) and is being directed by Dr. Carolina Zingale.

Nature and Purpose:

I have been recruited to volunteer as a participant in this simulation that will consist of three components. These components will investigate: a) the location and format of the conflict probe, b) alternatives to the existing display monitors at the radar (R-side) and data (D-side) positions, and c) three alternative pointing devices to the workstation trackball. This simulation will evaluate these issues in high traffic scenarios using a simulated En Route Automation Modernization (ERAM) system. I understand that the participants will be randomly assigned to work as either R-side or D-side controllers in some conditions. Depending on the condition, I will also be asked to wear a head-mounted oculometer to record eye movements or electromyographic (EMG) sensors to record information about muscle activity when using different pointing devices. The results of the study will be used to determine the benefits and feasibility of integrating these components into the future en route environment.

Experimental Procedures:

Twenty-four en route Certified Professional Controllers (CPCs) from Level 11 and 12 facilities will participate in the simulation. Four participants will arrive at the lab at a time. They will spend 8 days at the lab over a 2-week period. They will travel in on a Monday and travel out on Friday of the following week. At the start of the simulation, the participants will be randomly assigned to work as either an R-side or D-side controller for conditions that require R-side/D-side teams. Each participant will remain in the assigned position for all conditions that require teams. Other experimental conditions will require that each participant work as an R-side alone.

The participants will work from about 8:00 AM to about 4:30 PM every day with a lunch break and at least two rest breaks. The first morning will consist of an initial briefing to review project objectives and participant rights and responsibilities. It will include initial familiarization training on the simulated airspace, the system, and the procedures. The participants will then go the laboratory to begin hands-on training on the first of the three simulation components. They will complete practice scenarios prior to completing the test scenarios. All scenarios will be about 45-minute in duration.

During designated scenarios in the conflict probe and display evaluation components of the simulation, the R-side participants will wear a head-mounted oculometer to record eye movement data via infrared technology. The exposure to infrared illumination while wearing the oculometer is less than 4% of the intensity of that experienced when outside on a sunny day.

During designated scenarios in the pointing device evaluation, the participants will wear wireless electromyographic (EMG) recording sensors to obtain data about arm and wrist movement and muscle activity when using each device. The participants will wear short- sleeve shirts to allow access to the upper arm and upper back/neck area. Sensors will be applied to the skin using hypoallergenic gel, adhesives, and Velcro straps. Before attaching the sensors, we will wipe the skin with alcohol pads and/or an abrasive skin cleanser to remove oils to obtain the clearest possible signals. For some participants, we may also need to trim hair or shave small areas of skin at the location where the sensors will be applied.

The participants will provide workload ratings when prompted at designated intervals throughout each scenario. An automated data collection system will record system operations and generate a set of standard Air Traffic Control (ATC) simulation measures, including safety, capacity, efficiency, and communications. After each scenario, the participants will complete questionnaires to report their overall workload, situation awareness, and performance and to rate various aspects of the test condition. The simulation will be audio and video recorded.

After the participants have completed each of the simulation components, they will gather for a final debriefing session to provide final comments and feedback.

Anonymity and Confidentiality:

My participation in this simulation is strictly confidential. Any information I provide will remain anonymous: no individual names or identities will be associated with the data or released in any reports.

Benefits:

I understand that the only benefit to me is that I will be able to provide the researchers with valuable feedback and insight into the effectiveness of potential ATC tools and workstation configurations. My data will help the FAA to determine the benefits and feasibility of these modifications in this environment.

Participant Responsibilities:

I am aware that to participate in this study I must be a certified professional controller who is qualified at my facility and holds a current medical certificate. I must also have normal or corrected-to-normal (20/20) vision and do not wear bifocals, trifocals, or hard-contact lenses that are incompatible with the eye-tracking device used in this simulation. I will control traffic and answer the questions asked during the study to the best of my abilities. I will not discuss the content of the experiment with anyone until the study is completed.

Participant Assurances:

I understand that my participation in this study is completely voluntary and I can withdraw at any time without penalty. I also understand that the researchers in this study may terminate my participation if they believe this to be in my best interest. I understand that if new findings develop during the course of this research that may relate to my decision to continue participation, I will be informed. I have not given up any of my legal rights or released any individual or institution from liability for negligence.

The research team has adequately answered all the questions I have asked about this study, my participation, and the procedures involved. I understand that Dr. Zingale or another member of the research team will be available to answer any questions concerning procedures throughout this study. If I have questions about this study or need to report any adverse effects from the research procedures, I will contact Dr. Zingale at (609) 485-8629.

Discomfort and Risks:

I understand that I will not be exposed to any foreseeable risks or intrusive measurement techniques. The only anticipated discomfort may be some skin redness at the site of the EMG sensor placement or some discomfort from the oculometer head mount. I agree to immediately report any injury or suspected adverse effect to Dr. Carolina Zingale at (609) 485-8629.

Signature Lines:

I have read this informed consent form. I understand its contents, and I freely consent to participate in this study under the conditions described. I understand that, if I want to, I may have a copy of this form.

Research Participant:____________________________________ Date:__________

Investigator:____ Date:__________

Witness:____ Date:__________

Appendix B: Biographical Questionnaire

Participant # ___________ **Date** ___________

Biographical Questionnaire

Separation Management 2

Instructions:

This questionnaire is designed to obtain information about your background and experience as a certified professional controller (CPC). Researchers will only use this information to describe the participants in this study as a group. Your identity will remain anonymous.

Demographic Information and Experience

1. What is your **gender**?	○ Male	○ Female	
2. What is your **age**?	_____ years		
3. How long have you worked as an **Air Traffic Controller (include both FAA and military experience)**?	_____ years _____ months		
4. How long have you worked as a **CPC for the FAA**?	_____ years _____ months		
5. How long have you actively controlled traffic in the en route environment?	_____ years _____ months		
6. How long have you **actively controlled traffic** in the terminal environment?	_____ years _____ months		
7. How many of the **past 12 months** have you actively controlled traffic?	_____ months		
8. Rate your current **skill as a CPC**.	Not Skilled	①②③④⑤⑥⑦⑧⑨⑩	Extremely Skilled
9. Rate your **level of motivation** to participate in this study.	Not Motivated	①②③④⑤⑥⑦⑧⑨⑩	Extremely Motivated

Participant # ___________ **Date** ___________

This section of the questionnaire is designed to obtain background information about your computer use and any associated muscle strain or discomfort.

10. With **which hand** do you operate the trackball at the controller workstation?	____ Left ____ Right

11. To what extent do you experience **muscle strain** or discomfort when working at the controller workstation during a typical shift?	Not At All	①②③④⑤⑥⑦⑧⑨⑩	A Great Deal

12. Place a check next to any areas where you typically experience **physical discomfort or strain** when using the controller workstation.	____ None, I do not experience any discomfort or pain. ____ Neck and shoulder region ____ Forearm ____ Wrist ____ Hand or fingers ____ Other: please specify _______________

13. How many **hours do you spend on a computer** (excluding the controller workstation) at work or home on a typical day?	_____ 1 hour or less _____ 1 – 2 hours _____ 2 – 3 hours _____ 3 – 4 hours _____ 4 or more hours

14. To what extent do you **experience muscle strain or discomfort using a computer** (excluding the controller workstation) at work or home on a typical day?	Not At All	①②③④⑤⑥⑦⑧⑨⑩	A Great Deal

15. What type of pointing device do you use on the computer?	____ Mouse ____ Trackball ____ Joystick ____ Other. Please specify: ______________

16. With which hand do you operate the computer pointing device?	____ Left ____ Right

Please use the space below to provide any other comments regarding fatigue or strain you experience when using the controller workstation or a computer.

Appendix C: Post-Scenario Questionnaire

Participant # ___________ **Date** ___________

Post-Scenario Questionnaire

Overall Performance, Workload, Situation Awareness, and Simulation Ratings

1. Rate the **overall difficulty** of this scenario.	Extremely Difficult	①②③④⑤⑥⑦⑧⑨⑩	Extremely Easy
2. Rate your **overall level of ATC performance**.	Poor	①②③④⑤⑥⑦⑧⑨⑩	Excellent
3. Rate your **overall workload**.	Poor	①②③④⑤⑥⑦⑧⑨⑩	Excellent
4. Rate your **workload due to communications** with pilots.	Poor	①②③④⑤⑥⑦⑧⑨⑩	Excellent
5. Rate your **overall level of situation awareness**.	Poor	①②③④⑤⑥⑦⑧⑨⑩	Excellent
6. Rate your **situation awareness for *current* aircraft locations**.	Poor	①②③④⑤⑥⑦⑧⑨⑩	Excellent
7. Rate your **situation awareness for *projected* aircraft locations.**	Poor	①②③④⑤⑥⑦⑧⑨⑩	Excellent
8. Rate your **situation awareness for potential aircraft loss-of-separation**.	Poor	①②③④⑤⑥⑦⑧⑨⑩	Excellent
9. Rate your **situation awareness for potential handoff/airspace violations**.	Poor	①②③④⑤⑥⑦⑧⑨⑩	Excellent
10. Rate the **performance of the simulation pilots** in terms of their responding to control instructions and providing callbacks.	Poor	①②③④⑤⑥⑦⑧⑨⑩	Excellent

11. What aspects of this scenario were easiest to work with? Why?

12. What aspects of this scenario were hardest to work with? Why?

13. Do you have any additional comments or clarifications about your experience in this scenario?

Participant # ___________ **Date** ___________

Pointing Devices

These questions pertain to your use of the pointing device provided in the scenario just completed. Fill in one circle to indicate the extent to which you agree with each statement.

PD1. The device was **comfortable** to use.	Completely Disagree	①②③④⑤⑥⑦⑧⑨⑩	Completely Agree
PD2. The device was **effective** in supporting ATC tasks.	Completely Disagree	①②③④⑤⑥⑦⑧⑨⑩	Completely Agree
PD3. The device allowed me to **accurately** select objects on the display (i.e. the curser went to the intended target and I didn't have to make many corrective movements).	Completely Disagree	①②③④⑤⑥⑦⑧⑨⑩	Completely Agree
PD4. The device allowed me to **quickly** select objects on the display (i.e. the curser moved quickly across the screen with little effort)	Completely Disagree	①②③④⑤⑥⑦⑧⑨⑩	Completely Agree
PD5. It was easy to interact with **toolbars and macros**.	Completely Disagree	①②③④⑤⑥⑦⑧⑨⑩	Completely Agree
PD6. It was easy to interact with **data blocks**.	Completely Disagree	①②③④⑤⑥⑦⑧⑨⑩	Completely Agree
PD7. I rarely made mistakes with this device (e.g., accidental button presses or moved the cursor without intending to).	Completely Disagree	①②③④⑤⑥⑦⑧⑨⑩	Completely Agree
PD8. The position of the buttons was **intuitive**.	Completely Disagree	①②③④⑤⑥⑦⑧⑨⑩	Completely Agree
PD9. Rate your overall level of **muscle strain or discomfort** you experienced in the scenario just completed.	None	①②③④⑤⑥⑦⑧⑨⑩	A Great Deal
PD10. Place a check next to any areas where you experienced discomfort or strain in the scenario just completed.	____ None, I did not experience any discomfort or pain. ____ Neck and shoulder region ____ Forearm ____ Wrist ____ Hand or fingers		

PD11. Please provide any additional information about your experience using the pointing device provided in this scenario.

Appendix D: Exit Questionnaire

Exit Questionnaire

Separation Management 2
Simulation Realism and Research Apparatus Ratings

Please respond to each of the following items based upon your overall experience in the simulation. Fill in one circle to indicate your response to each item.

1. Rate the **realism of the generic airspace** compared to actual ATC operations.	Not at all Realistic	①②③④⑤⑥⑦⑧⑨⑩	Extremely Realistic
2. Rate the **realism of the simulation hardware** compared to actual equipment.	Not at all Realistic	①②③④⑤⑥⑦⑧⑨⑩	Extremely Realistic
3. Rate the **realism of the simulation software** compared to actual equipment.	Not at all Realistic	①②③④⑤⑥⑦⑧⑨⑩	Extremely Realistic
4. Rate the **realism of the simulation traffic scenarios** compared to actual NAS traffic.	Not at all Realistic	①②③④⑤⑥⑦⑧⑨⑩	Extremely Realistic
5. To what extent did the **WAK online workload rating technique interfere** with your ATC performance?	Not At All	①②③④⑤⑥⑦⑧⑨⑩	A Great Deal
6. How effective was the **training** provided?	Not At All Effective	①②③④⑤⑥⑦⑧⑨⑩	Extremely Effective
7. ***Answer only if you wore the oculometer***: To what extent did the oculometer interfere with your ATC performance?	Not At All	①②③④⑤⑥⑦⑧⑨⑩	A Great Deal
8. ***Answer only if you wore the EMG sensors***: To what extent did the EMG monitoring equipment interfere with your ATC performance?	Not At All	①②③④⑤⑥⑦⑧⑨⑩	A Great Deal

Exit1. Please include any additional comments about the simulation that you would like us to know about.

Pointing Devices

These questions pertain to your use of different pointing devices in the simulation. Please rank each device from best (1) to worst (4) for each item.

Please rank…	**Trackball**	**Mouse**	**Handshake Mouse**	**Alternative Trackball**
9. …the most comfortable (1) to the least comfortable (4).				
10. …the most accurate (1) to the least accurate (4).				
11. …the fastest to use (1) to the slowest (4).				
12. …the most sensitive (1) to the least sensitive (4).				
13. …the best (1) for interacting with data blocks to the worst (4).				
14. …the best (1) for interacting with toolbars & macros to the worst (4).				
15. …the best (1) location of the buttons to the worst (4).				

Exit4. Please include any additional comments on your experience using the different pointing devices.