A Comparative Evaluation Between Computer Mouse and Touchpad Usability in the Modern World

Michael Balas
Department of Computing and Software
McMaster University
1michaelbalas@gmail.com

ABSTRACT

Computer mice and touchpads are ubiquitous modes of interfacing with computers, each with their unique set of advantages and disadvantages. This research endeavor sought to investigate the efficiency and satisfaction of cursor and gesture control between mouse and built-in touchpad input devices. Ten adult subjects with prior experience using both devices were recruited to perform many tasks and trials that elicited the key strengths and weaknesses of each. Overall, both devices had comparable speed, accuracy and user preference, though they differed significantly during specific tasks. The mouse was significantly faster with path tracing and double/right-clicking tasks, while the touchpad was better suited for keyboard homing tasks and gesture controls, as well as demonstrating greater robustness against fatigue effects. User preference was consistent with performance, and device assessment questionnaires found no significant differences between mouse and touchpad.

Author Keywords

Cursor Control; Computer Mouse; Trackpad; Touchpad;

INTRODUCTION

Fast, accurate and natural interface control is crucial for direct-manipulation graphical user interfaces (GUIs) and is therefore a determining factor in task performance and user adoption. Hosts of interacting elements continually evolve input technologies and may engender considerable performance differences across cultures and time. This can be seen from the first ever human-computer interaction (HCI) user study by English, Engelbart and Berman, who comparatively evaluated display selection techniques between several cursor-controlling devices, such as the Grafacon and a knee-controlled lever [3]. Indeed, the mouse - which had just been created by Engelbart - was found to be the best of the devices tested; not only because of its fast movement time and low error rate, but also because it was satisfying to use and caused little fatigue [3]. Since 1967, the mouse has consistently outperformed other interfacing technologies and remained as the most ubiquitous and preferred input device in computing [10].

M. Balas is conducting this investigation to see how humans interface with and input commands to computers in a controlled testing environment. The two input devices that are evaluated are mouse and touchpad, each with equal ubiquity and offering similar effectiveness.

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Perhaps as revolutionary as the mouse, the touchpad (also called trackpad) was introduced in 1994 when Apple Computer, Inc. incorporated it in the PowerBook 500 series of notebook computers. Shortly thereafter, they became the primary input technology for interfacing with laptops [1]. Compared to computer mice, touchpads provide a more direct interface [13], require reduced muscular effort [8], occupy less space and offer a much gentler learning curve [2]. These advantages brought the mouse's reputation as the best input device into question and stirred researchers to compare user performance between touchpad and mouse. However, given that most of these studies were performed just as the touchpad was being introduced, results and conclusions were limited since the majority of subjects were unfamiliar with this input modality, which was still undergoing rapid iterations of design decisions [10,13,15]. Furthermore, many of the tasks used to compare between touchpad and mouse were not fully representative of a HCI and played into the strengths of the mouse (e.g. rapid cursor positioning and selection) [5,8]. Studies that did employ generalizable tasks and considered unique features of the touchpad (such as gesture control or closer proximity to the keyboard) typically investigated only subjective evaluations from participants [9,11,14]. These reasons have, at least in part, likely contributed to the findings that the mouse outperforms the touchpad as well.

The aim of this study is to compare the usability between mouse and touchpad in an age and culture where both are equally as widespread and regularly operated. As defined by the International Organization for Standardization (ISO 9241-11), usability refers to the extent to which a product can achieve specified goals with effectiveness, efficiency and satisfaction [6]. This will be evaluated using a multi-tasked testing environment consisting of various ISO as well as novel HCI tasks (which are often singly used in similar studies), in combination with typing and gestural controls, that aims to mimic and generalize to real-life user cases. Performing many different tasks in one trial may also elicit the degrees of fatigue experienced for each device. Both touchpad and mouse offer equal effectiveness (i.e. they can achieve the same goals), albeit in different ways (scrolling, for example), and so effectiveness will not be discussed. Their efficiency in achieving goals, however, are contested in the scientific literature. In this study, efficiency was evaluated by error count (EC) and completion/movement time (MT). It is also important to recognize that users do not necessarily prefer the fastest and/or most accurate input device, as demonstrated by Sears and Shneiderman [12], and thus satisfaction is also a key factor to consider. User satisfaction with each device was measured by a preference survey and subjective questionnaires with Likert scale ratings. This study only compares between the wireless Apple Magic Mouse 2 and 2017 MacBook Pro built-in touchpad.

All previous studies comparing between mouse and touchpad input modalities (among others) have demonstrated that the mouse is faster [5,8-11,13-15]. They have also found that users are always more satisfied using the mouse, even in cases where it is outperformed by the touchpad [8]. The device with greatest accuracy varies between studies due to different designs, tasks and user backgrounds. Adult populations with prior touchpad familiarity typically produce more errors with the mouse [8,9], however, and so it is expected that in this study with a similar population, the touchpad will be more accurate. Given that the trials in this study will extend beyond simple point-and-click tasks and facilitate multi-handed use, it is also expected that the touchpad will demonstrate faster completion times and greater satisfaction among users compared to previous reports. Especially since the touchpad affords more natural gestural controls (e.g. pinching to zoom) and is closer to the keyboard, whereas the mouse requires sequential operations and a large range of movements.

RELATED WORK

Mackenzie, Kauppinen and Silfverberg evaluated the movement time, error rate and throughput of mouse, trackball, joystick and touchpad input devices whilst proposing and validating new performance measures as well [10]. 12 University students were recruited, all of whom were regular users of a GUI and mouse, though none were regular touchpad users. For each device, the subjects performed a simple multidirectional point-select task in ISO 9241-9, whereby 16 circular targets arranged in a circular layout were sequentially selected on opposing sides of the layout circle [7]. Only one task condition was used (i.e. constant distance and target size), and the order of devices was counterbalanced via a balanced Latin square [10]. Similar to the previous study, the touchpad had lower yet non-significant error rates (7.0%) compared to the mouse (9.4%), while the mouse was significantly faster (by 500ms) than the touchpad. The mouse also had a significantly greater throughput (4.9bps) than the touchpad (2.9bps).

Shanis and Hedge compared the use of mouse, touchpad and MultiTouch (a multifunctional gestural interface) input technologies on performance (speed and errors), wrist posture (obtained through video-motion analysis), comfort and preference (evaluated using questionnaires) [13]. For each interface, 12 right-handed subjects performed three experimental tasks: data-entry (transcribing numbers from randomly generated tables into text boxes), cursor positioning (completing as many laps as possible within 30 seconds around a square track), and text editing (correcting electronic text documents using the keyboard and accompanying input device) [13]. Data-entry times were comparable and non-significant between numberpad/mouse and numberpad/touchpad conditions. The mouse was 30% and 76% faster than the touchpad during the text-editing and cursor-positioning tasks, respectively. The mouse was also rated as the most comfortable and easiest to use interface. However, similar to the previous studies, these results are likely biased by the participants' lack of familiarization with both touchpad and MultiTouch technology. The mouse also produced the least amount of wrist extension, but because the MultiTouch and touchpad were built into the keyboard, the effects of wrist extension were likely confounded by keyboard slope.

Kar and colleagues performed similar experiments using a mouse, trackpad and 3D motion-and-gesture control (3DMGC) to compare user performance, posture and subjective evaluation [8]. 12 right-handed graduate students with years of both mouse and trackpad experience were recruited. For each interface, the experiments started with four blocks of Fitts' Radial Reciprocal Clicking trials, an ISO 9241-9 standard [7], followed by various dragging, clicking, sliding and typing tasks, each performed twice. A video camera recorded participant posture. Results showed that the mouse exhibited slightly greater error rates than the touchpad (6.51% compared to 6.38%) and was only 160ms faster on average. The smaller differences in speed and error rates between mouse and touchpad likely contradicts previous studies due to greater participant familiarity and experience with the touchpad. The mouse was still rated best for general comfort and overall performance, followed by the trackpad. Rapid Upper Limb Assessment (RULA) analysis did not show significant differences in final scores between interfaces.

Hertzum and Hornbaek investigated the performance of 12 young (12-14 years), 12 adult (25-33 years), and 12 elderly (61-69 years) participants when pointing with mouse and touchpad (both of which they were all familiar with) [5]. The experimental task was a modification of the Multidirectional Tapping Test (ISO 9241-9) [7], whereby participants alternated between selecting a central target and one of eight circularly surrounding targets that appeared in random order. Target distance (three levels), width (two levels), and input device selection method was counterbalanced across participants. Similar to the study by Kar et al. [8], participants rated the mouse more favourably than the touchpad. However, this study reported greater differences between input devices, in which all three age groups were 962ms slower and made 2.9% more errors with the touchpad than the mouse. This is likely because the adult participants of this study, who are approximately the same age as the University students from previous studies, experienced similar error rates and movement times between mouse and touchpad. The overall differences became apparent only when including the young and elderly populations, who were shown to perform worse with the touchpad.

Kotin and Harper evaluated user preference between mouse and touchpad input devices when using gestural controls on the Windows 8 operating system [9]. They recruited 26 participants (aged 21-50 years), the majority of which were unfamiliar with Windows 8, though all used both mice and touchpads at least 5 hours per week. After completing a point-and-click Fitts task (randomized target angle and distance) with each input device, participants were trained and subsequently guided to perform a list of Windows 8 specific gesture tasks (i.e. Edge-Swipes, Snap and Tile functions). After completing the task list with each input device, participants completed Likert scale ratings that measured preference and subjective performance. There was no mention of counterbalancing between input devices. While there was no significant difference in error rates between input modalities for the Fitts task, mouse movement time (1.10s) was significantly faster than touchpad (1.65s). Participants demonstrated significant preference for the mouse in 9 of 11 subjective performance questions, and 65% of them preferred using the mouse for Windows 8 gesture tasks. Empirical user performance in completing gesture tasks was not recorded.

Ulrich and colleagues collaborated with a power utility to assess the usability of input devices (mouse, trackpad and touchscreen) for a new turbine control system at a nuclear power plant [14]. 25 licensed operators and other plant personnel were recruited and manipulated turbine control software using each of the input devices (no mention of counterbalancing between input device or operator experience with mouse or touchpad). Only eight of the operators completed the full complement (quantitative and qualitative measures) of trials, while the remaining 17 only completed the subjective questionnaire. Trials consisted of large navigation and small arrow button selections, text entry, and dropdown value selection. The touchpad was empirically (50% slower than mouse on average) and subjectively (accuracy, speed and comfort) found to be the least effective and desired input device in this context.

Maleckar et al. compared and evaluated the usability of the computer mouse, touchpad, and smartphone touchscreen for web browsing [11]. 32 users with a mean age of 28 years were recruited through snowball and convenience sampling, each with an average of 15 and 8 years of experience for mouse and touchpad, respectively. The authors built a custom web page where the subjects had to complete seven tasks: (i) open a URL address; (ii) copy/paste a URL address; (iii) copy/paste text; (iv) scroll up-down; (v) scroll left-right; (vi) zoom in the context of a web page; and (vii) navigate a map. The mouse was 37% faster than the touchpad and ranked as the easiest interface among the three, while touchpad was rated as the hardest (even though it performed faster compared to touchscreen). The authors did not record errors. The easiest task for all three devices was opening a link and scrolling text up and down. Mouse and touchpad interfaces experienced the worst performance when zooming on the web page, likely because the majority of participants were unaware of zooming with touchpad pinching gestures or scrolling the mouse wheel with the control (ctrl) key [11].

METHODOLOGY

Participants

6 male and 4 female subjects (aged 20.2 ± 1.2 years) attending McMaster University were recruited through convenience sampling, each with 5 years of average experience for both mouse and touchpad, as well as an average usage of 15 and 16 hours per week for mouse and touchpad, respectively. All participants were familiar with Apple software, and all but three regularly used an Apple laptop. The inclusion criteria of this study ensured that participants were right-handed, with at least 3 years of experience and at least 2 hours of average weekly usage for both mouse and touchpad. Subjects were excluded from the study if they were left-handed or ambidextrous, or had poor (<20/20) and non-corrected vision or other visual impairments (e.g. colour-blindness). All recruited participants met the inclusion criteria and gave informed consent, which had been reviewed and approved by the McMaster Research Ethics Board.

Apparatus

The experiment was conducted on a 2017 MacBook Pro (15-inch monitor) running macOS Mojave (version 10.14). The two input devices used were the built-in MacBook touchpad with tactile feedback (i.e. no lift-and-tap or separate buttons) and the Apple Magic Mouse 2 (both devices had all features and gesture controls enabled, except for touchpad tap-to-click). Gain settings were set to the default for both devices, as was the cursor pointer. The experimental software (described in procedure) was developed using JavaScript (version 1.7) and displayed in full-screen browsers (Google Chrome). The code from tasks 1-4 has been modified and adapted from Cornell University's product evaluation software [4]. The most notable changes involved tracking and recording a greater range of errors, as well as continuing tasks regardless of errors to prevent increasing MT as a result of user mistakes.

Procedure

Prior to testing, subjects were briefed on the experiment and asked to read and sign consent forms. The multi-tasked trial (MTT) consisted of six individual tasks (ITs), each separated by different gestural controls. First, each task was independently introduced to participants who then completed one practice attempt. Participants then performed the same task twice with data collection averaged over both (each separated by a one-minute break). Upon completing all six tasks independently, the investigator demonstrated proper completion of the MTT. A practice round was given before data collection commenced for two testing trials, each separated by two-minute breaks and averaged together.

For tasks that consisted of rapid cursor positioning/selection (tasks 1, 2, 4, and 5), active targets that required a single left mouse-button click were displayed in blue, while inactive targets were displayed in grey. Regardless of whether the selection was correct, the tasks continued to alternate between targets after each click (to prevent increasing MT due to errors). Tasks 1-5 are close variants or combinations of ISO 9241-9 performance tests [7], while Task 6 was introduced in this study to evaluate scrolling and zooming performance. All tasks began after the user clicked on a start button, whereby the software started tracking all mouse or touchpad events. However, the timer would only start once the first target was selected and ended with the last (with the exception of Task 6, where timer start and stop was controlled by start and end buttons, respectively). All tasks are described in the order in which they appear in the MTT below.

Task 1: One-dimensional reciprocal clicking

The first task used a traditional Fitts' Law reciprocal clicking exercise with two targets on opposing sides of the screen (Figure 1). Participants alternated clicking between both targets with the left-mouse button as quickly and accurately as possible. Any click made outside the active target was recorded as an error.

This task was completed after 30 click events, regardless of error (i.e. each target would become active 15 times). To access the next task, participants were instructed to gesture right into the next workspace.

Task 2: Two-dimensional radial reciprocal clicking

This next task had eight circular targets arranged circumferentially around a central circular target (Figure 2). Only two targets were visible to the subject at once: the central target and a second which appeared randomly in one of eight locations in the circumferential layout. After reciprocally selecting between both six times (i.e. after six click events), the second target was replaced by a new one in one of the seven remaining possible locations. This process was repeated by the participants until all eight targets in the circular layout were reciprocally selected with the central target (order was randomized). Errors were recorded for any selections made outside the active target. Accessing the third task required the user to access Mission Control (a bird's eye view of all open windows) via gesture controls and switch to another window in the same workspace.

Task 3: Spiral path tracing

In this task the subjects started from the center of a spiral, held down the left-mouse-button and passed the starting line. They went through the spiral path while tracing their cursor movement until reaching the finish line (Figure 3). Errors were recorded each time the cursor trace (shown in red) intersected the spiral track or was interrupted (by letting go of the mouse button). Subjects were monitored and instructed not to purposefully pass directly through track lines (in other words, sacrificing accuracy for speed). To access the next task, subjects gestured to the next workspace on the right.

Task 4: Pointer-keyboard homing

Similar to Task 1, subjects alternated between two rectangular targets on opposing sides of the screen. After a target on either side was selected, the subject used the built-in keyboard to type in a word displayed in the active (highlighted in blue) central panel (Figure 4). This panel did not have to be clicked.

Mistypes were not recorded as errors (keyboard accuracy is not under investigation), and backspacing was not required (only the correct letter at a specified location was accepted). The same set and order of ten-lettered words were used by all participants and differed for each practice round and trial (participants could not anticipate the words). Typing progress was shown via red text (to denote letters that have already been typed in). After completing 24 rounds (i.e. 24 words typed in or 12 selections for each target), this task was completed and the next was available upon switching windows using Mission Control.

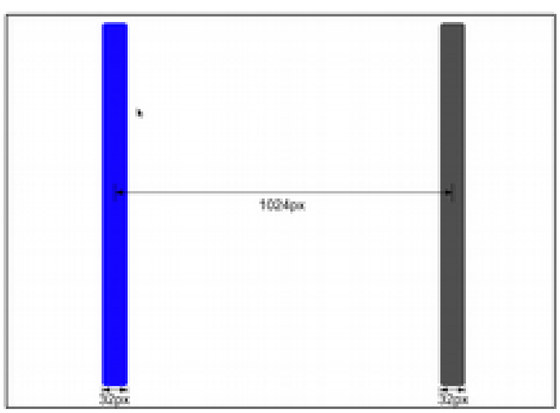

Figure 1. One-dimensional reciprocal clicking task.

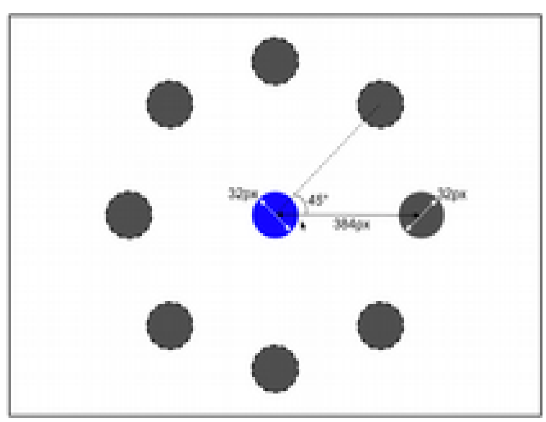

Figure 2. Two-dimensional radial reciprocal clicking task. Dotted border lines indicate remaining target positions.

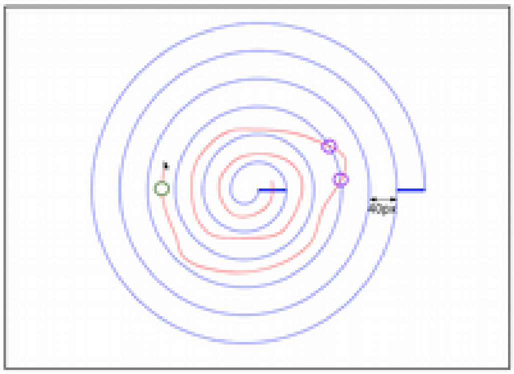

Figure 3. Spiral path tracing task. The width of each spiral is 40 pixels (px) with a total of four turns before finishing. The purple circles show intersection errors while the green demonstrates a mouse-up error.

Task 5: Radial double-and-right clicking

This task used a layout identical to Task 2, though with two different types of targets (Figure 5). The central target (displayed in red now), had to be double-clicked for a successful selection (single left-mouse button clicks were recorded as errors and did not continue the task). The circumferential targets (now displayed in green) had to be right-clicked, opening a context menu with four options, one of which was randomly chosen to be the target (highlighted in blue). The subject selected (left-mouse button click) the highlighted option before returning to the central target. Selecting the incorrect (non-highlighted) option or produce an error and continue the task. After reciprocally selecting between both targets six times (i.e. after three double-click, three right-click and three potential single-click events), the green target was replaced by a new one in one of the seven remaining possible locations, determined randomly. The subject gestured left to the original workspace (used in Task 1) and used Mission Control to switch windows.

Task 6: Scroll-and-zoom

This task evaluated the scrolling and zooming capabilities of mouse and touchpad. A total of 15 checkboxes were displayed on the screen, each separated vertically by 2000px (Figure 6). They were divided into three groups of five, wherein each group occupied different horizontal positions on the screen (left, middle and right). The subject scrolled vertically and horizontally to sequentially check all targets. 2000px after the last checkbox in the first two groups, a right-facing arrow indicated horizontal scrolling to the next group.

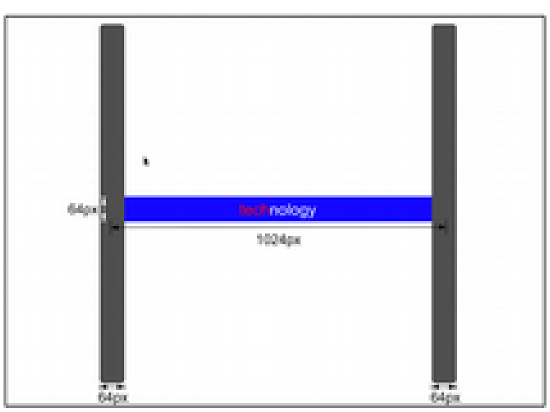

Figure 4. Pointer-keyboard homing task.

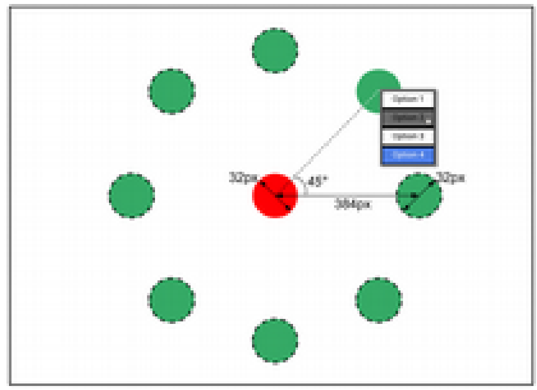

Figure 5. Alternative radial clicking task. Dotted border lines indicate remaining possible target positions. Hovering over menu options provides users with feedback over which target they will select (see *Option 2* for example).

Every second checkbox for each group was minimized by a factor of 10, and so the subject zoomed in to check the box (which was surrounded by a red background to denote its presence), and then zoomed back out to continue the task. Errors were recorded whenever the subject did not select a checkbox, misclicked or scrolled past (horizontally or vertically) a checkbox in the viewport without first selecting it. The task begins once the subject clicks on the start button at the top left (event listeners and timer are both initialized) and ends when the subject clicks the end button at the bottom right. This task completes the trial.

Participants were instructed to select targets and complete tasks as quickly and accurately as possible. Each complete trial lasted approximately five minutes. The experimental software collected data (e.g. key presses, target selections) continuously throughout each trial and logged timestamps for each task. The movement time for each gesture control was calculated from the difference between successive task

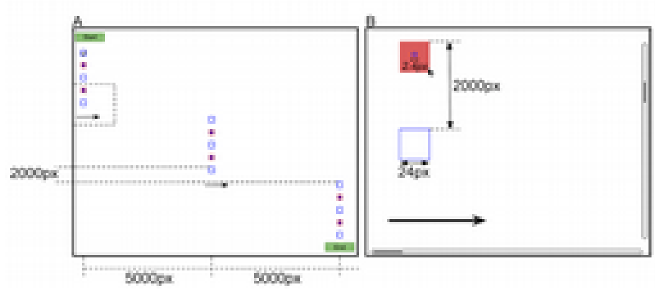

Figure 6. A) Complete view of the scroll-and-zoom task. B) Zoomed in view of the dotted box shown in Figure 7A. The side length of each square checkbox is 24px (minimized checkboxes surrounded in red are 2.4px).

timestamps. Incorrect gesture controls (e.g. moving to the left instead of right workspace) were manually recorded by the investigator while observing participants.

After completing all tasks and trials, participants completed a device assessment questionnaire produced from ISO 9241-9 that assesses operation and comfort using 13 questions and a 5-point Likert response scale [7]. Participants additionally specified their preferred input device for performing each task, gesture control and the overall trial.

Design

The experiment was a within-subjects design. Participants were randomly assigned to one of two groups (6 participants per group) to offset any potential order-effects by counterbalancing. The order of devices (i.e. mouse followed by touchpad and vice versa) differed for each group according to a balanced Latin square. The independent variable is input device with two levels: mouse or touchpad. The dependent variables measured usability and included MT (the reciprocal of speed, measured for each independent task and the entire trial in milliseconds), EC (percentage of misclicks, unsuccessful target selections or other previously defined errors), questionnaire, and survey responses.

RESULTS

All statistical analysis was performed using the R programming language (version 3.5.0). Performance data and questionnaire responses were analyzed using paired t-tests and evaluated at the $\alpha=0.05$ significance level, while the frequency of reported input device preference is presented in Supplementary Table 3.

IT Performance

The average MTs and ECs for each IT is shown in Supplementary Table 1. The mouse was shown to be significantly faster than the touchpad for Task 3 ($t_{(9)}=2.27$, $p=0.049$) by two seconds and Task 5 ($t_{(9)}=5.09$, $p=6.5e^{-4}$) by 12 seconds, while the touchpad was faster for Task 4 ($t_{(9)}=6.35$, $p=1.3e^{-4}$) by 9.5 seconds, on average. The touchpad also produced significantly less errors than the mouse for Tasks 4 ($t_{(9)}=2.33$, $p=0.044$) and 5 ($t_{(9)}=2.37$, $p=0.042$), with 0.7 and 1.3 less errors per trial on average, respectively.

MTT Performance

When performing all tasks sequentially over an entire trial, there were no significant differences in total MT ($t_{(9)}=0.89$, $p=0.39$) or total EC ($t_{(9)}=1.29$, $p=0.23$) between mouse (268025ms ± 17272ms, 8.2 errors ± 2.3 errors) and touchpad (263107ms ± 19065ms, 6.95 errors ± 1.7 errors). However, comparing each of the tasks from the MTT independently between input devices yielded results similar to the previous experiments of ITs. The touchpad was again significantly faster ($t_{(9)}=6.85$, $p=7.5e^{-5}$) for task 4, while the mouse was significantly faster ($t_{(9)}=3.5697$, $p=6.3e^{-3}$) for only task 5. The touchpad also experienced significantly less errors ($t_{(9)}=2.65$, $p=0.026$) during task 5 of the MTT.

Fatigue Effects

Since the trials involved continuous input device manipulation and sustained focus for several minutes, the author explored whether either device demonstrated an increase in MT or EC over time, particularly closer to the latter half of the trial. Such an increase may indicate that the user is prone to experiencing fatigue with the device when used excessively. This was evaluated by performing paired t-tests between each of the ITs and the corresponding MTT tasks for a given device. The touchpad demonstrated no significant differences in MTs or ECs between IT and MTT tasks (i.e. no fatigue effects). The mouse, however, exhibited significantly slower MTs in the MTT tasks for Task 4 ($t_{(9)}=5.26$, $p=5.2e^{-4}$), Task 5 ($t_{(9)}=3.73$, $p=4.7e^{-3}$) and Task 6 ($t_{(9)}=4.60$, $p=1.3e^{-3}$). Differences in EC were also non-significant for the mouse. Figure 7 and Supplementary Figure 8 depict the change in MT and EC, respectively, between ITs and MTT tasks for mouse and touchpad.

Gesture Controls

All participants performed the gesture controls correctly and as instructed during the MTTs. The touchpad was faster than the mouse for all transitions between tasks and significantly faster for transitions between tasks 2-3 ($t_{(9)}=4.82$, $p=9.5e^{-4}$), tasks 4-5 ($t_{(9)}=2.48$, $p=0.034$) and tasks 5-6 ($t_{(9)}=10.67$, $p=2.1e^{-6}$). Thus, the touchpad outperforms the mouse during Mission Control gesture commands. The data for gesture control speed using both mouse and touchpad is shown in Supplementary Table 2.

Questionnaires

The ISO 9241-9 device assessment questionnaire produced no significant differences in Likert responses between input devices. Mouse and touchpad received identical or near-identical average scores for physical effort, accuracy, operation speed, force of actuation and arm fatigue. The greatest differences occurred when rating wrist fatigue (touchpad has one point higher for greater wrist fatigue on average, $t_{(9)}=2.12$, $p=0.063$) and ease of use (mouse has 0.5 points higher for easier use on average, $t_{(9)}=1.86$, $p=0.096$).

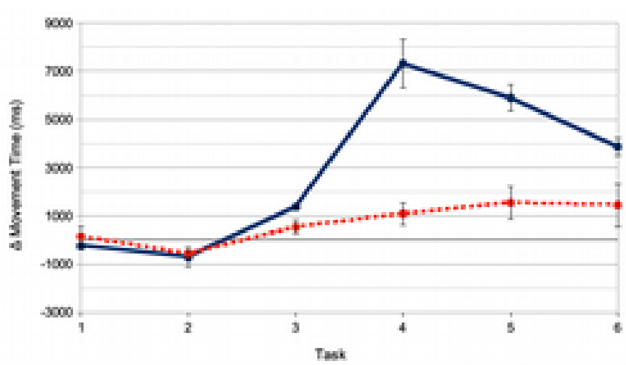

Figure 7. Change in MTs between MTTs and ITs for mouse (blue solid line) and touchpad (red dotted line). The black zero line indicates no change.

User Preference
The majority of users preferred using the mouse for tasks 2, 3 and 5 whereas the touchpad was preferred for task 4 and both types of gesture controls. Overall, the preferred input device was split evenly among participants.

DISCUSSION
The mouse and touchpad demonstrated comparable MTs and ECs over the entire trials. These nonsignificant differences are unsurprising given that these input devices remain equally as ubiquitous in the modern world as well as in this study population, and were evenly preferred overall by participants. Furthermore, the study population was comprised entirely of young adults, who have been shown to perform more consistently among devices compared to other age groups [5].

While mouse and touchpad were shown to perform with equivalent efficiency and user satisfaction overall, this study also uncovered significant differences in MTs, ECs and user preferences occurring during tasks that were specifically tailored to one input device or the other. As hypothesized, the touchpad performed significantly faster and more accurately than the mouse for task 4 (keyboard homing). This is likely due to its closer proximity to the keyboard, as well as the fact that both hands remain positioned in the same way between typing and swiping (unlike the mouse which must be grasped and held). Conversely, the mouse was significantly faster for task 5 (double and right radial clicking), as one might expect, likely due to the separation of mouse buttons (right button for right click rather than two fingers clicking at once on the touchpad) and greater ease with which to double click a button compared to a pad. These reasons may also explain why the touchpad produces significantly less errors for this task, since the increased time between right and single clicks (potentially due to no separation of buttons) gives the user more time to scan and point towards the correct selection option. Furthermore, it would make Task 3 (spiral tracing) more difficult to perform as the user would need to move the pad while simultaneously holding it down, and this is demonstrated in the ITs where the mouse MT is significantly lower (because mouse button selections are separated from mouse hand movements).

To the best of the author's knowledge, this is the first HCI study that empirically explores fatigue effects and input device performance. Given that participants are making hundreds of different types of selections consecutively and without pause during the trials, it stands to reason that performance would eventually decline, either due to mental or physical exhaustion or both. By comparing tasks that are performed independently and separated by breaks to those that are not for each input device, the results show that the touchpad is more robust to the effects of fatigue. The reason the mouse experiences the greatest reduction in speed during the fourth trial, rather than the last or second-last, could be due to the fact that the fourth trial was also the most physically demanding since the user must repeatedly cycle between mouse and keyboard. Since ECs were already low and the tasks were simple, there was no indication of fatigue affecting accuracy in the trials presented here.

Very few studies have compared input devices using multi-touch gestural controls [9], and again this is the first study that empirically records, analyzes and differentiates these controls between mouse and touchpad. Specifically, users performed either right/left swipes between workspaces or accessed Mission Control to view and select other windows within the same workspace. While no errors were observed for either device, the touchpad was significantly faster for all transitions involving Mission Control. Accessing Mission Control with the Apple Magic Mouse 2 requires fine control whereby the user must double-tap with two fingers (making sure not to accidentally click), whereas the touchpad simply requires them to swipe up with three or more fingers with no risk of misclicking.

The results of this study are restricted to a fairly low sample size of ten, all of which is derived from the same population, limiting the generalizability of the results. Moreover, only one instance of each input device was evaluated in this study (the Apple Magic Mouse 2 and built-in MacBook touchpad), and future studies should consider evaluating the same tasks over different types of mice and touchpads. Future studies should also examine the frequency with which users perform different tasks (e.g. right-clicking versus scrolling) and use that to allocate proportions of different task times and difficulties to create testing environments that generalize well to real-world scenarios.

CONCLUSION
The goal for this study was to assess the usability of mouse and touchpad over different HCI tasks that were designed to mimic real-world use. Six tasks that evaluated single- and multi-dimensional cursor pointing and selecting, path tracing, keyboard homing, alternative selections, scrolling and zooming were presented to participants who completed them both individually and as part of a larger trial. Within the trial, tasks were transitioned between each other using two types of gestural controls: left/right workspace-switching and Mission Control window-switching.

Since both devices are equally as effective at achieving goals, usability was evaluated by efficiency (measured by MT and EC) and user satisfaction (measured by preference and questionnaire responses). Unlike previous studies, where experiments were typically tailored towards the mouse, the results presented here demonstrate similar and nonsignificant results between mouse and touchpad over the entire trials. However, significant differences arise in efficiency (both MT and EC) and user satisfaction (preference surveys) when evaluating tasks individually as both devices are better suited for different operations. For instance, the touchpad performs better for keyboard homing tasks while the mouse is superior for double and right-clicking.

This is also the first study to empirically investigate the effects of fatigue on device performance as well as the usability of gestural controls. In both cases, the touchpad outperformed the mouse by demonstrating greater user preference and speed for gestural controls while not exhibiting any significant deteriorations in performance over the length of the trials.

In summary, this study demonstrates that mouse and touchpad are essentially equivalent in overall usability, though they can vary significantly under certain conditions as they are better suited for different tasks by design. These results underscore the importance of designing HCI experiments that accurately simulate user tasks of interest, as well as the impact that experimental design or length can have on performance.

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