Deconstructing the Touch Experience

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ABSTRACT

In this paper, we evaluate the performance and experience differences between direct touch and mouse input on horizontal and vertical surfaces using a simple application and several validated scales. We find that, not only are both speed and accuracy improved when using the multi-touch display over a mouse, but that participants were happier and more engaged. They also felt more competent, in control, related to other people, and immersed. Surprisingly, these results cannot be explained by the intuitiveness of the controller, and the benefits of touch did not come at the expense of perceived workload. Our work shows the added value of considering experience in addition to traditional measures of performance, and demonstrates an effective and efficient method for gathering experience during interaction with surface applications. We conclude by discussing how an understanding of this experience can help in designing touch applications.

Author Keywords

Touch, mouse, experience, interactive surfaces, direct vs. indirect, horizontal vs. vertical, PENS

ACM Classification Keywords

H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION

Developers of interactive surface applications have integrated a variety of input devices for system interaction, including tangibles [19], secondary handheld displays [45], ray-casting [34], and above-table interactions [46]; however, the use of direct-touch input (e.g., [5]) and indirect mouse input (e.g., [43]) have been the most prevalent forms of interaction. Because of their widespread use, the performance differences of mouse and touch input have been studied in terms of speed and accuracy (and to a lesser extent, preference) for a variety of interactive tasks, such as object selection [20], moving target acquisition [23], shape matching [6], and docking [23]. Although throughput and errors are important considerations when evaluating input devices, there is a dearth of research examining how the *experience* of using interactive surfaces changes based on input type. In contrast to traditional usability evaluation, which focuses primarily on performance and cognition, user experience evaluation (UX) shifts the focus to affect, sensation, meaning, and value of interaction [22].

Although experience evaluation has been used to evaluate hedonically inspired systems, such as computer games [39], it is just as important for evaluating applications designed for productivity and work. For example, consider the implications for designers of interactive surface applications if using touch input improved a user's perceived competence with a command and control system, or if using a tangible interface gave users a heightened sense of control and volition in undertaking the design work of a tabletop layout task, or if using a mouse opened teams up to hearing alternate views from colleagues in a collaborative analytics task. Not only would the experience of using surface applications be improved in these scenarios, but the enriched experience could also result in enhanced productivity through better solutions that are achieved more rapidly.

To determine whether input type affects experience with interactive surface applications, we conducted an evaluation of the two most common input types (direct touch input and mouse input) on the performance of—and experience with—both horizontal (e.g., table) and vertical (e.g., wall) surfaces. After considering the most popular elements of interaction design for surface applications, we represented the common interactive tasks of *monitoring*, *responding*, *zooming*, and *selecting* in a casual game-like application. Through an experiment with 48 participants, we found that using touch input improves performance in terms of both speed and accuracy, and also enhances the experience of using the system in terms of enjoyment, intrinsic motivation, positive feelings, perceived competence, perceived autonomy, perceived relatedness, and immersion of system use. In addition, participants preferred to use touch, and surprisingly this was not attributed to the intuitiveness of the controller, and these benefits did not come at the expense of perceived workload. Finally, we found no differences in experience as a result of surface orientation, suggesting that our results are applicable to designers of both interactive horizontal and vertical applications.

Our research has several important contributions. First, we establish that touch improves experience over mouse consistently over a variety of measures. Second, we show that

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the improvements to experience do not come at a performance cost, but are actually accompanied by improved speed and accuracy. Third, we demonstrate an effective method for gathering experience with surface applications that is also efficient—our measures took minutes to gather and analyze, yielding a 'discount' method for experience evaluation of interactive systems that provides value, without requiring a significant investment of time, money, or training. Fourth, we discuss the implications of the improved experience of touch input for designers of interactive surface applications.

In an age where interactive systems are becoming more prevalent and more complex, the competition among surface applications for dominance is fierce; understanding experience with technology is as important as understanding performance. Our work demonstrating that direct touch improves performance and enhances experience is a first step toward the comprehensive, robust, and holistic evaluation of experience with interactive surface applications.

RELATED WORK

In this paper, we apply an established evaluation technique for games to the domain of interactive surface applications. In this section, we describe the common techniques used for evaluating multi-touch surfaces, and introduce the techniques used in this paper to add to this understanding.

Evaluating Multi-touch Surfaces

Multi-touch research has largely been driven by the invention of new technology capable of sensing multiple hands, fingers, or people [5,8,15]. Researchers have evaluated this technology and multi-touch interaction in general by investigating performance, by observing people's behaviour, and by querying people's expectations of its use.

Multi-Touch Performance Evaluation

Research has explored the effects of a variety of hardware conditions on human performance with interactive surfaces. For instance, Ryall et al. [37] investigated the effect of display size and group size on task performance and Wigdor et al. [51] looked at the effect of display orientation on perception of on-screen 2D graphics. Hancock et al. [9] evaluated the perception of on-screen 3D graphics, and Valkov et al. [48] explored the effects of depth perception using 3D stereo on touch interaction.

A significant amount of the research on interactive tables and walls involves the design, implementation, and evaluation of novel interaction techniques for these displays. These often include menu systems [24,7], movement and rotation techniques in both 2D and 3D [10,21,44,35] as well as interaction with specific data visualizations (e.g., [27]).

The evaluation of these display factors and perceptual phenomena, as well as the evaluation of novel interaction techniques, most frequently makes use of performance measures to validate findings. Specifically, common tasks found in these evaluations include the moving and rotating of 2D or 3D virtual objects or the sorting or piling of on-screen objects. Many studies also include follow-up questionnaires or interviews, or observations made by the experimenter with anecdotes about qualitative phenomena not well described by the performance data. While the use of follow-up data can provide a richer understanding of the data in the study, the questions asked are rarely standardized and are difficult to compare between studies.

Observing Behaviour

Research has also directly investigated the qualitative aspects of the physical setup. These studies have led to valuable frameworks of behaviour including an understanding of how people adopt territories when using tables [41] and walls [1], and how they behave in both public settings [17] and more private ones [36]. These examples each involved the examination of behaviour using physically similar conditions in order to inform the design of digital displays. Observational studies have also been used "in the wild" to determine how people use multi-touch technology in a more realistic setting [13,14,16,31]

Rather than investigating performance, these observational studies described multi-touch interaction in terms of measures such as the number of touches used and when they were used, or the types and nature of gestures. These studies also described body language and movement around the interactive tables or walls. Many of these studies suggested that interactive tables and walls can be highly engaging [6,16,23] and sometimes identify elusive or difficult-to-measure phenomena, such as the cool-factor [16]. While these observational studies provide very rich data about the use of technology, the studies described in this research are not easy to reproduce, and the method of identifying novel or interesting aspects of behaviour often relies on experimenter expertise and intuition.

Measuring Expectation: User-Defined Gestures

A common idea in much of the interactive surface literature includes the notion that touch interfaces are intuitive or easy to use. This has led to a kind of reversal of the evaluation process [28,29,52]: rather than designing gestures to be "intuitive", researchers ask participants in a study to describe the gestures they *expect* to be able to perform to accomplish specific tasks.

While this technique was designed to determine a gesture set for interactive surfaces, it involves a measure of agreement to evaluate the suitability of a gesture. Morris et al. [28] also describe a method for comparing these gestures to designer-created gestures. Specifically, this work asks participants whether the gesture would "be a good way to execute that command" and whether it would be "easy to perform". The work suggests that high agreement relates to ease of use and suitability of gesture.

Comparing Touch and Mouse Interaction

In this work, we describe a study that compares the experience of using a mouse to that provided by touch interaction. The mouse/touch comparison has been made in prior work; however, prior work has focused primarily on the performance metrics discussed previously. Tan et al. [47] found an increase in performance of tasks requiring spatial memory and recall when using touch devices, through kinesthetic cues. Early work by Shanis and Hedge [43] showed that the mouse beat multi-touch for data entry and cursor positioning (in terms of speed) but cite familiarity with the devices as a contributing factor. Forlines et al. found significant increases in speed when performing target selection using multi-touch, but a decrease when performing shape matching [6]. They also found that participants had a preference for the touch-table over the mouse [6]. Kin et al. [20] found that target selection speed was improved in multi-touch devices, with the majority of the improvements coming from single-handed selections. Leftheriotis et al. [23] showed that multi-touch is more efficient than the mouse when doing target acquisition tasks of moving targets and shape docking tasks. In the current work, we replicate many of these performance findings, but add to it a more complete understanding of the experience of using touch vs. mouse in both horizontal and vertical setups.

One exception to the focus on performance measures is the study by Leftheriotis [23]. This work used a validated scale measuring flow to find that multi-touch was more hedonic than the mouse. The authors interpret this as enjoyment; however there is no discussion of whether the differences were significant, and the evaluation of experience in the study was limited to this single validated scale.

Because of the collaborative affordances presented by interactive surfaces, there has also been significant work done on collaboration around tables and walls. As our study focuses on single-person interaction, we do not discuss the breadth of collaborative work here; however, as with the single-user studies presented, research on surface collaboration typically uses a combination of performance measures and behaviour observation.

Evaluating Experience

Although uncommon in surface research, focusing on user experience—as opposed to human performance—has a history of use when evaluating interactions with technology. Norman [30] argued that we should consider emotion in design in a move away from usability analysis toward user experience analysis. Similarly, the rise of the field of affective computing—which considers “computing that relates to, arises from, or deliberately influences emotion” [32]—following Picard’s seminal publication on the topic, has placed an emphasis on understanding the affective and cognitive-affective responses that users have to their technological interactions. Hassenzahl and Tractinsky [12] present a review of the early voices that pushed for considering hedonic aspects of experience evaluation alongside pragmatic aspects. They consider the approach of a positive HCI, where designers are concerned with providing high-quality experiences, rather than being merely concerned with preventing usability problems (similar to the notion that absence of disease does not equal health). Finally, the evaluation of play technologies, where the primary goals are to challenge and entertain the user, has focused more broadly on experience over usability by adopting variations on approaches designed for traditional usability evaluation [25].

More recently, theories of motivation have informed the design of scales that assess experience from the perspective of need satisfaction [39]. In particular, this approach promotes that intrinsic motivation is foundational to the enjoyment of interactive experiences, and can be attributed to volition and achievement inherent in the person (as distinct from external motivators, such as deadlines). The concepts used to describe a motivated experience are:

Competence. The experience of competence derives from challenge, and the personal effort of mastering challenges.
Autonomy. The experience of autonomy derives from volition and willingness to perform a task. Experiencing greater autonomy will allow a person to feel more in control.
Relatedness. The experience of relatedness is a heightened feeling of belonging to a group, or being connected to others. Although some have argued for leaving out the subscales on relatedness in single-user systems [18], it is possible that input types could differentially support a participant’s feeling of connection to others, and thus was included them in our study.
Immersion. The experience of immersion or presence is described as the sense that one is within the world. Immersion is supported by greater competence and autonomy.
Intuitive Control. Controls are intuitive when they do not interfere with one’s sense of presence, are easily mastered, and make sense in context.

STUDY: EVALUATING THE EXPERIENCE OF TOUCH

We designed an experiment to better understand performance and experience with mouse and touch input on vertical and horizontal surfaces. Specifically, we were interested in developing a deeper understanding of a person’s need satisfaction, motivation, and affective state when using touch devices and comparing that to an understanding obtained through more standard metrics of performance and workload. We were also interested in how the surface orientation of touch interaction would affect these measures.

Study Design

The study was a 2×2 within-subjects design with *display orientation* (vertical and horizontal) and *input device* (touch and mouse) as factors. Each participant completed four conditions in one of four orders (Table 1). Each condition included up to one minute of training and five minutes of play. After each condition, participants completed validated questionnaires on workload, experience, and need satisfaction.

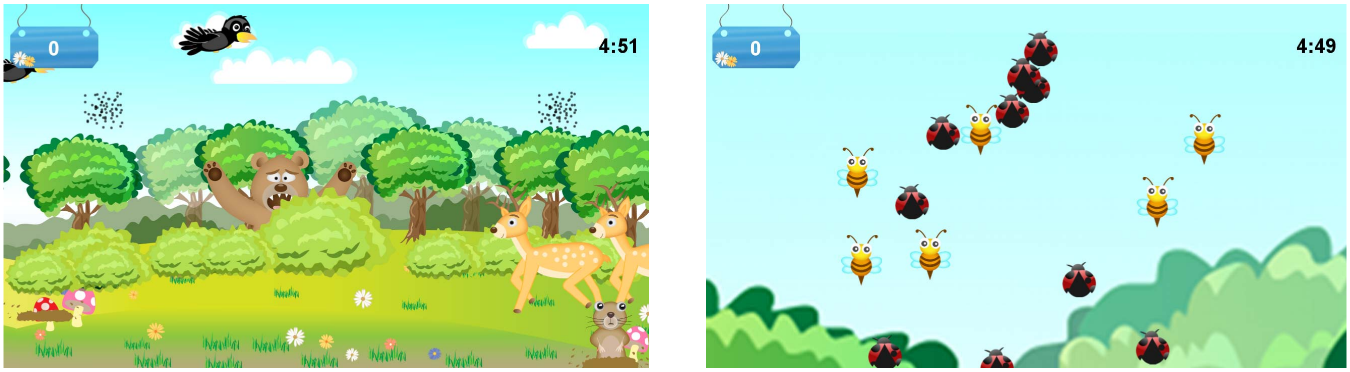

Figure 1 shows the basic gameplay (left) showing two insect swarms (dots above the tree line) and a zoomed in insect swarm (right). The animals, insects, insect swarms and clouds were animated. Participants tapped or clicked to shoot animals and insects.

	<1	5		<1	5		<1	5		<1	5	
1	Tr	HT	Q	Tr	HM	Q	Tr	VT	Q	Tr	VM	Q
2	Tr	VT	Q	Tr	VM	Q	Tr	VT	Q	Tr	VT	Q
3	Tr	HM	Q	Tr	HT	Q	Tr	HT	Q	Tr	HM	Q
4	Tr	VM	Q	Tr	VT	Q	Tr	HM	Q	Tr	HT	Q

Table 1 Study Ordering. Training (Tr) took up to one minute. Each Condition (H = Horizontal, V= Vertical, T = Touch, M = Mouse) took 5 minutes. Participants had a variable time to complete the condition questionnaires (Q).

Participants

The study ran simultaneously at two different universities, and was approved by the research ethics board at both institutions. Participants were recruited through mailing lists and posters. There were 48 participants (24 at each location), aged 19-36 (*Mdn*=25), with 16 females. The study took approximately 45 minutes to one hour, and participants were given $10 or a $10 gift card for participating.

Apparatus

Figure 2 shows the experimental setup with both a vertical and horizontal display.

The study took place in both locations using identical Dell S2340T multi-touch displays. The base of the display was located 7.6 cm from the edge of the table. The initial position of the mouse was located in line with the base and 2.5 cm from the edge of the display. The display's location relative to participants was controlled; however participants were told they could adjust the chair placement for comfort. An effort was made to keep the equipment consistent between locations; however, two models of a common mouse (Logitech LZ026HR and LZ107HU) were used. See Figure 2 for the setup.

Task

During each condition, the participants played a simple 2D shooting gallery style game. We chose a simple game as a task for several reasons. First, the game abstracts, simplifies, and repeats actions common to interactive surface use (i.e., monitoring, response, zoom, selection). Second, many surface interaction studies have also made use of games as both an example application [3] and a mechanism for testing collaborative work [42]. Third, the use of validated scales for understanding differences in user experience has been demonstrated for video games [39,2]; thus, there is some advantage to having participants answer questions in this context.

In this game, animals appeared on the screen, either by popping up in the middle, or crossing from side-to-side. Participants shot these animals by either clicking on them once (mouse), or tapping with a single finger (touch). Each animal was worth one point. To keep the bandwidth of input consistent, only one tap could be active on the screen at a time (i.e., it was not possible to shoot in multiple places at once by using multiple fingers). Dragging and shooting was also not possible in any condition – participants had to make a discrete selection of the target. Participant score was shown in the upper left corner and a timer was shown in the upper right corner (Figure 1).

During the game, insect swarms would appear at random in three fixed locations on the display. In order to shoot these insects, participants would have to zoom in using the scroll wheel (mouse) or using a standard multi-touch pinch gesture (touch). The insects in the swarm moved in quick circles making them harder to hit, but were worth 2-5 points to encourage participants to zoom. Zooming out made the swarm disappear from the screen, even if not all of the insects had been shot. Figure 1 shows a zoomed in swarm.

Participants were instructed to be as accurate as possible while getting the highest score they could. To increase the challenge, participants were informed that there was a high score to beat (1223).

Measures

After each condition, participants completed a series of validated scales. These included the interest-enjoyment scale of the Intrinsic Motivation Inventory [38] (IMI), the Positive and Negative Affect Scale [50] (PANAS), the Player Experience of Needs Satisfaction [39] (PENS), and the NASA task load index [49] (NASA TLX). At the end of the study participants were asked to provide demographic information, to rank each condition, and to provide any comments.

Workload and Performance

To determine the relative workload of the input device and display orientation, we included the NASA Task Load Index (TLX) [49], which was designed to assess workload during tasks. The TLX includes the six subscales: Mental Demands, Physical Demands, Temporal Demands, Own Performance, and Frustration. We report the combined workload score as described by [11]. To determine performance during the task, we calculated a variety of metrics from the game logs, including overall score, or the sum of points for all targets hit, which reflects the speed of system use. We also measured the total number of interactions with the system. In the touch condition, the total number of interactions was defined as the total number of single taps combined with the total number of zoom gestures. A zoom gesture was defined to have ended when one or more fingers involved left the surface of the screen. In the mouse condition, this was defined as the total number of clicks and scrolls, where a scroll was defined to have ended if there was a 150 ms pause before the next change in scroll wheel value was detected (a value determined by inspection and in line with the approach taken for touch). We calculated the hit rate (defined as the percentage of the total number of targets hit over the total number of targets shown), which reflects accuracy in system use. Finally, we calculated the number of insect swarms used (i.e., the number of completed zoom-ins). For an insect swarm to be considered used, the participant would have to completely scroll or zoom in. We gathered this metric to reflect the tradeoff of effort (of zooming) for payoff (in increased score).

Experience

To determine enjoyment of the task, we assessed intrinsic motivation using the 18-item Intrinsic Motivation Inventory [38], which has been used to evaluate experience with video games (e.g., [33]). A series of items are rated on 5-point Likert-scales, ranging from 1 (not at all) to 5 (quite a bit). We only report the interest-enjoyment subscale of the inventory, which reflects intrinsic motivation. To determine overall pleasure of the task, we assessed emotional valence using the Positive Affect Negative Affect Schedule-Expanded (PANAS-X) [50]. In the PANAS-X, participants are asked to state their level of agreement with 20 emotion adjectives on a Likert-scale ranging from 1 (very slightly or not at all) to 5 (extremely). The PANAS-X has been used to evaluate the enjoyment of video games (e.g., [33]).

To deconstruct experience into its underlying constructs, was used the Player Experience of Need Satisfaction Scale (PENS) [39], which investigates game experience from the perspective of Self-Determination Theory [40], and has been used successfully to evaluate games (e.g., [39], [2]). We used PENS after each condition, and participants rated their agreement with a series of statements using a 5-point Likert-scale from 1 (not at all) to 5 (quite a bit). PENS assesses competence, autonomy, relatedness, immersion, and intuitive control [39].

RESULTS

After determining that there were no systematic differences as a result of location (i.e., the two universities)[1], we performed a 2 (orientation) × 2 (input device) repeated measures analysis of variance (RM-ANOVA) on each of the performance metrics and each of the validated scales. Pairwise comparisons were corrected using Bonferroni's method of adjusting α. We first present results of the more common measures of performance, and then describe the results using the validated measures of experience.

Workload and Performance

We present the results for objective performance (from system logs) and subjective workload.

Speed (Score). There was a significant main effect of input on score ($F_{1,47}=14.9$, $p\approx.000$, $\eta_p^2=.25$) with participants scoring significantly higher with touch than with mouse (Figure 3). Because score is our main performance metric, and all games lasted exactly 5 minutes, this result suggests that touch outperforms mouse in terms of speed, which is in line with previous work on selecting stationary [6,20] and moving [23] targets. There was no main effect of orientation ($F_{1,47}=.5$, $p=.473$) and no interaction of orientation and input ($F_{1,47}=.05$, $p=.491$).

Number of Interactions. There was a main effect of input on the total number of interactions ($F_{1,47}=14.8$, $p\approx.000$, $\eta_p^2=.24$), where the number of interactions was almost 50% higher in the touch conditions than in the mouse conditions. Thus, participants were engaging with the system more in the touch conditions (Figure 3). There was no main effect

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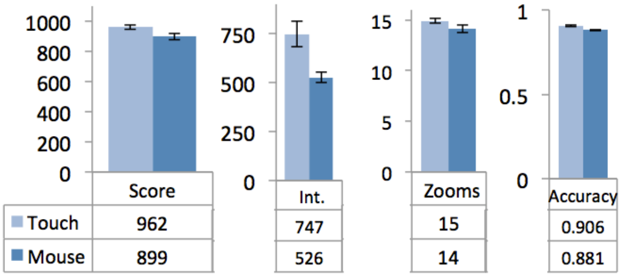
[1] There was only one significant effect of (or interaction involving) location, which was on score ($F_{1,47}=5.237$, $p=.027$, $\eta_p^2=.10$). Participants at one location had a significantly higher score (means of 970 vs. 891, SE=24). It is possible the differences in score between the two locations may be attributed to the slightly different setup, or simply to the expertise in the population that was recruited. There was, however, no interaction of location on any of the factors under consideration.

of orientation ($F_{1,47}=1.0$, $p=.334$) and no interaction of orientation and input ($F_{1,47}=1.8$, $p=.191$).

Accuracy (Hit Rate). There was a main effect of input on the hit rate ($F_{1,47}=18.4$, $p \approx 000$, $\eta_p^2=.29$), with participants hitting a higher percentage of targets with touch than with the mouse (Figure 3). There was no main effect of orientation ($F_{1,47}=0.01$, $p=.927$) and no interaction of orientation and input ($F_{1,47}=2.77$, $p=.102$).

Zooming. There was also a main effect of input on the number of insect swarms used ($F_{1,47}=6.9$, $p=.015$, $\eta_p^2=.13$) with more insect swarms being used in the touch conditions (Figure 3). During the limited time of the play session, participants zoomed in on average one time more in the touch conditions. There was no main effect of orientation ($F_{1,47}=0.6$, $p=.452$); however, there was a significant interaction between input and orientation ($F_{1,47}=9.2$, $p=.002$, $\eta_p^2=.19$, $M_{VT}=14.8$, $M_{HT}=15.0$, $M_{VM}=14.4$, $M_{HM}=13.8$, $SE_{VT}=.29$, $SE_{HT}=.26$, $SE_{VM}=.37$, $SE_{HM}=.46$), where pairwise comparisons show that there was a significant difference between mouse and touch in the horizontal condition ($p=.003$), but not in the vertical condition ($p=.176$).

Workload. There were no main effects of input ($F_{1,47}=1.36$, $p=.25$) or orientation ($F_{1,47}=.03$, $p=.857$) on the combined NASA-TLX scale for subjective workload; however, there was a significant interaction between orientation and input ($F_{1,47}=12.71$, $p \approx .000$, $\eta_p^2=.21$, $M_{VT}=6.1$, $M_{HT}=5.8$, $M_{VM}=5.7$, $M_{HM}=5.9$, $SE_{VT}=.23$, $SE_{HT}=.22$, $SE_{VM}=.20$, $SE_{HM}=.22$). Pairwise comparisons reveal significantly higher ratings of workload for touch in the vertical orientation ($p=.017$), but no differences between touch and mouse in the horizontal orientation ($p=.589$)



	Score	Int.	Zooms	Accuracy
▨ Touch	962	747	15	0.906
■ Mouse	899	526	14	0.881

Figure 3 Mean and SE of Score, Total Interactions (Int.), Zooms and Accuracy. Table shows means.

Experience

We present the results of enjoyment, affect, need satisfaction, and preference (Figure 4).

Enjoyment. There was a significant effect of input on interest-enjoyment ($F_{1,47}=17.89$, $p \approx .000$, $\eta_p^2=.28$), with touch being perceived as more enjoyable than mouse. There was no main effect of orientation ($F_{1,47}=.08$, $p=.777$) or interaction of orientation and input ($F_{1,47}=.04$, $p=.850$).

Affect. The significant main effect for positive affect ($F_{1,47}=9.50$, $p \approx .000$, $\eta_p^2=.17$), showed that touch was perceived as more positive, whereas the marginal effect for negative affect ($F_{1,47}=3.92$, $p=.054$, $\eta_p^2=.08$) showed that mouse input was perceived as more negative. There was no main effect of orientation ($F_{1,47}=.42$, $p=.519$, $F_{1,47}=.41$, $p=.524$) or interaction of orientation and input on either positive or negative affect ($F_{1,47}=1.04$, $p=.312$, $F_{1,47}=3.73$, $p=.059$).

Competence. The significant main effect for competence ($F_{1,47}=9.03$, $p<.01$, $\eta_p^2=.16$), showed that users perceived themselves as more competent when using touch than when using a mouse. There was no main effect of orientation ($F_{1,47}=.82$, $p=.371$) or interaction of orientation and input ($F_{1,47}=1.52$, $p=.224$).

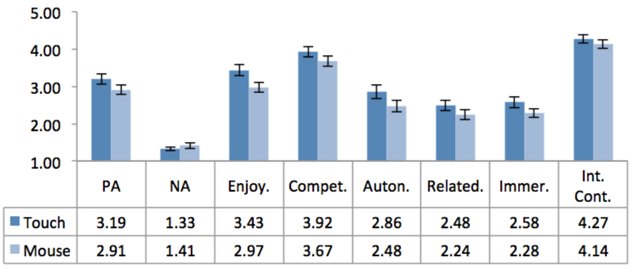
Autonomy. The significant main effect for autonomy ($F_{1,47}=8.45$, $p<.01$, $\eta_p^2=.15$), showed that users perceived themselves as more in control (i.e., operating under their own volition) when using touch than when using a mouse. There was no main effect of orientation ($F_{1,47}=2.68$, $p=.108$) or interaction of orientation and input ($F_{1,47}=.06$, $p=.811$).

Relatedness. The significant main effect for relatedness ($F_{1,47}=4.90$, $p<.05$, $\eta_p^2=.09$), showed that users perceived themselves as more connected to others when using touch than when using a mouse. There was no main effect of orientation ($F_{1,47}=.09$, $p=.761$) or interaction of orientation and input ($F_{1,47}=.98$, $p=.328$)

Immersion. The significant main effect for immersion ($F_{1,47}=12.84$, $p<.01$, $\eta_p^2=.22$), showed that users perceived themselves as more immersed when using touch than when using a mouse. There was no main effect of orientation ($F_{1,47}=.43$, $p=.518$) or interaction of orientation and input ($F_{1,47}=1.73$, $p=.195$).

Intuitive Control. There was no significant main effect for intuitive control ($F_{1,47}=2.07$, $p=.16$), showing that users did not perceive either touch or mouse to be more intuitive to use. There was also no main effect of orientation ($F_{1,47}=.00$, $p=.964$) or interaction of orientation and input ($F_{1,47}=.20$, $p=.660$).

Preferences. We asked participants to rank the conditions in order of preference (scale 1-4, 1=best). A Friedman test revealed that participants ranked the conditions differently ($X^2_3=32.1$, $p \approx .000$). Pairwise comparisons using Wilcoxon signed-ranked tests revealed that Horizontal Touch was ranked significantly higher than Horizontal Mouse ($z=4.5$, $p \approx .000$) and Vertical Touch was ranked significantly higher than Vertical Mouse ($z=2.0$, $p=.049$), showing that participants preferred touch, regardless of orientation. Vertical Mouse was ranked significantly higher than Horizontal Mouse ($z=3.4$, $p=.001$); however, there was no difference between Vertical and Horizontal Touch ($z=.8$, $p=.421$), showing that orientation did not affect preferences for touch, but that participants preferred using a mouse with a vertical display over a horizontal display; the horizontal mouse condition was the least familiar.



	PA	NA	Enjoy.	Compet.	Auton.	Related.	Immer.	Int. Cont.
■ Touch	3.19	1.33	3.43	3.92	2.86	2.48	2.58	4.27
■ Mouse	2.91	1.41	2.97	3.67	2.48	2.24	2.28	4.14

Figure 4 Mean and SE of Positive Affect (PA), Negative Affect (NA), Enjoyment (Enjoy.), Competence (Compet.), Autonomy (Auton.) , Relatedness(Related) , Immersion(Immer.), and Intuitive Controls (Int. Cont.). Table shows means.

Summary of Findings

There were no effects of orientation on any of the measures of performance or experience. The only interaction involving orientation suggests that input type did not affect perceived workload for horizontal use, but did for vertical use. This makes sense, as the participant would be more fatigued from having to hold their arm up in the vertical condition when using touch, but would experience no differences of physical effort from using the mouse to interact with a vertical or horizontal display.

The differences resulting from input type showed that touch outperformed mouse in terms of both speed (score) and accuracy (hit rate), and also supported more interactions overall and a higher number of insect zooms. These results suggest that there was no speed/accuracy tradeoff as a result of input type, and that participants engaged more with the system in the touch conditions. Not only did touch provide better performance, but touch also outperformed mouse in terms of positive affect, interest-enjoyment, competence, autonomy, relatedness, and immersion. These results show that participants were significantly happier (positive affect) and had more fun (interest enjoyment) when using the multi-touch display. In addition, participants felt more competent (competence), more in control (autonomy), more related to others (relatedness) and more immersed (immersion). Finally participants ranked touch significantly higher than mouse for both vertical and horizontal orientations.

The differences between touch and mouse for performance and experience cannot, however, be attributed to differences in workload or intuitive control, as we found no main effects of touch on ratings of workload or intuitive control. This contrasts the general assumption that touch is more intuitive but also more fatiguing.

DISCUSSION

Participants systematically rated their experience with touch better than that of the mouse over several factors. There may be several reasons for these differences. First, participants actually performed better in terms of both speed and accuracy with the touch interface than the mouse. They may have perceived this difference (either intuitively or by viewing the score) and felt more competent, because they actually were more competent. Second, we don't know how the challenge of each interface was interpreted: perhaps touch was more challenging due to the physical nature, or less challenging because you could use two hands. Third, the higher number of total interactions and higher number of zooms in the touch conditions suggest that participants were engaging with the system more in the touch conditions. This increased engagement may be reflected in their responses. Fourth, there may be something inherently more appealing about the direct nature of multi-touch interaction particularly when applied to a game.

Participants had higher percentage of targets hit with touch over mouse (accuracy). However, combined with the higher number of total interactions this also suggests that touch was less efficient (it may take more than one touch to hit an animal or insect). Despite this potential lack of efficiency, experience measures were overwhelmingly in favor of the touch condition, suggesting that this was either unimportant to, or not noticed by participants.

It should also be noted that the NASA TLX measures perceived workload, not actual workload. This is interesting in light of the input by orientation interaction found in Workload. If touch does indeed have a higher workload, but the same perceived workload as a mouse, this means that participants may get fatigued by the higher workload, but not perceive the differences. Perhaps a longer experiment could be conducted to further investigate perceived and actual fatigue.

The zooming interaction of input by orientation may have been caused by participant perspective. Participants were observed to lean over the screen in the horizontal touch condition and sit back for all other conditions. This different perspective may have led them to interact more with the very small insect swarms.

Further, the game used is a single player game, but the results indicated significant differences in feelings of relatedness. These findings are not intuitive: how can a single player game make us feel close to others? We can answer this question by considering the continuum of feeling related. It is not the case that using touch input lets us experience deep connections to other people; but that compared to using the mouse, the feeling of being connected increases. Relatedness is defined by acknowledgement, support, and impact; among these, only impact does not depend on external assessment. Thus, we assume that the differences in performance and competence support the feeling of having an impact, and therefore to an increase in relatedness.

Extension Beyond Games

We expect that the same trends of needs satisfaction, affect, interest/enjoyment, and presence/immersion to be similar for non-gaming situations. Consistently, our results confirm the performance results in other studies, in particular the work relating to selection of stationary and moving targets [6,20,23]. This suggests that our results are more related to input device than task, which was kept consistent across conditions. Our expectation is that if you change the task, the trends will stay the same. The magnitude of differences in affect and interest/enjoyment, for example, may become more pronounced as we expect people to enjoy a game.

As for the actual tools themselves, PENS and IMI in particular may need to be adjusted slightly to suit situations other than games. The words "player" may need to be changed to "person" and "game" to "task". Despite these changes, we expect that these scales can be applied to many technologies, as the task may change but not the construct that is being evaluated. It should also be noted that there is a similar scale to PENS, not in the context of games, called the Basic Physiological Needs Satisfaction scale (BPNS) [4]. BPNS can be applied to work settings; however, it does not measure immersion or intuitiveness of controls.

The Value of Understanding Experience

We designed our study to require only very simple interactions with hands and fingers, in part to provide a comparable condition to the mouse, but also to demonstrate the power of the validated scales as a tool for measuring experience. With even simple interactions, there were significant differences found in experience that provide a richer understanding for why touch interaction may be a better choice for this type of repeated selection task.

While the performance metrics demonstrate that people can achieve higher scores and tend to interact more when using touch, the experience metrics add to that understanding by demonstrating that they also feel better and more engaged (PANAS-X), more competent, autonomous, and related (PENS). Indeed, these experience metrics may partly explain why people interacted more when using touch than when using a mouse.

While the findings of our study suggest benefits for touch over mouse, and highlight differences between vertical and horizontal setups, we consider the primary contribution of this paper to be the demonstration of these experience measures as a tool to enrich our understanding of more commonly applied performance metrics, at a lower cost than running an observational study. Observational studies are time intensive and require a significant amount of training in order to get interesting and significant results. Validated scales, in contrast take minutes to apply and analyze with minimal training

That is, while other lab studies have shown similar performance improvements when using touch, and other observational studies provide frameworks and models for understanding behaviour at and around touch devices, this work demonstrates a clear benefit to people's affect, need satisfaction, and engagement when using touch interaction. Specifically, we strongly recommend that future researchers include these validated scales when conducting studies involving multi-touch surfaces, and expect they will result in a deeper understanding of differences between techniques and technologies.

Designing for the Touch Experience

Our study builds on previous studies of touch interaction, but provides additional insights to designers. In particular, improved feelings of competence through touch can be used when designing interfaces for novices, but should be carefully considered when designing safety critical systems, when careful consideration of one's actions is vital. Our results also indicate that touch interaction improves positive affect and feelings of autonomy, which may be valuable in the design of interfaces intended to support creativity, or in assistive technologies designed to support feelings of independence and improved well-being.

Our results also provide evidence that touch interaction is a good choice in the design of immersive interfaces. This has immediate implications in the design of games, but also in the design of software that may require focused or long-term engagement, which includes many work applications.

Limitations of the Study

As with any single study, we made design decisions that introduce tradeoffs. Specifically, the game we used is very simple. It does not involve complex, cognitively demanding tasks (much like previous work involving simple computer tasks), and as a result, our play sessions were very short (5 min). It is also difficult to argue that the game is enjoyable over the full 20 minutes of play, and some participants expressed boredom near the end. It could be interesting to use a more complex game to see if the differences are more (or less) pronounced; however, as the complexity of the game task increases, so does the required training time. It also becomes more difficult to create a touch based game with an equivalent mouse version.

We show many significant differences, some of which are small in value. This is both a limitation and strength. While we would like the interfaces to create vastly different experiences, we have shown that these tools can be used to detect even small, but consistent, differences in experience.

Participants could also use two hands in the touch condition, which may account for higher speed. Even though only one touch could be active on the screen, with two hands they may have a smaller distance to the target. Additionally, participants were not able to hit insect targets without zooming in, even though the precision enabled by the mouse might make have made this possible to accomplish. Enabling this ability may have highlighted some of the precision benefits inherent in mouse interaction. Nonetheless, a future study that uses these validated scales could reveal a more nuanced understanding of this benefit.

CONCLUSION AND FUTURE WORK

In the work, we evaluated the differences in performance and, more importantly, experience between direct touch and mouse input on horizontal and vertical surfaces using a simple application and several validated scales. We make several contributions. First we show that touch improved experience using a variety of measures related to enjoyment, engagement, volition, and competence. Second, we show that these improvements do not come at a performance cost, but that performance was also improved using touch. Third, we show that our findings are not affected by the orientation of the display, suggesting that the advantages of touch are applicable to both horizontal and vertical screens. Fourth, we demonstrate an effect and efficient method for gathering experience with surface applications. Finally, we discuss the implications of improved experience of touch input for designers of interactive surface applications.

There are several avenues for future work. This straightforward method for understanding experience could be extended to other input devices used on interactive surfaces such as tangibles and secondary handheld displays. Also, while our initial work, presented here, applies these scales in a game-like application, future work should be done to validate the scales used in other contexts.

As interactive surfaces become more prevalent, the focus on experience—over and above usability—is fundamental for product designers looking to establish their brand. As researchers, we make choices in the design of our interaction techniques and we can add value to our work by explaining the experiential differences that result from these choices. Our work demonstrates for one domain (touch vs. mouse) how deconstructing experience using established theories and scales can provide significant value for our understanding of how people interact with technology.

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