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Sameerajan Suresh\textsuperscript{a}, David Kaber\textsuperscript{b} & Michael Clamann\textsuperscript{b}

\textsuperscript{a} Human Interfaces, Inc., Austin, Texas, USA

\textsuperscript{b} North Carolina State University, Raleigh, North Carolina, USA

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Effects of Laptop Touchpad Texturing on User Performance

Sameerajan Suresh¹, David Kaber², and Michael Clamann²
¹Human Interfaces, Inc., Austin, Texas, USA
²North Carolina State University, Raleigh, North Carolina, USA

This research assessed user performance with different laptop touchpad textures. In specific, the study measured discrete movement task time and accuracy. It was hypothesized that texturing would increase task times but improve accuracy by providing users with tactile references. A variable representing the frictional potential of pads was introduced into an established model of discrete movement performance (Fitts’ Law) in an attempt to accurately model user performance under experimental task conditions. Results revealed touchpad texturing to degrade task performance. However, accuracy in pointing tasks was not significantly affected. Results also revealed that the expanded form of Fitts’ Law, including a parameter for representing the frictional potential of pad texturing, was more predictive of actual movement task time and accuracy. It was hypothesized that texturing would increase task times but improve accuracy by providing system functions beyond cursor movement using a combination of fingers. These design and capability changes have implications for human performance that need to be quantified as a basis for future systems development.

1. INTRODUCTION

With the rapid evolution of laptops and portable computers, integrated touchpads have become familiar controls for interacting with graphical user interfaces. The key advantage of touchpads over other pointing devices is their compact design and effectiveness in converting short finger movements to gross cursor motions through high-control gains. Touchpads have been the subject of substantial research conducted to improve user experiences (Buxton, 2007; Dillen, Phillips, & Meehan, 2005; Douglas, Kirkpatrick, & MacKenzie, 1999; Douglas & Mithal, 1997). In the present study we compared various touchpad surface textures to identify performance differences in terms of speed and accuracy and to characterize the effects of texturing using mathematical models of human performance.

Touchpads are typically constructed of several layers of material. The top layer, which a user touches, is typically made of plastic, metal, or glass and conceals additional layers containing horizontal and vertical rows of electrodes. These electrodes form a grid separated by additional layers of thin insulation. Beneath these layers is a circuit board providing constant alternating current to the electrode layers. Current in the electrode grid is interrupted by downward pressure from a user’s finger, indicating the finger’s position. The initial location where the finger touches the pad is registered so subsequent finger movement is related to the initial contact point. Varying degrees of pressure at the pad may be applied for different functions (e.g., dragging, clicking, etc.).

Since being introduced as input devices, touchpads have undergone various design changes, including surface material types, pad sizes, gain factors and variable gains, and edging. More recently, their usefulness has expanded further with advances in multitouch technology, which allows users to invoke system functions beyond cursor movement using a combination of fingers. These design and capability changes have implications for human performance that need to be quantified as a basis for future systems development.

2. PREVIOUS WORK

A number of user interaction studies have been conducted with touchpads as a basis for improving the technology. For example, Akamatsu and MacKenzie (2002) compared changes in forces applied to touchpads and mice during a series of pointing tasks. The authors recorded force data using a forceplate with a high-sensitivity strain gauge and found that participants increased force on the mouse during the honing phase (as they approached a target) but decreased surface force with the touchpad in the same movement phase. Although subjects decreased force at the pad surface, the study also found that task time was longer with the touchpad than the mouse. This finding is consistent with other previous studies (Douglas et al., 1999; MacKenzie & Jusoh, 2001; MacKenzie & Oniszczak, 1998). The decreased force on the touchpad at the close of pointing can be explained by a user lifting their finger from the surface. The longer movement time with the touchpad can be explained by the need for more exacting corrective movements during the honing phase, occurring near to the target.

A touchpad is typically positioned close to a laptop keyboard, which is advantageous for quick task performance;
however, this also poses a disadvantage regarding inadvertent activation of the cursor via the pad. Users often accidentally run their palm over the touchpad causing the screen cursor to shift unexpectedly (U.S. Patent Application No. 12/431,920, 2009). To reduce inadvertent activations, designers have modified the physical features of pads (e.g., edges, borders, recesses) to maintain user awareness of pad location in laptop use. Several contemporary laptops, manufactured by Lenovo, Dell, and others, use raised bumps on the touchpad surface, or texturing, toward preventing inadvertent activations. This feature produces a tactile cue that helps a user identify the edges of the touchpad (Hill, 2009; Kim, Smith-Jackson, & Nam, 2013) and allows them maintain awareness of the functional boundary of the touchpad while continuing to look at the computer screen.

Pad texturing is particularly effective for thinner laptops because even small recesses, marking touchpad boundaries, affect the laptop’s overall thickness. In addition, variations of texturing within pads have been implemented to provide tactile indications of functional regions within the pad, such as those for page scrolling. Textures typically consist of bumps of varying diameter, height, spacing, gloss, and hardness. Many different touchpad textures have been evaluated in terms of appearance and feel criteria using these parameters (Hill, 2009). Previous testing has involved comparing the surrounding palm rest texture to pad samples to ensure users could detect when their fingers moved beyond the pad boundaries (Hill, 2009). However, little empirical or quantitative research has been developed and/or used by manufacturers as a basis for selecting touchpad textures. Instead, textures are often selected based on subjective perceptions of appearance and feel from focus groups.

Using texture as a tactile cue increases friction at the touchpad surface during normal interaction. Bumps pose some resistance to finger motion on the pad. Coefficients of kinetic friction depend on the force applied at a surface; however, in general, the coefficient of kinetic friction on touchpad surfaces range from 0.1 for glass touchpads to 0.6 for textured touchpads (Winfield, Glassmire, Colgate, & Peshkin, 2007). The effect of friction on performance in a target acquisition task was studied by Richard and Cutkosky (2000). The degree of friction was controlled by requiring subjects to maneuver a pointing device on an aluminum block or a rubber pad. Results indicated that low or moderate amounts of kinetic friction at an input device significantly improve performance in computer-based target acquisition, in terms of both speed and accuracy. This supports the notion that increased surface texturing of touchpads might serve to promote user control in cursor pointing tasks. Performance results were also supported by subjective ratings indicating subject preference for higher friction in input conditions.

Lévesque et al. (2011) conducted experiments to observe the effect of programmed friction in a haptic device on touch interaction. They identified an advantage of variable friction in accuracy in a targeting activity, in line with Richard and Cutkosky’s (2000) findings. On this basis, we hypothesized (H1) that friction between a user’s fingertip and a touchpad would produce similar accuracy and task time effects. Furthermore, Lévesque et al. (2011) results suggest that user perceptions of performance with input devices under frictional conditions is representative of actual performance observations in terms of accuracy and task time. We hypothesized (H2) that any user perceptions of performance with touchpads or preferences for pads would be in line with task accuracy and completion time.

3. MODELING DISCRETE MOVEMENT TASK PERFORMANCE

Fitts’s (1954) Law provides a predictive model for estimating discrete movement task time between a defined start point and a target with a specific width at a specific distance or amplitude from the start. Because the original experiments, Fitts’s Law has been extended to computer-based tasks to predict the time it takes to move a cursor to a particular display element using a pointing device, as in the task employed by Richard and Cutkosky (2000). Fitts’s Law has subsequently been empirically validated for a variety of computer pointing tasks and input devices (Hertzum & Hornbæk, 2013; Hinckley, Jacob, & Ware, 2004; MacKenzie & Soukoreff, 2003; McGuflin & Balakrishnan, 2002). For example, a formulation of Fitts’s Law applied by Card, English, and Burr (1977), expresses the average time it takes to use a mouse to move a cursor to a target from a fixed point, as a linear function of Fitts’s Index of Difficulty (ID), originally expressed as:

$$ID = \log_2 \left( \frac{2D}{W} \right),$$

where, D is the distance the cursor must move from the start point to the target, and W is the width of the target. Although this model is based only on target width and distance, it “has proven [to be] one of the most robust, highly cited, and widely adopted models to emerge from experimental psychology” (MacKenzie, 1992). Since its formulation, other researchers have validated variants of the ID, including adding constants of 0.5 or 1.0 within the parentheses (Ware & Balakrishnan, 1994).

One of the limitations of Fitts’s Law, however, is that it is often inaccurate in predicting reaction times for low values of ID (Meyer, Smith, & Wright, 1982; Welford, 1960). This indicates that minimum Fitts task times based on actual human performance are greater than the original Law predicts. Numerous researchers have made suggestions for improving Fitts’s Law to address this limitation, which is likely due to task environment factors (MacKenzie, 1992; Welford, 1960, 1968). For example, MacKenzie and Ware (1993) derived a version of Fitts’s Law, integrating ID and computer system lag variables,
by using a multiple regression model, which predicted degraded performance with increased system lag. MacKenzie and Ware’s results indicated that lag significantly degraded sensory-motor performance with interactive systems. The authors concluded that lag was an important system parameter when modeling discrete movement task performance, with effects becoming evident at 75 ms and substantial degradations occurring beyond 225 ms. Ware and Balakrishnan (1994) expanded on this study and tested the effects of lag in one- and two-dimensional target acquisition tasks. The effects of lag were modeled by modifying Fitts’s Law to include measured system lag as a multiplier of the ID. The authors presented the following equation:

\[ MT = a + (b (c + \text{MachineLag}) ID_e), \]

where MT represents movement time; ID represents the index of difficulty; “MachineLag” represents the machine processing delay to respond to user control movements; and a, b, and c represent experimentally determined constants. a and b are used in most versions of Fitts’s Law (Ware & Balakrishnan, 1994). These two constants are identified using regression analysis on the movement time data and represent the intercept and slope, respectively. The c and MachineLag multiplier were subsequently added by Ware and Balakrishnan. a represents the sum of the initial time and the time required to confirm the acquisition of the target, b represents the speed of the control device, and c is the human processing time required to make a control movement. Ware and Balakrishnan’s results were consistent with previous Fitts’s Law studies estimating human processing time between 100 and 200 ms (Carleton, 1981; Fitts, 1954). In general, this study confirmed that lags in computing system responsiveness to user inputs at control interfaces can degrade performance.

Pavlovych and Stuerzlinger (2009) also studied the effects of computer system lag on speed and accuracy in 2D pointing tasks, when using a mouse. Reliable mouse position tracking was achieved through a textured worksurface. Results indicated that performance depended on the ID of the pointing task. The authors found no significant performance effect of low level lag (about 58 ms) but that task error rates increased with each 50 ms increase due to a 0.8 bit-per-second reduction in displayed information for subjects. Pavlovych and Stuerzlinger observed a 10% to 15% increase in error rate for lags ranging from 33 to 133 ms over baseline. Again, these findings support the extension of Fitts’s original model for discrete movement tasks with small ID values and in situations in which computer system lag may occur.

In general, the aforementioned studies support adaptation of Fitts’s Law, including adding parameters to the original model, to reflect system and/or human factors for accurately predicting discrete movement task performance. The alternative formulations of Fitts’s model appear to have utility, such as that used by MacKenzie and Ware (1993). Given the consistency of previous results, we hypothesized (H3) that introduction of a frictional parameter in Fitts’s Law (akin to a system lag variable) would promote accuracy in predicting performance with textured touchpads, compared to the original form of the Law. The Ware and Balakrishnan (1994) formulation of Fitts’s Law was adapted for this research.

4. SUMMARY

The objective of this study was twofold: first, to identify performance differences in terms of speed and accuracy due to various forms of touchpad textures, and second, to determine whether a modified version of Fitts’s Law could be used to predict the performance effect of touchpad texturing. As demonstrated by Richard and Cutkosky (2000), rougher touchpad texturing with a higher coefficient of kinetic friction was expected to significantly degrade task time (H1.1). Furthermore, based on Akamatsu and MacKenzie’s (2002) results, the greatest effect was expected during the ballistic phase of motion, in which cursor speed was highest (H1.2). Finally, accuracy was expected to be greater with rougher touchpad texturing owing to the fact that textures slow user finger motion and provide position references through bumps. Such references may reduce overshoots in target acquisition (H1.3). This hypothesis was also consistent with the findings by Richard and Cutkosky.

5. METHODS

5.1. Participants

To test the aforementioned hypotheses, an experiment was conducted with 10 participants (five male, five female) recruited from the North Carolina State University student population. All participants were between the ages of 19 and 40 years and were required to have 20/20 or corrected vision. The latter requirement was verified prior to the experiment using a Snellen Eye Chart. A preexperiment survey revealed that all participants were right-handed and experienced computer users, spending an average of 40 hr per week using computers, with no upper extremity pain or disabilities. All participants were experienced in touchpad use.

5.2. Apparatus

Three identical 15-in. Lenovo L512 ThinkPad laptops with Synaptics touchpads (driver version 15.0.18.0) were used in the experiment. Each touchpad had a different Mylar textured surface, labeled “A,” “B,” and “C.” Touchpad B had no texture (i.e., no bumps). It was machined to have a depth of 0.02 mm (relative to the laptop surface) and was treated with a smooth ultraviolet (UV) coating. Touchpad C (high texture) was surface treated with UV-printed bumps with 0.7-mm diameter, 1.2mm pitch, and height of 0.055 ± 0.01 mm. (In pixelized displays, such as a textured touch pad, pitch describes the size of the dots—in our case, bumps—or the distance between dots of similar
characteristics. The texture properties for these two touchpads were provided by the manufacturer. Touchpad A (low texture) was also surface treated with UV printed bumps with 0.7-mm diameter, 1.2-mm pitch, and height of 0.03 ± 0.01 mm. Texture properties for Pad A were not provided and had to be identified using a Hirox microscope. Figure 1 presents a cross-sectional microscopic image of a single dimple, along with the height profile.

The three laptops used for running the test trials (labeled A, B, and C, corresponding to the touchpads) were placed adjacent to each other on a large desk (see Figure 2). Participants shifted between the laptops to perform a Fitts’s type target acquisition task. An 18.4-in. Fujitsu Siemens Xi3650 laptop was used for task training. The touchpad integrated in this laptop was made by Alps Electric.

5.3. Task and Variables

We used the Motion Time Evaluator (MTE) software developed by Schedlbauer and Pastel (2007). This software presents a Fitts target acquisition task and automatically records trajectory and movement time information. The application displays a cursor at the center of the screen along with a circular target at a random position, according to a Fitts task ID setting. Participants are instructed to navigate the cursor to the target as quickly and accurately as possible using their index finger on the surface of the touchpad and to click the left (pad) button with the thumb to select the target. The procedures were consistent with previous pointing task studies (e.g., MacKenzie & Oniszczak, 1998).

The independent variables included the touchpad texture (three levels: none, low, high) and the Fitts task ID (three levels) for a total of nine conditions. The surface characteristics of the pad textures, including the height of the bumps, were used to define the level of friction in modeling the Fitts task. The three levels of Fitts ID were achieved by increasing the distance between the cursor starting position and target location. Table 1 summarizes the target distances in pixels from the start location and the associated ID. The target width and height (i.e., 50 pixels) and start location were held constant for all trials, as the ID and touchpad conditions changed. Targets could appear at any angular direction (in increments of 10°) from the center of the screen. The direction of the location of each target was varied within the ID condition; however, combinations of target positions were held constant across participants.

Movement time, accuracy and subjective ratings of comfort and accuracy represented the dependent variables. The MTE software recorded movement times in milliseconds. Movement of the task cursor began when participants moved or applied pressure to the touchpad. The ending time was recorded when a participant depressed the left touchpad button. Accuracy was calculated using the following equation:

\[ \text{Accuracy} = \left[ 1 - \left( \frac{D}{A'} - 1 \right) \right] \times 100\% , \]

where D was the actual distance traveled by the cursor to a target in a test trial and A’ was the straight line distance between the cursor start position and target location.

TABLE 1
Distances and Index of Difficulty (ID) Values for Each ID Condition

<table>
<thead>
<tr>
<th>Condition</th>
<th>Distance (Pixels)</th>
<th>ID Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ID1</td>
<td>325</td>
<td>2.9</td>
</tr>
<tr>
<td>ID2</td>
<td>250</td>
<td>2.6</td>
</tr>
<tr>
<td>ID3</td>
<td>125</td>
<td>1.8</td>
</tr>
</tbody>
</table>
Subjective ratings of comfort and accuracy were made at the end of the experiment using a 10-point rating scale with 1 (strong approval) and 10 (strong disapproval). Participants rank-ordered the touchpads (A, B, and C) in terms of comfort, accuracy in performance, desire to use the pad on a daily basis, and overall preference. They also provided comments on their experiences with the pads.

5.4. Procedure

Each participant trained in the Fitts task using the Fujitsu laptop touchpad prior to formal testing by repeating blocks of 50 trials until asymptotic performance was achieved. Once the training process was complete (approximately 10 to 15 min), participants completed 50 MTE trials under each of the nine test conditions in random order for a total of 450 observations on each participant. The movement time (milliseconds) and accuracy were recorded for each trial. The test trials were followed by the subjective ratings and questionnaire.

6. RESULTS

6.1. Task Speed and Accuracy

Diagnostics on the movement time response revealed the data to be best fit by a lognormal distribution, consistent with previous Fitts’s Law studies (Schedlbauer & Pastel, 2007). Outliers in the movement time data were identified using a statistical approach and investigation of experiment records. Movement times for each of the nine conditions, greater than the mean movement time plus or minus 2 standard deviations, were considered as potential outliers. These observations were subsequently investigated for a root cause of statistical deviation. It was found that the majority of statistically deviant observations occurred in trials in which participants failed to follow the instruction of obtaining the target with the cursor as quickly and as accurately as possible. These data points were removed from the data set and replaced with condition means for conservative statistical comparison of conditions. The average movement times, in milliseconds, are summarized in Table 2.

A repeated measures analysis of variance (ANOVA) model was constructed to test whether the touchpad texturing, task ID, and interaction of these terms influenced movement time. Results revealed both pad texture, $F(2, 72) = 3.56, p = .033$, and ID, $F(2, 72) = 41.88, p < .001$, to be significant. A plot of the movement time data suggested that the smooth Touchpad B produced faster performance across task IDs (see Figure 3). The plot also showed that performance time generally decreased with decreasing ID. Post hoc analysis using Tukey’s Honestly Significant Difference indicated that movement time was not significantly different between the two textured pads, A and C, but both produced longer times ($p < .05$) than Touchpad B. Post hoc results also confirmed that task performance was best ($p < .05$) under the lowest task difficulty condition. The interaction of the touchpad texture and ID was not significant.

<table>
<thead>
<tr>
<th>Movement Phase</th>
<th>ID</th>
<th>Pad A (Medium)</th>
<th>Pad B (Smooth)</th>
<th>Pad C (High)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td>ID1</td>
<td>1,006</td>
<td>970</td>
<td>1,035</td>
</tr>
<tr>
<td></td>
<td>ID2</td>
<td>941</td>
<td>895</td>
<td>958</td>
</tr>
<tr>
<td></td>
<td>ID3</td>
<td>864</td>
<td>806</td>
<td>811</td>
</tr>
<tr>
<td>Ballistic</td>
<td>ID1</td>
<td>341</td>
<td>331</td>
<td>349</td>
</tr>
<tr>
<td></td>
<td>ID2</td>
<td>342</td>
<td>323</td>
<td>352</td>
</tr>
<tr>
<td></td>
<td>ID3</td>
<td>321</td>
<td>325</td>
<td>324</td>
</tr>
<tr>
<td>Honing</td>
<td>ID1</td>
<td>665</td>
<td>638</td>
<td>687</td>
</tr>
<tr>
<td></td>
<td>ID2</td>
<td>599</td>
<td>573</td>
<td>606</td>
</tr>
<tr>
<td></td>
<td>ID3</td>
<td>543</td>
<td>480</td>
<td>487</td>
</tr>
</tbody>
</table>

The influences of the independent variables on ballistic and honing phase movement times were also assessed, similar to Akamatsu and Mackenzie (2002). The ballistic and honing phases of the Fitts task trials were identified by generating velocity profile plots and graphically identifying the first knee point, or decrease in velocity, along a cursor trajectory for all 4,500 target acquisitions observed during the experiment. The same repeated measures ANOVA model applied to overall task time was used to identify main effects of touchpad texturing and ID on ballistic movement time. Test results revealed both the touchpad texture, $F(2, 72) = 3.72, p = .029$, and ID, $F(2, 72) = 5.36, p = .007$, to be significant in the ballistic phase. Post hoc analyses on these results were performed using Tukey’s test. All three touchpads were significantly different from each other.
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ID1
ID2
ID3

Average Movement Time (ms)

Pad A (medium)
Pad B (none)
Pad C (high)

FIG. 4. Average ballistic phase movement times for all Index of Difficulty (ID) and touchpad conditions. Note. Error bars represent 1 standard deviation.

($p < .05$) with the smooth pad (B) yielding the fastest times and the high texture pad (C) producing the slowest time. Tukey’s test for the influence of ID revealed ID1 and ID2 to be statistically similar, but both were significantly different ($p < .05$) from ID3. ID1 and ID2 led to the longest performance times. The interaction of touchpad texture and ID was not significant in movement time in the ballistic phase. Under the lower difficulty condition (ID 3), movement time appeared to be relatively consistent across textures (see plot in Figure 4).

The repeated measures ANOVA was also applied to the movement time data collected during the honing phase (Figure 5). In this phase, pad texture was marginally significant, $F(2, 72) = 2.88, p = .063$, and task ID was significant, $F(2, 72) = 48.27, p < .001$. Post hoc tests on the main effect of texture revealed Touchpads A and C to be similar, whereas both were significantly different ($p < .05$) from the smooth Pad B. Performance was fastest with Touchpad B compared to the other two pads. Post hoc tests on the ID effect revealed all three levels to be significantly different from each other ($p < .05$). Task performance was fastest in the ID3 (low difficulty) condition and slowest in the ID1 condition. The interaction of pad texture and task ID was not significant for honing phase time.

An ANOVA was used to examine the effect of touchpad textures and ID on task accuracy. The results of this analysis revealed no significance of touchpad texture, $F(2, 72) = 0.76, p = .471$, or ID, $F(2, 72) = 0.90, p = .411$.

6.2. Subjective Preferences

Due to the discrete nature of the survey data and lack of characterization of a normal distribution, a Kruskal-Wallis test was performed with touchpad texture as the predictor and perceived accuracy and perceived comfort as response measures. Test results revealed a marginally significant effect of touchpad texture ($p = .0679$) on perceived comfort. Perceived accuracy, however, was not significantly influenced ($p = .225$). Related to this, given the small sample size for the study, the power of the statistical test on accuracy ratings was limited and a larger sample size might have revealed a significant difference among pads. Based on these findings, additional pairwise Kruskal-Wallis tests were performed on the comfort ratings for the various pad types. Only the smooth pad (B) produced significantly higher ($p = .0433$) comfort ratings, as compared to the high texture touchpad (C).

In general, the comfort rating results indicated that participant perceptions were consistent with the performance differences observed in target acquisition time for the various touchpads. Perceptions of comfort were found to be significantly positively correlated with performance ($r = .382, p = .0368$). Although there were no differences among pad types in terms of the objective or subjective accuracy responses, the ratings of perceived comfort corresponded with the objective measures of target acquisition. The correlation coefficient was marginally significant ($r = .313, p = .0924$). The findings of the participant survey were, therefore, in agreement with the previous observation of Richard and Cutkosky (2000).

6.3. Comparison of Performance Models

Linear regression analysis was used to assess the fit of the experimental data to MacKenzie’s form of Fitts’s Law (incorporating a 1.0 constant) as well as the adaptation of Ware and Balikrishnan’s (1994) formulation incorporating a parameter to represent pad friction potential. For the Fitts’s analysis, the ID measure was calculated for each trial using the following equation, adapted from MacKenzie (Ware & Balikrishnan, 1994):

\[
\text{Target Acquisition Time (ms)} = 100 \times \log_{2} \left( \frac{W}{2D} + 1 \right)
\]
where D is the distance of the movement and W is the width of the target. The width of the target was fixed at 50 pixels; therefore, the three distances of motion for the experiment task conditions (see Table 1) caused the ID to vary across conditions. The three forms of Fitts’s equation used for the regression analyses are summarized in Table 3.

The ID parameter for the Ware and Balakrishnan (1994) formulation differed from the Fitts’s formulation in that it took into account the surface characteristics of the touchpads. Specifically, the ID was multiplied by the average pad bump height. (The multiplier of 0.02 mm in the equations for Pad B represents the difference in surface elevations of the touchpad and laptop. The value also captures any variation in machining of the touchpad surface.) Therefore, a model was determined for each type of pad by level of task difficulty, as shown in Table 4.

The observed target acquisition time was used as the response in all models. Goodness of fit assessments were made using R² values for the three Fitts models and for each of the nine Ware and Balakrishnan formulations. The R² values were aggregated across all models within formulation type. Results revealed average values of 0.21 and 0.31 for the Fitts and Ware and Balakrishnan formulations, respectively. The two sets of R² values for the movement behavior models used for the study participants are summarized in Table 5.

A paired t test was conducted on the R² values for the Fitts versus Ware and Balakrishnan models to determine if there was a significant difference in the degree of fit to the actual movement time data. The test revealed a significant difference (t = 3.014, p = .015) with a mean model fit of 0.0956 and a standard deviation of 0.0317. The Ware and Balakrishnan formulation of Fitts’s Law, incorporating an additional parameter to represent the influence of friction potential on movement time, generated approximately 10% better fit to the experiment data than a formulation of Fitts’s movement behavior model without the additional parameter. This finding suggests consideration of physical characteristics of touchpads that contribute to kinetic surface friction is important for predicting user performance in discrete movement tasks.

### Table 3
Formulations of Fitts’s Equation Used for Each Participant, by Index of Difficulty (ID) Condition

<table>
<thead>
<tr>
<th>Condition</th>
<th>Distance (Pixels)</th>
<th>ID Value</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>ID1</td>
<td>325</td>
<td>2.9</td>
<td>MT_i = a + b (2.9)</td>
</tr>
<tr>
<td>ID2</td>
<td>250</td>
<td>2.6</td>
<td>MT_i = a + b (2.6)</td>
</tr>
<tr>
<td>ID3</td>
<td>125</td>
<td>1.8</td>
<td>MT_i = a + b (1.8)</td>
</tr>
</tbody>
</table>

Note. MT = movement time; i = 1–10.

### Table 5
Aggregated Goodness of Fit Assessments for Fitts’s and Ware and Balakrishnan’s (WB) Models for Each Participant

<table>
<thead>
<tr>
<th>Participant</th>
<th>Fitts R²</th>
<th>WB R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.06</td>
<td>0.41</td>
</tr>
<tr>
<td>2</td>
<td>0.31</td>
<td>0.39</td>
</tr>
<tr>
<td>3</td>
<td>0.16</td>
<td>0.18</td>
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### 7. DISCUSSION

In line with H1, overall task performance degraded with the higher potential coefficient of kinetic friction present in the rougher touchpad surface. The fastest performance was achieved with the smooth pad, as compared to the two textured alternatives, and task time increased with greater touchpad bump height. This finding supported H1.1 and was in agreement with Richard and Cutkosky’s (2000) results. Furthermore, the touchpad texturing effect was apparent across levels of ID with the greatest effect occurring when transitioning from low (ID3) to moderate (ID2) difficulty in the discrete movement task. This finding was in line with Fitts’s (1954) early work showing that changes in ID affect discrete movement time.

Touchpad texturing appeared to have a greater effect on movement time in the ballistic phase as compared to the honing phase (H1.2). Post hoc analyses on the texture effect on ballistic motion within the task ID conditions revealed all textures to increase task time when participants were posed with higher difficulty target acquisitions. Regarding the honing phase, the smooth touchpad produced significantly faster performance, as compared to the two textured pads. A probable cause for this is that during fine cursor movement, any degree of touchpad surface roughness affects finger movements in a relatively consistent manner as the distances moved are typically very small.

The task ID was also found to affect performance significantly in both phases of motion. However, in the ballistic phase, participants tended to perform similarly under the moderate and high ID. In the honing phase, performance under each of the three ID conditions yielded significantly different results. These findings imply that beyond a certain ID, ballistic motion control of a cursor is relatively consistent, or possibly reaches a maximum velocity. This observation would also depend on the gain setting of the pointing device.
Contrary to H1.3, increases in touchpad roughness did not lead to significantly increased pointing accuracy. On average, the smooth pad (B) proved worse than the low textured pad (A) but better than high roughness pad (C). Our statistical results were different from previous research where low kinetic friction, simulated on a pointing device (Richard & Cutkosky, 2000), was found to improve performance in terms of accuracy. There was also no significant effect of task ID on cursor position accuracy. Previous research findings by Bahrick, Bennett, and Fitts (1955) and Briggs, Fitts, and Bahrick (1957) suggested an improvement in accuracy with increased movement distance or higher IDs in Fitts-type tasks. The present results are contradictory to these findings as well as the observation by Weiss (1954) that increased subject perception of cursor movement contributed to accuracy (i.e., longer task durations). A probable reason for the touchpad textures not having an effect on accuracy is that the bumps were closely spaced and users might not have been able to perceive each as a unique surface irregularity. The tactile resolution of the fingertip is approximately 1 mm (Sanders & McCormick, 1993; VanBoven & Johnson, 1994). The distance between each bump on the surfaces of our textured pads was less than this resolution, and users might have perceived the texture on the touchpad as being one single surface.

The postexperiment questionnaire data revealed a marginal effect of touchpad texture on perceived comfort. Half the participants preferred using the smooth pad rather than the two textured alternatives. This finding supported H2. Several participants also commented that the rougher the textures were, the more "weird" they felt under their fingertips. However, counter to H2, the touchpad texture did not appear to be significant to participant ratings of perceived comfort. This finding is probably due to some of the participants feeling they were more precise while using the textured pad with the greatest roughness, whereas others felt they performed better using the smooth touchpad.

It was also hypothesized (H3) that a revised form of Fitts’s Law without the friction parameter, which supported the need for an additional parameter to address variations in the characteristics of the touchpad pointing device. This observation was consistent with previous findings by MacKenzie and Ware (1993). Results confirmed that a model parameter representing the kinetic friction potential of the touchpad surface was important for more accurately explaining motor control behavior. Our findings show that an increase in surface roughness interacts with the level of discrete movement task difficulty to cause a negative effect on task performance time. With respect to the low goodness of fit values for some of the discrete movement models, the regression analyses on the data for each participant revealed individual differences in minimum performance times (i.e., model intercept values). The values for each participant’s overall movement time prediction model are summarized in Table 6. The mean intercept value was 811.03 (SD = 97.65).

These differences among participants support the ANOVA models on overall movement time as well as the ballistic and honing phase movement times. It was also observed that for persons with lower minimum task times, the rate at which movement time increased across IDs was greater than for others with...
higher minimum performance times. Some participants essentially exhibited a broader range of task performance capability. It is also possible that the performance time data yielded a nonlinear response to texture. Future research should assess the goodness of fit of nonlinear models to discrete movement time data for touchpads.

8. CONCLUSION

The widespread use of laptop computers motivates optimizing pointing device design and performance. Detailed performance analysis of physical and functional design features can support manufacturer decision making in the highly competitive laptop and computer peripheral markets. The results of this study indicate that texturing touchpad surfaces to provide tactile cues on pad boundaries needs to be balanced with the potential negative effects of surface friction on user performance.

This research assessed how touchpad texture influences human motor control behavior in generic computer-based point and click tasks, as well as perceived user comfort and accuracy in performance. A discrete movement task simulation was used along with two textured touchpads and a smooth alternative. Findings indicated that the degree of texturing was significant in task time across different degrees of pointing task difficulty. Furthermore, user performance under specific difficulty conditions appeared to be mediated by pad texture. There was, however, no effect of texturing on the objective accuracy of pointing in the simulation. Overall, the research showed that although the cursor control accuracy was not influenced, there was speed degradation as the pad surface roughness increased.

In a further breakdown of the discrete movement task performance, it was found that the degradation in pointing task time due to pad texturing was worse in the ballistic versus honing phase of the task. During the ballistic phase under higher levels of task difficulty defined by an index of difficulty, performance was relatively consistent. On the other hand, during the honing phase, there were significant differences in performance among all levels of ID. It was, however, found that alternative pad textures produced relatively similar degradations in performance within a setting of ID.

The results of the present research need to be interpreted and applied with caution based on several caveats of the experiment. First, a small sample of users was recruited for participation in this study. Although the sample included thousands of observations on each participant and provided adequate statistical power of the tests, a large more diverse sample would be desirable for further generalizability of results, in particular with regards to the subjective data. Second, participants were not surveyed on touchpad ownership, which may have introduced biases in subjective preferences toward the textured or smooth pads. Next, the discrete movement task used in the study was artificial in nature and not representative of goal-directed point-and-click tasks executed by a user at a common desktop computer interface. For example, people rarely perform 50 sequential point-and-click operations under normal use.

Finally, a very limited set of touchpad textures were examined in this study. Only three alternatives were provided by a partnering manufacturer, and the physical characteristics of the two textured pads (e.g., bump height) were somewhat close.

Furthermore, it is possible that the fine characteristics of the touchpad texture such as diameter, height, density, and pitch angles were not dramatic enough to influence participant performance, particularly, target acquisition accuracy as expected. Other pad textures with greater bump height and pitch angles might lead to greater perceptions of the touchpad surface and the capability to accurately control a cursor.

REFERENCES


ABOUT THE AUTHORS

Sameerajan Suresh is a Usability Researcher with Human Interfaces, Inc. in Austin, Texas. He received his MS in industrial and systems engineering, specializing in ergonomics, from North Carolina State University in 2011.

David Kaber is a professor of industrial and systems engineering at North Carolina State University and associate faculty in biomedical engineering and psychology. He received his Ph.D. in industrial engineering from Texas Tech University in 1996. His current research interests include human–computer interaction and interface design as well as computational modeling of user performance for usability analysis.

Michael Clamann has worked in industry as Human Factors Engineer since 2002, supporting government and private clients in domains including aerospace, defense, and telecommunications. He received his PhD in industrial and systems engineering from North Carolina State University in 2014.