Evaluating Swabbing: a Touchscreen Input Method for Elderly Users with Tremor

Chat Wacharamanotham, Jan Hurtmanns, Alexander Mertens,
Martin Kronenbuerger, Christopher Schlick, Jan Borchers
RWTH Aachen University
52056 Aachen, Germany
{chat@cs, jan.hurtmanns@, a.mertens@iaw, c.schlick@iaw, borchers@cs}.rwth-aachen.de
mkronenbuerger@ukaachen.de

ABSTRACT
Elderly users suffering from hand tremor have difficulties interacting with touchscreens because of finger oscillation. It has been previously observed that sliding one's finger across the screen may help reduce this oscillation. In this work, we empirically confirm this advantage by (1) measuring finger oscillation during different actions and (2) comparing error rate and user satisfaction between traditional tapping and *swabbing* in which the user slides his finger towards a target on a screen edge to select it. We found that oscillation is generally reduced during sliding. Also, compared to tapping, swabbing resulted in improved error rates and user satisfaction. We believe that swabbing will make touchscreens more accessible to senior users with tremor.

Author Keywords
older adults, touchscreen, tremor, accuracy, evaluation, tapping, swabbing, input methods

ACM Classification Keywords
H.5.2 Information Interfaces and Presentation: User Interfaces—*Evaluation/methodology*

General Terms
Human factors, Experimentation

INTRODUCTION
Although tremor affects only 0.4% of the world population, when focusing on older adults, this number increases to 6.3% (age 60–65) and 21.7% (age $\geq$ 95) [8]. With the global increase of the senior population [11], tremor will be a significant concern in designing assistive technologies in the future.

Although touchscreens have several benefits—they provide direct hand-eye coordination, need minimal training, and require less space [10], users with tremor have difficulties using touchscreens. In particular, tremor-induced oscillations cause the finger to deviate from the target or to produce duplicate inputs. Although this can be alleviated by increasing target size and space between targets, this would require more screen space, which is often limited.

Our initial observations [9] indicated that sliding the finger across the screen during swabbing appeared to dampen deviation, but this observation has not been confirmed empirically. Neither has swabbing been compared to tapping, the basic touchscreen interaction technique.

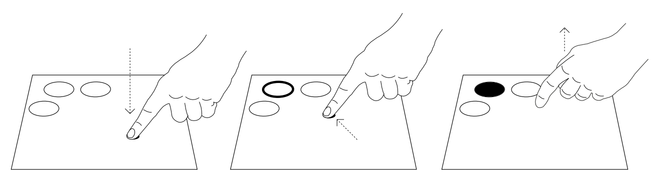

Figure 1. The three steps of swabbing: touch, slide towards the target, and lift.

After a review of related work, we report on a study of finger oscillation during swabbing and tapping in four actions of touchscreen interaction (hovering, tapping, sliding, and resting), and comparing error rate and user satisfaction between swabbing and tapping. We discuss our findings that (1) sliding reduces the oscillation of finger tips, and that (2) compared to tapping, swabbing resulted in improved error rates and user satisfaction.

RELATED RESEARCH
Swabbing Input on Touchscreens
Swabbing is a single-touch selection method proposed by Mertens et al. [9]. The user touches any area on the screen and slides his finger towards the target placed on an edge of the screen (see Figure 1). After the finger moved beyond a distance threshold, a linear regression is calculated from recent touch coordinates to determine the intended target, which is then highlighted. To select the target, the user either lifts his finger or slides it across the target and beyond the screen. To cancel the highlighting, the user slides the finger backward.

Swabbing can potentially reduce errors by reducing finger oscillation during sliding (visually observed in [9]) and by

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giving the user a chance to preview and correct an error in the highlighting step. The target placement eliminates the users' anxiety of overshooting and maximizes the opening angle from the initial touch point towards each target. Swabbing trades off input speed for accuracy because sliding always takes longer than tapping.

Other Input Techniques for Users with Tremor

Finger interactions differ from interactions using a stylus [1] or indirect pointing devices, e.g., a mouse [10]; these differences limit the adoption of existing input methods for touchscreens and for seniors. We review the limitations in adopting some methods and compare them to swabbing as follows.

With Goal Crossing [12], the user crosses the mouse cursor over the target to select it. The benefit, which is also maintained in swabbing, is that the user does not have to aim at a limited target area. Crossing targets on a touchscreen for a longer time, however, is demanding especially for elderly users because they cannot rest their hand on the surface—only the finger is supported. Since only trajectories are needed in swabbing, the sliding distance can be shorter than the distance to the target. Nevertheless, the swabbing technique also supports crossing.

With Barrier pointing [3], a physical screen edge and plane is used to catch the stylus or to guide stroke movements, which can increase selection accuracy. Nevertheless, when applied to finger interaction, the hand covers the targets during selection. Also, physical screen edges are disappearing on modern devices such as Apple's iPad.

With Touch [6], a target is selected if the stylus enters its bounds, and the stylus can be landed or lifted anywhere. Touch can increase input accuracy for older users but was not designed for users with tremor. The oscillation might cause neighbor targets to be touched. Increasing the space between targets is possible but often limited by screen space. With swabbing, the trajectory determines only one target at a time.

RESEARCH QUESTION

In order to evaluate the potential benefits of swabbing, we addressed the following research questions. (1) How does tremor oscillation change during different actions of touchscreen interaction for tapping and swabbing? (2) Will swabbing help users to select a target on a touchscreen more accurately than tapping? (3) Will users be satisfied with swabbing?

PARTICIPANTS

Users with *intention tremor*—tremor during target-directed movements— were recruited from a local hospital; none of them had used any touchscreen device before. Each participant drew a spiral (see Figure 2), to determine tremor strength: slight (< 0.5 cm), moderate (0.5–1 cm), marked (1–2 cm), and severe (> 2 cm)[1].

[1]As recommended by the Movement Disorder Society [2].

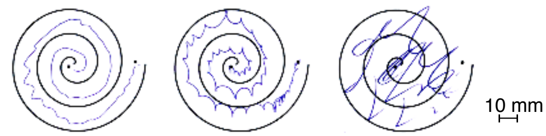

Figure 2. The spiral drawings from users with different tremor strengths (left to right: slight, marked, severe)

HARDWARE SETUP

As shown in Figure 3, we placed an HP TouchSmart tm2-1090eg[2] on a stand with the screen surface inclined 20° from the desk surface. The desk height was at the same level of the elbow when the user's arm was orthogonal to the ground. From the top view, the screen was placed in front of the user at a distance within the length of the forearm. Each participant used a fixed finger angle throughout the study.

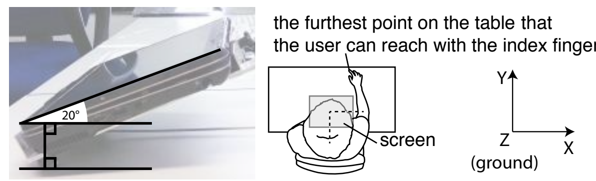

Figure 3. The hardware setup. Left: The screen surface is 20° inclined from the desk surface. Center: The top view of screen position. Right: Axes of the accelerometer.

EXPERIMENT 1: FINGER OSCILLATION

We hypothesized that the finger will exhibit less tremor while sliding on the screen. Therefore, we measured the acceleration of the fingertip in four actions: hovering over a spot, resting on a spot, repeatedly tapping on a spot, and sliding (to the left and right) in a designated area. We omitted visual feedback in order to prevent the bias to any feedback.

Procedure

Similar to [4], we used a velcro ring to attach a tri-axis accelerometer (GForce3D-3[3]) to the back of the extreme joint of the test finger; the entire tip of the finger was uncovered.

For each action, we recorded 10 seconds of acceleration data and discarded the first and the last second due to extreme variance, likely caused by the onset and the completion of the task. The data was transformed into the frequency domain by a Fast-Fourier Transform (See Figure 4 for an example.) The *peak magnitude* of each action was the highest magnitude within the tremor frequency (3–10 Hz) [4]. A *significant axis* has a peak magnitude of more than 0.1 G.

Result and Discussion

The results from all participants (age: 58–87, M = 73, SD = 7.89, $q1$ = 70.50, $q3$ = 77.50) are shown in Figure 5. In general, the peak magnitude in sliding was consistently lower than in the other actions. Although there were differences across users, the results suggest that sliding can lessen the oscillation magnitude in the significant axes.

[2]http://h10025.www1.hp.com/ewfrf/wc/product?product=4107117

[3]http://infusionsystems.com/catalog/product_info.php/products_id/157

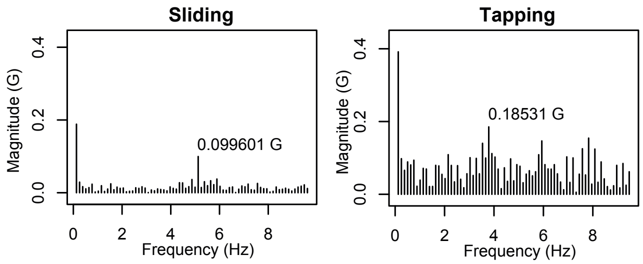

Figure 4. An example of a spectrum plot with the peak magnitude labeled. The peak magnitude in sliding is lower than in tapping.

Gender	Handedness	Tremor strength	Action with highest peak magnitude	Significant axes (ordered by intensity)	T: lower magnitude in tapping	S: lower magnitude in sliding
M	R	▮▮▮▮	Rest	YZ	Z	Y
M	R	▮▮▮	Rest	YZ	Y	Z
M	L	▮	Hover	XYZ	Y	–
F	L	▮▮	Hover	ZXY	–	XYZ
F	L	▮▮	Hover	YXZ	–	XYZ
M	R	▮▮▮	Hover	ZYX	XY	Z
M	L	▮▮▮	Hover	–	–	XYZ
F	R	▮▮	Hover	–	–	XYZ
M	L	▮▮▮▮	Hover	YZX	–	XYZ
M	L	▮▮▮▮	Hover	YZX	YZ	X

Tremor strength
▮ Slight
▮▮ Moderate
▮▮▮ Marked
▮▮▮▮ Severe

Axis direction
X: to the right
Y: to the front
Z: to the ground

Figure 5. Participant profile and finger oscillation results in sliding (S) versus tapping (T), with one participant per line. The peak magnitude was lower in sliding in severe axes in the majority of cases.

EXPERIMENT 2: ACCURACY AND USER SATISFACTION

Based on our results, we hypothesized that in a target selection task, swabbing will decrease the error rate and will increase the user's satisfaction compared to tapping.

Procedure

In each trial, participants performed either a tapping or swabbing action to select a designated target laid out as shown in Figure 6. In both methods, participants started each trial on a crosshair located on the same side as the hand. In swabbing, they had to start sliding from the center of the screen. The targets were in a square grid for tapping and were on the edges of the screen for swabbing. To prevent a learning effect, there was no hit/miss feedback. The targets were spread evenly across the screen because previous research has shown that finger selection accuracy can differ for different areas [5].

For this experiment, selection was initiated after the finger had moved beyond 50% of the average of the shortest distance from center point to target (a screen edge) and the longest distance (to a screen corner.) We omitted feedback (highlighting the target) to prevent users from developing a strategy for swabbing in the later trials.

We did a 2×3 within-group study ({tapping, swabbing} × {16, 25, 36} possible targets on the screen), with 15 trials per condition. The order of methods and number of targets was counterbalanced. Each participant had 10 trials for training with 9 targets on the screen before beginning with each method. We recorded the number of selection errors and timestamped touch movements (landing, sliding, and lifting). After the experiment, participants rated their satisfaction of each method with the Post-Study User Satisfaction Questionnaire (PSSUQ) [7] translated into German.

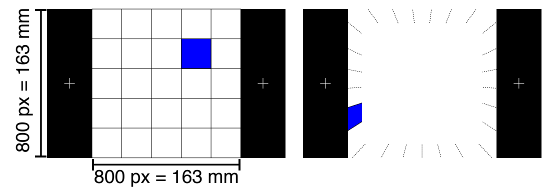

Figure 6. The screen layout for tapping (left) and swabbing (right).

Result and Discussion

Six users participated in this experiment (age: 70–87, M = 75, SD = 5.62, $q1$ = 71.50, $q3$ = 75.75); tremor strength: 1 slight, 1 moderate, 2 marked, 2 severe). As shown in Figure 7, the median error rate in swabbing was lower than in tapping. A two-way repeated measures ANOVA on error proportion with quasibinomial error distribution revealed no significant interaction effect among participants, number of targets, or methods. There were significant main effects of method, $F(1,35) = 5.258$, $p = .029$, and number of targets, $F(2,35) = 5.505$, $p < .001$, which supports H1.

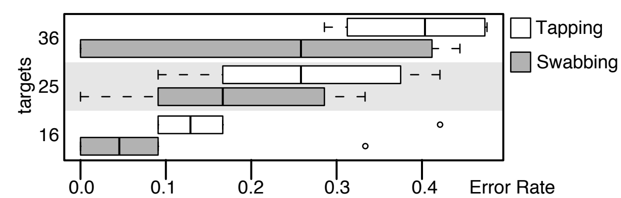

Figure 7. Summary of error rates. Swabbing has lower error rates in general, with a high variance in the 36 targets condition.

Although there was no significant interaction effect of method × number of targets on error rate, the positive impact of swabbing appeared to be strongest for the 16 targets layout. This is likely due to two reasons: (1) the high variance of error rates in 25 and 36 targets and (2) the lack of statistical power due to the small number of participants (power = 0.35 at effect size Cohen's $f = 4$).

Nevertheless, swabbing had a significant advantage for the 16 targets condition (grid target width = 41 mm). This could be especially useful for devices with numeric keypads such as a phone.

Although this study only compared tapping on a grid layout of targets to swabbing on a radial layout of targets, we conducted a preliminary study beforehand to test only nine targets and tapping on a swabbing layout. We found that most users could accurately tap in 9 targets (less than 20% error) because the target size was large (54 mm wide). We found no reduction of error rates in tapping on the swabbing layout.

As shown in Figure 8, swabbing was significantly slower than tapping for 25 and 36 targets, but the main effect of participants and the interaction between participants and method make it inconclusive. The time of tapping, which is a single-contact, and the time of swabbing, which is a continuous contact, cannot be directly compared because swabbing time depends on the contact area, pressure, finger humidity, angle, and direction of movement.

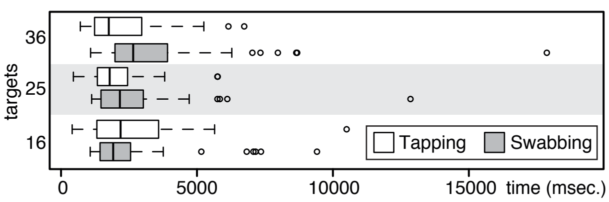

Figure 8. The summary of times to select each target. The time the user takes in swabbing is close to the time in tapping.

A summary of the PSSUQ results is shown in Figure 9. Friedman rank sum tests showed a significant effect of method on overall satisfaction, $\chi^2(1, N = 6) = 5$, $p = .025$, and on System Usage, $\chi^2(1, N = 6) = 6$, $p = .014$. There was no significant effect in Interface Quality, $\chi^2(1, N = 6) = 0.67$, $p = .414$. Although swabbing was inherently slower than tapping, participants were satisfied with this input method. The result indicates that users with tremor prefer more accurate input methods to faster ones. This supports H2.

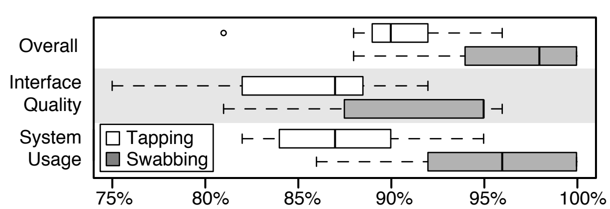

Figure 9. PSSUQ results. The overall rating and the rating for the System Usage was higher for swabbing.

CONCLUSION

We have compared swabbing to tapping as input methods for elderly users with tremor. In general, sliding can lessen finger tremor when interacting on a touchscreen. Overall, swabbing improved error rates and user satisfaction. Although this result is promising, future experiments with more participants are needed.

Based on our findings we derived at two design implications:

When to choose swabbing: Tapping is a viable choice for square targets that are at least 54 mm wide. When the target width is smaller than 41 mm, swabbing becomes a better alternative.

Speed-accuracy tradeoff: Elderly users with tremor may prefer a more accurate input method, even if it is slower.

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