Comparing Direct and Remote Tactile Feedback on Interactive Surfaces

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Abstract. Tactile feedback on touch surfaces has shown to greatly improve the interaction in quantitative and qualitative metrics. Recently, researchers have assessed the notion of remote tactile feedback, i.e., the spatial separation of touch input and resulting tactile output on the user's body. This approach has the potential to simplify the use of tactile feedback with arbitrary touch devices and allows the design of novel tactile stimuli by stimulus combination. However, a formal comparison of direct and remote tactile feedback during touch input is still missing. Therefore, we conducted three consecutive laboratory studies. First, we compared the effects of both direct and remote tactile stimuli on the user's performance during touchscreen interactions. No difference was found in the positive effects of both types of feedback. Second, we evaluated the impact of the remote tactile actuator's position on the user's body. For remote tactile stimuli, we found improved accuracy and interaction speed, regardless of the body location. Third we analyzed remote tactile feedback under additional cognitive load. The results support the positive effects of tactile feedback on user performance and subjective evaluation. These findings encourage us to further exploit the potential of remote tactile feedback to simplify and expand the multimodal interaction with arbitrary touch interfaces.

Keywords: remote tactile feedback, interactive surfaces, touch input

1 Introduction

Using the direct touch of our fingertips or hands to activate or manipulate digital information is currently becoming a widespread interaction paradigm. Touchscreen interfaces are ubiquitously used from mobile devices or medical systems to vending machines or in-vehicle interfaces. They are cheap, flexible and easy to use, and will continue to form the de facto standard for interaction with multi-functional systems [5]. Touch interfaces heavily rely on visual feedback to indicate the results of a user's input, but nevertheless are also used in dynamic multi-tasking and heavy-visual-load scenarios such as driving a vehicle. Their interactive screens only present a flat surface to the interacting fingertips. Non-visual feedback up to now is mostly restricted to an audible beep or an ambiguous tactile buzz, but researchers and designers have started to think about more meaningful tactile feedback for direct touch interactions. Active tactile stimuli can inform the user about the position, form and function of visual elements and confirm input actions. This additional feedback channel has shown to reduce the errors made, to improve interaction speed and to boost subjective appraisal of direct touch interactions as a whole [3,15,23]. Consequently, the use of the full subtlety and potential of our sense of touch has become a main interest of researchers and engineers of touch interfaces. A recent and promising approach to providing rich tactile feedback is the spatial separation of tactile and visual displays, i.e. remote tactile feedback. To communicate supplemental stimuli, actuators are integrated into the user's direct environment or wearable interfaces. In comparison to direct tactile stimuli, the use of this remote tactile feedback has some innate advantages: It can be used to provide haptic stimuli for touch interactions, which do not depend on the size, form or material of the interactive surface or to create novel haptic stimuli by applying different actuators on several locations on the user's skin. However, to this day, no formal comparison of the effects of directly and remotely applied tactile feedback for touch interactions has been provided. In this paper, we present the results of three consecutive user studies we conducted for the following reasons:

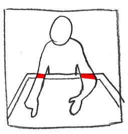
1. To compare the effects of solely visual, visual + direct tactile and visual + remote tactile feedback on objective measures (accuracy, total task time) and subjective measures (naturalness, ranking of modalities) of touch-based text input.
2. To analyze the effects of remote tactile feedback and the body location in which it is applied on task performance during drag-and-drop interaction on a tabletop.
3. To assess the effects of remote tactile feedback on task completion time during multi-touch input under increased cognitive load.

2 Tactile Feedback on Interactive Surfaces.

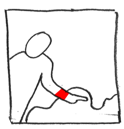
Adding tactile feedback to interactive surfaces such as the touchscreen of a mobile phone or an interactive tabletop display has been a topic for researchers and engineers for over a decade [8, 19]. Tactile information can be conveyed on the form, surface structure, malleability, state, meaning, function or distance of a depicted interactive virtual element. Studies in multimodal interaction already show the importance of non-visual feedback in dynamic scenarios entailing noise, movement, distraction, attention-shifts or cognitive load such as entering text on a mobile device or handling in-vehicle infotainment systems [4,14]. Primarily tactile feedback is investigated as a feedback mechanism on touch surfaces and it results in significantly increased speed and accuracy of input [3,8]. It can even bring the performance of touchscreen keyboards close to the level of real, physical keyboards [11]. In addition, haptic stimuli during touch input reduce visual and cognitive load [20,15] and prevent occlusion [7]. In addition to such objective measures, palpable stimuli on otherwise flat touch surfaces also increase the user's subjective appraisal of the interaction. Studies show an enhanced feeling of realism and naturalness [3,9,23]. Technically, the actuators for the presentation of direct tactile stimuli in touch surfaces can be electrical, electromechanical, pin-based, piezo-driven and even pneumatic [6]. Accordingly, prototypical implementations mostly fall into one of three categories: In the first, the screen or the mobile device is actuated as a whole [25,2]. However, such touch devices can only provide a single touch stimulus, which is the same for every finger. The second category uses tangible user interfaces (TUI) to give tactile feedback. These devices offer great flexibility in the design of stimuli and interactions [13,17]. However, the interaction itself loses the beneficial characteristics of direct manipulation, suffers from visual occlusion and lacks scalability. The third approach is the segmentation of the display into multiple individually movable elements, i.e., 'tactile pixels' [10, 23]. With individual electromechanical actuators for every tactile pixel, this approach is still hardly scalable und lacks visual and tactile resolution.

3 Remote Tactile Feedback

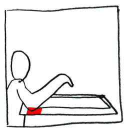
Remote tactile feedback (RTF) can potentially eliminate some of the drawbacks mentioned above. The more general approach of tactile sensory relocation has been extensively analyzed and reproduced in the fields of accessibility and sensory substitution [1, 12]. Few researchers have incorporated relocated tactile stimuli on touch surfaces before, but could show promising effects on usability and performance: McAdam et al. [18] used the vibration motor in users' mobile phones to provide haptic feedback during interactions with a touchscreen. Results showed significantly increased text entry rates when remote tactile feedback was given. Richter et al. [24] proposed the use of remote tactile stimuli during touch interactions as a way to simplify the design and implementation of actuator technology. Tactile stimuli were applied to the non-dominant forearm. The authors characterize their work as a way to easily create synchronized remote tactile stimuli during touch interactions. Other recent papers show the potential of remote tactile feedback to create novel forms of haptic stimuli by combining different types of actuators (e.g., vibrotactile and linear moving) on the body. A haptic armrest was used to communicate tactile surface characteristics and forms of buttons on touch surfaces [26]. Users indicated the high hedonic and pragmatic quality of the created stimuli. We can think of the following additional benefits that result from the spatial separation of manual input and tactile output:



Multi Haptics: Individual tactile feedback for each point of contact with the interactive surface can be given. In contrast to conventional approaches (see section 2), this enables simultaneous, but different haptic feedback for each hand touching the surface.



Arbitrary Surfaces: The interactive surface is not restricted to a specific form and size. For example, organic interactive surfaces (i.e., made from clay [21]) could be enriched with additional tactile stimuli.



Stimuli before and after interaction: With tactile actuators being in permanent contact with the user's skin, tactile cues describing proximity or acknowledgement of a touch interaction can be given before or after the finger actually touches the screen.

Using remote tactile stimuli as a form of multimodal feedback raises the following question: *Can remote tactile stimuli on touch surfaces be compared to direct tactile feedback in terms of benefits in objective and subjective measures?* If remote tactile feedback has the potential to reduce error rates, increase interaction speed or user satisfaction with touchscreen input to a degree comparable to direct tactile stimuli, this would further support our approach of exploiting the inherent potentials of RTF.

4 Evaluations

We conducted three user studies comparing the effects of both direct and remote tactile stimuli on the user's performance during touchscreen interactions, evaluating the impact of the remote tactile actuator's position on the user's body and analyzing remote tactile feedback under additional cognitive load.

4.1 Effects of direct vs. remote tactile feedback

So far, we assumed that the communication of direct and remote feedback has comparably positive effects on the touch interaction as a whole in terms of improving accuracy, increasing interaction speed and the positive effect on subjective ratings. Therefore, we had the following hypotheses:

H1.1: Accuracy is higher with tactile feedback during touch input tasks than without tactile feedback.

H1.2: Total task time is lower with direct and remote feedback than without tactile feedback.

H1.3: Less keys are missed when typing with direct and remote feedback than without tactile feedback.

H1.4: Users will prefer interactions with tactile feedback to interactions without tactile feedback.

Study design. The study had a within subject/repeated measures design. A text input task with a given phrase set had to be performed. There were three feedback conditions: no feedback, direct tactile feedback and remote tactile feedback. They were presented in counterbalanced order to avoid unwanted training effects. The dependent variables were accuracy, total task time and key misses.

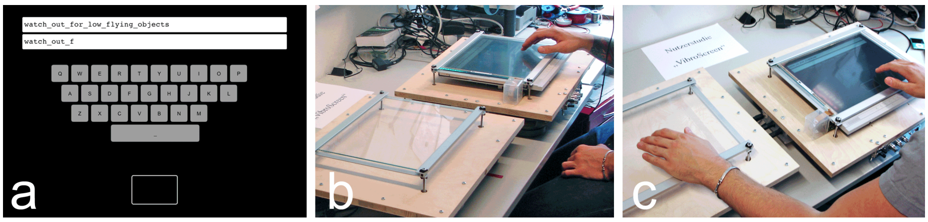


Fig. 1. (a) screenshot of text input task; (b) setup for *no feedback* and *direct tactile feedback*; (c) setup for *remote tactile feedback*

Apparatus. To analytically compare directly and remotely applied tactile stimuli we used a rather artificial, purpose-built device. Our goal was to make psychophysical conditions such as the distribution of mechanoreceptors and perception of tactile stimuli as comparable as possible for both feedback types. Thus, we chose the fingertips of the index fingers on the dominant and non-dominant hand as the stimulus area.

The prototype is depicted in figures 1 and 2. The horizontal tactile touchscreen consists of two transparent capacitive touch-sensing panels[1], which are mounted to modified voice coil actuators[2]. Speakers are a common method to communicate tactile stimuli [6]. Both touchscreens are freely movable in vertical direction. A standard 15 inch screen is installed under one of the panels. When the user touches the panel above the display, direct tactile feedback is given by shaking or moving the panel vertically. In contrast, for remote tactile feedback, the user's index finger of the non-dominant hand is rested in the center of the additional touch panel. When the user touches the other touch panel over the display with his dominant hand, the remote touch panel is shaken or moved vertically. This setup is exclusively used for the comparison of both feedback types.

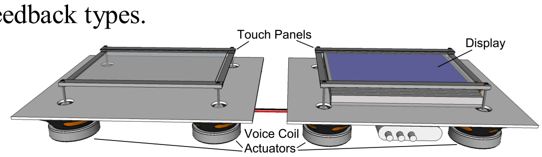


Fig. 2. The purpose-built tactile touch screen device used in the first evaluation.

Experimental Setup and Task. A screenshot of the display during the evaluation is shown in figure 1. The participants were sitting and wore headphones with music to block external noise. The task was to enter the depicted text phrase using the on-screen interface. In order to obtain generalizable results, we used 10 phrases out of the established 500 phrases published by MacKenzie [16]. The input method was designed as a targeting task. We chose a text-input based on drag-and-drop, incorporating the take-off metaphor by Potter et al. [22]. Dragging-and-dropping is a common task on interactive surfaces; an extensive amount of information can be communicated during the long contact with the surface. For entering a character, the user had to put the finger on a start area on the bottom of the graphical user interface. The start area turned red to indicate that it was activated. Then the user could drag his or her finger over the screen on to a key of the QWERTY keyboard. Each key gave a short feedback impulse, when it was entered. The sine wave for regular keys has a frequency of 170 Hz and is enabled for 40 milliseconds. According to physical keyboards, the keys F and J are marked by sine waves with a frequency of 70 Hz enabled for 80 milliseconds. A letter was typed by lifting off the finger from the respective key. The resulting letter was shown on the screen. This very artificial text-entry method is comparable to methods such as take-off on standard touchscreens [22]. To ensure that mistakes had no effect on the task time, there was no error correction. Participants were told that the correct letter should be entered at the correct position. When they made a mistake they should go on with the next letter. Furthermore, they were told to enter the phrases as accurate and as fast as possible.

Participants. Twelve participants (five female) with an average age of 22 years took part in the study. All participants stated that they had experiences with touchscreens before. All were right-handed.

1 3M MicroTouch SCT3250EX 15.68" Surface Capacitive USB Touch System
2 Dynavox DY-166-9A, 4 Ohm, 80W, resonance frequency 50 Hz

Procedure. Each participant was introduced to the prototype and typed three phrases in a demo application to get used to the typing method and the three different stimuli. Subsequently participants received the task and the measurement started. The order of the three feedback types was counterbalanced. For each modality, the order of the 10 phrases was randomized. After each feedback modality, subjects were asked to fill out a questionnaire containing a semantic differential with five-point Likert scales to evaluate the resemblance to reality, signal communication and usability for direct and remote tactile stimuli, as well as personal preference.

Results. From the study described above, we obtained the following results:

<u>Accuracy</u>**:** We define the accuracy rate as the number of characters correctly entered divided by the overall length of the phrases entered. The median of the accuracy rate is 0.963 in the *no feedback* condition, 0.930 in the *local feedback* condition and 0.955 in the *remote feedback* condition. An analysis of variance (ANOVA) showed no significant differences between the three modalities (F(2, 33) = 0.87, p = 0.43). Accordingly, H1.1 cannot be affirmed.

<u>Total Task Time:</u> Similarly to the accuracy an ANOVA shows that the measured times for each feedback condition have no significant differences (F(2, 33)= 0.44, p = 0.65). The median for the *no feedback* condition is 310.5 seconds, for the *direct feedback* condition 354.0 seconds and for the *remote feedback* condition 316.1 seconds. Accordingly, H1.2 cannot be affirmed either.

<u>Missed Keys</u>*:* An ANOVA shows no significant differences between all three modalities (F(2, 33)= 0.29, p = 0.76). The median is 14.5 key misses without feedback, 12 key misses with local feedback and 8.5 key misses with remote feedback. Although H1.3 cannot be affirmed, the median values are clearly in favor of remote feedback.

<u>Subjective user ratings:</u> The ratings for realism, signal design and usability on the five-point Likert scale were highly positive, especially for understandability and simplicity (see figure 3). Again, we found no larger difference between the values for direct and remote tactile stimuli. Seven out of twelve subjects voted for local tactile feedback as the most pleasant type of interaction in the experiment, four voted for remote tactile feedback and one for the *no feedback* condition. Subjective ratings are in favor of tactile feedback. In summary, H1.4 can be affirmed.

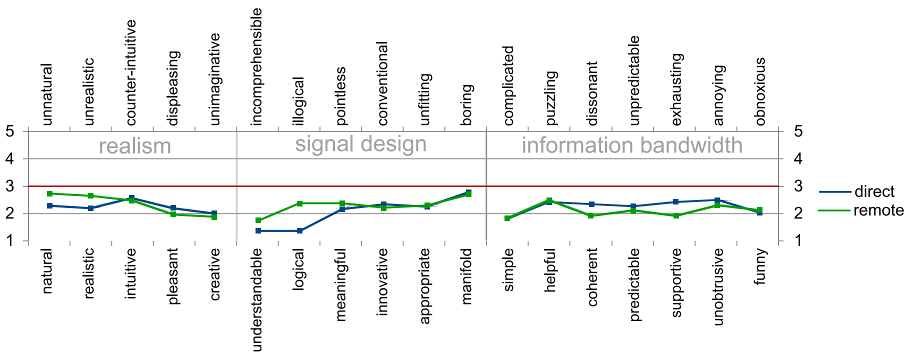


Fig. 3. Subjective evaluation of direct and remote tactile stimuli. Discrete values connected for readability.

4.2 Effects of RTF on Performance during Standard Touch Interaction

In the second study, we evaluated the influence of remote tactile feedback on interactions performed on a tabletop. One goal was to verify the assumption that RTF has the potential to improve interaction on touch surfaces in terms of speed and errors [18]. We also had the goal of comparing the effects of dominant and non-dominant RTF:

H2.1: Remote tactile feedback in touch input tasks will increase interaction speed and reduce error rate.

H2.2: When moving remote tactile feedback to the non-dominant hand, the benefits will be reduced.

Study Design. The independent variable of the study was the feedback given to participants during touch interactions. In addition to the omnipresent visual feedback, RTF was applied to the dominant or the non-dominant wrist. Using a within-subject design, each participant performed the interaction tasks with all three types of feedback (no RTF, non-dominant RTF and dominant RTF). The monitored dependent variables were interaction speed as well as the number of errors made.

Apparatus. Tactile feedback was applied using vibrating pancake motors, which were attached to the participants' arms by wristbands (see figure 4). This body position was chosen according to McAdam and Brewster's results on testing distal tactile feedback on different body locations, identifying the wrist as most promising for improving interaction speed [18].

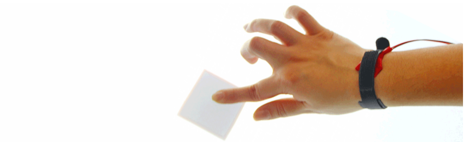


Fig. 4. Remote tactile feedback provided by wrist-worn actuators during tabletop interactions.

Interaction Task. The drag-and-drop gesture was chosen due to its constant use in touch interfaces. A blue square with an edge length of 50 pixels had to be dragged into an only slightly larger red target area (54 pixels wide). Time measurement started as soon as the blue square was touched and stopped with the fulfillment of the task. Dropping the square outside of the target area caused the error counter to be increased by one. Participants received a tactile cue whenever the square was dragged completely into the target area and thus ready to be dropped. The same information was given visually, the square turned green when it is ready to be dropped. In consequence, the tactile information was redundant. We chose this setting in order to identify the benefits of additional tactile feedback.

Procedure. After receiving information about the functionality of the tabletop and the vibrotactile wristbands, participants had the chance to practice the drag-and-drop task without, with non-dominant and with dominant remote tactile feedback. The actual study consisted of 90 drag-and-drop tasks, 30 for every type of feedback. To avoid order effects, the feedback types were counterbalanced. To conclude the study, participants were interviewed for impressions and opinions about remote tactile feedback.

Participants. 18 Participants took part in the study, six of them female, non of them color-blind. The average age was 28 ranging from 22 to 38. All of them had used touch interfaces before. Three participants were left-handed.

Results. After removing outliers, at least 460 data items remained for each type of feedback. The arithmetic mean of the time was calculated for the drag-and-drop tasks, resulting in 2.590 milliseconds for trials without tactile feedback, 2.333 milliseconds for non-dominant tactile feedback and 2.345 milliseconds for dominant feedback. A one-way repeated measures ANOVA showed that the independent feedback variable had a significant influence on the time participants needed for the drag-and-drop tasks, $F(1.25, 21.19) = 5.49$, $p < .05$[3]. Bonferroni post-hoc tests ($p < .05$) could not confirm a significant difference between any mean times ($p < .09$ for none/non-dominant tactile feedback and $p < .08$ for none/dominant tactile feedback). However, these low p-values show a tendency towards faster interactions with remote tactile feedback. Participants were approximately 10% faster with this kind of feedback (see figure 5). Concerning the number of errors made, an ANOVA showed that remote tactile feedback had no significant influence. In summary, H2.1 must be rejected for error rates but can be affirmed concerning interactions speed. No difference in task completion time or error rates was discovered when non-dominant or dominant feedback was applied. This result can be supported by qualitative results. 12 participants stated that the body position in which tactile feedback was received had no influence on task performance. Thus, H2.2 cannot be confirmed. The advantages of remote tactile feedback are relevant even if it is moved further away from the actual touch input. This could allow a more flexible positioning of tactile actuators on the body.

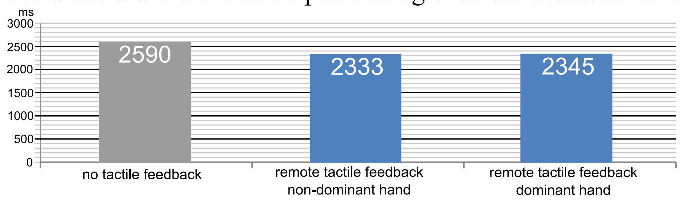


Fig. 5. Mean times in *ms* for the single-touch drag-and-drop task. Drag-and-drop is approx. 10% faster when remote tactile feedback is given, regardless of the body side of application.

4.3 Effects of RTF during Multi Touch Interaction under Cognitive Load

For the third study using the same tabletop, multi-touch gestures for scaling and rotating virtual objects were added to the interaction task. Consistently to the second study, this was tested for both non-dominant and dominant feedback on users' wrists.

H3.1: Remote tactile feedback during multi-touch input increases interaction speed.

H3.2: When moving remote tactile feedback to the non-dominant hand, the benefits will be kept.

Furthermore, an additional auditory task was assigned to participants, which had to be completed simultaneously to the touch interactions. This was due to the research of Leung et al. [15] who stated that the advantages of tactile feedback are enforced under

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[3] Mauchly's test revealed a violation of sphericity, $\chi2(2) = 14.86$, $p < .05$. Degrees of freedom were corrected using Greenhouse-Geisser ($\varepsilon = 0.62$).

high cognitive load. The second goal was to find out if this result can be also verified for remote tactile feedback.

H3.3: Additional cognitive load will increase the benefits of remote tactile feedback.

Study Design. The first independent variable was the feedback provided during the touch interactions. Conditions were visual feedback only, additional remote tactile feedback on the non-dominant wrist and feedback on the dominant wrist. The other independent variable was the presence or absence of the additional task creating cognitive load. Using a within-subject design, the interaction tasks were divided into six blocks: two for each type of feedback, once without and once with additional cognitive load. The sequence of the blocks was counterbalanced. The dependent variable was the task completion time for the touch interactions.

Interaction Task. The task was a combination of three single-touch and multi-touch gestures for manipulating a square on the tabletop display. First, the size of a square with an edge length of 50 pixels had to be doubled using a scaling gesture. Second, the resulting square had to be rotated by 180 degrees clockwise using the corresponding rotating gesture. For both gestures, participants were instructed to use the index fingers of both hands. Finally, the square had to be moved into a slightly larger target area using drag-and-drop. Task completion time was measured from the first contact to the square until the square was dropped into the target area. Additionally, we calculated the times needed to perform every single gesture. To signal if the correct size, orientation or position was reached, the square's color changed from red to green. Remote tactile feedback was applied according to the visual cues, so that no additional information was provided. The auditory task added to create additional cognitive load was designed according to Leung et al. [15]. A random sequence of letters from O to V was read out loud with a speed of 100 letters per minute. Approximately five times per minute, the same letter appeared three times in a row. Participants were instructed to signal this event by speaking out the word "now". This auditory task had to be completed simultaneously to the interaction task. To ensure an acceptable task fulfillment, it was tracked how many occurrences of repeated letters were noticed.

Procedure. After completing a demographic questionnaire, participants were familiarized with the functionality of the tabletop and the vibrotactile wristbands. Next, they had time to practice both interaction and auditory task. During the main part of the study, the six blocks with different types of feedback and the additional cognitive load were completed. In each block, the interaction task was repeated ten times to obtain an adequate number of task completion times. A qualitative interview about experiences made with the remote tactile feedback concluded the study.

Participants. The study was completed by 18 participants (five female) with an average age of 28 ranging from 26 to 32. None were left-handed or color-blind.

Results. After removing outliers, we calculated arithmetic means to gain an average task completion time for each of the six conditions (see figure 6). The first result shows the additional auditory task causing participants to need significantly more time for the touch interactions. This was the case for all gestures, independent from the type of feedback. Thus, the auditory task caused the intended additional cognitive load. This was also supported by the qualitative feedback. Considering the time needed for completing the interaction task without additional cognitive load, an ANOVA was performed for every gesture. The results show a significant impact of the type of feedback on task completion time of the scaling gesture, $F(2, 34) = 5.28$, $p < .05$. Bonferroni post-hoc tests identified remote tactile feedback on the dominant wrist to decrease the duration of the task significantly, $p < .05$. Compared to the condition without tactile feedback, a time advantage of 18% was reached. Although non-dominant feedback reduced task completion time by 10%, no significance was found. Thus, hypothesis 3.1 can only partially be confirmed. For drag-and-drop and rotation, no significant influences of the feedback were found. This can be explained by the additional visual feedback: when the square was ready to be dropped, it changed color from red to green, which was not the case in the earlier study. This indicates that the provided visual feedback was sufficient in this case. This was conformed by 16 participants, who stated that they did not need additional tactile feedback here.

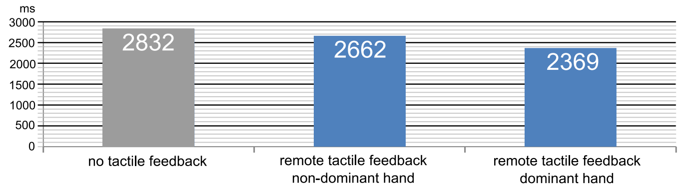

Fig. 6. Mean times in *ms* for multi-touch scaling with three feedback modes. Scaling is significantly faster with dominant remote tactile feedback

For none of the gestures a significant difference between task completions times of the two conditions with remote tactile feedback was discovered. This underlines the results from the second study. In other words: remote tactile feedback can be applied on both the dominant and the non-dominant arm without changing the influence on task completion times when performing single- and multi-touch gestures on a tabletop. This is also true for conditions with increased cognitive load. Accordingly, participants agreed that the body side did not matter for the application of the tactile cues. Thus, hypothesis 3.2 can be confirmed. After adding the auditory task and thus increasing the cognitive load, ANOVAs did not reveal any significant influence of the type of feedback on the task completion times. This result is true for all three gestures. The observation could be explained by the domination of the visual and auditory communication channels, which causes the tactile channel to lose importance. This assumption was supported by two participants after the study, stating that they were not sure if there even was any tactile feedback during the conditions with the auditory task. Thus, hypothesis 3.3 has to be rejected.

5 Limitations and Discussion

The limited sophistication of our tactile devices and the resulting loss of tactile bandwidth might be the main reason for the statistical non-significance of some of our results. Both actuators used in the evaluations were purpose-built for these occasions. We used inexpensive off-the shelf materials such as voice-coil actuators and vibration motors. Thus, unwanted noise, latency and unnatural posture of subjects might have created unwanted effects. In the evaluations, we provided simple tactile stimuli as location information (first study) and semantic affirmation of action (second and third study). The stimuli were given redundantly to visual feedback; no extra information was encodeded haptically.

6 Conclusion and Future Work

We compared the effects of direct and remote tactile feedback, analyzed the implications of the location of actuators on the body, and assessed multi touch feedback under increased cognitive load. The results are in favor of remote tactile feedback: users could decrease the number of missed keys during text input on touchscreens. When given in addition to redundant visual cues, remote tactile feedback on the dominant arm significantly decreased the task completion time for scaling gestures on a tabletop. When applied to the non-dominant arm, the total task time could be decreased by 10%. When asked about their subjective opinion, users are in favor of tactile feedback in general. Over 90% of the participants preferred tactile feedback to no tactile feedback. For remote tactile stimuli, over 30% even preferred it to direct tactile stimuli. We also found that the location of the feedback on the user's body had no effect on subjective appraisal. For future implementations of remote tactile feedback, we are working on incorporating other locations of the human body such as the back (e.g., by the seat of a car) or the forearm (e.g., by wearable devices or the frame of the touch surface). Thus, the diverse density of mechanoreceptors in the skin has to be taken into account. With remote tactile feedback, a dedicated tactile display for every single pixel of the interactive surface is not necessary. Thus, we will incorporate tactile feedback into non-flat or large touch interfaces. Finally, we are working on the creation of novel tactile stimuli by combining thermal and vibrotactile remote actuators on the skin. In summary, the results of our evaluations back our assumption of the positive effects of remote tactile feedback on the performance of the user. Advantages of additional non-visual stimuli are observable regardless of the location of application on the body. The unique potential of RTF will extend and enrich the design and use of direct touch interfaces as a whole.

7 References

1. Bach-y-Rita, P. and Kercel, S. Sensory substitution and the human-machine interface. Trends in cognitive sciences 7(12), 2003, 541-546.
2. Bau, O., Poupyrev, I., Israr, A., and Harrison, C. TeslaTouch. Proc. UIST 2010, 283-292.
3. Brewster, S., Chohan, F. Brown, L. Tactile feedback for mobile interactions. Proc. CHI '07, 159-162.
4. Burke, J. et al. Comparing the effects of visual-auditory and visual-tactile feedback on user performance: a meta-analysis. Proc. ICMI'06.
5. Buxton, W., Multi-Touch Systems that I Have Known and Loved. Microsoft Research, (2007).
6. Chouvardas, V.G., Miliou, A.N. and Hatalis, M.K. Tactile displays: Overview and recent advances, Displays 29, 185-194 (2008).

7. Forlines, C. and Balakrishnan, R. Evaluating tactile feedback and direct vs. indirect stylus input in pointing and crossing selection tasks. Proc. CHI'08, 1563–1572.
8. Fukumoto, M. and Sugimura, T. Active click: tactile feedback for touch panels. CHI'01 EA, 121–122.
9. Hale, K. S. and Stanney, K. M., Deriving Haptic Design Guidelines from Human Physiological, Psychophysical, and Neurological Foundations, IEEE COMPUTER GRAPHICS AND APPLICATIONS VOL 24, 33-39, (2004).
10. Harrison, C. and Hudson, S.E., Providing dynamically changeable physical buttons on a visual display. Proc. CHI'09, 299-308.
11. Hoggan, E., Brewster, S.A., and Johnston, J. Investigating the Effectiveness of Tactile Feedback for Mobile Touchscreens. Proc. CHI '08, 1573-1582.
12. Kaczmarek, K. A., Webster, J. G., Bach-y-Rita, P., and Tompkins, W. J. Electrotactile and vibrotactile displays for sensory substitution systems. IEEE Transactions on Bio-Medical Engineering, 38(1), 1-16, (1991).
13. Lee, J., Dietz, P., Leigh, D., and Yerazunis, W. Haptic pen: a tactile feedback stylus for touch screens, Proc. UIST'04, 291-294.
14. Lee, J. H., Poliakoff, E., and Spence, C. The Effect of Multimodal Feedback Presented via a Touch Screen on the Performance of Older Adults. Haptic and Audio Interaction Design, 128–135, (2009)
15. Leung, R., MacLean, K., Bertelsen, M., and Saubhasik, M. Evaluation of Haptically Augmented Touchscreen GUI Elements under Cognitive Load. Proc. ICMI '07, 374–381.
16. MacKenzie, I.S. and Soukoreff R.W., Phrase sets for evaluating text entry techniques. CHI'03 EA, 754.
17. Marquardt, N., Nacenta, M., Young, J., Carpendale, S., Greenberg, S., and Sharlin, E. The Haptic Tabletop Puck: Tactile Feedback for Interactive Tabletops. Proc. ITS'09, 93-100.
18. McAdam, C., and Brewster, S. Distal tactile feedback for text entry on tabletop computers. Proc. BCS-HCI '09, 504–511.
19. Nashel, A. and Razzaque, S. (2003). Tactile virtual buttons for mobile devices. CHI'03 EA, 854-855.
20. Oakley, I., McGee, M.R., Brewster, S. and Gray, S. Putting the Feel in Look and Feel. Proc. CHI '00, 415-422.
21. Piper, B., Ratti, C., and Ishii, H. Illuminating clay: a 3-D tangible interface for landscape analysis. Porc. CHI'02, 355–362.
22. Potter, R. L., Weldon, L. J., & Shneiderman, B. (1993). Improving the accuracy of touchscreens: an experimental evaluation of three strategies. Sparks of innovation in human-computer interaction, 161, (1993).
23. Poupyrev, I., Maruyama, S., and Rekimoto, J. Ambient touch: designing tactile interfaces for handheld devices. Proc. UIST '02, 51-60.
24. Richter, H., Blaha, B., Wiethoff, A., Baur, D. and Butz, A. Tactile Feedback without a Big Fuss, Proc. UbiComp 2011, 85-89.
25. Richter, H., Ecker, R., Deisler, C., and Butz, A. HapTouch and the 2 + 1 State Model. Proc. AutomotiveUI '10, 72-79.
26. Richter, H., Löhmann, S. and Wiethoff, A. HapticArmrest: Remote Tactile Feedback on Touch Surfaces Using Combined Actuators, Proc. AMI'11.