Natural Interaction with Hand Gestures and Tactile Feedback for large, high-res Displays

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ABSTRACT

Human beings perceive their surroundings based on sensory information from diverse channels. However, for human-computer interaction we mostly restrict the user on visual perception. To investigate the effect of additional tactile feedback on pointing and selection tasks we conducted a comparative evaluation study based on ISO 9241-9. The 20 participants performed horizontal and vertical one-directional tapping tasks with hand gesture input with and without tactile feedback on a large, high resolution display. In contrast to previous research we cannot confirm a benefit of tactile feedback on user performance. Our results show no significant effect in terms of effective index of performance and even a significant higher error rate for horizontal target alignment when using tactile feedback. Furthermore we found a significant difference in favor of the horizontal target alignment compared to the vertical one in terms of the effective index of performance.

Categories and Subject Descriptors

H5.2. Information interfaces and presentation: Input devices and strategies; B4.2. Input / Output Devices.

General Terms

Design, Experimentation, Human Factors

Keywords

Hand gestures, tactile feedback, Fitts' Law, controlled experiment, input device, large high-resolution display.

1. MOTIVATION

In application domains where collaboration, presentation or exploration and analysis of large information spaces are predominant tasks large high-resolution displays are widely used. These wall-sized displays offer great opportunities for information visualization [20] and improve user orientation and search performance [3], but also require more physical navigation [2]. Users have to move in front of these displays to gain either in-depth knowledge or an overview since the display characteristics match or even exceed the capabilities of the human visual system in terms of resolution or field of view [13]. Therefore input devices and interaction techniques are needed which allow flexible interaction from any point and distance.

Inspired from previous research [5], [6], [19] we investigated hand gesture input as an interaction technique which meets the mobility requirement but also offers a very natural and direct way of interaction. Based on the linguistic findings of Kendon [11] and previous evaluation studies of Vogel et al. [19] we identified pointing and selection gestures and implemented a tracking library for gesture recognition in combination with a commercial finger tracking device (see chapter 4).

However, a general problem for the interaction with large high-resolution displays still remains. Since the display capabilities may exceed the human visual acuity users can not solely rely on visual feedback. Imagine a user moving backwards to a distant position to get an overview of the displayed information space: From there it is hard to visually perceive and therefore almost impossible to select a standard-sized button or menu item. In the following paper we therefore do not only describe the realization of our hand gesture interaction and the defined gesture set (see chapter 3) but also address the question if tactile feedback in addition to visual feedback can complement visual information. Thus, we investigated the effect of tactile feedback on user performance with a controlled experiment based on the ISO standard 9241-9. The 20 participants performed horizontal and vertical one-directional tapping tasks with hand gesture input with and without tactile feedback for target crossing. In chapter 4 we describe the experimental design in detail while we present and discuss the results in chapter 5. In the following chapter 2, we discuss related work and findings on tactile feedback for pointing devices.

2. Tactile Feedback for Pointing Devices

Scheibe et al. [16] observed that enhancing hand gesture interaction with tactile feedback seems to increase the reliability of interaction tasks. In a pilot study eight participants were asked to perform common interactions in a virtual car cockpit using the corresponding real-world gestures while wearing a tactile data glove system. Tactile feedback, sensed as an ongoing vibration on the fingertips, was given when a collision of a virtual object and a finger occurred. Tasks were performed with and without the additional feedback. Results showed that participants clearly preferred the tactile system and it was observed that particular small, almost by the real hand occluded objects were operated with greater reliability when tactile feedback was given. Hence tactile feedback seems to improve hand gesture interaction, however the outcome of the study neither gives evidence of the detailed impact on performance nor on error rate nor on movement time.

Other areas in the field of Human-Computer Interaction already make use of tactile feedback. Tactile feedback, being a part of haptic feedback, describes sensations which are applied directly to the skin and perceived by the human sense of touch including vibration, pressure, stretching and touch [14]. Braille displays allow visually impaired users to explore the internet, mobile phones vibrate when a text message is received and input devices give tactile clues like the discrimination between keys on keyboards. In comparing the results of a typing task performed by typists and casual users using a conventional and a piezo electric keyboard Barret & Krueger [4] found, that the performance of both user groups was significantly higher with the conventional keyboard. Here, lack of the familiar haptic feedback (kinesthetic feedback through key travel and tactile through key discrimination) directly decreases the performance. Effects of enhancing keyboard interaction with a stylus on a PDA with tactile feedback were evaluated by Brewster et al. [7]. Participants performed a text entry task once in a laboratory and once in an underground train. A vibrotactile actuator at the back of the device was used to generate two different stimuli which were used to either indicate a successful button press or signal an error. Results showed that tactile feedback improved the number of corrected errors significantly in both settings, reduced the error rate in the laboratory setting and lead to a lower overall workload of the participants who preferred the tactile system over the non-tactile system. Another evaluation considering pen based input was conducted by Forlines et al. [9]. Here tactile feedback was added directly to the stylus. In a selection task they did not only study the effect of different feedback conditions (tactile plus visual vs. visual only) but also direct vs. indirect input and selecting using pointing vs. crossing. Tactile feedback was given to confirm a successful selection. The authors discovered that although tactile feedback didn't show beneficial effects for all conditions, it improved the selection time for indirect pointing and direct crossing selection tasks. This outcome suggests that tactile feedback, while having the potential, doesn't per se guarantee for an improved interaction but that the accompanied interaction technique also influences the benefits of tactile feedback. Akamatsu & MacKenzie [1] found that the performance of a modified mouse could be improved through additional tactile feedback. In the tactile feedback condition a solenoid driven pin stimulated the tip of the index finger once the cursor overlapped the target area. The feedback was turned off when the target was selected, or the cursor was moved outside of the target area. Note that this differs from the feedback in Forlines et al. [9] as it is given before the user performs a selection task. Compared to the other feedback conditions, results showed that tactile feedback lead to the highest index of performance with 6.4 bits/s.

These studies show that tactile feedback can improve Human-Computer Interaction. Accordingly we raise the question whether tactile feedback can also improve hand gesture point and click interaction in terms of performance, movement time or error rate. The observations of Akamatsu & McKenzie [1] point into that direction, but don't allow taking it for granted. To investigate this question further we conducted a controlled experiment which is described in chapter 4. Before that we introduce the hand gestures we used in this experiment for pointing and selection.

3. Hand Gestures

Kendon [11] describes a variety of every day gestures which are used in combination with speech. These kinds of gestures are interesting for Human-Computer Interaction, as they are already known by the potential users and could therefore lead to a decreased learning effort and a better recall when used for interaction.

In the context of Human-Computer Interaction a pointing operation positions the cursor on a display with the user facing it; hence gestures which are used in this manor should be used. Kendon therefore identifies uses of the extended index finger and open hand where "[…] pointing gestures are regarded as indicating an object, a location, or a direction, which is discovered by projecting a straight line from the furthest point of the body part that has been extended outward, into the space that extends beyond the speaker." [11]. Even if both gestures share the same semantic theme the usage is slightly different. An extended index finger is used when one specific object or location is referred to, whereas pointing with the open hand indicates that the object is related to the topic but is not explicitly mentioned.

The exact location of a specific object is what users aim for when positioning the cursor over a target, which describes the usage of the extended index in pointing. Even if the semantic meaning would be identical, this gesture bears some drawbacks when used for interaction. Vogel and Balakrishnan [19] evaluated three combinations of point and click hand gestures and found that pointing with the extended index showed the highest error rate and the lowest ease of use score (1 out of 12). Another drawback is that this gesture requires higher tension than pointing with the open hand. These drawbacks discourage the usage of the extended index gesture for pointing. Pointing with the open hand though, requires less tension and leads to a hand posture that follows the recommendation of Hinckley [10] for the ergonomic design of input devices. Also the usage would resemble every day gesticulation, not as much as the extended index, but considering the discussed issues of both gestures, the open hand seems to be the best choice for being used as a pointing gesture. We therefore used the open hand with an absolute mapping for cursor positioning, where a straight line, defined by the orientation of the palm, was projected and intercepted with the display. The cursor was placed at the interception. This is in line with Kendon's regard on pointing gestures described above. Furthermore absolute positioning, compared to relative, prevents users from losing track of the cursor, which is reported as a usability problem on large displays by Robertson et al. [15].

To interact with objects, a selection gesture is needed as well. Ideally, such a gesture should fit well when used in combination with the pointing gesture and should furthermore be already well known from every day gesticulation or similar "selection" actions.

Besides pointing gestures Kendon [11] also describes a so called R-Family of precision grip gestures that are used when the speaker wants to be very exact and precise about something and therefore special attention is needed. Selecting in the context of Human-Computer Interaction shares this meaning, as the user wants to exactly select one specific object of the application. When performing a gesture of the R-Family the tips of the index finger and the thumb are brought together to form a shape that resembles a circle or a ring, a finger movement that can be used in combination with our selected pointing gesture quite well. Yet another advantage is that the movement of the gesture mimics the action of doing a left mouse click with every computer user being familiar with. It also provides implicit feedback due to the fingertip contact signaling that the gesture has been performed. Because of the similar meaning, the additional relation to simple mouse click actions and the implicit feedback we picked this gesture to be used for performing a selection. A selection, which is mapped to a single left mouse click, is triggered when the distance of the index finger and thumb tip fall below predefined thresholds of two metrics (see figure 1). The 3D positions of the fingertips are derived from the output data of the used tracking solution, described in chapter 4.1.

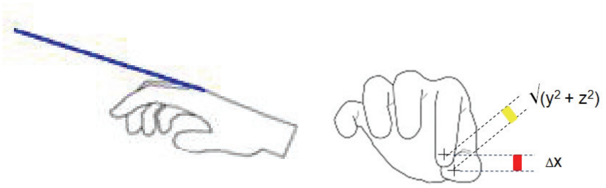


Figure 1: Pointing gesture (left) and selecting gesture (right)

4. Experiment

We conducted a controlled experiment to assess and compare the usability of the presented hand-gestures with and without tactile feedback as an input device for large high resolution displays. Therefore the experiment took place in front of the *Powerwall of the University of Konstanz,* a large high-resolution display. This section describes our experimental settings and hypothesis.

4.1 Materials

The Powerwall of the University of Konstanz is a wall-sized display with a resolution of 4640x1920 pixels and a physical dimension of 5.20x2.15 meters. It uses a multi projector system with soft-edge blending and is equipped with an optical tracking system developed by A.R.T. This tracking system uses six infrared cameras to cover the area in front of the display. The cameras are able to identify the position and movement of markers that can be placed on persons, e.g. to assess their current location and use this as an input variable. In combination with a non-intrusive data-glove, also developed by A.R.T, this system was used for finger tracking. The data-glove was enhanced with several markers on the back of the hand as well as on three fingers – the latter were attached similar to foxgloves (see figure 2). This construction enables the tracking of the exact position of one's hand as well as single fingers. If every marker is visible for the cameras, this system reaches an accuracy of <1mm. In order to provide a tactile feedback, we used an extension of this system described by [16]. Around the inside of the three fingertips covered by the markers, so called shape memory alloy wires are attached. A wireless connection provides the possibility to attach a low voltage which is perceived by the user as a continuous vibration. The tasks (see section 4.2) were presented and interaction was recorded via IEval, a software tool that can be used for pointing device experiments [12]. To accommodate for the natural hand tremor we integrated a band-pass filter that provides dynamic smoothing of the interaction without restricting fast movements. This decreases the effect of the interaction itself on the accuracy. We designed a short pre-test questionnaire to assess the participants' prior experience as well as some demographic data. For subjective assessment of the different experimental conditions we used the questionnaire provided by the ISO 9241-9, which asks participants to rate one device and then rate the second device in comparison to the first device. Users rated the non-tactile as the first device (absolute measurement) and the tactile feedback as the second device (relative to the non-tactile variant). The questionnaire consists of items like overall satisfaction as well as accuracy and fatigue of fingers/wrist/arm, etc. In total it comprises 12 items that have to be rated on a 7-point-scale.

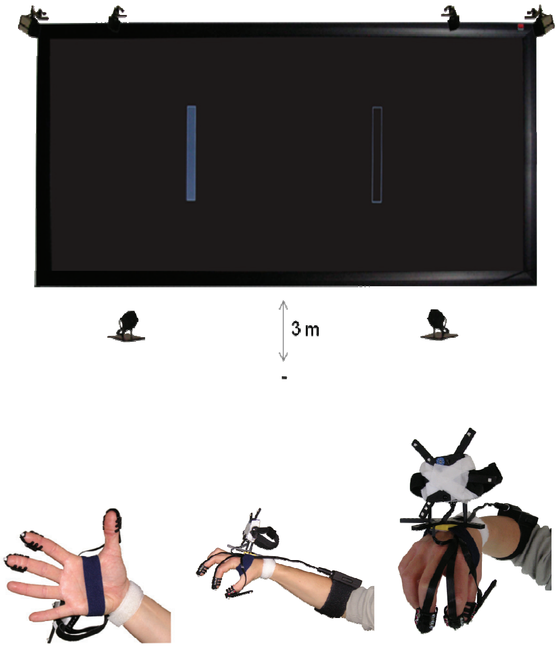


Figure 2: Powerwall (top), data-glove (down)

4.2 Tasks

We based our experiment on Fitts' Tapping Task as described and suggested by ISO 9241-9 to assess the performance of pointing devices. These tests are widely used and accepted (see [18] for a review). We used the one-directional tapping task which consists of two rectangular targets that are furthermore varied in terms of their width (W) and the amplitude (A) between them. Participants were asked to click on each of these targets in an alternating manner as fast and precise as possible. This "clicking" was done by using the selection gesture illustrated in chapter 3. In the tactile condition, tactile feedback was provided while the cursor overlapped the target area. The tactile feedback to the user's tips of the active fingers (index and thumb) was turned off only after selecting the target or after the cursor was moved outside of the target area. This integration of the tactile feedback is based on the work by Akamatsu & MacKenzie [1] who provided tactile feedback in a similar way while testing an enhanced mouse. We furthermore varied the target alignment, using horizontal as well as vertical aligned targets (see figure 3).

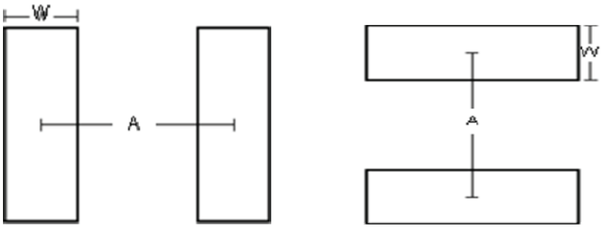


Figure 3: Horizontal and vertical alignment of tapping targets

To cover a wide set of difficulties that can be encountered when interacting in front of the Powerwall, we initially used 3 (W) x 3 (A) combinations for horizontal tasks and 2 (W) x 2 (A) combinations for vertical tasks. The latter was due to the limited vertical size of the Powerwall (2.15m compared to the 5.20m in horizontal) and the necessity that participants may also "overshoot" a target. Larger amplitudes or target widths for vertical tasks may have otherwise resulted in participants performing a selection gesture outside of the display. The exact pixel-values can be seen in figure 4 as well as the resulting indexes of difficulty. However during the experiment we observed that participants moved themselves to a larger extent in front of the display than expected, triggering the tracking cameras ineffective for the outer parts of the display. Therefore we had to exclude this amplitude for further analysis, resulting in a 3 (W) x 2 (A) combination for horizontal tasks and the corresponding reduction in terms of the index of difficulty from 5.6 bits maximum to 4.6 bits maximum (see figure 5).

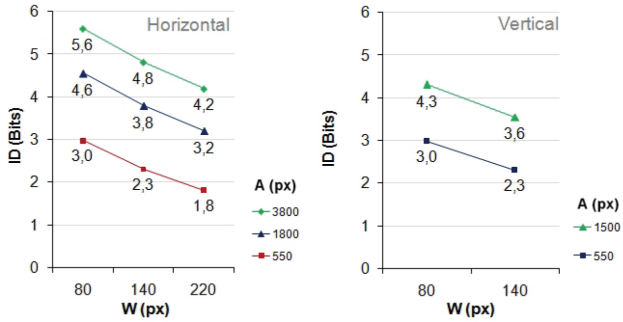


Figure 4: W x A combinations and resulting index of difficulties (different colors: amplitudes, x-axis: target sizes, left: horizontal, right: vertical)

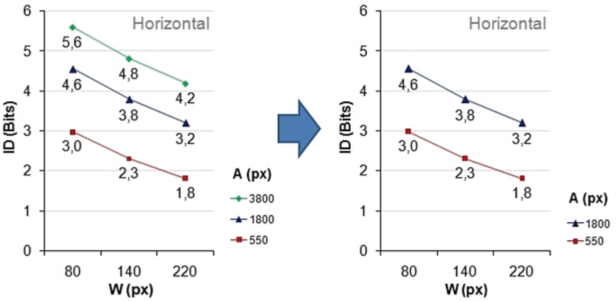


Figure 5: Resulting W x A combinations for horizontal alignment after exclusion of one amplitude condition (3800px)

4.3 Hypothesis

This section describes our experimental hypothesis as well as their foundation in the current literature.

4.3.1 H1: Tactile vs. non-tactile

We assumed that tactile feedback would result in a significant performance improvement, expressed by the effective index of performance (IPe) measurement. This hypothesis is in line with the literature review presented in chapter 2 that strongly suggests that tactile feedback is able to improve user performance in many ways, ranging from lower error rates to lower movement times. The effective index of performance includes both, movement time and error rates (see [18] for details) and therefore provides an appropriate measurement for this hypothesis.

4.3.2 H2: Horizontal vs. vertical target alignment

We assumed that the index of performance for horizontal targets (see figure 3, left) would be significantly higher compared to the vertical target alignment (see figure 3, right). This hypothesis is in line with findings by Dennerlein et al. [8]. In an experiment featuring a tunnel steering task, conducted via a stationary mouse and a regular display, they observed that users were able to guide the mouse cursor more quickly through horizontal areas of the task compared to the vertical areas. They ascribed this effect to differences in the joint kinematics, in particular to the multi-joint coordination. In a similar way, horizontal and vertical hand movement also relies on different muscles and joints, therefore we expected similar results. In the Dennerlein study, they were able to neutralize the effect via a force feedback mechanism that guided users to stay in the tunnel. We were therefore curious if and how tactile feedback might have an effect in our experiment as well on this phenomenon.

4.4 Experimental Design

We used a 2x2 within subjects design with feedback (tactile, non-tactile) and target alignment (horizontal, vertical) being the independent variables. A latin square design was used for counter-balancing in order to address possible effects of sequence, learning or fatigue. Our participants were randomly assigned to one of the resulting four experimental groups. As dependent variable we used the measurements provided by ISO 9241-9, namely movement time (MT, in milliseconds), error rate (ERR in %), and the effective index of performance (IPe in bits/s). The latter combines the movement time and error rate in one single measurement. Since participants were asked to perform a task as fast and precise as possible it should be considered as the most important measurement.

4.5 Participants

We selected 20 participants to take part in our experiment. Of those, 15 were male and five female. The average age was 30.8 years with a standard deviation of 9.9 years. All of them were regular computer users, while 13 already had some experience with large displays (standard projector or Powerwall). None of the participants had prior experience with a data glove or something similar.

4.6 Procedure

Each session started with the pre-test questionnaire. Users were then equipped with the data-glove followed by a short functionality test of the tactile feedback. In the next step, participants were asked to step in the center in front of the Powerwall, three meters away from the display. They were instructed about the interaction, the gestures they should use to interact, and to be as fast and precise as possible.

A training session was started then, consisting of a full block of vertical and horizontal tasks as well as non-tactile and tactile feedback, whereas the sequence was based on the participants assigned test condition. During training we used 2 (W) x 2 (A) combinations and ten trials for each combination, resulting in 160 trials. The selection of the reduced WxA combinations was done based on the goal to keep the training rather short and at the same time to reach similar difficulty levels as in the following real tasks. During these each participant completed two blocks of the assigned condition, and now 16 trials for each WxA combination, resulting in 832 trials. All participants together completed 16640 trials of which 14720 trials were used for analysis, due to the tracking problem mentioned in chapter 4.2.

After completion of the tapping test, participants were asked to fill in the ISO 9241-9 questionnaire. The experiment lasted in total about one hour per session and participants were given 5 EUR as compensation.

5. Results

This section describes the analysis and results of our experiment. We started our analysis by calculating the model fit, averaged across all participants, for Fitts' Law. Results show that we have a very high model fit for each of the factor combinations, with r^2 constantly above .99. Therefore we can assume that the Fitts' Law model fits quite well for our experiment.

Our first hypothesis stated a significant difference in favor of the tactile feedback in terms of the effective index of performance (IPe). Results of our RM-ANOVA however show that this is not the case. For both horizontal and vertical target alignment the non-tactile feedback performed better, however the differences are very small and not significant (horizontal means: 3bits/s non-tactile vs. 2.99 bits/s tactile, SD: 0.29 bits/s vs. 0.31 bits/s; vertical means: 2.53 bits/s non-tactile compared to 2.46 bits/s tactile, SD: 0.23 bits/s vs. 0.28 bits/s, see figure 6). Therefore we have to reject our hypothesis in favor of the null-hypothesis, stating there is no significant difference.

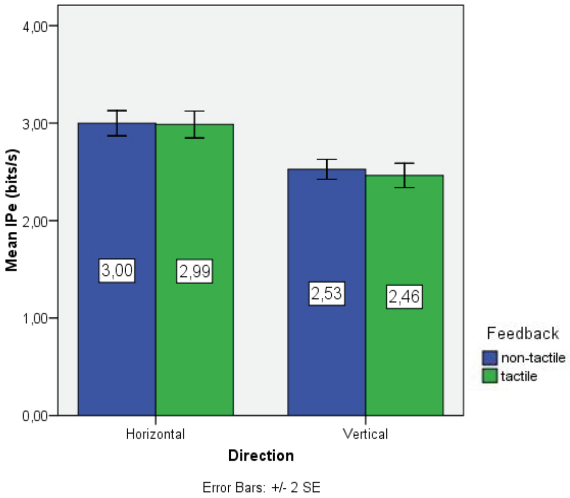


Figure 6: Effective index of performance for horizontal and vertical target alignment

Our second hypothesis stated a significant difference in favor of the horizontal target alignment compared to the vertical one in terms of the effective index of performance. As it turns out, this is indeed the case ($F_{1,19}$ = 124.857 p < .001, horizontal mean: 2.99 bits/s, SD: 0.29 bits/s vs. vertical mean: 2.49 bits/s, SD: 0.25 bits/s) Therefore, we can accept our hypothesis. However in contrast to the study by Dennerlein et al. [8] the tactile-feedback did not compensate for these differences. We further analyzed the effect of the tactile feedback in terms of error rate and movement time. Results show that the movement time is slightly lower for both vertical and horizontal target alignment when providing the user with tactile feedback. However these differences are not significant (see figure 7).

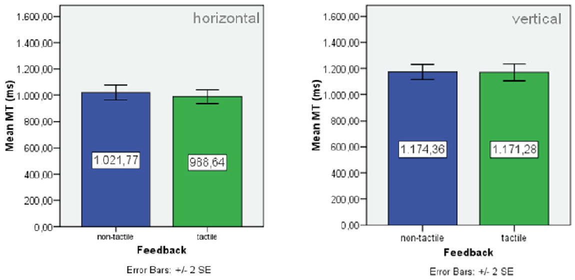


Figure 7: Influence of tactile feedback on movement time

Regarding the error rate results look different (see figure 8). For the horizontal target alignment we discovered a significant higher error rate when using tactile feedback ($F_{1,19}$ = 9.17 p = .007, 10% vs. 12%, SD: 4.8% vs. 6.2%) – for vertical alignment the difference was not significant ($F_{1,19}$ = 2.61 p = .112).

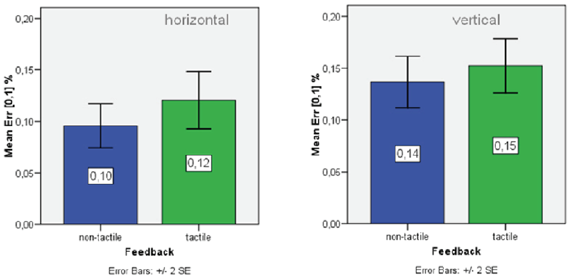


Figure 8: Influence of tactile feedback on error rate

Regarding the subjective feedback derived from the questionnaire our participants rated nearly the entire items positive for the non-tactile feedback (with the exception of arm fatigue, see figure 9). The second part of the questionnaire asks to rate the tactile-feedback relative to the non-tactile. Results show that our participants either liked or disliked the tactile-feedback, resulting in three nearly discrete groups (7 dislikes, 7 likes, 6 undecided, see figure 10). We looked for correlations between task performance and whether a participant was in the “I like tactile” or “I dislike tactile” group. However there was no significant effect.

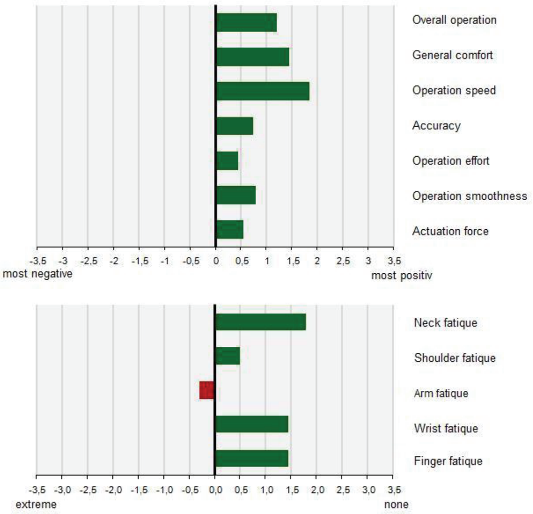
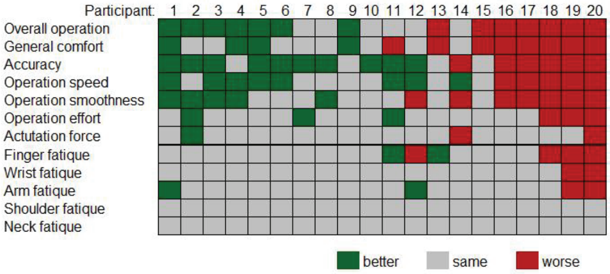


Figure 9: Subjective user rating for non-tactile feedback



Participant:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Overall operation	🟩	🟩	🟩	🟩	🟩	🟩	⬜	⬜	🟩	⬜	⬜	⬜	🟥	⬜	🟥	🟥	🟥	🟥	🟥	🟥
General comfort	🟩	⬜	⬜	🟩	🟩	⬜	⬜	⬜	🟩	⬜	🟥	⬜	🟥	⬜	🟥	🟥	🟥	🟥	🟥	🟥
Accuracy	🟩	🟩	🟩	⬜	🟩	🟩	🟩	🟩	⬜	🟩	🟩	🟩	⬜	🟥	⬜	🟥	🟥	🟥	🟥	🟥
Operation speed	🟩	⬜	🟩	🟩	🟩	🟩	⬜	⬜	⬜	⬜	🟩	🟩	⬜	🟩	⬜	🟥	🟥	🟥	🟥	🟥
Operation smoothness	🟩	🟩	🟩	🟩	⬜	⬜	⬜	🟩	⬜	⬜	⬜	🟥	⬜	🟥	⬜	🟥	🟥	🟥	🟥	🟥
Operation effort	⬜	🟩	⬜	⬜	⬜	⬜	🟩	⬜	⬜	⬜	🟩	⬜	⬜	⬜	⬜	⬜	⬜	🟥	🟥	🟥
Actutation force	⬜	🟩	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟥	⬜	⬜	⬜	⬜	⬜	🟥
Finger fatique	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟩	🟥	🟩	⬜	⬜	⬜	⬜	🟥	🟥	🟥
Wrist fatique	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟥	🟥
Arm fatique	🟩	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟩	⬜	⬜	⬜	⬜	⬜	⬜	🟥	🟥
Shoulder fatique	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
Neck fatique	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜

🟩 better ⬜ same 🟥 worse

Figure 10: Relative user rating for tactile feedback

6. Conclusion

In analogy to human non-verbal gestural communication we introduced hand gesture interaction as a natural and flexible interaction technique for large, high-resolution displays. Based on previous findings of Kendon [11] and the experimental results of Vogel & Balakrishnan [19] we identified suitable gestures for pointing and selection tasks and realized gesture recognition in combination with a commercial finger tracking device. The non-tactile version of our hand gesture interaction was very well received by the participants, with 11 positive and only one negative rated item on the ISO satisfaction questionnaire. Also the effective index of performance with a mean of 2.53 bits/s for vertical and 3 bits/s for horizontal target alignment is promising and suggests that hand gesture interaction provides an adequate and valuable interaction technique for large, high resolution displays.

Besides investigating the general usability of hand gesture interaction for large, high-resolution displays the main contribution of this paper is the evaluation of the effect of tactile feedback on it. The findings from [16], [9], [1] discussed in chapter 2 suggest that tactile feedback may improve user performance since the additional information channel can complement or substitute visual information. However our results show no significant effect in terms of effective index of performance and even a small but significant higher error rate for horizontal target alignment when using tactile feedback. One explanation might be that participants did not take advantage of the additional feedback since they relied more on their visual observations when initiating a selection, as this is more common and known. So, the performance did not show a difference as tactile feedback might have simply be tolerated but not used by the participants. However in the negative case, the additional tactile feedback could even interfere with the visual information. We know from cognitive science that tactile and visual stimulations are not processed with the same lag and velocity and measured reaction time differ [17]. Users may react irritated if the same information (target reached) gets delivered from different channels at different times. Moreover some participants mentioned that they felt to be set under pressure by the additional feedback, what could also be a reason for the slight drawback considering the error rate. Basically, the findings of previous research on tactile feedback could not be directly transferred to hand gesture interaction. Our empirical results showed no benefit of tactile feedback at least in our test setting, in which visual and tactile information were provided.

Furthermore our study confirmed the findings of Dennerlein et al. [8] concerning the effect of movement direction on user performance. The results showed with 2.99 bits/s horizontal versus 2.49 bits/s vertical a significant effect in terms of the effective index of performance. However in contrast to their results the tactile-feedback did not compensate the differences between horizontal and vertical target alignment, which could be due to the fact, that in Dennerlein’s study force feedback restricted mouse movement whereas tactile feedback in this evaluation only served as an additional information but did not physically hinder users in their movement. Therefore the effect of movement direction should be considered when designing user interfaces and interaction techniques for hand gesture interaction.

7. ACKNOWLEDGMENTS

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