Tactile Information Coding by Electro-tactile Feedback

Peter Schmid, Mona Bader and Thomas Maier
Institute for Engineering Design and Industrial Design, Department of Industrial Design Engineering, University of Stuttgart, Pfaffenwaldring 9, Stuttgart, Germany

Keywords: Electro-tactile Feedback, Tactile Information Coding, Human Machine Interaction, Human Machine Interface, Touch Interface, Tactile Perception.

Abstract: Touch user interfaces offer a wide range of interaction and manipulation possibilities. However, when interacting with this technology, the feedback is usually only provided via the visual or audio-visual channel of perception. Therefore, the study investigates how electro-tactile feedback can support the interaction with touch interfaces. The aim is to use electro-tactile feedback to transmit information during an adjustment task on a touch interface. For this purpose, five different types of electro-tactile feedback were investigated in a user study with 15 test persons. During the execution of a main task, a simple adjustment task had to be done in parallel on the electro-tactile touch interface. The electro-tactile feedback supports the execution of a main task and a secondary task, but the study also shows that by concentrating on the electro-tactile feedback the actuation time is extended.

1 INTRODUCTION

On touch-sensitive screens, information can not only be displayed but also edited directly. It is possible to execute as many complex functions on a small interaction surface. When using this technology, feedback to the user is usually audio-visual, the feeling of a haptic feedback is completely lost. According to Hoggan et al., the loss of haptic feedback when operating a virtual input element leads to a higher error rate and a lower input speed (Hoggan et al., 2008). Studies by Harrison et al. and Koskinen et al. show that haptic feedback makes interaction with touchscreens more efficient and satisfying (Harrison et al., 2009; Koskinen et al., 2008). Studies from Schmid et al. or Winterholler show that in situations with high audio-visual information content, tactile information can be used to support people in the performance of a primary and secondary task (Schmid et al., 2019; Winterholler, 2019).

With regard to the design of haptic feedback, there are already standards such as DIN EN ISO 9241-910 or VDI/VDE 3850-3, which focus on haptic feedback for touch user interfaces as a supplement to auditory or visual feedback (ISO, 2011; VDI/VDE, 2015). According to DIN EN ISO 9241-112, information coding can reduce the cognitive load on users by supporting them in the performance of the task and by providing necessary information in an unambiguous way when interacting with a machine (ISO, 2017).

Therefore, the focus of this paper is on the electro-tactile information coding of a virtual slider control element concerning a medical use case. In an operating room, there is a lot of noise and all feedback from medical devices is visual or acoustic. This leads to an overload of the human perception channel. Consequently, concentrated work by doctors is not possible. (Siegmann & Notbohm 2013)

However, there is still another perception channel, which is completely unused in operating medical instruments. To reduce the overload of the audio-visual perception channel we can address the haptic or tactile perception channel.

For the investigation of electro-tactile coding we considered gas insufflation. Minimally invasive surgery uses gas insufflation to fill the abdomen with CO_2 in order to increase the operating field. For this purpose, we derived five interface modules, which are needed to control the gas insufflation. In addition to a start/stop module, it is necessary to control the CO_2 pressure, the gas flow as well as the smoke extraction and gas consumption. Currently these functions provide only a visual or acoustic feedback in gas insufflation. Hence, this project will evaluate the tactile perception channel of humans with regard to its supporting capacity in terms of tactile feedback design. According to Schmid & Maier, different

Schmid, P., Bader, M. and Maier, T.
Tactile Information Coding by Electro-tactile Feedback.
DOI: 10.5220/0010066300370043
In *Proceedings of the 4th International Conference on Computer-Human Interaction Research and Applications (CHIRA 2020)*, pages 37-43
ISBN: 978-989-758-480-0

tactile coding patterns on a touch user interface can be used for information coding by intensity design of the electro-tactile feedback during a sliding input gesture. Different design options are available, depending on a discrete or continuous feedback. The identified tactile coding patterns divide into tactile coding features and tactile coding ranges for both discrete (Fig. 1a) and continuous feedback (Fig. 1b). The tactile coding feature describes a single point, a so-called tick mark of the slider on the touch user interface, which can indicate to the user, for example, a middle as well as a beginning and end or maximum and minimum values by means of a tactile intensity change (Fig. 1c). Tactile coding progressions, on the other hand, describe areas such as the increase or decrease in tactile feedback in a defined range (Fig. 1b). (Schmid & Maier, 2020)

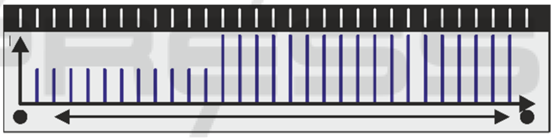
2 METHOD

The research of Winterholler demonstrates the possibility to transfer haptic information by coding of physical rotary control elements. (Winterholler 2019)

In contrast, this study investigates electro-tactile information coding using virtual sliders on an electro-tactile touch user interface (Fig. 2). The slider control elements differ in the type of tactile feedback. For this purpose, five different control elements are implemented based on discrete or continuous feedback. With discrete feedback, the user feels individual feedback impulses with his finger during the adjustment process, similar to a slider with tick marks. With continuous feedback, on the other hand, the user perceives continuous tactile feedback with his finger during the adjustment process. In addition to the discrete or continuous feedback, the intensity level of the feedback also varies.

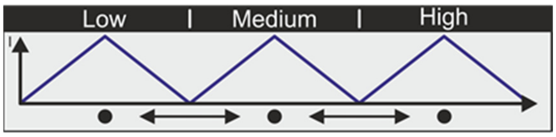
This is why this study focuses on the information coding on the one hand of a fine adjustment task, in particular for adjusting a defined value along a scale, and on the other hand the coding of different areas along a scale. Fig. 1 shows the five different indicators. Each slider is built on a scale (x-axis) coded by different characteristics and intensity levels (y-axis) of tactile feedback. Fig. 1a shows the characteristic of a discrete tactile feedback. This means the test person feels different feedback marks while sliding along the virtual scale. The tactile coding of control element 2 represents a continuous input in two ranges ("Stop"-"Start") with different intensities of tactile feedback (Fig. 1b). The aim of this tactile area coding is to investigate whether a separation of two ranges is perceptible by the intensity level and contributes to a better performance of the main task. Control element 3 characterises continuous feedback with three tick marks. In contrast to control element 1, the marking of the tick marks is achieved by continuously increasing and decreasing intensity along the virtual slider. When the test person slides along the virtual slider, hill and dale are perceived, which are generated by the variation of the intensity level (Fig. 1c). The fourth control element contains the same function as control element 3. A distinction is also to be made between the three setting ranges. In contrast to control element 3, however, the ranges are coded by three continuously different intensity levels. (Fig. 1d). Interface element 5 has a feedback impulse to separate the ranges "Reset" and "Start". If the user sets the slider from "Start" to "Reset", he feels a short resistance at the transition, which represents the transition between the two ranges (Fig. 1e).

The study evaluates whether the tactile feedback supports the operation of the five interface elements and thus improves the concentration on a main task performed in parallel. It should also be determined whether the operation with electro-tactile feedback requires less effort.

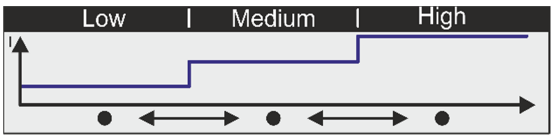


a) Interface element 1: discrete input

b) Interface element 2: continuous input with discrete markers

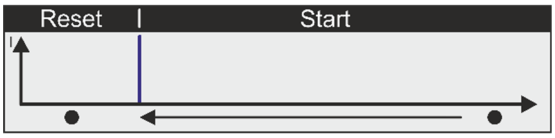


c) Interface element 3: continuous input



d) Interface element 4: continuous input

Figure 1a: Schematic structure of the tactile coding of the interface elements 1-4.



e) Interface element 5: continuous input with a discrete mark

Figure 1b: Schematic structure of the tactile coding of the interface element 5.

Besides the schematic representation of the tactile coding of the control elements, Fig. 2 shows the implemented test interface with which the adjustment tasks are carried out. Fig. 2 demonstrates the start/stop module, the module for CO_2 pressure, the gas flow module as well as the smoke extraction module and gas consumption module.

Figure 2: Test interface of the slide control elements for the adjustment tasks with electro-tactile feedback.

2.1 Participants

For the experiments 15 volunteers are available, 11 of them men and 4 women aged 22 to 35 years. The average age is 26 years (SD=3.05 years). None of the test persons pursues a hobby or a job that puts so much strain on the fingertips that their sensation would be severely restricted. Test persons suffering from skin or nerve diseases of the hands are also excluded. All test persons are students in a technical course of studies or academic employees of the institute. The test persons have no experience with the existing type of haptic feedback on touch screens. The test duration is about 30 minutes.

2.2 Test Setup

The experimental set-up consists of a main and a secondary task (Fig. 3). The use case for the investigation of electro-tactile slider operation is in the field of medical technology. In a medical intervention the focus lies on the human being or the operating field, within which very precise work must be carried out. Therefore, the main task of this experimental setup is to perform a dexterity task, which requires concentrated work. The secondary task in the operating theatre can, for example, be the operation of medical equipment. Therefore, the main task of the experiment is to hold a stylus with its metallic tip in a 5 mm diameter hole as still as possible without touching the edge. For this purpose, the circuit board for the main task is placed to the dominant hand of the test person. The main task is therefore performed with the dominant hand, while the arm is slightly bent but not supported. The contact of the stylus with the edge of the hole is detected.

Similarly, in this test scenario, the electro-tactile display is to be operated parallel to the dexterity task. The secondary task is an adjustment task on the electro-tactile touch interface. The electro-tactile display with the test user interface is placed beside the test person. The tablet is connected via a cable to a laptop on which the test program is opened.

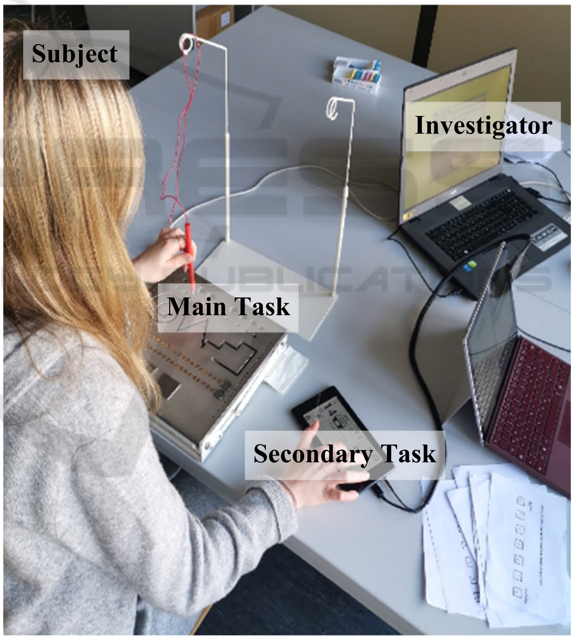


Figure 3: Experimental set-up.

2.3 Experimental Procedure

After the welcome, the investigator informs the test person about the operation of the test user interface and the test procedure. This is followed by information on privacy, consent to the study and the collection of demographic data. In addition to age and gender, it is also recorded whether the test person has a hobby or a disease that would result in a reduction in fingertip sensitivity. In the subsequent introductory and learning phase, the test person is allowed to test the controls, feel the feedback and become familiar with the perception. No further explanations of the haptic feedback are given.

During the test, 11 different adjustment tasks are performed on the five control elements with and without haptic feedback. The adjustment tasks were selected on the basis of a benchmark for the operation gas insufflation. For this purpose, the operation of gas insufflation in everyday clinical practice was analysed and the operation was transferred to the use case tested in this study with regard to electro-tactile feedback. The different adjustment tasks are performed with the non-dominant hand, while the main task is performed in parallel with the dominant hand. An adjustment task must always be carried out in a sliding movement without settling. As soon as the correct position of the main task is assumed, the experimenter gives a signal, whereupon the adjustment task may be started. There are four adjustment tasks for control element 1. Two adjustment tasks are also carried out for control element 2, 3 and 4. One adjustment task is provided for control element 5. The exact adjustment tasks are listed below in table 1.

Table 1: Adjustment tasks for experimental procedure.

Task	Description	Type of Feedback
A1	Set slider value from 0 to 12	control element 1
A2	Increase slider value of 12 by 6	
A3	Decrease slider value of 18 by 2	
A4	Set slider value from 18 to 26	
A5	Set slider to "Start	control element 2
A6	Set the slider to “Stop”	
A7	Set the slider from “Low” to “High”	control element 3
A8	Move the slider from “High” to “Medium”	
A9	Move the slider from “Low” to "High"	control element 4
A10	Set the slider from “High” to "Medium"	
A11	Set the slider to “Reset”	control element 5

After each adjustment task, the task completion of the secondary task, the setting time, the errors concerning the primary task, the distraction caused by the haptic feedback, as well as the effort during the adjustment task of the test person are recorded. The respondent using a 7-level Likert scale evaluates the test criteria distraction through feedback and the effort during the adjustment task.

3 RESULTS

The results of the study are presented below. First, the comparative presentation of the results of the measured values recorded during operation without and with haptic feedback are presented. These parameters include the objectively measured variables such as task fulfilment, setting time and the number of errors of the main task. The effort during the adjustment task of the test persons as well as the distraction caused by the feedback was also recorded by a subjective survey.

3.1 Task Fulfilment of the Secondary Task

There are no differences concerning the task fulfilment of the adjustment task executed with and without tactile feedback. With regard to the task fulfilment of the adjustment task, no significant differences between the control tasks and the design of the electro-tactile feedback of the control elements could be identified.

3.2 Setting Time

Fig. 4 shows the recorded setting times of all feedback variants. For comparison, the setting times per adjustment task for operation without and with feedback are placed next to each other. Each adjustment task is plotted in form of a box plot in order to be able to draw conclusions about the dispersion of the adjustment task. The setting times vary between 0.14 and 5.21 seconds. For tasks A1, A2, A3, A4, A5 and A8, the setting times change only minimally from operation without to operation with haptic feedback. For the other five tasks (A6, A7, A9, A10), the setting times are slightly longer when operating with than without feedback. For task A9, the setting time is even increased by almost 47%. The trend thus shows an increase in setting time due to haptic feedback. Therefore, the control elements 1 to 5 were tested to significant differences by a Wilcoxon Test. With the exception of A 11, no significant differences in setting time were found between the control elements concerning the adjustment tasks A1 to A11 with and without haptic feedback. A significant difference ($z=-2.471$, $p=0.015$, $n=15$) was found for A 11. Consequently, in this study the setting time with haptic feedback is not significantly higher than without feedback.

3.3 Error Number of the Main Task

Fig. 5 shows the number of errors. The number of errors are the contacts with the edge of the bore during the execution of the main task. It can be seen that the number of touches is lower when performing a secondary task with haptic feedback. The greatest improvement in the average number of contacts can be seen with adjustment task A4 (Fig. 4). In this task, the slider is set from the value 18 to the value 26. However, it should also be mentioned that the variance of the measured values is particularly high. Consequently, the number of touches varies greatly among the test persons. In a difference test, using the Wilcoxon test it is also evident that the differences in control element 1 are significant concerning the adjustment tasks A1, A3 and A4. With regard to adjustment task A1 (z=-2.659, p=0.008, n=15) and A4 (z=-3.190, p=0.001, n=15), the difference in operation with and without haptic feedback is high significant lower. For control element 2, 3 and 5, on the other hand, the haptic feedback has no significant effect on the number of touches for the main task. Further significant differences are found for task A10 (z=-2.292, p=0.022, n=15). Here, too, the haptic feedback results in a lower number of touches of the main task.

3.4 Effort during Adjustment Task

The box-plot diagram in Fig. 6 shows the results in terms of the effort during the adjustment task. The evaluation results vary between no effort and high effort. The highest effort is in the fourth task (A4). The averaged effort here is 4 out of 6. The effort for task A5 is only minimally higher on average when operating without haptic feedback than when performing task A6. Comparing task A7 and A9, on average, the effort involved in operating without feedback is slightly higher for control element 3 than for control element 4. The two control elements differ only in the way they provide haptic feedback. Fulfilling the task with feedback requires on average the same stress with task 7 as without feedback. The effort induced by task A11 is rated as the highest. To have a closer look at the results a Wilcoxon Test was conducted. As we can see in Fig. 5 the effort of task A1 (z=-2.460, p=0,014, n=15), A2 (z=-2.373, p=0,018, n=15), and A3 (z=-2.310, p=0,021, n=15) is significant less rated concerning the adjustment task with and without electro-tactile feedback. Also task A4 (z=-3.671, p=0,001, n=15), A10 (z=-2.598, p=0,009, n=15) and A11 (z=-2.739, p=0,006, n=15) show a high significant better rating.

3.5 Distraction through Feedback

The results of the evaluation of how much attention is paid to haptic feedback during a task are shown in Fig. 7 as a box plot across all adjustment tasks. The evaluation is on a scale from no distraction to high distraction. The median values lie between three for A1 and four for the tasks A3 and A7 to A11. Furthermore, it is noticeable that for the tasks A5 and A6, with an average rating below three, somewhat less attention is paid to feedback than for the tasks at the other control elements. In tasks A9 and A10 on

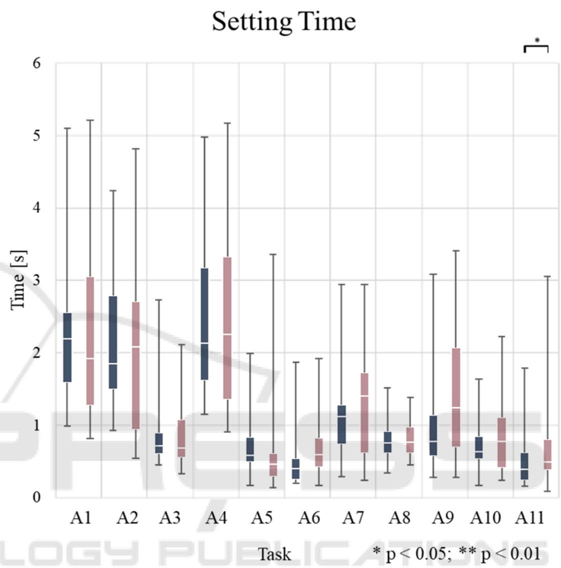


Figure 4: Setting time concerning the secondary task.

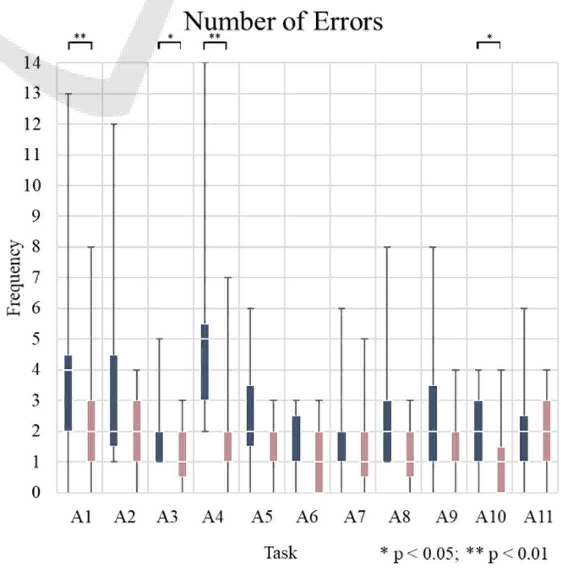


Figure 5: Number of errors concerning the main task.

control element 4, on average a little more attention is paid to haptic feedback than in tasks A7 and A8. For task A11, haptic feedback is also used relatively heavily. The median value here is four. Significant or high significant differences could not be found.

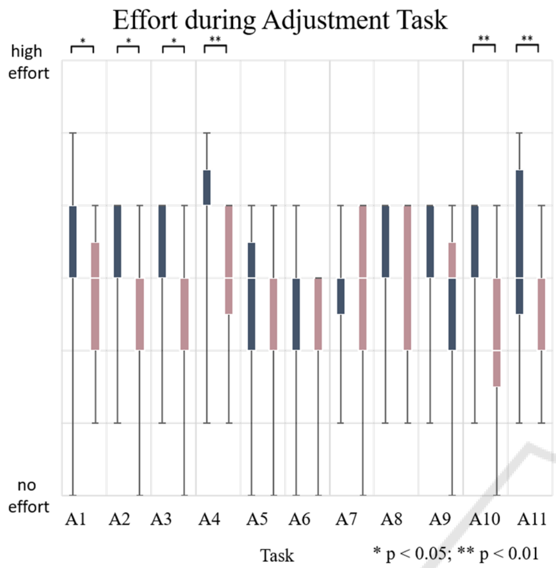


Figure 6: Effort of the secondary task during operating in a main task.

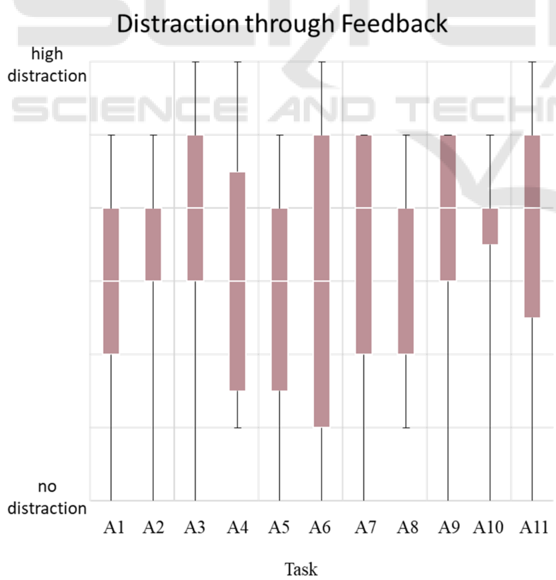


Figure 7: Distraction caused by the electro-tactile feedback operating in a main and secondary task in parallel.

4 DISCUSSION

Using control element 1, it is evident that it makes sense to code an interface element with short tick mark distances by means of haptic feedback pulses. On the one hand, the error rate on a task performed in parallel during operation is improved (Fig. 5), on the other hand the operation is perceived as significantly less strenuous, as can be seen in Fig. 6. The feedback contributes greatly to orientation on the control element. Adjustment tasks with feedback pulses of higher intensity (tasks A2, A3 and A4) show stronger improvement values. This leads to the conclusion that a consistently strong feedback is more suitable. With small changes in settings and strong feedback, the tick marks are partly counted via the tactile feedback pulses. In theory, even blind operation would be conceivable here. Moreover, the feedback feels pleasant for many test persons.

With both adjustment tasks (A5 & A6), control element 2 shows an improvement both in errors on a parallel activity and in the induced effort (see Fig. 5 and 6). This indicates that the haptic feedback facilitates operation even with a short adjustment distance and the change between only two states. The execution of task A5 is somewhat more difficult. However, the ability to concentrate on the parallel task is improved more than in task A6. The induced effort, on the other hand, is improved more by the haptic feedback in task A5.

In comparison of control element 3 and 4, the haptic course with the intensity jumps causes a stronger improvement than the haptic course with the extreme points of intensity. When performing tasks A5 and A7, the greatest difference between the two haptic progressions can be seen. While the effort does not change for control element 3 and the errors of the main task improves by only about 8%, it improves by about 27% for control element 4 and effort by about 15% (Fig. 6). This reveals that for control elements with three ranges and large distances between them, a jump in feedback intensity is preferable. However, even here the test persons cannot feel the exact location of the haptic feature (intensity jump). However, they recognize the different intensity levels in the different ranges.

Control element 5 is the only one that shows a greater improvement in effort required for operation than for concentration on parallel activity (Fig. 5 and 6). Consequently, the haptic feedback facilitates the task. The test persons experience a clear support by the feedback and feel a significantly lower effort.

The haptic feedback has a positive effect on all control elements. The accuracy of the execution of a parallel activity is improved for all control elements. The haptic feedback during operation also has a positive effect on the perceived effort during the execution of a parallel task for all control elements.

5 CONCLUSION

The study reveals that the test persons can concentrate better on their main activity if they feel a haptic feedback when operating the touch user interface in parallel. The reduction in the number of touches across all test subjects and all five control elements is 37% overall. The greatest improvement in errors concerning the main task on parallel activity is found at control element 1. The individual feedback impulses contribute to orientation, are partially counted and improve the concentration on the parallel task the most. The subjectively induced effort is experienced as less when operating the user interface in parallel with haptic feedback than operating without haptic feedback. The setting time, however, shows an increase over all tasks and test persons. In addition, the feedback used for the control elements feels too weak. The information coding behind the haptic feedback is also partly not intuitively understandable. This should be further improved. After a short explanation at the end of the test, the coding could usually be understood quickly. It is therefore interesting to see how much the errors of the main task improves when the test persons are briefly introduced to the coding logic of the feedback before the start. Exercise also leads to a better use of the feedback and further contributes to an increase in the ability to concentrate and a reduction in effort. The setting time, which tends to increase with feedback also shortened through practice.

In conclusion, the haptic feedback has a high potential with touch screens. There is a great level of freedom in design and a wide variety of technical approaches to implementation. In addition, this study is able to show that haptic feedback at the user interface both improves the concentration on a parallel activity and reduces the effort during operation.

ACKNOWLEDGEMENTS

This work is founded by the German Research Foundation (DFG) within the scope of the research project “Ageing-appropriate adaptive electro-tactile touch user interfaces in a translatory application”, grant MA 4210/6-3.

REFERENCES

Harrison, C., Hudson, S. (2009). Providing dynamically changeable physical buttons on a visual display. In *Proceedings of the 27th International Conference on Human Factors in Computing Systems. Boston* (pp. 299-308). ACM Press.

Hoggan, E., Brewster, S. A. & Johnston, J. (2008). Investigating the Effectiveness of Tactile Feedback for Mobile Touchscreens. In *Burnett, M., Constabile, M. F., Catarci, T., Ruyter, B.,,Tan, D., Czerwinski, M. & Lund, A. (Hrsg.) Proceedings of the 26th Annual Conference on Human Factors in Computing Systems.* New York (pp.1573-1582). ACM Press.

International Organization for Standardization. (2011). Ergonomie der Mensch-System-Interaktion. Teil 910- Rahmen für die taktile und haptische Interaktion (EN ISO 9241-910).

International Organization for Standardization. (2017). Ergonomie der Mensch-System-Interaktion. Teil 112- Grundsätze der Informationsdarstellung (EN ISO 9241-112).

Koskinen, E., Kaaresoja, T., Laitinen, P. (2008). Feel-good touch: Finding the most pleasant tactile feedback for a mobile touch screen button. In *Proceedings of the 10th International Conference on Multimodal Interfaces.* Chania (pp. 531-538). ACM Press.

Schmid, P., Winterholler, J., Maier, T. (2019). Untersuchung zum Entlastungspotential des visuellen Informationskanals durch das nutzerzentrierte Design eines Drehbedienelements. Stuttgarter Symposium für Produktentwicklung 2019.

Schmid, P., Maier, T., Wizani, M. (2019). Electro-tactile feedback as support for an adjustment task on touch control elements?. In: *eProceedings Human Systems Integration (HSI).* Biarritz.

Schmid, P., & Maier, T. (2020). Adaptiv elektrotaktile Feedbackgestaltung zur Kompensation altersbedingter Verluste bei der Bedienung von Touch-Bedienoberflächen. *GfA Frühjahrskongress 2020: Digitaler Wandel, digitale Arbeit, digitaler Mensch?* GfA Frühjahrskongress.

Siegmann, S. & Notbohm, G. (2013). Noise in hospitals as a strain for the medical staff. In: *The Journal of the Acoustical Society of America. 133(5). 3453.*

VDI/VDE, Gesellschaft Mess- und Automatisierungstechnik. (2015). Gebrauchstaugliche Gestaltung von Benutzungsschnittstellen für technische Anlagen. *Blatt 3: Merkmale, Gestaltung und Einsatzmöglichkeiten von Benutzungsschnittstellen mit Touchscreens*. VDI/VDE 3850.

Winterholler, J. (2019). Haptische Informationsübertragung von Drehmomentverläufen im Kontext einer Haupt- und Nebenaufgabe. Universität Stuttgart, Stuttgart. Institut für Konstruktionstechnik und Technisches Design, Forschungs- und Lehrgebiet Technisches Design, Dissertation.