Tactile signals in a signaller workplace:

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Abstract

The haptic sense is seldom used in railway technology. This paper explores if using the haptic sense (in form of a tactile signal) to transmit information in an unobtrusive manner can be used in an operations control room. To gain more insight, an experiment was conducted in a railway laboratory where persons working as signallers became randomized tactile signals transmitted via a smartwatch. They were asked to record each time they recognized a signal. At the same time, they had to give a short rating of their subjective stress level. After the end of the session, participants filled in a short questionnaire to give their opinion of the suitability of the method. Overall, the participants were not overly disturbed by getting tactile signals. They see them as a valid way to transmit information. However, not all signals were recognized so the reliability of transmission needs to be raised.

Keywords: haptic signals, railway operations, railway signallers, tactile signals

1 Introduction

Railway signallers work in a very complex environment. They get very different information which they need to process in a timely manner. Modern technology can help to structure how information is provided and can therefore help them to work efficiently. While it is typical to transmit visual and acoustic signals, the usage of haptic signals in railway signaller workplaces is not known.

In our paper, we analysis if haptic signals transmitted by a smartwatch can be used in a railway signaller setting, using the perceived subjective stress level as well as the grade of physical interaction as condition.

2 Railway operations

To have a train running on schedule, a seamless coordination between infrastructure, control systems, operations control and the train itself is necessary. While in modern system installations many processes are automatic, the train signaller remains the one responsible for the safety of operations and needs not only to monitor the operation but also has several functions to fulfil. To allow him to do this safely and punctual, it is necessary for the signaller to always have up to date, reliable information available. Naturally, this means that he/she1 receives many information which need to be structured. This is especially important when working in control centres with electronic interlockings where a large area is controlled by a single person. Another influencing factor in large control centres is the fact that information transmission needs to be unobtrusive as several signallers are working in close proximity.

In older installations, there are usually less information to be transmitted and often a signaller works alone in an interlocking. Here, it is more important to make sure that no information is forgotten as, e.g. being bored and under challenged can lead to errors.

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[1] For ease of use we will use the male form (especially for pronouns) in the following text. Of course, female and diverse persons are always included.

3 Haptic/Tactile Signals

3.1 Definition of haptic/tactile signals

In (Hayward et al., 2004) it is defined that "*The word "haptics" refers to the capability to sense a natural or synthetic mechanical environment through touch*." Often, haptic feedback is distinguished in tactile feedback and kinaesthetic feedback. For our experiment, tactile feedback was used. Tactile perception describes the reception of stimuli via the skin. The perception of these stimuli takes place through receptors distributed over the entire body. The receptors for mechanical stimuli, also called mechanoreceptors, are located in the outer layers of the skin and enable the perception of pressure, touch, vibration and tension (Grunwald et al., 2001). In order to trigger a sensation on the skin, the stimulus intensity must exceed the threshold known as the absolute threshold (Pape et al., 2014). Compared to the auditory and visual sensory channels, tactile information can be perceived most quickly with a reaction time of approx. 80-150 ms (Gerke, 2015).

Even if the physical parameters of vibration are the same, the individual perception of vibration can differ greatly between people. For example, physiological aspects (age, gender and skin condition) and psychological aspects (concentration, motivation and intelligence) influence the individual perception threshold. (Manteuffel and Bärenz, 2012). This needs to be taken into account when implementing tactile feedback in work processes.

3.2 Multimodality

Regarding multimodality, it needs to be distinguished between transmitting the same information over different channels and transmitting different information over different channels. As we do not expect that tactile signals are used for any type of safety related information, the first approach will not be relevant. However, given the amount of information that overall is transmitted to a signaller, the second approach would be valuable.

That the approach will work can be argued using the multiple resources model according to Wickens et al. (2012). It represents the human resources for the simultaneous performance of cognitive processes. A limitation of the cognitive system is assumed, in which the total capacity of the cognitive system is composed of different, independent individual capacities called dimensions. The model postulates that two simultaneously executed tasks interfere with each other if they require the same resources. The use of different resources allows several tasks to be carried out in parallel without loss of performance.

Wickens et al. (2012) classify resources into the following four dichotomous dimensions:

(a) Stages: perception, cognition, reaction.

b) Modalities of perception (modalities): visual, auditory, tactile

c) Visual channels (visual processing): focal vs. ambient

d) Processing modes (codes and responses): spatial vs. linguistic

3.3 Tactile displays

Tactile displays vibrate. Vibration refers to mechanical oscillations of bodies and substances (BAuA, 2020). A vibration is characterised in particular by frequency and amplitude. The generation of vibration in tactile displays is done by motors, so that the tactile stimulus can be classified as a forced and undamped vibration (Irretier, 2000). The vibrations are in general sinusoidal because most motors generate the vibration through rotating masses. When designing tactile displays from scratch, thoughts need to be given to frequency, amplitude, specific pattern etc, considering where the display will be used and which and how much information needs to be transferred. However, as the smartwatch to be used in the experiment can only be partially manipulated, we will not go into detail here.

Tactile displays can be classified in terms of the way they present information. With passive displays, the user only receives the information by actively touching the device, e.g. with Braille. Active displays, on the other hand, transmit stimuli or information to people without them having to focus their full attention on it. The best-known examples of this are smartphones that emit an alarm by means of vibration when muted (Haas and van Erp, 2014). In our experiment we use active displays.

3.4 Existing applications of tactile signals

The following examples show how tactile signals are used to transmit information in a safety critical context. They were chosen to show a variety of application opportunities. The examples were collected in (Möller, 2021).

Warning system for stall detection in aviation: Most civilian and military aircraft are equipped with a so-called stick shaker, which triggers a vibration of the control horn to warn the pilot of the onset of a stall (SKYbrary, 2019).

Flammable and toxic gases: When working in the immediate vicinity of flammable and toxic gases, an individual warning device continuously checks the ambient air with a sensor and alerts the user in case of a dangerous concentration of harmful gases. The device warns by acoustic, tactile and optical signals. (Industrial Scientific, 2020; Schultheis, 2015).

Forestry: The "D2Forest" system consists of two communicating components, the "Beeper" and the "Keeper". If a forestry worker is in the danger zone of a forestry machine, both parties are alerted visually, acoustically and by vibration via their devices (Forst&Technik, 2016).

Automotive industry: The automotive industry has identified potential for haptic feedback through the steering wheel, the accelerator pedal and the driver's seat. Car models with multimodal warning systems including components with tactile feedback have already been introduced on the market (Choi and Kuchenbecker, 2013; Gaffary and Lécuyer, 2018).

Aids for the visually impaired: Smart canes for the blind serve as aids that recognise obstacles and warn the user by means of vibrations in the handle, as well as wristbands that navigate the user with exclusively tactile stimuli through a coupling to the smartphone (Hagen, 2017; Drees, 2019).

3.5 Tactile signals in the railway context

Today’s operations control rooms usually have alarms in form of acoustic or optic signals. In large operations control rooms with many signallers working alongside, this can lead to errors, additional stress or confusion. That effect was shown, e.g. for acoustic signals by Lumsden, 2008. But it is not only a question of convenience. A study published by Wegener et al., 2011 has found that up to 40 percent more information can be retained if it is transmitted hapitcally. While the haptic channel is used in the several industries as seen above, there are no significant applications in railways so far.

In Burkhardt et al., 2017, the general applicability of haptic signals as part of safe and reliable information transmission was discussed. In Burkhardt et al., 2018, experiments were described which explored the general suitability of haptic signals emitted from a smartwatch in a railway environment. For one, it was shown that signals were recognized in a timely manner even in a running train. And secondly, the ability to recognize haptic signals while performing a supervisory task was demonstrated.

4 Experiment

4.1 Research questions

Tactile signals can help to guide a signaller without using the auditory or visual channel. To do so, it needs to be researched how well a tactile signal can be identified. For a final and conclusive decision many different dependencies need to be researched. In the following experiment we will look at the following aspects:

- How well are tactile signals given by a smartwatch recognized by a participant?

In detail, three dependencies will be explored further:

- Is recognition of the tactile signals depending on the chosen signal pattern? If it can be shown that all signals are perceived similarly reliable, this can later be used to transmit different information with different signals.
- Is there a dependency to the subjectively perceived stress level? Railway is all about reliability and safety. Even if it has no direct safety relevance, it is necessary to make sure that the dependency between stress and signal recognition is well understood and the system is modelled taking this into account.
- Are tactile signals better perceived when doing a more passive work than when being active? While the aspect of being less intrusive is very important for a future application in an electronic interlocking/modern control room, the advantages of such a system to transmit information might be even more necessary in an older type of interlocking as here modern means of information transmission and display are not so readily available.

Finally, the subjective opinion with regards to tactile signals was derived:

- Do participants think that tactile signals should be used in a control room?

4.2 Method

The following experiment was conducted. A participant is scheduled to work at an interlocking simulator. The participant is working as railway signaller for about 45-minutes. He must fulfil the demands of the ongoing operation. These are supervision of the current railway traffic situation, setting new routes for trains entering the system, manually setting signals or points in a specific position in areas where automatic route setting is not possible, communication and other tasks. As the work is done in a network of six interlocking stations which are all manually handled, disruptions are possible and will happen randomly. The experiment was done in three settings:

- signaller working at a mechanical interlocking (two versions: signaller mechanical interlocking and warden mechanical interlocking; the main difference is the amount of responsibility)
- signaller working at an electromechanical interlocking
- signaller working at an electronic interlocking (solid state interlocking)

During the experiment, at random times (the minimum time between two signals is 2 minutes and the maximum is 4 minutes), a smartwatch gives one of three possible different tactile signals. The signals are

- long vibration, long pause, long vibration,
- short vibration, long pause, short vibration and
- long vibration, long pause, short vibration, long pause, long vibration, long pause, short vibration.

The long signal part is approx. 400ms and the short one 100ms long. Each time the signaller recognizes that a signal is transmitted, he makes a note in an app running on a tablet, marking his subjectively perceived state of stress on a scale from 0.5 to 7. The watch and the tablet are synchronized and all information are stored in one protocol for each test. At the end of the experiment, participants answer a short questionnaire regarding the overall experience with the smartwatch and the personal perception of it. The participants have the opportunity to make suggestions if and how a smartwatch can be used in a signaller setting. Questionnaires are only given out once even if a participant is participating twice on different interlockings.

4.3 Equipment

Railway lab of TU Berlin (EBuEf)

The Chair of Railway Operations and Infrastructures of the TU Berlin owns a railway laboratory consisting of an extensive model railway display, where trains running on a schedule are controlled by interlockings of different types. This leads to very authentic railway operations in the experiment as several disruptions occur due to, e.g. the abilities of the other people involved in the operations at that time. It was discussed to use a pre-recorded operation with distinctive disruptions, but this idea was not followed. The advantage of using a pre-recorded set would have been that the operations would be comparable in all experiments. However, as the abilities and experiences of the participants as well as the concrete demands on each signaller varied it was decided that the subjective feeling of stress would be sufficient as condition in this experiment and so the integrated approach was followed. The same timetable was used in all settings and as it is developed especially for educational purposes it is supposed to put a comparable operational requirement on all interlockings.

Figure 1: Railway laboratory of TU Berlin

Interlockings

Three types of interlocking were used in the experiment.

The simulation of the railway electronic interlocking (ESTW, solid state interlocking) is based on the German variation of the electronic interlocking but was programmed by the chair. It very closely resembles the original German interlockings in optic and functionality, which is proven by the fact that it is used regularly for teaching of future signallers. In an electronic interlocking the signaller sits at a chair, using a mouse to push buttons on the screen. From time to time it is necessary for him to make or get short phone calls. ESTW are the most common interlockings (based on controlled units) and (besides some very recent, rather prototype-kind off, new developments) the most advanced ones.

Mechanical interlockings (MInt) are the oldest type of interlocking. Each interlocking consists of a row of large levers which are used to e.g. set switches and signals. The work of the signaller is rather strenuous as the levers are heavy and have to be moved up and down quite frequently. In the experiment, two different mechanical interlockings were used: a signaller one (MINt sig.) and a so-called warden one (Mint ward.). The actual work is the same, however the signaller is having the authority and in general has more to do than a warden. Additionally, both warden and signaller have to block trains, that is they have to use another tool where they move a crank lever.

The electromechanical interlocking (EmInt) was developed around 1900 with the goal to reduce the physical strain on signallers. Instead of levers, small knobs had to be turned and brought into certain positions to set switches, routes and signals. The crank lever for blocking has to be used also.

The interlockings were chosen because of the different level of physical activity involved in working with them. The physical activity can be rated from low to high as follows: ESTW < EmInt < Mint.

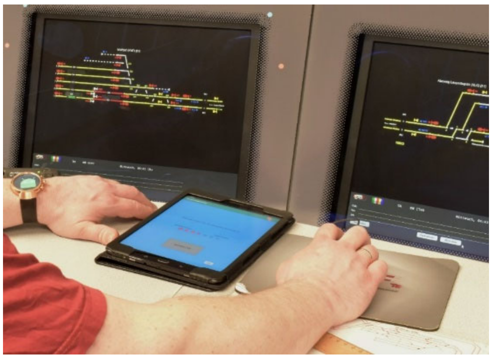
With regards to MInt for warden and signaller, the physical activity should be comparable.

Smartwatch/Tablet/ Software for recording reaction on stimulation (Figure 2)

The used smartwatch was model ASUS ZenWatch 3 (WI503Q). Main criteria for choosing this watch was its AndroidWear operation system. In combination with an Android tablet or smartphone it was relatively simple to setup a program controlling the behaviour of the watch and collect the rating of the users subjectively perceived state of stress. Unfortunately, as it is a commercial watch the exact specifications of the tactile signal are not known.

Different Android tablets were used to collect the stress ratings. Because the tablets have no influence on the haptic characteristics of the used smartwatch having different models is acceptable. The software running on the smartwatches and the tablets were the same for each device type. The software on the smartwatch was a simple listener task waiting to start one of the three given different tactile signals. The software on the tablet controls by chance which tactile signal should be given by the smartwatch. The user interface of the software gave the user the opportunity to select the stress level. Both information, the random selected signal type and the selected stress level were stored together with a time stamp in two different files on the tablet for further evaluations.

Figure 2: Interlocking screens, tablet and smartwatch



4.4 Participants

There were two groups of participants. The ESTW studies were done with people who are members of the EBuEf associations and responded to a call for participation. Their experience in working with the ESTW varied but all were knowledgeable enough to start working at an ESTW without further instructions. ESTW data was collected in November 2019. The participants in the studies with the MInt and EmInt were students who participated as part of their course work. As such, the same student might have worked on different interlockings during different runs of the experiment. They did have at least several hours of experience before participating in the study. Data was collected in December 2020 and January 2021.

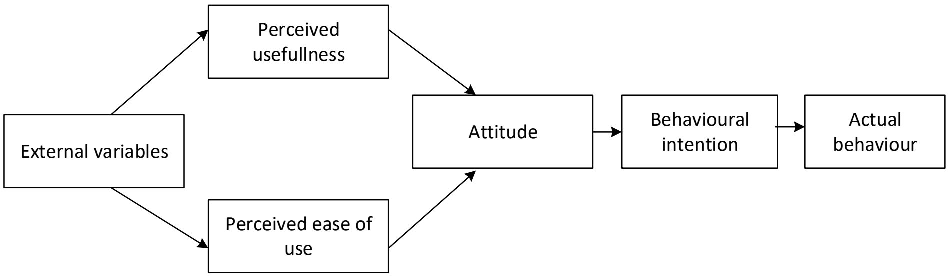
Overall, the level of expertise varied between the groups. The variable we assessed in the experiment was stress. Therefore, having different level of expertise does not lead to misleading results as it can be argued that the level of expertise relates directly to the subjectively perceived level of stress.

4.5 Questionnaire

The development of the questionnaire was done using the basic idea of the Technology Acceptance Model (TAM). The Technology Acceptance Model was first introduced by (Davis, 1989). It helps to understand and evaluate the relationship of users with potential new technologies, looking especially at the perceived usefulness and perceived ease of use. It is assumed that users are more likely to adopt a technology with a high expected usefulness.

The general structure of the TAM is presented in Figure 3.

Figure 3: TAM Structure (based on (Davis, 1989))



We used the general idea of the TAM to evaluate the perceived usefulness and the perceived ease of use as well as the behavioural intention. Regarding external variables, we asked participants regarding age and experiences as signaller assuming that these two variables can have an influence on the results obtained. We did not look at attitude in detail and there was no actual behaviour to be observed as we have no final system setup to be actually used in an operations centre.

To gather the necessary information, a questionnaire was provided. The questionnaire was in German, due to page limit of this paper we only give the English translation as done by the authors.

Table 1: Questionnaire structure

External variables	
Age groups	18-25, 26-40, 40-60, over 60
Practical Experience as signaller	yes/no
Perceived Usefulness	
I can imagine that tactile alarms can be used in an interlocking	5-point-Lickert scale from “do not agree” to “completely agree”
Ease of Use	
I perceive the tactile signals at the arm as uncomfortable	5-point-Lickert scale from “do not agree” to “completely agree”
I perceive the tactile signals as hindering	
I prefer acoustic signals to tactile ones	
I prefer optic signals to tactile ones.	
I assume that most people would be able to work with a tactile signalisation	
Intention of Use	
For which messages would you accept tactile alarms?	Open question
Further suggestions	Open question

We limited the number of questions and kept it very simple. We only have one question regarding Perceived Usefulness. We expected that only very few of the participants would have a detailed knowledge of how an interlocking works. However, this knowledge is crucial to actually have an opinion regarding usefulness. We focussed on Ease of Use as we did not expect that answers to this correlate significantly with prior operations experience. We have one open question regarding Intention of Use. Here, creativity is a bonus and so we think and expect that even without having detailed practical knowledge of working as a signaller people can provide good and helpful suggestions. Lastly, we included the option for participants to give further feedback and additional comments. This way, we not only got a structured feedback, we also made them feel more included in the experiment and in the ongoing research. Details can be seen in Table 1.

5 Results

5.1 General data

Table 2: Overview

	ESTW	MInt/EmInt
No. participants	15	17[2]
gender	m - 14, f – 1, d - 0	m – 13, f – 3, d - 0
Experience as signaller	y – 4, n - 11	y – 2, n - 14
Age goup 18 to 25	5	16
26 to 40	8	0
40 to 60	1	0
over 60	1	0

5.1.1 Quantitative data

There were systematic aspects to take into consideration after evaluation of the data. Most participants obviously pushed the recording button before the experiment actually had started, probably to just try it out. These data sets were not considered. Also, in some cases the last stimuli came just at the end of the experiment. Therefore, if there was no reaction to the last stimuli, this data was not part of the evaluation

How well are tactile signals given by a smartwatch are recognized by a participant?

Table 3: Signals

	MInt (sig.)	MInt (ward.)	EmInt	ESTW
Given signals	156	155	143	218
Recognized signals	106	123	92	202
Missed signals	50 (32%)	32 (21%)	51 (36%)	16 (8%)
Wrongly identified signals	-		-	10

The results regarding the given, missed and wrongly identified signals can be found in Table 3. Especially in ESTW, tactile signals are well identified. With regards to the ten false positives at the ESTW, seven were given by the same signaller. It should be tried to better understand why such a case happens.

[2] Questionnaires were only given once to each participant. As some students participated more than once, the number of data and the number of questionnaires does not match; one person participated but did not give back the questionnaire.

Is there a dependency to the subjectively perceived stress level?

The overall data support the hypothesis (Table 4), even though not mathematical correlation can be given yet. Especially helpful is the comparison between MInt signaller and MInt warden, who have the same task, slight differences in responsibility and operational demand. The lower stress level of the MInt warden leads to a lower rate of missed signals. Significance is missed only slightly, so more experiments will be conducted.

Table 4: Dependency of missed signals to stress level

	MInt (disp.)	MInt (ward.)	EmInt	ESTW
Missed signals (percentage)	50 (32%)	32 (21%)	51 (36%)	16 (8%)
Average stress level	3,09	2,2	3,67	2,34

Is recognition of the tactile signal depending on the chosen signal pattern?

In three of four studies the signal type two was less well recognized than the two other ones (Table 5). While the data is not yet conclusive it can be assumed that the pattern of the tactile signal does have an influence of how well it is recognized.

Looking again at the signal types,

1. a long vibration, long pause, long vibration,
2. a short vibration, long pause, short vibration and
3. a long vibration, long pause, short vibration, long pause, long vibration, long pause, short vibration.

the second signal type is the only one with short vibration length. Reason might therefore be that short signals are not easy to recognized especially when doing physical work. This leads to the conclusion that a minimum signal length should be set. While 100ms is still in the acceptable length as given in literature (see Van Erp 2002), it does not seem to be long enough in the given context.

Table 5: Percentage of missed signals

	MInt (disp.)	MInt (ward.)	EmInt	ESTW
overall	32%	21%	36%	7%
Signal type 1	32%	21%	33%	8%
Signal type 2	38%	24%	50%	7%
Signal type 3	28%	17%	29%	7%

Are tactile signals better perceived when doing a more passive work than when being active?

It was assumed that the percentage of missed signals gets lower when the signaller does less physical work. Looking more into detail of the data used to generate Table 4, the ratio of missed signals to given ones for each participant was calculated. A t-test with $\alpha=0,05$ has shown, that the results are significant for ESTW to MInt (Signaller) and ESTW to EmInt. As the subjective stress level of the participants of MInt and EmInt is the same on average (see Table 4), this difference very likely comes from the higher physical demands of MInt/EmInt in comparison to ESTW. There is no significant difference between MInt and EmInt with regards to missed signals even so the physical strain is very different. It needs to be further researched if another aspect influences the missed signal ratio, e.g. the cognitive demands coming from working it.

5.1.2 Questionnaire

Due to an organisational error, one question had to be removed when assessing the results of the questionnaire. The results of the remaining, closed questions can be found in Table 6, for the open question in Table 7. It was decided to keep the results from the ESTW study (professionals/members of EBuEf association) and the MInt and EmInt (students) separate as the former one have overall a more general overview of railway operations than can be assumed from students. All questions had to be answered on a 5-point-Lickert scale from "do not agree" to "completely agree"

Table 6: Results of the Questionnaire (EBuEf association (ESTW) / students (MInt/EmInt))[3]

	average	median	Standard deviation
Perceived Usefulness			
I can imagine that tactile alarms can be used in an interlocking	3,47/3,19	4/3	1,13/1,22
Ease of Use			
I perceive the tactile signals at the arm as uncomfortable	1,47/1,88	1/2	0,64/0,89
I perceive the tactile signals as hindering	1,73/1,63	2/1	0,80/0,89
I prefer tactile signals to acoustic ones	3,27/2,64	4/3	1,28/1,34
I prefer optic signals to tactile ones.	3,20/3,00	4/3	1,37/1,32
I assume that most people would be able to work with a tactile signalisation	3,60/3,36	4/3,5	1,06/1,15

Perceived usefulness

On a 5-point-Lickert scale from "do not agree" to "completely agree", the average of the answers lies at 3,47/3.19. All participants agree with the statement; however, the students are less convinced. People can see tactile signals used in an interlocking.

Ease of Use

Tactile signals given by a smartwatch are not seen as uncomfortable or hindering.

Regarding the relation of tactile signals to acoustic and optic signals, optic signals are preferred to tactile ones which are preferred to acoustic ones. This shows the potential of tactile signals. However, to verify these results, especially the relationship and importance of tactile, acoustic and optic signals in comparison to each other should be evaluated.

Lastly, participants very well can see tactile signals used by people. No major barrier is expected.

Intention of use (Table 7)

The question was open and allowed the participants to give feedback and general ideas about the integration of tactile signals. It needs to be considered that railway operation varies widely within a country (due to different technical solutions) and even more between different countries. Therefore, not all given suggestions might make sense to an international, non-German reader. Some people gave more than one suggestion, many participants had no suggestions at all.

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[3] For the evaluation of the results, the Likert-Scale answers were always coded from 1 (do not agree) to 5 (completely agree).

Table 7: Results of the Questionnaire for Intention of Use

What should be transmitted via tactile signal…	number of mentionings
information about expected trains	8
information about disruptions	7
warnings from e.g. defect detectors	2
incoming phone calls	3
general information necessary for dispatching trains	2
information if a train is waiting on one of the tracks	1
information about leaving trains	1
individual personal information/alarms	1
backup for information in case that a person needs to leave the operations desk for a (short) time	1
information about urgent actions	1
general uncritical information/ no safety-critical information	3
train numbers	1

Regarding the research question, the following conclusions can be drawn.

Do participants think that tactile signals should be use in an operation room?

Yes. However, details need to be looked at and the areas of implementation need to be carefully identified.

Further suggestions

Participants gave significant less feedback as further suggestions (12 replays). This feedback was also less systematic, partly concerning feelings, partly technical aspects. The only aspects which was mentioned more than once was the concern that the vibration was not strong enough to be easily recognized. Here, more research is necessary to determine what a "good vibration" - that is a good haptic signal given by a smartwatch - actually is.

Conclusion

The experiment gave a first feedback with regards to a potential use of haptic signals/tactile screens in a railway control room. The results are promising. Signals are in general easy to identify, a dependency to physical activities and stress could partly be shown. More research is needed. Overall the participants gave the technology a good rating. They see different scenarios for including such technology in real live setting. However, there are still several issues to be researched, especially about what and when information should be transmitted via haptic/tactile signals and how (strong) a vibration should be.

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