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SUITCEYES

01.01.2018 – 30.06.2021

Smart, User-friendly, Interactive, Tactual, Cognition-Enhancer, that Yields Extended Sensosphere
Appropriating sensor technologies, machine learning, gamification and smart haptic interfaces

[Deliverable D7.5]

Demonstrators Of Gamified Scenarios Iteration II Navigation & Communication With The HIPI

Courtesy of LightHouse for the Blind and Visually Impaired, see http://lighthouse-sf.org

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Dissemination level		
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CO	CONFIDENTIAL, restricted under conditions set out in Model Grant Agreement	
CI	CLASSIFIED, information as referred to in Commission Decision 2001/844/EC.	

Deliverable Type		
R	Document, report (excluding the periodic and final reports)	
DEM	Demonstrator, pilot, prototype, plan designs	X
DEC	Websites, patents filing, press & media actions, videos, etc.	
OTHER	Software, technical diagram, etc.	

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Glossary	
Abbr./ Acronym	**Meaning**
Dx.y	Deliverable of Work Package x, Number y
HIPI	Haptic Intelligent Personalized Interface
PCB	Printed Circuit Board
PWM	Pulse Width Modulation
GND	Ground

SCL	Serial Clock
SDA	Serial Data
GPIO	General Purpose Input/Output
I2C	Inter-Integrated Circuit

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Executive Summary

In this deliverable, we report on two separate developments. First, we describe the improvements of the prototype implementing the gamified scenario *Follow Your Partner* and its evaluation. Second, we present the prototype of a new input device that was evaluated in a proof-of-concept study.

We added a 4-by-4 grid of vibration actuators on the back of the third-generation prototype of the *Follow Your Partner* scenario. The 4-by-4 grid is used to convey short messages, such as information on one's own progress and start/end of the game. Additionally, we have added the opportunity for users of the prototype to request information on the games' progress. Both will be evaluated in a user study with German participants as soon as possible with regard to current situation with the COVID-19 pandemic (as of: June 30th 2020). However, the study is already prepared and described in D7.4 *User Evaluation II*. The structure of this study is similar to the pilot study conducted in November 2019.

The concept of a "Tactile Board" as an interface between the deafblind individual and communication partners or the HIPI has been developed. This concept is intended to form the basis of the next gamification scenario on enhancing social interaction. A prototype of this concept was implemented and will be evaluated in a proof-of-concept study with German participants, as soon as the situation allows the conduction of user studies (as of: June 30th 2020).

Introduction and Rationale

As described in D7.4 *Outlook*, the goal of our work in the last few months was twofold. On the one hand we aimed at improving the prototype we have already developed (*Follow Your Partner* scenario), on the other hand, we prepared the basis for the development of the next gamified scenario that will foster social interaction.

Third-Generation Prototype of "Follow Your Partner" Scenario

For our main target group, individuals with deafblindness, there are devices that convey information via simple vibration patterns, such as time or the filling level of a cup [1, 11, 13]. These devices are mostly targeted to one specific use case, which makes the understanding of the vibration patterns easy. The HIPI of SUITCEYES, however, aims at conveying complex information in different contexts. This requires a wide range of different vibration patterns and a deep understanding of the system itself. To maximize the use of the HIPI for individuals with deafblindness, they need to carefully learn the various functionalities and vibration patterns. Therefore, the process that teaches users how to use and understand the HIPI is crucial.

Our goal is to provide users of the HIPI with an intuitive and fun learning process. This is accomplished by implementing gamification scenarios that teach users how to use the HIPI. The scenario *Follow Your Partner* is the first gamified scenario that was implemented into the HIPI. It was created to teach individuals with deafblindness how to navigate with the HIPI and to understand different vibration patterns.

The feedback from the pilot study in November 2019 was very positive (see D7.4 *User Evaluation II*). Participants seemed to have fun and learned the different vibration patterns very quickly. The results encouraged us to improve the scenario and the prototype, in order to make the teaching process even more intuitive. In another user study this year, we evaluated the new prototype and the gamified scenario with more participants. In the section *Prototype I: Gamification of Navigation* the improvements of the prototype are presented, followed by a description of the evaluation and its results.

Prototype As Foundation For Fostering Social Interaction

As explained in the previous deliverable (D7.4), the next gamified scenario will focus on fostering social interaction for users of the HIPI.

Due to the extent of the dual sensory loss, individuals with deafblindness may present a high risk of developing depression, social isolation and reduced self-confidence [4, 5]. Therefore, our goal is to increase the quality of life of individuals with deafblindness, by supporting meaningful social interactions between them and their interaction partners.

The challenges individuals with deafblindness face in social interactions were first revealed in the user interviews conducted in 2018. The participants mentioned social interactions as the most important aspect they enjoy about games and also the most important aspect they miss about games they had to abandon due to an aggravation of their disability. In a co-creation session with an individual with deafblindness, a family member, a caregiver and several researchers the challenges in social interaction were specified. The participants of this co-creation study highlighted that several aspects can be enhanced by assistive tools, e.g. initiating social interactions, language and conveying non-verbal or environmental information [10].

As a basic requirement to enhance and foster social interaction of individuals with deafblindness, an input device needed to be developed. We have created a prototype that gives users of the HIPI the opportunity to provide input, such as queries, messages or commands. In the next step, the new prototype was evaluated in a proof-of-concept study, in order to investigate, if this way of providing input is suitable for users of the HIPI. A detailed description of the concept and the implementation of the tactile board can be found in *Prototype II: Gamification of Social Interaction*.

Concept Integration: Haptograms

In both prototypes described in this deliverable, "Haptograms" are an important concept. Especially, for the *tactile board* (see section *Prototype II*), for which haptograms were selected as the primary way of communication between individuals with deafblindness and their communication partners or the HIPI. Thus, this section briefly introduces the concept of haptograms.

In this context, haptograms are defined as dynamic dot patterns on a 4-by-4 grid [3], either represented on a textile touch screen (tactile board), or on the back of the user of the HIPI (Follow Your Partner gamified scenario). The dot patterns can encode simple words, phrases or whole concepts, depending on their definition [3]. Within the project, an extensive haptogram-vocabulary will be defined, based on words, phrases and concepts needed to send and receive messages to/from the ontology. Further, we also aim to provide users of the HIPI with the option to define their own haptograms and definitions, based on their individual needs and preferences. A first step in this direction is described in section *Prototype II – Gamification of Social Interaction.*

The concept of haptograms was adapted from a system developed by Korres and Eid [7], providing a tactile display via point-clouds, using acoustic radiation pressure. However, Korres and Eid represented tactile shapes, whereas the adapted concept in SUITCEYES represents the potential for a messaging language and therefore conveys conceptual content (i.e., ideograms and logograms). The approach of conveying conceptual content, such as ideograms, was informed by Lathinen [8] and Lathinen, Palmer and Lathinen [9], who describe how ideograms reproduced on different body parts by combinations of hand strokes, gestures or pressure can evolve into a simple, tactile language [2].

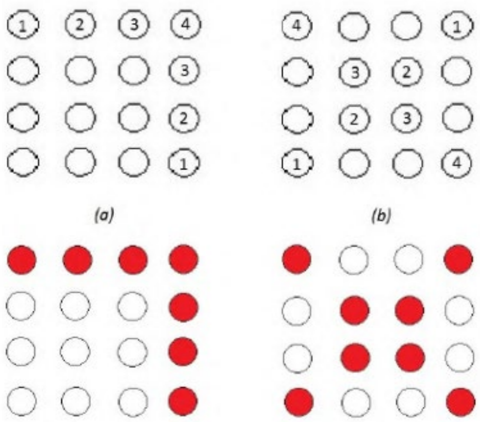

Figure 1: Unfolding sequences of two dynamic haptograms. Source: [2]

In our application case, in which the haptograms are meant to be displayed on the users' body, e.g., his or her back, the resolution of the tactile display was greatly reduced compared to the system of Korres and Eid, as the back has a low capacity for distinguishing signals. Like hand strokes and gestures, our haptograms are represented as dynamic patterns. More specifically, this means that each dot pattern has a pre-defined firing sequence (see Figure 1). It has been found that, on the back, dynamic patterns are much easier to perceive than static patterns [6].

Prototype I: Gamification of Navigation

This section describes the third iteration of the prototype presented and evaluated in deliverable D7.4. Several valuable insights and results could be derived from the pilot study in November 2019. Therefore, we have spent the last few months into improving both, the newly developed gamified scenario *Follow Your Partner* and the second-generation prototype.

We will start this section with a short recap about the second-generation prototype and the gamified scenario *Follow Your Partner,* next, we give details about the changes that have been made, regarding the scenario, the prototype and its hard- and software implementation. Further, we give a description of the new garment that has been developed by the Swedish school of Textiles in Borås.

In order to evaluate the adaptions of the scenario and the prototype, we have planned another user study, similar to the pilot study. The plans will be described in the end of this section. However, due do the strong impact of the COVID-19 pandemic, we were greatly restricted in our work and could not conduct the study as planned. Therefore, we will present the prototype and the study plan, however, the *Results* will be left out, as to date (as of: June 30th 2020), we could not conduct the study.

Description of the Existing Prototype

The prototype implements the gamified scenario *Follow Your Partner*, which is designed to teach individuals with deafblindness how to confidently navigate with the HIPI. Additionally, the gamified scenario can train skills, such as spatial orientation and the understanding of complex tactile feedback.

Gamified Scenario: Follow Your Partner

The gamified scenario is played in pairs of two. The wearer of the HIPI (individual with deafblindness) is an agent following a suspect, i.e. his or her partner (preferably seeing and hearing, for safety reasons). Vibrations around the waist indicate direction and distance of the suspect to the agent. The agent is asked to follow the suspect, while keeping an optimal distance. The distance information is encoded in a fast, slow or steady rhythm of the direction information.

Sometimes the suspect looks around. This is indicated by taps on the chest: the agent must stand still so that the suspect does not discover the agent. A tap on the shoulder shows that the agent can move on.

After a predefined play time, the agent is asked to catch the suspect. This is indicated with all actuators vibrating simultaneously. If the agent manages to grab the suspect during this vibration period, the agent has won the game. If the agent is too slow, the game is lost.

The Second-Generation Prototype

The second-generation prototype is a vest with 5 vibration actuators around the waist, two micro-servo actuators on the chest, two on the shoulder blades and a camera attached on the sternum, which detects ArUco markers (see D7.4) used for navigation (see Fig. 1).

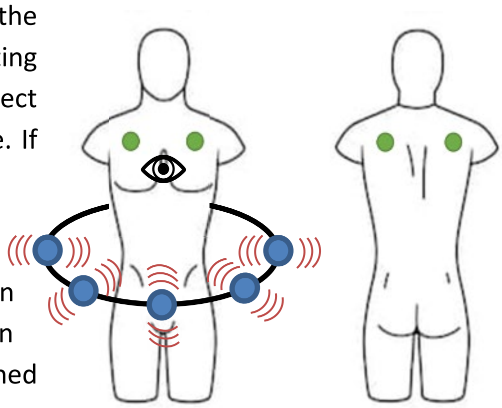

Figure 2: Architecture of second-generation prototype.

Improvements

In this section, we present the changes that have been made regarding the second-generation prototype and the gamified scenario.

Gamified Scenario: Follow Your Partner

The story of the gamified scenario has stayed the same, however, two additional features were added to the third-generation prototype:

I. the wearer of the HIPI can proactively request information on the game's progress
II. the wearer of the HIPI gets information if he or she has won or lost the game

The Third-Generation Prototype

As a result of the pilot study (see D7.4), the adaptions of the gamified scenario and with regard to future gamified scenarios, several modifications to the prototype were necessary.

Two main adaptions for the third-generation prototype were derived from the pilot study: the expandable one-size-fits-most garment should be changed in size and the micro-servo motors on the chest and the shoulder blades should be adapted.

First, the small size of the garment was designed smaller to better fit female bodies and the expanded large size of the garment was designed larger to better fit male bodies. Second, the tapping signal, indicated by the micro-servo motors were too weak to be reliably perceived *("This tapping on the back is very weak. You can make it stronger."* [P1], *"I cannot feel anything. Is there anything tapping on my back?"* [P2], *"Oh, I can feel it, but it is very weak."* [P3], *"I almost feel nothing. I am distracted by the vibrations around the waist."* [P4]). We have replaced all four micro-servo motors with only one vibration actuator on the top of the shoulder (see Fig. 2, left). The stop signal is now indicated by a continuous vibration on the shoulder. As soon as the vibration stops, the user can continue.

The biggest addition to the prototype was the integration of a 4-by-4 grid of coin-vibration actuators on the back of the prototype (see Fig. 2, right). With this grid, a high flexibility in conveying many different vibration patterns with varying complexity has been added to the prototype.

This feature was added primarily with having future gamified scenarios in mind. However, we will now already make use of the 4-by-4 grid in the *Follow Your Partner* scenario. For example, two simple vibration patterns were defined to indicate, if the agent has won or lost the game. Additionally, the 4-by-4 grid is used to inform the deafblind individual about the progress of the game.

One participant of the pilot study highlighted the usefulness of progress information for the gamified scenario. The individual with deafblindness stated that a timeline would be helpful to assess one's own progress and performance, as well as estimate the duration of the game ("*What about a timeline? I could easily see how close I am to winning. This would be motivating!*" [P2]). From the user interviews conducted in WP2, this request could be supported several times: *"I just sit around and ask myself: 'When will it be my turn again? How long will*

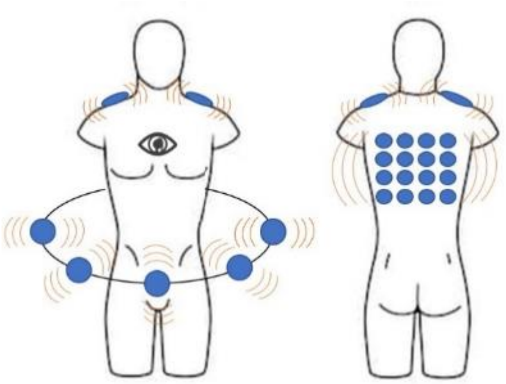

Figure 3: Architecture of third-generation prototype.

the game last? What has changed from last round?'" [P11], *"[… w]hile playing, I quickly lose track of things […]"* [P26], *"Big board games take too long and are not fun, if you have to wait so long and don't know what the others are doing and who is close to winning."* [P39]. We have taken this wish seriously and implemented a pattern that indicates the agent's progress in the game. The agent can trigger the request for progress information proactively via a physical button attached to the prototype (see Figure 3).

Figure 4: *Button used to request progress. Revision including additional details on participants with deafblindness.*

For simplicity and a proof-of-concept, progress is split into four discrete stages: 0 – 25%, 25 – 50%, 50 – 75% and 75 – 100%. Each of these stages is depicted via a separate dynamic haptogram that is expressed through the 4-by-4 grid on the back of the user's HIPI, where each vibration motor is switched on sequentially. The pattern drawn on the user's back resembles a circular progress bar filling up in a clockwise direction. Figure 4 shows all four haptograms.

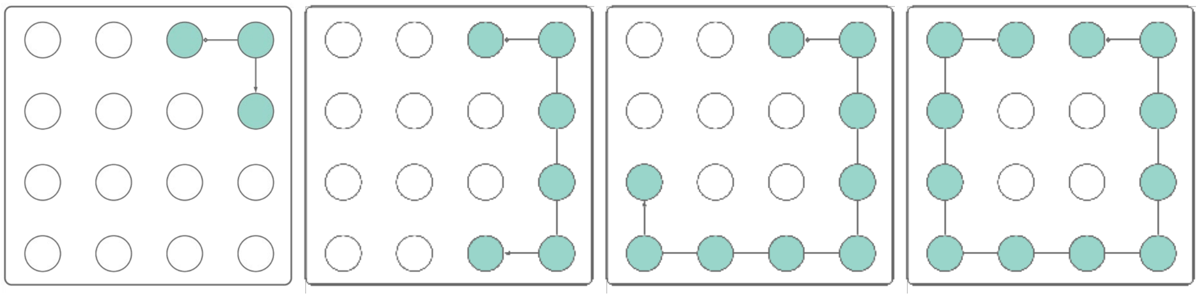

Figure 5: Haptograms conveying progress at discrete stages.

Hardware

The addition of sixteen coin-vibration motors used for the 4-by-4 grid to convey haptograms meant that several changes to the hardware became necessary. As the RedBear Duo (see D7.4) only allows up to thirteen PWM-controlled vibration motors to be connected, we decided to replace it with the Adafruit PCA9685 I2C driver (Link). This provides up to sixteen PWM outputs and can also be chained with other PCA9685 drivers. We have chained two drivers together allowing us to connect up to 32 vibration motors. One PCA9685 is connected to the Raspberry Pi's pins for SDA, SCL, GND and 3V. A single power bank provides power for the Raspberry Pi and a PCA9685 PCB. Chained drivers receive power via their connection to a preceding PCA9685 PCB.

Furthermore, we replaced the micro-servo motors used in the 2nd generation HIPI with two cylinder-vibration motors (the same ones employed around the waist). Allowing the user to request their progress along the route was made possible through the addition of a push-button connected to a GPIO port of the Raspberry Pi.

Finally, to increase the overall robustness and decrease complexity, we replaced all daughterboards with a single custom printed PCB that allows 25 PWM-controlled vibration motors to be connected.

Figure 5 shows how the individual hardware components are connected to each other.

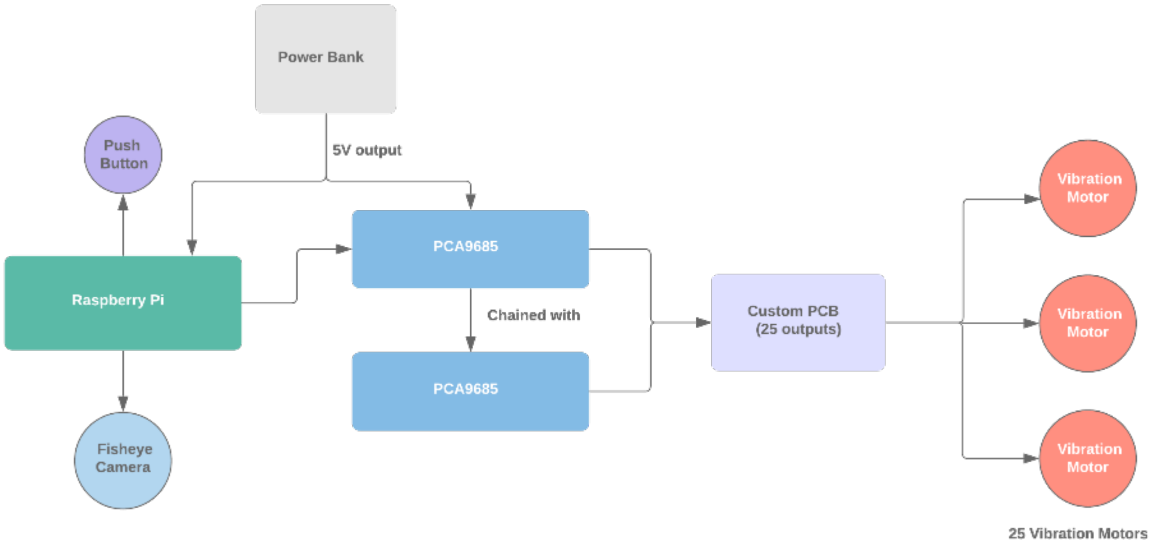

Figure 6: Improved Architecture implemented in Prototype v3.

Software

The changes to the hardware also meant adjustments in the software had to be undertaken. The code initially driving the vibration motors on the RedBear Duo was moved to a Python script running on the Raspberry Pi that uses the I2C protocol to communicate with the PCA9685 driver.

Textile

The textile of the third-generation prototype was designed by WP5 (see in Figure 7). It consists of two layers: an outer and an inner layer. The design of the outer layer is similar to the previous version (prototype II, D7.4), i.e. a one-size-fits-all design and the flexible placement of the vibration actuators via detachable pockets. However, in this prototype textile cables have been integrated, using a technique called '*pipping*'. Using this method, all cables have been tied together and integrated into the prototype which makes the prototype a lot more appealing and easier to use. The inner layer consists five individual straps, housing the 4-by-4 grid of the vibration actuators. The individual straps allow the local adjustment of each row to fit different body shapes and sizes.

Figure 7: Textile of the third-generation prototype. *Left*: Front of the vest with textile cables (green), Velcro strap for attaching the camera and pockets to place the vibration actuators on around the wait. *Right*: Inner layer with five individual and adjustable Velcro straps for creating the 4-by-4 grid.

Evaluation

Similar to the pilot study, the goal was to evaluate our gamified learning scenario *Follow Your Partner* with the improved and extended prototype. The study is described here, although it could not take place due to COVID (see results).

Research Questions

The underlying research questions for the second user study of the gamified scenario *Follow Your Partner* were threefold:

1) Are participants able to understand and distinguish the different haptic stimuli?
2) Do the participants perceive the gamified scenario as fun and useful for learning?
3) Is there a significant learning effect between the first and the third experimental trial?

Participants

In total we had planned to conduct the study with 10 participants with deafblindness from Germany. Those who already participated in the pilot study are excluded from this study, to avoid bias in the results. Any degree of deafblindness is accepted in the study, to ensure a study population representative for the highly diverse target group.

Procedure

In the beginning, all participants will be informed about the project, the goals of the study and all metrics that will be assessed. If they agree to participate in the study, they will sign a letter of consent. To facilitate this process for the individuals with deafblindness, they will be provided with all documents a couple of days before the study. We will highlight that the participation in the study is completely voluntary and participants can withdraw from the study at any time without giving reason.

In the next step, the prototype will be fitted and adapted to the participant and some functional tests of the vibration actuators will ensure that the prototype works correctly and that participants can perceive the signals. In parallel to the functional tests, the gamified scenario *Follow Your Partner* and all relevant feedback stimuli (i.e. direction, distance, stop, continue, request progress information, catch signal, start/end of game) will be explained to the participants.

The study is separated into one training and three experimental trials. In the training trial, the participant can freely explore the feedback stimuli. The experimental trials represent a stepwise learning process, in each of which new features and feedback stimuli are added to increase complexity. Each experimental trial lasts approx. five minutes and before its start, the participant gets an introduction on the gamified scenario and the newly available features, respectively. In each trial, the participant is guided along the same predefined route, featuring straight lines, two 45° turns, two 90° turns and two 180° turns (see Figure 6). The participant is guided by the experimenter, holding up ArUco Markers. Another researcher accompanies the participant, who ensures that the participant does not walk outside of the pre-defined safety zone of the route. After completing an experimental trial, the participant is asked to fill out a self-designed questionnaire on how easy-to-use the participants perceive the newly added feature(s). All items are rated on a 5-point Likert scale, ranging from “1 = String Disagreement” to “5 = Strong Agreement”. After completing the third experimental trial and also the third part of the questionnaire, the study concludes with the NASA-TLX scale [12], assessing the perceived cognitive demand of the gamified scenario.

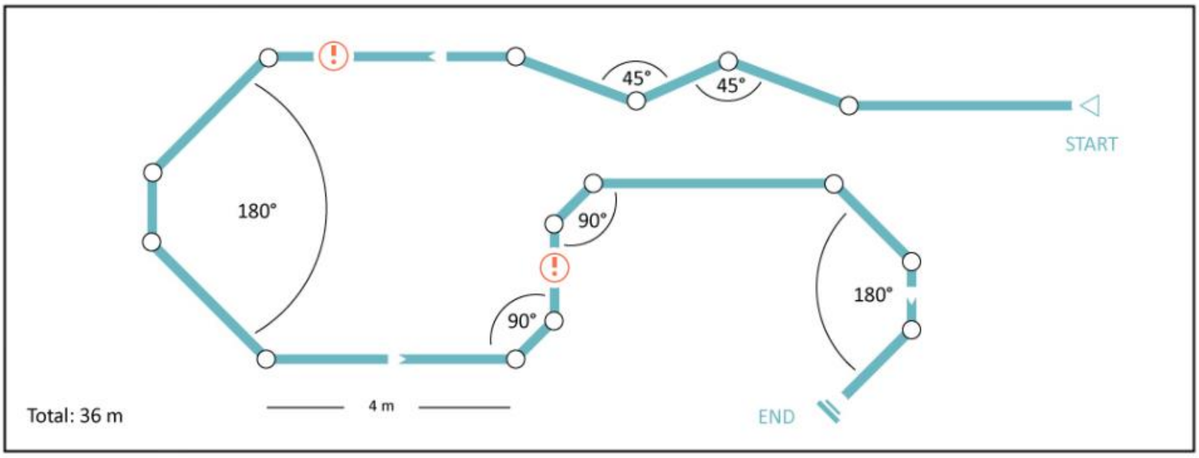

Figure 8: Predefined route for Follow Your Partner. The exclamation mark marks positions in which the suspect turned around and the agent needed to stop moving.

Training Trial 1

In this phase, the participant familiarizes with the different feedback stimuli and can ask any questions related to the gamified scenario or the stimuli. As soon as the participant feels confident, the first experimental trial starts.

Experimental Trial 1

In the first experimental trial, only the navigation (i.e. direction and distance information) with the prototype is introduced and evaluated. Additionally, the signal for the final catch event is introduced. After completing the pre-defined route, the participant is asked to fill out the first part of the questionnaire, inquiring his or her confidence during the first trial and the ease-of-use of the stimuli related to navigation (see Table 1).

Table 1: First part of the questionnaire

1. I felt confident during the first trial.	1	2	3	4	5
2. I was nervous during the first trial.	1	2	3	4	5
3. I could clearly identify the vibrations indicating the direction.	1	2	3	4	5
4. It was easy for me to follow the given path provided by the vibrations.	1	2	3	4	5
5. I could clearly identify the frequency of the vibrations (distance information).	1	2	3	4	5
6. It was easy for me to adjust the distance according to the vibration frequency.	1	2	3	4	5
7. I could clearly identify the signal to catch the suspect.	1	2	3	4	5
8. It was easy for me to catch the suspect during the dedicated time period.	1	2	3	4	5
9. In sum, the navigation with the vibrations around the waist was easy.	1	2	3	4	5

Experimental Trial 2

In the second experimental trial, besides all stimuli related to navigation and the catch signal, the participant can also proactively request his or her own progress in the game, by clicking on the physical button. After completing the second trial, the participant is asked to fill out the second part of the questionnaire, inquiring again the confidence of the participant compared to the first trial and the ease-of-use of the navigation and the new feature (see Table 2).

Table 2: Second part of the questionnaire

10. I felt more confident during the second trial.	1	2	3	4	5
11. I felt less nervous during the second trial.	1	2	3	4	5
12. I feel that I understood the navigational signals better compared to the first test.	1	2	3	4	5
13. It was easy for me to request information about my progress in the gamified scenario	1	2	3	4	5
14. It was easy for me to understand the progress information.	1	2	3	4	5
15. I intuitively understood the progress information presented on request.	1	2	3	4	5
16. In sum, the navigation with the vibration around the waist was easier compared to the first trial.	1	2	3	4	5

Experimental Trial 3

In the third experimental trial, the missing three feedback stimuli are added: the signal to stop moving, when the suspect turns around. In this trial, the gamified scenario is evaluated completely, i.e., with maximum complexity regarding the haptic feedback. The study concludes with the third part of the questionnaire, assessing comparisons to the previous trials, the ease-of-use of the new features and an overall evaluation of the gamified scenario as a whole (see Table 3). In addition, the questionnaire evaluates the perceived cognitive load of the gamified scenario on each participant, by using the standardized NASA-TLX scale (see Table 4).

Table 3: Third part of the questionnaire

17. I felt more confident in the third trial.	1	2	3	4	5
18. I felt less nervous during the third trial.	1	2	3	4	5
19. I was aware of the opportunity to request progress information.	1	2	3	4	5
20. I could easily make use of the progress request during the gamified scenario.	1	2	3	4	5
21. I did not have any difficulties with navigation anymore.	1	2	3	4	5
22. I could clearly identify the signal to stop.	1	2	3	4	5
23. It was easy for me to stop fast enough to avoid being detected.	1	2	3	4	5
24. I could clearly identify when to continue.	1	2	3	4	5
25. I could clearly identify if I had won or lost the game.	1	2	3	4	5
26. In sum, there are too many different stimuli.	1	2	3	4	5
27. In sum, I find the haptic feedback provided intuitive.	1	2	3	4	5
28. The incremental trials helped me to learn all features without difficulties.	1	2	3	4	5
29. The gamified scenario helped me to learn how to use the vest.	1	2	3	4	5
30. I enjoyed playing „Follow Your Partner“.	1	2	3	4	5
31. I would like to play this game again, if I had a vest like this in the future.	1	2	3	4	5
32. I feel confident in navigating indoors with this vest.	1	2	3	4	5

Table 4: NASA-TLX scale, final part of the questionnaire

Mental Demand:	How mentally demanding was the task?
Low	High
Physical Demand:	How physically demanding was the task?
Low	High
Temporal Demand:	How hurried, or rushed, was the pace of the task?
Low	High
Performance:	How successful were you in accomplishing the task?
Good	Poor
Effort:	How hard did you have to work to accomplish the task?
Low	High
Frustration:	How irritated, insecure, discouraged, stressed, and annoyed were you by the task?
Low	High

Results

Due to COVID-19 pandemic the study could not be conducted as planned. Even in 2021, the safety regulations for persons with impairments were too high. Instead, an extensive article on the resulting device was published: Theil, A. et al. 2020. Tactile Board: A Multimodal Augmentative and Alternative Communication Device for Individuals with Deafblindness. 19th International Conference on Mobile and Ubiquitous Multimedia (New York, NY, USA, Nov. 2020), 223–228. [15]. These results have also been documented in a video: https://www.youtube.com/watch?v=36bj-6xvPmU&t=1s

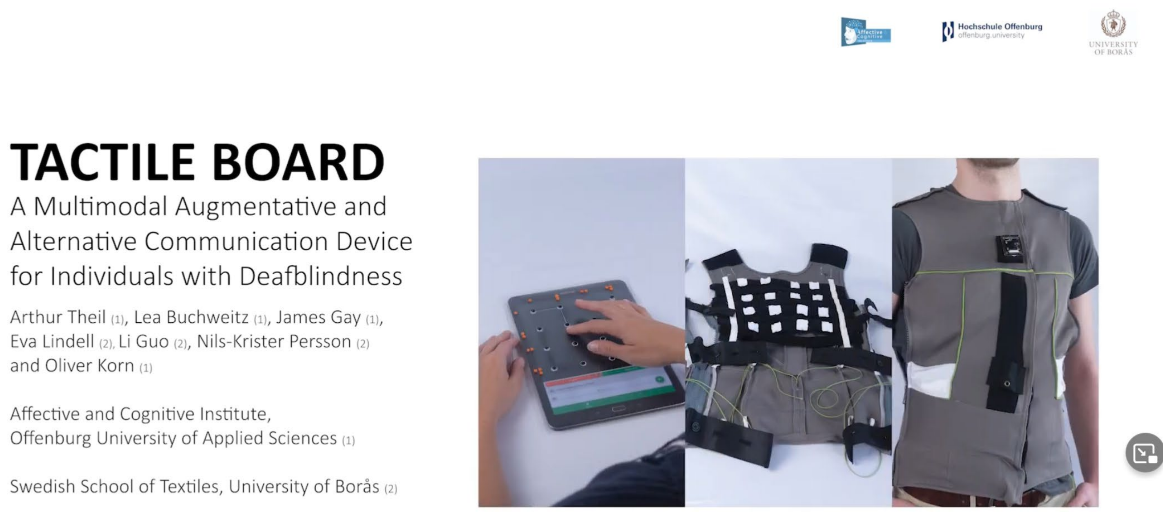

Figure 9: Video presenting the tactile board.

Prototype II: Gamification of Social Interaction

This section describes a new prototype, called the "Tactile Board" that has been newly developed during the last months. It provides the opportunity for both conversation parties, individuals with deafblindness and their impaired or non-impaired communication partners, to actively initiate and engage in conversations.

The tactile board is intended to form the basis of the next gamified scenario that will foster social interaction. In this context, the tactile board will not only empower deafblind individuals to proactively initiate conversations, social interactions or other queries, but will also provide a great learning platform for the target group to learn the language of haptograms and to become accustomed to using it as a new way of communication. The tactile board has two different modes: it can either serve for direct communication with a partner, or for sending queries to the ontology for communication with the HIPI. As this prototype is an innovative, new development that has evolved over numerous intensive discussions at HSO, our first goal is to conduct a proof-of-concept study, to assess if individuals with deafblindness perceive this device as useful and easy-to-use.

We start this section with a detailed presentation of the tactile board prototype, followed by a description of its implementation. Lastly, we report on the plans of a proof-of-concept study with individuals with deafblindness to see, how the prototype is perceived. However, as already reported in the previous section, we were unable to conduct the study due do the strong impact of the COVID-19 pandemic (as of June 30th 2020). Therefore, the study plan and the prototype will be described, however, we cannot report on any *Results* yet.

Description of the Prototype

The tactile board is the first iteration of an innovative interaction device. In this version, it provides an interface to a communication partner, which makes direct communication possible. For a proof-of-concept, only a one-way interaction is implemented: individuals with deafblindness can create simple sentences, which are recognized by the system and translated into written words, for sighted communication partners to read (direct communication). The input modality with which individuals with deafblindness provide their sentences are haptograms.

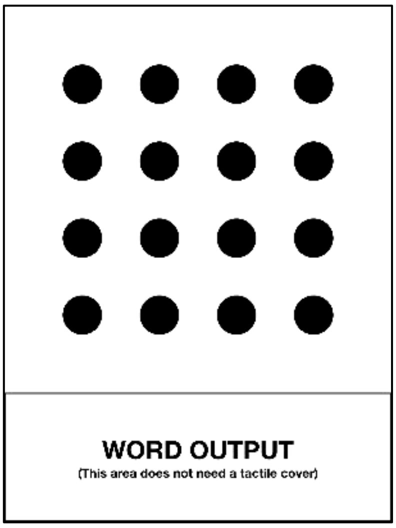

Figure 10: Concept of the user interface of the tactile board

The foundation of the tactile board is a tablet with a 4-by-4 grid of dots that can be used to draw a single stroke pattern on the touch screen (see Figure 10). Each single stroke pattern represents the input of a haptogram. If a known pattern is entered, the dictionary of the tactile board recognizes and translates the pattern into written English and displays it on the bottom of the touch screen (see Figure 6). The dictionary of the tactile board is customizable, which makes the addition of new pattern-word pairs possible. More specifically, each user can define one's own haptograms and their corresponding translations.

In order to make the user interface on the touch screen also accessible for individuals with deafblindness, the upper portion of the touch screen is covered with a textile cover (see Figure 7, Right). The textile cover represents the tactile version of the user interface. Similar to the touch display, the textile cover provides a 4-by-4 grid of tactile and conductive dots that can transmit a touch signal onto the touch screen of the tablet when being tapped. Additionally, each dot is connected to its direct neighbors (also diagonal) via a tactile, conductive line, to make the swiping motion more accessible. By starting to tap on one dot and then sliding the finger over a connecting line to the next, individuals with deafblindness can input a single stroke pattern in a controlled way, just like with the normal app.

The output area is not covered by the textile. For the sake of simplicity, the first prototype of the tactile board is only designed for interactions between a deafblind individual and a sighted or non-impaired communication partner.

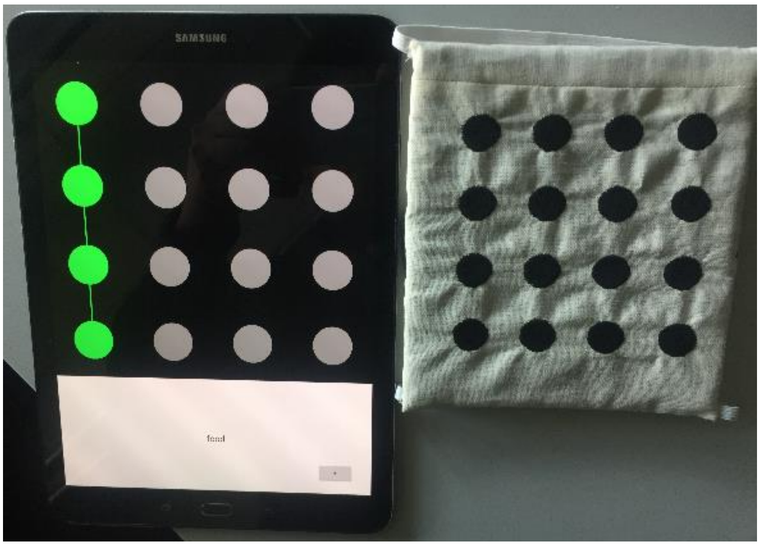

Figure 11: Prototype of the tactile board. Left: User interface on a tablet. Right: the cotton textile cover representing the tactile version of the user interface.

Implementation

Hardware

The hardware used for the tactile board is a Samsung Galaxy Tab S2 with a screen of 9.7 inch and a resolution of 2048 x 1536. No further requirements needed to be met, apart of a touch screen and a sufficiently large screen (i.e., larger than a smartphone).

Software

The software is an application developed for Android OS. It is based on a library called *PatternLockView* (https://github.com/aritraroy/PatternLockView) that allows the implementation of a customized pattern locking mechanism. We used this library to create a 4-by-4 grid on which single stroke patterns can be encoded (see Figure 6, left).

The 4-by-4 grid was complemented with a customizable dictionary, providing the user with the possibility to connect patterns to words. The dictionary recognizes any duplicates and does not allow more than one definition for each word or patterns.

Textile

WP5 has designed two textile covers one with three and one with two layers. The principle of the textile covers was having a conductive material that, when in contact with the touchscreen, simulates a touch point. Additionally, the textile covers should provide tactile references where to move/press with the finger.

A key aspect in the construction was to create an architecture with spacing between the conductive material and the touchscreen so that only if the dot was pressed the conductive fabric would contact the screen. The textile cover made from cotton (Figure 11, left), features a layer of conductive fabric that triggers a touch point on the touchscreen as soon as it gets pressed. In contrast, the textile cover made from leather (Figure 11, right) features buttons that are made using conductive thread.

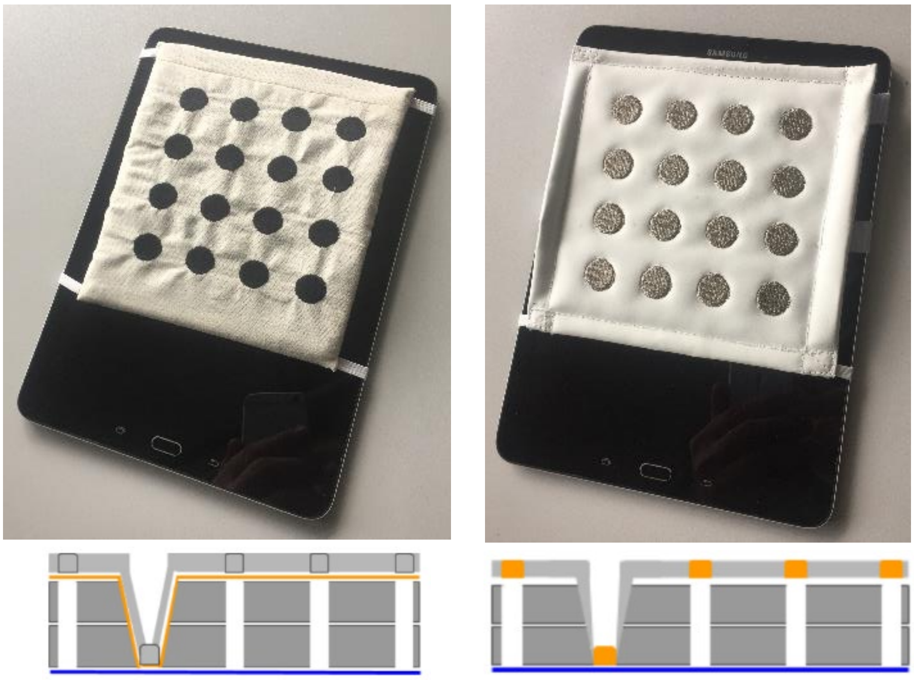

Figure 12: Textile covers with architecture. Left: textile cover made from cotton with a layer made from conductive fabric (yellow) and a spacing layer preventing the conductive fabric from touching the touchscreen (blue). Right: textile cover made from leather, with buttons made from conductive thread (yellow) and a spacing layer preventing the conductive buttons to touch the touchscreen (blue).

Evaluation

This study is designed as a proof-of-concept study, which aims at assessing, if participants with deafblindness perceive the tactile board as helpful and easy-to-use. It was not conducted as planned due to COVID-19. If the concept will be accepted, it can be used in several situations:

- to foster social interaction
- to teach people with deafblindness how to use SUITCEYES' HIPI and
- to train them in understanding and using haptograms on a regular basis.

Research Questions

Five research questions are forming the basis of the proof-of-concept study:

1) Are participants able to understand haptograms provided on their back?
2) Are participants able to draw haptograms using the tactile board?
3) Are participants able to reproduce the haptogram they felt on their back on the tactile board?

4) Do participants perceive the tactile board as helpful?
5) Do participants perceive the tactile board as easy-to-use?

Participants

Four individuals with acquired deafblindness participated in the study (2 female; mean age = 46 years old). All four participants were fully deaf, however, two participants communicated verbally with the help of cochlear implants (CIs). Participants who used Sign Language were accompanied by professional interpreters, who assisted with communication throughout the study. Furthermore, participants presented varying eyesight characteristics: one participant had a field of view of 100 degrees and a visual acuity of 2% to 5%; while the other three participants had tunnel vision with fields of view between 3 to 7 degrees and a visual acuity of up to 70%. Either written or verbal informed consent was given by all participants and their interpreters [14].

Procedure

In the beginning, all participants will be informed about the procedure and background of the study. If they agree to participate in the study, they will be asked to sign a letter of consent. Each participant is informed about the opportunity to opt-out of the study at any time, without giving reasons. In this case, all data would have been deleted instantly.

The study starts with a short period of learning haptograms. Each participant will be provided with two simple haptograms on his back, communicating simple verb-noun instructions (e.g., bring water or touch shoulder). In this phase, the haptograms are transmitted repeatedly on the participant's back until the participant has memorized the query.

As soon as the participant feels confident to memorize the query, he will be asked to pass on this query to a communication partner using the tactile board. Both haptograms should be entered on the tactile board one after another. If the haptograms are entered correctly, the translation will be displayed as written output on the bottom of the tablet display. The communication partner (a non-disabled person) will be asked to read the written output and fulfill the query (if valid). This will indicate a successful communication to the individual with deafblindness.

After completing the simple conversation, the participant receives a self-designed questionnaire, based on the research questions, including demographic data, prior experience with technological communication devices and his experiences with the use of the tactile board as an input device. More specifically the usefulness, ease-of-use and intention for future use was acquired.

Questionnaire

In the questionnaire's first section the participants will be asked about demographic information such as ethnicity, mother tongue, gender and age, as well as information on education and preferred methods of communication (e.g., (Tactile) Sign Language or finger alphabets). Additionally, they will be asked to specify their disabilities, ranging from fully deaf & blind to residual vision and/or to residual hearing.

In the second part participants should rate six different communication devices regarding their familiarities with them on a 5-point scale ranging from *Not at all familiar (1) to Very familiar (5).* Next participants will be asked about the frequencies in which they use these devices, again using an adapted 5-point Likert scale: *Never (1), Less than once a month (2), Once a month (3), Several times a month (4), Almost every day (5).*

In the third part of the questionnaire free space has been provided to add comments on subjective opinions about the tactile board as well as three rating questions assessing participants' experiences regarding the perceived usefulness, the ease-of-use and intention to use the tactile board again.

Results

Again, due to COVID-19 pandemic the study could not be conducted as planned. Even in 2021, the safety regulations for persons with impairments were too high. Instead, an extensive article on the resulting device was published (also mentioned in the description prototype 1): Theil, A. et al. 2020. Tactile Board: A Multimodal Augmentative and Alternative Communication Device for Individuals with Deafblindness. 19th International Conference on Mobile and Ubiquitous Multimedia (New York, NY, USA, Nov. 2020), 223–228. [15]. These results have also been documented in a video: https://www.youtube.com/watch?v=36bj-6xvPmU&t=1s

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