Tactile Navigation with Checkpoints as Progress Indicators? Only when Walking Longer Straight Paths

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ABSTRACT

Persons with both vision and hearing impairments have to rely primarily on tactile feedback, which is frequently used in assistive devices. We explore the use of checkpoints as a way to give them feedback during navigation tasks. Particularly, we investigate how checkpoints can impact performance and user experience. We hypothesized that individuals receiving checkpoint feedback would take less time and perceive the navigation experience as superior to those who did not receive such feedback. Our contribution is two-fold: a detailed report on the implementation of a smart wearable with tactile feedback (1), and a user study analyzing its effects (2). The results show that in contrast to our assumptions, individuals took considerably more time to complete routes with checkpoints. Also, they perceived navigating with checkpoints as inferior to navigating without checkpoints. While the quantitative data leave little room for doubt, the qualitative data open new aspects: when walking straight and not being "overwhelmed" by various forms of feedback in succession, several participants actually appreciated the checkpoint feedback.

CCS CONCEPTS

• **Human-centered computing~Empirical studies in HCI**
• **Human-centered computing~Haptic devices** Human-centered computing~User studies • Human-centered computing~Empirical studies in interaction design • Human-centered computing~ Accessibility theory, concepts and paradigms • Human-centered computing~Accessibility systems and tools

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Figure 1. Spatial navigation for deafblind persons using a wearable device providing vibrotactile feedback.

KEYWORDS

Haptics, Smart Textiles, Vibrotactile, Navigation, Wayfinding, Spatial Guidance, Assistive Technology

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1 INTRODUCTION

Persons with both vision and hearing impairments have to rely primarily on tactile feedback, which accordingly is frequently used in assistive devices – and is preferable to audio feedback in many cases, even for users without hearing impairments [9]. While thermal feedback is a potential alternative [25, 26], the latency of thermal devices, especially when cooling down, makes them inadequate for the quick communication [11] required for spatial navigation. Aiding persons with deafblindness [6] in such tasks by developing an unobtrusive wearable device (Figure 1) is an important aim of the European project SUITCEYES [13].

Many researchers approach the topic of navigation by looking at technologies which help sensing the spatial environment, like the ActiveBelt developed in 2004 [24], the Tactile Wayfinder [8] developed in 2008, or the more recent Forehead Electro-tactile Display [10]. In contrast, our goal is to explore how feedback during navigation in an **already detected** spatial environment is best communicated by the assistive system. We focus on the use of checkpoints to give users feedback on their progress during navigation tasks. To achieve this, we had to use a Wizard-of-Oz approach to compensate the missing spatial recognition – an approach commonly used for complex navigation studies [21].

We are particularly interested in how checkpoints impact individual performance and user experience. As established in literature on goal-setting in the late seventies by Bandura and Simon [1], the effectiveness of positive feedback is related to its timing. Reward- and goal setting theory assumes that proximal feedback works better, and research has indeed shown that individuals who are presented with specific, proximal rewards are more motivated to pursue them [22]. Although vibrations can hardly be considered real rewards, they still provide positive feedback and a sense of progress which is missing if only navigational cues are given. Accordingly, we hypothesize that progress cues will have a positive impact on individuals' performance and the user experience during navigation tasks:

1. H1: Individuals take less time to complete routes with checkpoints, as compared to those without checkpoints.
2. H2: Individuals perceive navigating with checkpoints as superior to navigating without checkpoints.

Regarding hypothesis H2, the term "superior" is broken down into six aspects: confidence, control, transparency, fun, preference for a personal guide, and future potential (see section 4.1).

2 RELATED WORK

In this section, we describe approaches which use haptic perception [12] or, more precise, tactile feedback to communicate messages like navigational cues. While there are first approaches towards shape-changing haptic interfaces for communication [23], we focus on vibrotactile feedback which is more suitable for a wearable which is worn rather than held in the hand. Typically, vibrotactile feedback uses three signal parameters: frequency (pitch), amplitude (volume) and duration. Different aspects of vibrotactile feedback have been investigated in previous research: the positioning of motors, the tactile vocabulary, as well as virtual interaction [15]. A problem shared by many approaches is that wearable devices hardly can convey more complex messages [2].

While the ultimate goal of vibrotactile communication is conveying more complex messages, the work presented here focuses on the relatively simple use case of navigation. Indeed, the potential of this area has long been identified: Ertan et al. from MIT [5] in 1998 were among the first groups to use micro motors for delivering haptic navigational signals. While their short paper highlights the technological development and principal feasibility of the approach, the authors already foresaw that "such a system can be a useful navigation guide for individuals with severe visual impairments in an unfamiliar environment".

In the following two sub-sections we first discuss placement options for vibrotactile elements and then discuss the vocabulary.

2.1 Placement of Vibrotactile Actuators

Meier et al. [17] compared different positions on the body for wearables with vibrotactile feedback for navigation. A study with 16 participants indicated that vibration motors placed on the feet led to a higher accuracy than motors placed on the wrist or waist. They also evaluated the stress levels with visual versus vibrotactile feedback and found that vibrotactile feedback decreased stress more compared to visual navigation. This resulted in fewer errors and faster task completion.

Based on the work of Erp et al. [4] dating back to 2005, Heuten et al. [8] developed non-visual support for wayfinding that guides users by a tactile system. They designed a belt with vibrators that indicates directions and deviations from the path in an accurate and unobtrusive way. The belt was equipped with six vibrators with gaps of 60° between each other – a design we drew on in our implementation (see section 3). In a study with nine participants, they found that not all parts of the body around the hip have the same sensibility: thus, the vibrators should operate with different intensities depending on their position. An open field study showed that participants were able to follow vibrotactile navigation feedback, with a generally low deviation from the route. The walking speed was slower than usual, but the participants were able to walk at a relatively constant speed. However, it was not easy for the users to differentiate the directions; the perceived direction had a median deviation of 15°.

Oliveira et al. [19] evaluated a tactile belt similar to our solution (see section 3) for navigation in a virtual emergency situation with reduced sight. To communicate directions, they developed a vibrotactile vocabulary representing itineraries, warnings or obstacles. In a user study, the participants trained this vocabulary. In the case of a wrong answer, the correct answer was shown on the graphical user interface so the user could learn the patterns better as the study progressed. The participants were asked to follow different routes in a virtual representation of a mine twice. The first time, vibrotactile feedback was provided over the belt, the second time not. The results did not show any significant differences in the usage of vibrotactile feedback regarding the completion time of the task or the user's heart rate, but participants reported that they preferred the additional vibrotactile feedback.

To sum up, there is considerable research on the physical placement of actuators in wearables. However, in the SUITCECES project, our options regarding placement were limited: the project's aim is developing a wearable in form of a vest. The reason for preferring a vest to other wearables like shoes or gloves mainly is the acceptance: we had to ensure the wearable is easy to put on and off (even without sight) and offers enough space to experiment with actuator placement and patterns.

2.2 Vibrotactile Communication

Communicating information via haptic patterns is complex for the receiver – that is for the user who is supposed to make sense out of the vibrations. This is even more true for deafblind users who lack the two most prominent senses and, in many cases, also are subject to cognitive impairments.

The research of Cauchard et al. [2] focuses on the communication of progress information using vibrotactile vocabulary. They created different vibration patterns to communicate progress and evaluated them. All the patterns were inspired by the Morse alphabet and consisted of different variations of short and long vibrations. Based on the results of a first study with 10 participants, they merged the best recognized elements into a new pattern. In this pattern, long and short vibrations were combined to represent single values like the Roman numeral system. Using this vibration pattern, they ran a longitudinal study over 28 days with 22 participants using smartwatches. Every day, the participants received a number from a scale from 1 to 10 in the form of a vibration. One finding was that it was difficult to recognize whether the sent signal was short or long if there was no comparison vibration: for example, two short vibrations often got confused with two long vibrations. The higher the number of vibrations, the more difficult the system was to decode. Therefore, we decided to use a simple "all on" signal to indicate the passage of a checkpoint (see section 3).

Günther et al. [7] report similar results from a study evaluating a vibrotactile glove. They investigated the effect of the number of vibration motors on the comprehension of the navigation patterns. Therefore, they used two metaphors: pull and push. For the pull metaphor, the actuators closest to the target were activated, for the push metaphor, the actuators furthest to the target. It was shown that the pull metaphor was more accurate and faster and felt more natural to the users than the push metaphor. The highest number of used vibration motors led to the best results in both metaphors. This indicates that a higher number of motors, as already used by Heuten et al. [8], leads to better recognition.

As in the case of actuator placement, there is considerable research the vocabulary of vibrotactile systems. Regarding our prototypical vibrotactile system, we drew heavily on these established findings. Regarding semantics, we deliberately chose a simplistic approach for this prototype: instead of creating a more elaborate "vocabulary", the system only provides directional cues and gives feedback on progress. While this could have been established with a belt or a glove, the project's specifications, especially the desire for a scalability (see previous section) required that we focused on a vest-like garment.

3 TACTILE SYSTEM DEVELOPMENT

In this section, we describe the requirements for the tactile system (1), as well as its implementation on the hardware level (2) and on the software level (2). The aim is to provide fellow researchers and engineers with enough detail to replicate or build on our findings.

3.1 Requirements

We defined the following requirements for the tactile system:

Table 1. Requirements for the tactile system.

Requirement	Description
REQ-1	Tactile system must be able to trigger vibrations at defined parts of the body to guide users in the right direction.
REQ-2	Tactile system must be able to trigger vibrations by all motors to indicate progress at checkpoint passage.
REQ-3	Tactile system must be adjustable to accommodate for various body shapes and sizes while ensuring that vibrations are easy to perceive.
REQ-4	Tactile system must be battery powered to avoid the risk of users tripping over cables.
REQ-5	Tactile system must be steerable manually via a remote (smartphone application).

3.2 Architecture

The smartphone application communicates with the microcontroller via a BLE link (Bluetooth Low Energy) to control the intensity of the vibration motors. In a Wizard of Oz setup, an assisting researcher simulates the environmental detection and provides the steering signals for the vibration. This allowed us to test the smart wearable before more advanced modules such as collision avoidance and wayfinding were ready.

3.2.1 Hardware

The tactile system comprises the following components:

1. Microcontroller (RedBear Duo) connected to a controller board.
2. 12 vibrating coin actuators (Pololu shaftless vibration motors, 10 x 3.4 mm) connected in pairs to a separate daughter board.
3. 4 AA batteries to power the microcontroller.

The RedBear Duo is a thumb-sized development board equipped with a wireless module for both Wi-Fi and BLE communication, allowing applications to be programmed with Arduino, C/C++, JavaScript and Python. The microcontroller is connected to a controller board developed with the aim of covering the specific needs of each application. Based on a blank PCB board (4.9 x 4.4 cm), we soldered twelve 3-pin male headers, providing output in the form of PWM (Pulse Width Modulation) signals. Female headers on the board provide the basis for connecting the microcontroller. Soldered to the board is an additional 2-pin male header to provide power to the RedBear Duo through its VIN pin from an external battery pack.

In addition to the controller board, we used six daughter boards to connect the vibration motors. These daughter boards are also configured from blank PCB boards. Figure 2 illustrates the schematics of both the controller board and the daughter board.

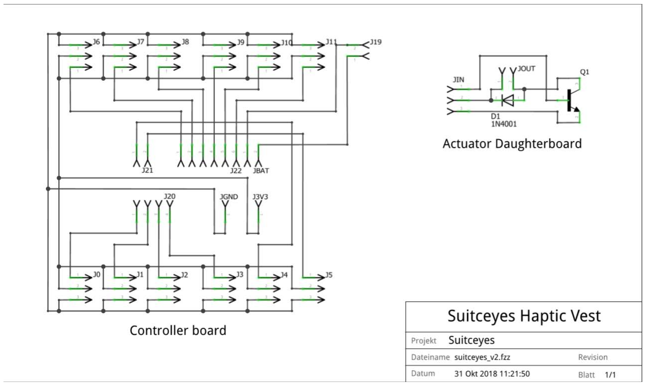

Figure 2: Circuit schematics of controller and daughter board.

We created this prototype using Pololu shaftless motors operating on voltages of between 2.5 to 3.5 V and delivering vibrational amplitudes of up to 0.75 g. To improve stimulation perception, we connected two motors in series to a daughter board.

3.3 Software

This section outlines the technical implementation, covering application of both the Arduino sketch running on a RedBear Duo and the Unity3D application running on an Android smartphone.

3.3.1 Arduino Sketch

The application running on the RedBear Duo was developed using an Arduino sketch written in C. This application provides a means of interfacing with pin-specific values (read / write options). It is also possible to set the frequency at which the actuators vibrate. The application accepts commands both on the basis of serial as well as BLE communication.

Serial communication uses the CmdMessenger framework. This framework is a messaging library built for the Arduino and .NET/Mono platform. Bluetooth Low Energy (BLE) communication is provided by the firmware's API: messages are sent as simple byte arrays and made up in a similar way to the CmdMessenger format, with the first byte of the array identifying the type of command. Subsequent bytes represent parameters of a command, e.g., vibration intensity. These simple message structures were the key to meeting requirements REQ-1 and REQ-2 by mapping specific pins to specific vibration motors on the body, as illustrated in Figure 3.

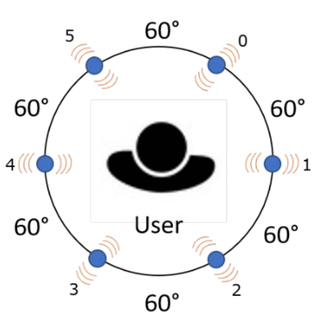

Figure 3: Placement of vibration motors.

3.3.2 Steering Application

The steering application was developed in Unity 3D to provide a simple way of transferring commands to the microcontroller. Figure 4 shows its minimalistic user interface.

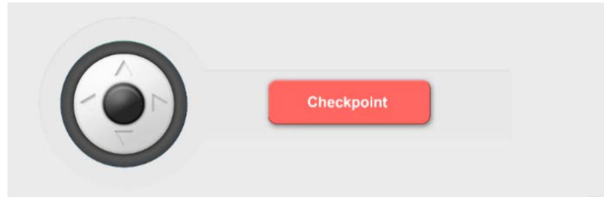

Figure 4: Minimalistic user interface of mobile application with virtual joystick.

The virtual joystick is used to trigger the vibrations on the vest, reflecting the direction. Vibrations either come from two adjacent motors or from a single motor at full intensity – rather than being split between two adjacent motors. This has the purpose of ensuring that vibrations can be perceived through thin material. For example, if a user were to walk straight ahead, i.e. the joystick is moved forward, vibration motors 0 and 5 (Figure 3) at the front of the garment vibrate at full intensity.

A defined threshold decides whether the vibrations are generated by a single motor or by two adjacent motors. For example, if a direction is provided at 20° CW, only motor 0 vibrates at full intensity. The red checkpoint button triggers a vibration of all motors at full intensity (REQ-2). The virtual joystick and the button provide an easy way of giving instructions to the RedBear Duo (REQ-5) that can trigger vibrations at specific points on the body (REQ-1) as well as induce vibrations at all motors (REQ-2).

3.4 The Wearable

An overall aim of the SUITCEYES project is to develop a smart wearable for haptic communication integrating the functionalities of sensing [3, 18], monitoring [14], and actuation [16, 20]. However, on the way towards this aim, this prototype is a deliberately simple, hands-on solution: we used a safety belt that fastens around the waist with a buckle strap (Figure 5) and can be tightened or loosened across the shoulders and waist. This makes it easy to adjust the garment to suit various body shapes and sizes, thereby ensuring the garment is close to the body (REQ-3).

Figure 5: The prototypical "smart" wearable uses a just safety belt and straps. The back pouch accommodates the hardware.

To accommodate the vibration motors and the daughter boards, we created six individually adjustable straps, each with two small pockets sewn onto them. Small patches of Velcro tape are sewn onto the material, making it possible to fasten the straps around the belt. The straps are attached to the belt in such a way that the small pockets containing the vibration motors are placed on the inside of the belt and firmly press them against the waist. This enhances the way in which vibrations are perceived. The motor placement on various body sizes is easily optimized by re-positioning the straps around the belt (REQ-4).

A small pouch at the back of the safety belt (Figure 5, right) holds the RedBear Duo and the battery pack powering it. Cables from the RedBear Duo can be routed to the various daughter boards via small apertures on either side of the pouch. All in all, we were able to meet requirements REQ-1 to REQ-6 in full.

4 STUDY

4.1 Method and Procedure

The study was done with 25 participants (mean age = 22.7 years, 14 female, 11 male). They all were German students without any disability. To simulate blindness and deafness, the participants used a blindfold and noise-cancelling earmuffs.

Before the experiment, the wearable and the goal of the study were explained. When putting on the vest, we ensured that the users aligned it correctly and adjusted it to their body size. In an initial session, each participant was trained to use the vest when moving in randomly selected directions: after the vibration, the participant had to indicate the interpreted direction with their hand. After the training session, we evaluated the efficacy of the checkpoints in a navigation task.

The evaluation was conducted in a cleared corridor of about 60 square meters (Figure 1), where we established two routes or courses with combinations of straight lines and turning points. Each route had four turning points and five checkpoints placed sequentially at every 20% of its completion, including the goal (Figure 6).

Route A

Route B

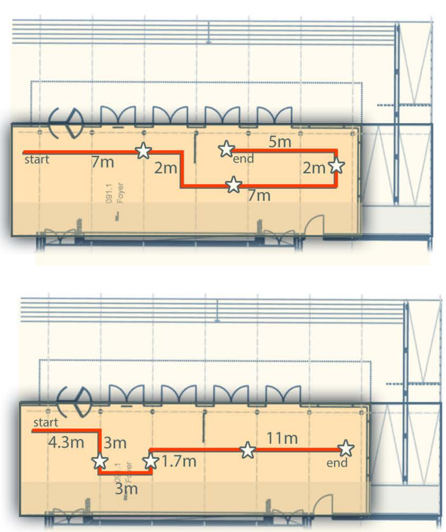

Figure 6. Routes A and B; stars represent checkpoints.

Route A featured two long distances (7.0 meters), one medium distance (5.0 meters), and two small distances (2.0 meters). Route B featured one long distance (11.0 meters), three medium distances (4.3 meters, and 3.0 meters twice), and one short distance (1.7 meters).

The participants were asked to apply the blindfold and the noise-cancelling earmuffs and were accompanied to the starting point of the route. There they tested the checkpoint feedback and were instructed to follow the direction of the vibration until it stopped. A constant vibration pattern was used to indicate direction. When reaching a checkpoint, all actuators were triggered simultaneously.

As an automated obstacle and distance detection system was not ready at that project stage, we followed a Wizard of Oz approach: as described in more detail in section 3, a researcher used a mobile application to steer the tactile feedback which guided the users. To document the routes, we attached colored post-it notes on the floor for turning points and checkpoints.

Participants started by completing route A, followed by route B. A simple factorial design with two conditions was followed: a) without checkpoints, and b) with checkpoints. All participants took part in trials under both conditions; the order was counterbalanced equally among participants: half completing the first route with checkpoints and the half start without checkpoints. After finishing each route, the participants were asked six questions on their experience, rated on a 5-point-Likert scale (from "completely disagree" to "fully agree"):

1. I felt confident while completing the route.
   [short: confidence]
2. I felt in control while completing the route.
   [short: control]
3. I was able to understand if I was progressing successfully toward the end of the route.
   [short: transparency]
4. I was having fun while completing the route.
   [short: fun]
5. I would prefer to ask another person for guidance rather than use the system.
   [short: personal guide]
6. I feel that the system would enable me to guide myself more independently.
   [short: future potential]

4.2 Results

4.2.1 Task Completion Times

H1. Individuals take less time to complete the routes with checkpoints, as compared to without checkpoints.

Participants took longer to complete routes A and B while receiving checkpoint feedback as compared to participants who completed these routes in the baseline condition (see table 1). Table 1 shows the total mean completion time (in seconds) of each course for both conditions.

Table 2. Overview of durations with and without checkpoints. The values in brackets are the standard deviations.

Course	WITH checkpoints	WITHOUT checkpoints	Significance
A	162.3s (46.2s)	94.4s (26.8s)	** p < .001
B	119.6s (28.9s)	101.8 (32.1s)	p < .1

As table 2 and figure 7 illustrate, the participants needed almost double the mean time (M) to complete route A with checkpoint feedback (M = 162.3s, SD = 46.2s) as compared to those who did not receive checkpoint feedback (M = 94.4s, SD = 26.8s). With t(20) = 4.3 and p < .001 this difference is highly significant.

With course B, the negative effect of checkpoints is not as striking. Nevertheless, the course took participants only about 85% of the mean time without checkpoints (M = 101.8s, SD = 32.1s) as opposed to with checkpoints (M = 119.6s, SD = 28.9s). While there is a clearly observable difference in duration, with t(22) = 1.4 and p < .1 this difference is only marginally significant.

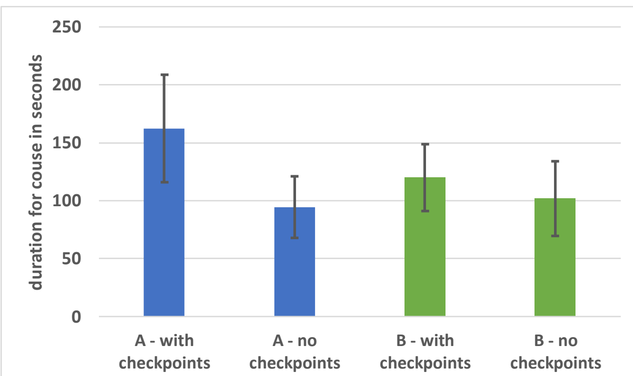

Figure 7. Mean completion times in seconds for courses A (blue) and B (green). The error bars show the standard deviation.

Despite the reduced significance in course B, it is obvious that the checkpoints did not yield the results expected in H1 (less time) but increased the amount of time required. Thus, H1 must be rejected.

Indeed, there is considerable evidence for H1: Individuals take more time to complete the routes with checkpoints, as compared to without checkpoints.

4.2.2 Assessing Progress

H2: Individuals perceive navigating with checkpoints as superior to navigating without checkpoints.

In this section, we present the findings from the six questions asked after each course, referenced in short with the terms confidence, control, transparency, fun, personal guide, and future potential (see section 4.1).

First, we conducted t-tests to examine if the routes had a significant impact on the perception. As table 3 illustrates, the values were almost identical.

Table 3. Mean values of the perceived experience in the two courses. Values in brackets show standard deviations.

Check-points	Item	Course A	Course B	Signi-ficance
WITH	confidence	3.3 (0.9)	3.5 (1.2)	p > .1
	control	2.7 (0.8)	2.9 (0.9)	p > .1
	transparency	3.3 (1.3)	3.2 (0.9)	p > .1
	fun	3.6 (1.4)	4.0 (1.4)	p < .1
	personal guide	2.8 (0.9)	2.8 (0.8)	p > .1
	future potential	3.5 (1.2)	3.6 (1.1)	p > .1
WITH-OUT	confidence	4.6 (0.6)	4.5 (0.5)	p > .1
	control	4.1 (0.6)	4.0 (0.7)	p > .1
	transparency	4.2 (0.8)	3.8 (0.8)	p > .1
	fun	4.6 (0.5)	4.2 (0.7)	* p < .05
	personal guide	2.5 (1.0)	2.8 (1.2)	p > .1
	future potential	4.6 (0.6)	4.5 (0.5)	p > .1

Only for 'fun' there is a marginally significant difference between the two courses with checkpoints and a significant difference without checkpoints. However, in general the route layout did not have a strong impact on the user experience. Thus, we aggregated the mean values of both courses in table 4.

Table 4. Aggregated mean values of the perceived experience of both courses. Values in brackets show standard deviations.

Item	WITH checkpoints	WITHOUT checkpoints	Signi-ficance
confidence	3.4 (1.1)	4.5 (0.6)	** p < .001
control	2.8 (0.9)	4.0 (0.7)	** p < .001
transparency	3.2 (1.1)	4.0 (0.8)	* p < .005
fun	3.8 (1.4)	4.4 (0.6)	* p < .005
personal guide	2.8 (0.8)	2.6 (1.1)	p > .1
future potential	3.6 (1.1)	4.5 (0.6)	** p < .001

As Figure 8 illustrates, the analysis is rather clear: the hypothesis H2 that "individuals perceive navigating with checkpoints as superior to navigating without checkpoints" must be rejected.

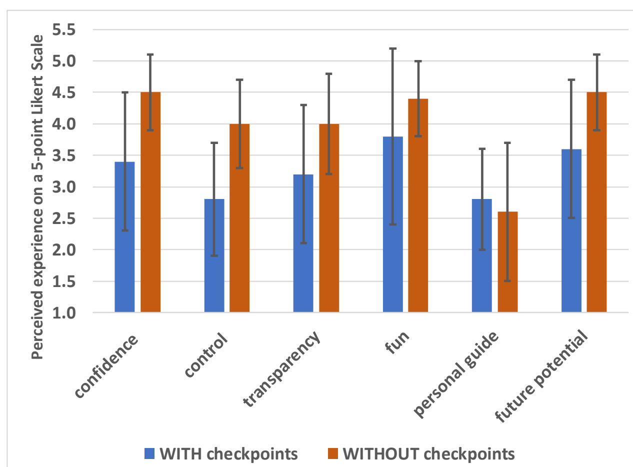

Figure 8. Aggregated mean values of the experience with and without checkpoints. Error bars show the standard deviation.

Indeed, there is strong evidence for a revised H2': Individuals perceive navigating with checkpoints as **inferior** to navigating without checkpoints.

First, there is a very strong difference in the perceived confidence. With M = 3.4 (SD = 1.1) with checkpoints compared to M = 4.5 (SD = 0.6) without checkpoint feedback and $t(39) = -4.5$, $p < .001$ this difference is highly significant. Almost, but not quite as high is the difference in perceived control. With M = 2.8 (SD = 0.9) with checkpoints compared to M = 4.0 (SD = 0.7) without checkpoints and $t(47) = -5.5$, $p < .001$ this difference again is highly significant. For transparency, with M = 3.2 (SD = 1.1) with checkpoints compared to M = 4.0 (SD = 0.8) without checkpoints and $t(47) = -2.9$, $p < .005$ the difference is significant. For perceived fun, we also found a significant difference with $t(36) = -1.8$, $p < .005$ with M = 3.8 (SD = 1.4) with checkpoints compared to M = 4.4 (SD = 0.6) without checkpoints.

When it comes to preferring a personal human guide to the technical system, there is no significant difference with M = 2.8 (SD = 0.8) with checkpoints compared to M = 2.6 (SD = 1.1) without checkpoints and $t(41) = 0.8$, $p > .1$.

Finally, when looking at the future potential of the system, the users again clearly preferred the version without checkpoint feedback. With M = 3.6 (SD = 1.1) with checkpoints compared to M = 4.5 (SD = 0.6) without checkpoints and $t(41) = -3.4$, $p > .001$ this difference is statistically highly significant.

4.3 Discussion and Qualitative Findings

The results both from task completion times and from the questionnaire on the perceived experience clearly show that checkpoints are indeed no improvement per se. In both courses, users were faster without checkpoints, and in course A this difference was even highly significant. When asked about their experiences, the participants unanimously preferred the configuration of the tactile vest which did not provide feedback when checkpoints were passed.

The qualitative findings confirm these results but also offer additional insights not provided by mean values. The observers noticed that checkpoints had an especially negative effect on the participants' performance when they directly followed or preceded by a change in walking direction. This effect was also well described by participants, who felt "overwhelmed" with the different messages conveyed in a short time (i.e. checkpoint plus spatial directions).

Some participants had problems differentiating between the two signals: "I was just making sense of the checkpoint and right after I was getting another type of vibration (…) I wasn't sure if it was still the checkpoint, or something else so I stopped for a bit to make sense of it" (P12). For others, receiving checkpoints close to changes in direction was overwhelming in itself: "It just doesn't make sense to get a checkpoint update when you're already having to focus on successfully turning in the right direction – it's too much" (P2).

In consequence, checkpoint feedback was considered more helpful when participants were walking longer segments of straight paths, like sections 1 and 3 of course A (7 meters) and section 5 of course B (11 meters). One participant noted: "I really need them [checkpoint feedback] to know that all is right. I feel reassured that I won't crash into something, especially if I'm walking straight for a while" (P5). Another participant explained: "I found the checkpoints more useful toward the end, when I was walking straight. At the beginning they were too close to the turning, which kind of mixed things up for me" (P10).

This indicates that checkpoint feedback is perceived best when isolated from other sources of feedback (e.g. changes in direction) or in less cognitively demanding situations.

5 CONCLUSION

In this work, we investigated the effect of checkpoints as progress indicators when using a tactile navigation device. The participants were isolated from audiovisual stimuli, simulating complete deafblindness.

In contrast to our initial hypotheses (H1: Individuals take less time to complete the routes with checkpoints, as compared to without checkpoints; H2: Individuals perceive navigating with checkpoints as superior to navigating without checkpoints), our findings show that individuals take considerably **more** time to complete routes with checkpoints, and perceive navigating with checkpoints as **inferior** to navigating without checkpoints.

The quantitative data leave little room for doubt. Most findings are of high statistical significance – be it task completion times or the users' perceived quality of the experience: for five out of six aspects (confidence, control, transparency, fun, and future potential) the participants preferred the version of the tactile vest which did not provide feedback when checkpoints were passed.

However, the qualitative data (while in general confirming the findings) open up new aspects: when not being "overwhelmed" by various feedback signals in succession, several participants actually appreciated the checkpoint feedback. It is likely that this modality works best when walking straight and / or for a longer time.

6 LIMITATIONS AND FUTURE WORK

Blindfolded students wearing noise-cancelling earmuffs are not persons with deafblindness. Thus, the generalizability of the findings may be limited. However, considering that impairments or multiple senses are often accompanied by mild or even severe cognitive impairments, the sensation of being "overwhelmed" by input will probably rather increase than decrease for actual users with multiple sensory impairments. Nevertheless, the study should be repeated with these user groups.

Another limitation is the distance covered: the authors think that checkpoint feedback might work much better with longer distances. The qualitative findings also suggest this: several users appreciated checkpoint feedback when walking straight and / or for a longer time. Also, a curved path (with less sharp turning points) might yield different results. Thus, a study with longer distances, more variance across the paths, and longer time periods is required.

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