Master's Thesis

Olfactory cues as a way to improve spatial orientation of visually impaired

Bc. Pavla Křivanová

Supervisor: Ing. Dominika Palivcová

Field of study: Open Informatics
Subfield: Human-Computer Interaction
Department of Computer Graphics and Interaction
Faculty of Electrical Engineering
Czech Technical University in Prague

December 2021

MASTER‘S THESIS ASSIGNMENT

I. Personal and study details

Student's name: **Křivanová Pavla** Personal ID number: **465828**

Faculty / Institute: **Faculty of Electrical Engineering**

Department / Institute: **Department of Computer Graphics and Interaction**

Study program: **Open Informatics**

Specialisation: **Human-Computer Interaction**

II. Master’s thesis details

Master’s thesis title in English:

Olfactory cues as a way to improve spatial orientation of visually impaired

Master’s thesis title in Czech:

Využití čichu pro zlepšení prostorové orientace zrakově postižených

Guidelines:

Olfaction is still a neglected sense in the design of user interfaces. Until now, olfaction isn’t actively used in any of the interfaces that aim to improve spatial orientation for the visually impaired, despite the fact olfaction and spatial orientation seems to be tightly linked in human brains [1] and acquisition of spatial orientation is a crucial problem of the visually impaired.

Study and map how visually impaired currently use olfaction to improve their spatial orientation. Conduct a user research with the target user audience and focus mainly on the procedures that are used by visually impaired skilled in using olfaction in their day-to-day life.

Based on the acquired learnings, design an aid that will aim to employ olfaction to improve spatial orientation; then evaluate the usability of your design in an experiment with the target audience. Report your overall learnings and best-practices about employing olfaction in this use-case, and propose how to make those learnings accessible for wide audience so it is more likely that olfaction will be employed more in the UI design for visually impaired.

Bibliography / sources:

[1] JACOBS, Lucia F. From chemotaxis to the cognitive map: the function of olfaction. Proceedings of the National Academy of Sciences, 2012, 109.Supplement 1: 10693-10700.

Name and workplace of master’s thesis supervisor:

Ing. Dominika Palivcová, Department of Computer Graphics and Interaction, FEE

Name and workplace of second master’s thesis supervisor or consultant:

Date of master’s thesis assignment: **14.09.2021** Deadline for master's thesis submission: **04.01.2022**

Assignment valid until: **19.02.2023**

Ing. Dominika Palivcová Supervisor’s signature	Head of department’s signature	prof. Mgr. Petr Páta, Ph.D. Dean’s signature

III. Assignment receipt

The student acknowledges that the master’s thesis is an individual work. The student must produce her thesis without the assistance of others, with the exception of provided consultations. Within the master’s thesis, the author must state the names of consultants and include a list of references.

.

Date of assignment receipt Student’s signature

Acknowledgments

I want to thank all the people who supported and encouraged me during the work on this thesis. Especially Dominika Palivcová for professional advise and Martina Klimešová for kind support.

Declaration

I declare I have accomplished my final thesis by myself and I have named all the sources used in accordance with the Guideline on ethical preparation of university final theses.

Prague, 13 December 2021

Abstract

This research thesis objective is to examine the usage of the olfactory sense to improve the spatial orientation of visually impaired users. In the beginning, exploratory research is conducted with our target group. It is followed by the analysis of olfaction and olfactory interfaces, aids for spatial orientation of the visually impaired, and the role of olfaction in spatial orientation. We propose several design concepts and analyse them. The most suitable one is chosen to further prototype. We design and run an experiment to test the prototype of this selected design concept, and the results are discussed. Our extensive research also reports the best practices and findings that showed to be valuable in literature and our experiment. The aim of reporting our findings is for these aids to be easier to create in the future. As the final step of this thesis, a website design is formed. Its purpose is to educate a wide audience about our findings, raise awareness about these topics, and help to employ olfaction to aid visually impaired spatial orientation.

Key words: olfaction, olfactory cues, orientation, visually impaired

Abstrakt

Cílem této práce je výzkum využití čichu pro zlepšení prostorové orientace zrakově postižených uživatelů. Prvním krokem bylo provedení explorativního výzkumu s naší cílovou skupinou. Následovala analýza čichu, čichových rozhraní, pomůcek v oblasti prostorové orientace zrakově postižených a role čichu v prostorové orientaci. Dalším krokem byl návrh několika konceptů. Po jejich analýze byl vybrán nejvhodnější z nich k vytvoření prototypu. Byl navržen a proveden experiment k otestování prototypu tohoto zvoleného konceptu a diskutovány výsledky. V rámci našeho rozsáhlého výzkumu byly také shrnuty nálezy a techniky, které se v experimentu a rešerši ukázaly jako užitečné a mohly by v budoucnu usnadnit návrh pomůcek pro zlepšení prostorové orientace s využitím čichu. Posledním krokem této práce bylo vytvoření návrhu webových stránek. Tyto webové stránky mají za úkol informovat širokou veřejnost o našich zjištěních, rozšířit povědomí o probíraných tématech a napomoci tomu, aby byl čich využíván více při asistenci v prostorové orientaci zrakově postižených.

Klíčová slova: čich, čichové značky, orientace, zrakově postižení

Překlad názvu: Využití čichu pro zlepšení prostorové orientace zrakově postižených

Contents

1 Introduction **1**

2 User Research **3**
2.1 First user research 3
2.2 Second user research 11

3 Olfaction analysis **17**
3.1 Our olfactory sense 17
3.2 Scents and olfactory interfaces 19
3.3 Olfaction analysis summary 21

4 Orientation of visually impaired analysis **23**
4.1 Tools for improving spatial orientation 23
4.2 Analysis conclusions 30

5 Olfaction in spatial orientation **31**
5.1 Usage of olfactory cues 31
5.2 Smelling in stereo 32
5.3 Tracking specific location 32
5.4 Spatial representation 33
5.5 Olfaction in spatial orientation summary 33

6 Design concepts **35**
6.1 Design requirements 35
6.2 Design concept A: Scented watch 37
6.3 Design concept B: Office odour guide 40
6.4 Design concept C: Correcting necklace 43

7 Concept usability testing **47**
7.1 Experiment design 48
7.2 Results and discussion 53
7.3 Follow-up interviews 60

8 Website Design **63**
8.1 Scenarios 64
8.2 Design Process 64

9 Conclusions **69**

Chapter 1

Introduction

Olfaction might appear like a sense that is a bit overlooked overall in human-computer interaction. In spatial orientation, the situation seems to be no better. Therefore, attempts to incorporate olfaction info spatial orientation might look surprising and unusual. However, as we are going to discuss, olfaction has some favourable characteristics to consider.

Being oriented in space is a crucial task to master for the visually impaired, yet finding coping strategies to replace sight as the main input is very difficult. With the growing number of visually impaired people worldwide [1], finding new effective aids in this area is becoming more and more critical. Therefore, our goal is to research and analyse this often-neglected sense and its role in the spatial orientation of visually impaired users and propose designs that could effectively aid our target group in spatial orientation problems.

The first step is going to be examination our target group – visually impaired adults. Mainly, we are going to study how they navigate, which routes or places cause them trouble, how they use olfaction in spatial orientation, and what is their relationship with specific odours (chapter 2). We are going to define our research questions and conduct exploratory research with our target group to find the answers.

Then, we are going to continue with the analysis of our target group, their spatial orientation techniques and aids there are to help with spatial orientation. We are going to study olfaction and its link to spatial orientation as well.

The analysis takes place in these steps:

- We are going to analyse the olfactory sense – examine its advantages and disadvantages and discuss its role in spatial orientation (chapter 3). We are also going to review various olfactory interfaces.
- In chapter 4, we are going to examine spatial orientation strategies, terminology, and tools for the visually impaired.
- Then, we are going to review research regarding the role and attributes of olfaction in spatial orientation (chapter 5).

According to our learnings, we are going to design several concepts aiming to use olfaction to improve the spatial orientation of our target group and analyse their properties, advantages and disadvantages (chapter 6).

Considering all the essential properties of our design concepts, we are going to choose one of our concepts to further prototype and test. We are going to design an experiment to answer our defined research questions and to test our concept prototype with our target users, perform the experiment, and then present and discuss our results (chapter 7).

Finally, we are going to propose a design that can make our results and findings available to a broad audience (chapter 8). This way, anyone could use this website to educate themselves about topics and findings examined in this thesis. It could raise awareness about these topics and help employ olfaction to aid visually impaired people's spatial orientation.

Chapter 2

User Research

In this chapter, we are going to present our research work. Our first and second user study was done remotely with visually impaired participants. We are going to offer details about these studies and their findings in the following sections.

We conducted our research to help us answer the following questions:

- How visually impaired people orient themselves in space?
- Are any places or routes for them problematic in particular? Why?
- How visually impaired people use olfaction in their spatial orientation?
- What kind of olfactory cues do they use?
- Which odours are more pleasant for visually impaired people? Which odours are unpleasant?
- Do visually impaired people have any spaces associated with odours? To what extent?

Answers to these questions can help us understand our target group better and also allow us to design more meaningful solutions.

2.1 First user research

Our goal was to find out how our participants are using olfaction in their daily lives, how useful it is for them in spatial orientation, and their preferences about specific odours. We also wanted to find out how visually impaired adults orient in space in general.

2.1.1 Method

Our interviews were based on a questioner that contained both qualitative and quantitative questions and screening questions at the beginning.

Screening involved questions about age, olfactory impairments, and how long the vision impairment is present. There were also questions about using a guide dog and smoking —these more for our information to acquire more details a possibly draw some more insights.

Every semi-structured interview took around 30 minutes, done remotely.

2.1.2 Recruitment and participants

Our first research was remote user research done via phone calls with our participants. The possibly suitable participants were first contacted and recruited via email. All people we reached were visually impaired.

In the screening process (via email and at the beginning of the phone call interview), we excluded people with any olfactory impairment, people with vision impairment present less than a year, and people who always use the help of others for navigating themselves.

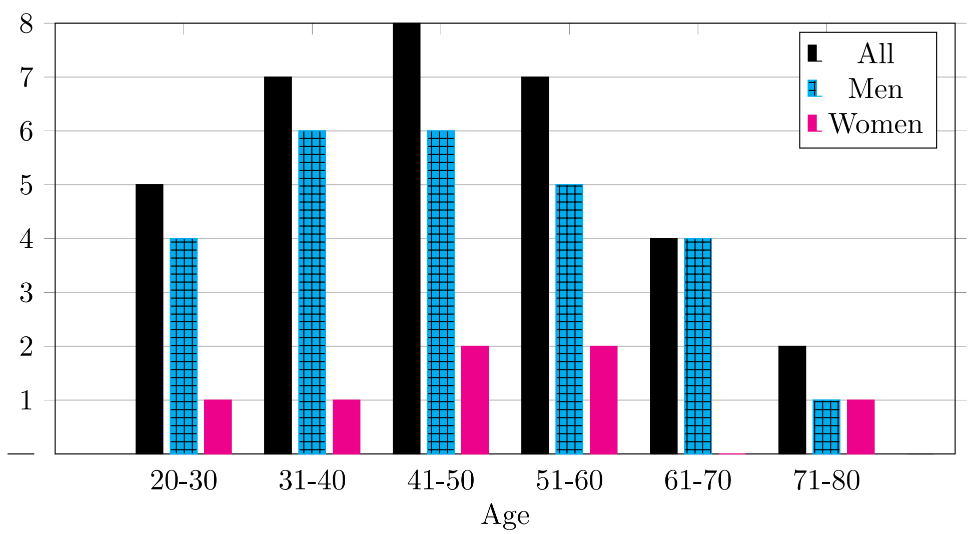

Figure 2.1: Overview of age and gender of participants from the first research

Excluding people with olfactory impairment is probably self-explanatory, as well as not reaching people with no vision impairment. We also wanted to exclude people who have vision impairment briefly because talking about topics related to their loss of vision could have been too uncomfortable and sensitive for them. Because of that, all our participants were visually impaired for more than five years.

All of the participants were visually impaired adults. We interviewed in total 33 participants with age varying from 23 to 74 years. As for gender, 26 were men and 7 were women (Figure 2.1).

Regarding smoking - most of our participant was not smoking (23), a few were occasional smokers (6), and the fewest were heavy smokers (4).

Six of our participants had a guide dog.

Most of our participants reported that they do not use vision for orientation at all (23), a third of them use vision a little, and one participant uses vision mainly. From the participants who use vision, all of them except one use vision the same way in interiors and exteriors. One uses it more in interiors.

2.1.3 Results

We asked about how participants learn new routes, we asked them about odour preferences, associations of odours and places, usage of olfactory cues in their spatial orientation and other topics. Here we present our findings.

Odours evaluation

We asked the participants to evaluate 20 specific odours depending on how pleasant they find them. To evaluate the pleasantness, we used a scale from 1 to 5, where 1 meant that the odour is very pleasant and 5 meant that the odour is very unpleasant.

The odours were flowery ones - *lavender, tree blossoms, jasmine, forest, roses*; some often used in the kitchen - *cinnamon, caramel, citrus, vanilla, nuts, coconut, mint, coffee, strawberries*; some based more on specific chemicals - *ethanol, acetone, chlorine, gasoline*; and others - *cigarettes* and *leather*.

The tables below are an overview of values demonstrating how pleasant our participants found chosen odours. We have divided the odours into six categories based on the mean value and standard deviation of all values for each odour:

- mean value ≤ 2 and standard deviation $\leq 1 \Rightarrow$ **Pleasant** odour (Table 2.1)
- mean value ≤ 2 and standard deviation $> 1 \Rightarrow$ **Rather pleasant** odour (Table 2.2)

Odour	Mean value	Standard deviation
Forest	1,2	0,5
Citrus	1,5	0,71
Vanilla	1,5	0,71
Tree blossoms	1,5	0,71
Strawberries	1,5	0,71
Roses	1,5	0,87
Coffee	1,5	1
Cinnamon	1,8	0,87
Jasmine	1,8	0,91
Lavender	1,8	0,95
Leather	2	0,9

Table 2.1: Odours marked as pleasant

Odour	Mean value	Standard deviation
Mint	1,7	1,02
Coconut	1,7	1,1

Table 2.2: Odours marked as rather pleasant

- mean value > 2 and < 4 and standard deviation $\leq 1 \Rightarrow$ **Neutral** odour (Table 2.3)

Odour	Mean value	Standard deviation
Caramel	2,1	0,93
Nuts	2,4	0,99

Table 2.3: Odours marked as neutral

- mean value ≥ 4 and standard deviation $> 1 \Rightarrow$ **Rather unpleasant** odour (Table 2.4)
- mean value ≥ 4 and standard deviation $\leq 1 \Rightarrow$ **Unpleasant** odour (Table 2.5)
- mean value > 2 and < 4 and standard deviation $> 1 \Rightarrow$ **Pleasant odours for some and unpleasant for others** (Table 2.6)

Odour	Mean value	Standard deviation
Cigarettes	4,2	1,23

Table 2.4: Odours marked as rather unpleasant

Odour	Mean value	Standard deviation
Chlorine	4,2	0,75

Table 2.5: Odours marked as unpleasant

We may need more than a few odours that are already frequently used in research involving olfaction (more in section 3.2) to create an olfactory interface for improving orientation. This odour evaluation is beneficial for determining which odours might be more useful for our olfactory interface design and which not.

There were some odours that our participants could not recall - *jasmine* and *nuts*. In one case, the smell of lavender as well. It is questionable whether these odours could cause trouble or not when used in an olfactory interface. It is true that the smell of jasmine might not be so typical and the smell of nuts not so strong. It is hard to say if the smell would not be recognizable for these participants the other way around - would they recognize that the odour they smell is jasmine or nut? Are they having trouble recalling the smell or labelling it? Whatever the case, we may consider not including these odours in future designs if possible.

We can see from the results that participants liked more *natural odours*, opposite to the more artificial ones.

Also, 21 from 33 participants had odours associated with food preparation (baking, cooking) or consumption.

Preferring the more natural odours and odours that are users in contact with more (like the smell of specific food and ingredients) seems to be more efficient for future designs. On the other hand, these odours could be present in the environment more often and interfere with chosen interface odours.

Interesting are also the differences in participants skills regarding recalling the odours. Some had trouble recalling anything with specific smells. Still, some were able to name more categories related to one odour (when asked about mint odour, one participant distinguished mint and eucalyptus and had completely different preferences about them). We have to consider such varying olfactory skills of our potential users.

Odour	Mean value	Standard deviation
Gasoline	3,2	1,41
Ethanol	3,3	1,05
Aceton	3,9	1,08

Table 2.6: Odours marked as pleasant for some and unpleasant for others

The findings of cigarette odour preferences are also interesting. More than half of our participants who smoke found the cigarette odour very unpleasant. Which also did more than half of non-smokers. Therefore, using this odour does not seem wise for our designs, even if the users mainly were smokers.

Odour associations to places

We also wanted to map the connection between places and olfaction. We asked the participants which places they have associated with odours. The most frequent answer was drugstores (15), then bakeries (8) and households (5).

We also selected specific places we wanted to evaluate from the participants' association and pleasantness point of view. We again used the scale from 1 to 5, where 1 meant that participants associated the place with an odour (and in the second case, that the associated odour is very pleasant), and 5 meant that they do not associate the place with any odour (and in the second case, that the associated odour is very unpleasant). Results are available in Table 2.7.

Some of the participants were not able to assign a specific number (evaluation) to some of these places. The number of participants who answered validly is also presented in Table 2.7.

We can see that drugstores were associated with certain odours the most and that the odours were considered pleasant. The second most associated places were hospitals and nature, but with very different preferences. Odours connected to nature found participants pleasant, but odours in hospitals a bit unpleasant. The least associated places with odours were offices.

Olfaction in spatial orientation

We asked the participants about how useful they think olfaction is for their spatial orientation. We again used a scale from 1 (very important) to 5 (unimportant). Between steps are 2 (important), 3 (moderately important),

Place	Association (mean value)	Number of answers	Pleasantness (mean value)	Number of answers
drugstores	1,26	23	1,59	32
restaurants, fast food, coffee shops	1,35	23	1,87	30
offices	3,6	23	3,55	22
hospitals	1,74	23	3,5	32
means of public transport	2,96	23	3,4	30
nature	1,74	23	1,41	32

Table 2.7: Place association with odours and their pleasantness.

and 4 (slightly important). Results are presented in Figure 2.2. Two participants were not able to specify how important role olfaction plays in their spatial orientation.

No participant found usage of olfaction in spatial orientation unimportant, which is a very promising finding. Moreover, 16 of 31 participants with valid answers found olfaction very important or important in their spatial orientation.

Participants also evaluated why they use olfaction for navigation. Out of 33 participants, 18 reported that olfaction is an important part of their navigation process. They use it to identify shops, entrances to the subway or changes in the environment. Another 13 participants said they use olfaction to confirm the correct location on their route and as an additional source of information.

Participants also use olfaction generally more in exteriors (24). In interiors reported usage 16 participants and both in exteriors and interiors 10 participants.

Spatial orientation in general

As for spatial orientation in general, participants used varying techniques to orient in space (for the first time somewhere). Some use the help of others (including professional assistance) to accompany them the first time they go somewhere new or give them a description of the new place/route. They stated also gaining as much information as possible about the new route/place before going there.

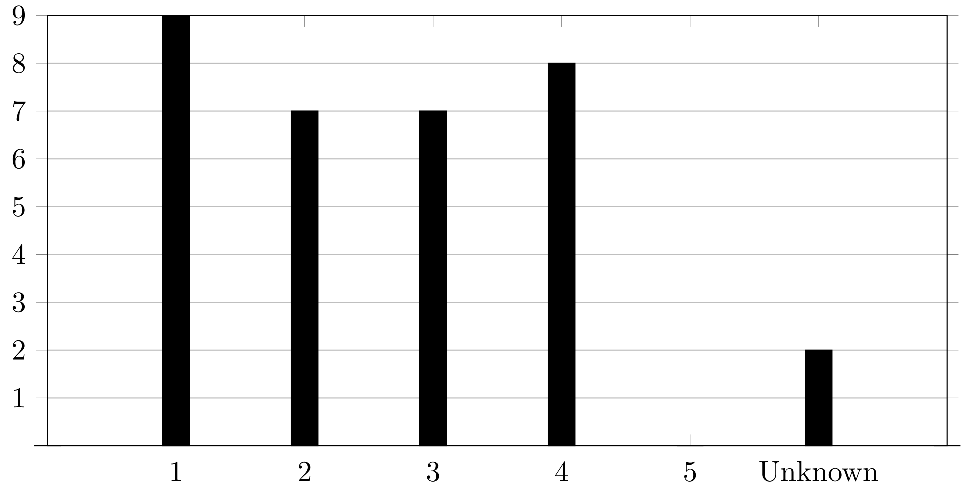

Figure 2.2: Evaluation of olfaction importance for spatial orientation.

Participants sometimes use acoustics for orientation (even using echolocation was mentioned); some stated they mostly use sound to orient. Some make notes (in Braille or voice recording) about their routes. They often mentioned also following significant orientation points and checking the surfaces and their changes. Some participants also described using VPN (sound beacons, more in section 4.1.5).

Participants mentioned having trouble in large open spaces like shopping malls, where they often need guidance.

Mainly, participants use a white cane to gain information about the surroundings. Some use a guide dog for more assistance.

2.1.4 First research summary

Here is the overview of our most important findings from our first user research:

1. From our odour evaluation, we can conclude that more **natural odours** like the smell of forest were more **pleasant** for our participants. Contrarily, more **artificial scents** like the smell of chlorine were **not pleasant** for them.

2. The **cigarette smell** was mostly **unpleasant** even for smokers.

3. Some odours were not very well recognizable, like **jasmine** or **nuts**.

4. Participants had **varying olfactory skills**.
5. Participants often associated with odours places like drugstores or bakeries, frequently **indoor places**. Moreover, **drugstores** were associated with certain odours the most.
6. From our selected places, participants had the least associated with odour **offices**.
7. Participants mentioned having trouble in **large open spaces** like shopping malls.
8. More than half of the participants found olfaction important or even very **important for their spatial orientation**. No participant found it unimportant.
9. Participants who use olfaction in their spatial orientation use it to help them identify shops, entrances to the subway, or changes in the environment. Some use it to confirm the correct location on their route or as an additional source of information.
10. From 33 participants, 18 said that olfaction is a **significant part of their navigation process**. In navigating, participants used olfaction to confirm the correct location, identify places, gain additional information, or detect changes in the environment.

2.2 Second user research

In our second user research, after analysis of the first user research, we wanted to explore more about specific topics regarding the spatial orientation of the visually impaired and olfaction usage. We focused on specific findings from our first user research (like trouble in shopping malls and usage of olfactory cues). Primarily, we wanted to gain some more interesting qualitative insights from our participants.

2.2.1 Method

Because of the outgoing coronavirus outbreak at the time, it was necessary to do the research remotely via phone calls again.

We used a questioner with 28 qualitative questions (not counting some subquestions and screening questions). The screening part was included again at the beginning, containing the same questions as in the first user research. Each semi-structured interview took around 30 to 60 minutes.

2.2.2 Recruitment and participants

We recruited the participants via email. In the screening process (via email and at the beginning of a phone call interview), we again excluded people with any olfactory impairment, people with vision impairment present less than a year, and people who always use the help of others for navigating themselves.

All our participants were visually impaired adults with visual impairment lasting for more than five years. The age of our participants was in the range from 30 to 73 years. We recruited four women ad five men, in total 9 participants (see Figure 2.3).

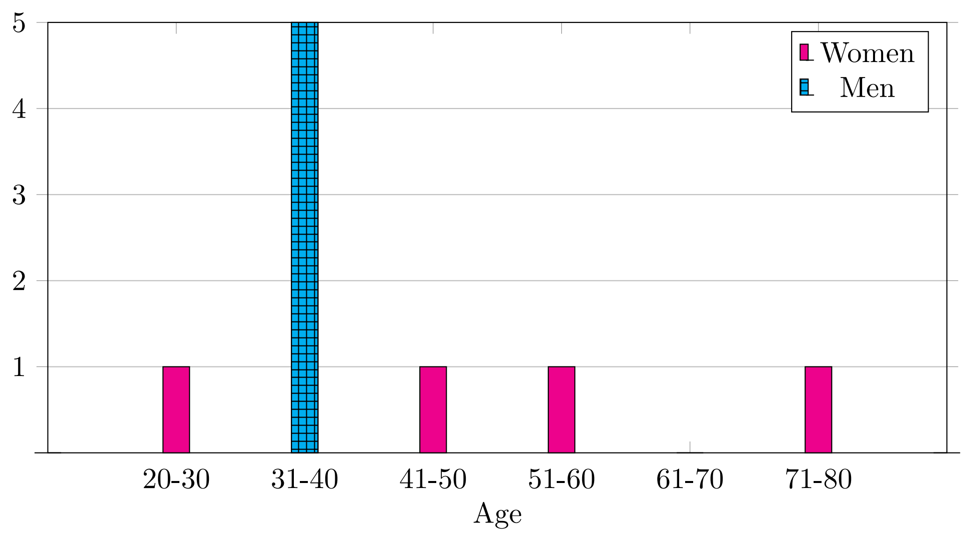

Figure 2.3: Overview of age and gender of participants from the second research

Of course, this is a too small number for drawing any quantitative conclusions, but that was not the aim of this research. We wanted some interesting qualitative facts and insights to gain more understanding of the problem and our target group.

None of the participants had been diagnosed with olfactory impairment. However, two participants reported slight difficulties with olfaction sensitivity after experiencing being ill with coronavirus.

All participants evaluated the usefulness of olfaction in spatial orientation with values 1 or 2 (on a scale from 1 to 5 where 1 means very useful).

We have also asked about smoking and using a guide dog. One of our participants was an occasional smoker, and the rest was non-smokers. Two of our participants stated that they use a guide dog.

2.2.3 Results

We asked about orienting in shopping malls, reorienting when lost, dealing with challenging routes, using olfactory cues on the routes and other topics. Here we present our findings.

Help and independence

When we were asking about solving different issues with learning the routes or orienting in large places, many participants mentioned the help of others. If they need help to find anything concrete or if they are lost, they ask others. Some go, for example, shopping only with the company of someone else (who is not visually impaired).

Not everyone was comfortable depending on the help of others. One participant mentioned that they always try to solve spatial problems themselves before asking for help.

Shopping malls

From our first user research, we found out that shopping malls present a problem for the spatial orientation of our participants, and we wanted to explore more the reasons why.

Participants found shopping malls too large, complex and open, with a lack of perpendicular corridors and system in general.

Some mentioned being afraid to knock over the unexpected obstacles around them. They frequently cannot anticipate obstacles, like chairs or benches freely placed in space or bags of other people lying around. Often there are also goods placed on the floor and not on the shelves.

They are also sometimes afraid to break something with a white cane, especially fragile things like glass walls separating the shops and the corridor or bottles of wine on the floor in some shops.

One participant described that also the colours in shopping malls cause them trouble. They can sometimes use visual contrast differences in the environment to navigate better still using their sight. But they said that because there is usually everything white in colour in a shopping mall, they cannot see their white cane there.

Some participants also complained about unhelpful assistance in shopping malls.

Changes present another problem. Participants described locations of the shops in shopping malls and also goods in the specific shops often changing. One participant mentioned that it can take them even half a year to learn where a particular item is in a shop and when they learn it, they change the location of the item.

Another mentioned problem was loud music that also complicates orientation for the visually impaired.

A few participants also said that shopping malls are impossible to learn in a reasonable amount of time, that it is too hard.

Big open spaces

However, shopping malls are not the only thing causing trouble. When we asked about the most challenging route to learn, we often heard answers like airports, hospitals or the main railway station - large open places, not routes.

Large spaces are often too big and too complicated for our participants. They mentioned a lack of system and a lack of symmetry. They found these places irrationally arranged. One participant said that these places are arranged to look good visually, not to help with orientation. A lack of perpendicular turns also causes issues for our participants.

Some of these big places also cause trouble because they are not visited very often. Participants, therefore, often have little motivation to learn to navigate in them.

Not enough descriptions in Braille was also mentioned.

A considerable amount of people is also not very comfortable for our participants. One participant mentioned that even if people walking around them can see, they bump into them anyway.

Olfactory cues

The participants mentioned using olfactory information points like a bakery or drugstores in shopping malls and the smell of the shops on the street.

They also often use the smell of food on the street, which confirms their correct location.

The usage of odours was not limited only to information points. It can help participants detect changes in the environment. One participant, for example, mentioned that they recognized a modification of the shop in a shopping mall because the smell was different than usual.

We also heard a statement that all routes are always connected to certain odours and that these odours are usually pleasant.

Some of our questions were investigating spatial orientation more in general. We wanted to know how participants confirm that they are in the correct location. Not to our surprise, almost all participants mentioned control of landmarks or information points (more about these terms in section 4.1.1). But also, several participants reported using olfactory cues to check if their location is correct (without us explicitly asking about it).

Face masks

The second research was conducted in - one could say - strange times. Because coronavirus influenced the lifestyle of basically everyone, we wanted to know how much it affected the spatial orientation of our visually impaired participants.

The biggest obstacle represented the face masks. Participants mentioned that their hearing is much worse while wearing it and that they have to be more careful when they go out. Of course, a problem with sensing olfactory cues was also mentioned. They also reported that the ability to communicate is also worse.

Wearing face masks, according to our participants, significantly influences visually impaired people's spatial orientation. It changes the way they move; they proceed more carefully and often have to pay more attention than usual. All that is mainly caused, according to our participants, because wearing face masks worsens the sense of hearing. One participant described that face masks cause different, unusual, sound reflections from the face. And that in a respirator, it is even worse. It is essential that our design of the olfactory interface does not disturb the sense of hearing.

2.2.4 Second research summary

Let us summarize the most valuable insights gained in our second remote user research with visually impaired participants:

1. **Dependence.** Participants were very often dependent on the *help of someone else* regarding spatial orientation.

2. **Big open spaces.** Spaces like hospitals, shopping malls, offices or airports often cause more trouble than routes.

They are too *asymmetrical*. Their aisles are *rarely perpendicular* to each other, there are *many obstacles*, or the space is too *crowded*.

3. **Shopping malls.** They present probably the biggest challenge for the visually impaired.

   They have all the problems associated with big open spaces and more. Participants described being *afraid to break* some fragile unexpected obstacles in their way. There are also *constant changes* and sometimes *not helpful assistance*.

4. **Olfactory cues.** Participants are able to use *olfactory information points*. Olfactory cues can also help to *detect changes* in the surroundings.

5. **Interference of hearing.** We heard participants describing having difficulties while wearing face masks because they *worsen the sense of hearing*.

Our first and second user research findings have provided answers to our research questions stated at the beginning of this chapter. We have learned how our participants orient, what places cause them trouble, how they use olfaction and olfactory cues, which odours seem pleasant and unpleasant to them, and how much some places have they associated with odours.

Now, we are going to continue our analysis through literature to learn more about our target group and their spatial orientation, our chosen sense - olfaction, and related research to these topics.

Chapter 3

Olfaction analysis

Olfaction might appear like a sense that is a bit overlooked overall in human-computer interaction, and concretely in spatial orientation, the situation seems to be no better.

In this chapter, we are going to discuss the characteristics of our olfactory sense. We are going to:

- take a look at the advantages and also disadvantages of the olfactory sense to analyse its potential for improving the spatial orientation of visually impaired people;
- talk about scents and how they influence us to understand their possible usage in olfactory interfaces;
- review the design of several olfactory interfaces for various purposes.

3.1 Our olfactory sense

"The sense of smell is perhaps the most pervasive of all senses, but it is also one of the least understood and least exploited in HCI" [2].

Olfaction has some interesting characteristics worth mentioning:

- Olfactory stimuli are processed differently than stimuli from vision, hearing and touch [2].
- Because of the different processing, olfaction does not interrupt sleep as easily as other mentioned senses [3, 2].

- Olfaction seems to be closely linked with the hippocampus (area of the brain associated with memory) and amygdala (area of the brain associated with emotions) [4].
- It has been suggested that the primary purpose of olfaction might be spatial navigation [5].
- Olfaction can improve the learning process. It can help with *"enhancing recall, recognition, and attention, all fundamental activities that foster learning"* [6].
- The number of olfactory stimuli that people can distinguish might be enormous. Literature specifies this number to 10 thousand odours, but distinguishing more than one trillion has also been stated [7].

Olfaction also has some unfavourable properties that are important to mention:

- There are several types of olfactory disorders which can lower the quality of olfaction (for example, an inability to identify specific odours) [8].
- There could be a complication using the olfactory interface for older adults since ageing can negatively influence olfaction quality [8].
- There can also be considerable variation regarding odour preference and perception of smell intensity [2].
- And finally, if people are exposed to smell for a longer period of time, it can cause the olfactory sense to adapt [9], and the perception of smell can become less efficient.

These disadvantages might be a bit discouraging. Of course, using olfaction cannot help all visually impaired users to improve spatial orientation. However, we could use olfaction in a multimodal interface. Using the olfaction and another modality could be more effective for our users than using that modality on its own.

Moreover, mentioned olfaction advantages seem to have the potential to improve spatial orientation. For example, the fact that olfaction is processed differently from vision, hearing and touch [2] might help with using olfaction as an additional source of information, which can add content to data from other senses. Its connection to memory [4] could also be particularly beneficial for usage in spatial orientation.

3.2 Scents and olfactory interfaces

Probably everyone has some favourite scents. Scents might influence people more than they realise. People choose perfumes they like, maybe buy candles that smell pleasant, someone might decide to go to a restaurant because they can smell the food outside on the street.

Some scents may influence us more than others. Understanding their diverse effects on humans might bring a more effective way to use them in olfactory interfaces to reach defined goals. Here, we are going to discuss some existing olfactory interfaces.

3.2.1 Effects of mint

Its unique place between scents has a mint odour.

In one experiment, there was an aim to explore how olfaction influences learning. The results showed that students smelling the fresh leaves of mint had slightly better results than students who did not smell anything [6].

The experiment mentioned above chose mint odour because of its effects on memory described in a study researching this effect. It tested how participants could remember a sequence of words. Half of them smelled mint during the learning phase; half of them smelled nothing. The group that smelled mint during the learning phase (and during the recall phase) had about 50% better results [Holloway, 1998 as cited in 6].

The effect on learning might be caused by the fact that the scent is present both during the learning and recall phase, no matter what the smell is. However, research suggests that peppermint odour may improve performance and focus [10].

3.2.2 Odour associations

We can see that some scents can have interesting effects on humans. Now, some studies focused more on the mapping and associations between odours and events or objects.

One experiment focused on the associations between certain scents (concretely: lemon, lavender, rose, and peppermint) and driving events. The driving events were of different levels of alertness and reaction times needed to handle them. Researchers used alerting scents - peppermint and lemon, and relaxing scents - rose and lavender (in the form of essential oil). Their results indicated that the mapping between scents and driving events participants created was that the relaxing scent (rose) was associated with more relaxing (less urgent) driving messages. On the contrary, more alerting scents (lemon, peppermint) together with lavender scent were associated with more alerting driving messages [11].

Olfaction can also play a role in recognising multimodal brands. One experiment examined how recognisable a brand is for the participants, depending on the olfactory, visual and verbal elements. The participants were the most successful in recognising a certain brand if all brand elements were corresponding. Their results showed that the brand was harder to recognise if there was a mismatch between the olfactory element and visual or verbal element (or both) [12].

3.2.3 Olfactory necklace

There was also an experiment involving the first olfactory computational necklace by Judith Amores and Pattie Maes. The authors made the necklace so it was easy to wear and also fashionable (a lot of components and the necklace battery is back behind the neck) [2].

The necklace could release the scent if the user pulled the front part down. It could also do it automatically based on a certain physiological state (heart rate, brain activity). It could be controlled wirelessly. The front part could be filled with 7 ml of scent (essential oil, for example). The scent is turned into vapour in defined intervals for the specified number of seconds. Each necklace could contain only one scent at a time. Researchers used tea tree, peppermint, and rose scents to be contained in the participants' necklaces [2].

There was a big difference between participants' perceptions of the released scents. For someone, it was too strong and contrarily for another one not enough. There were also differences in preference of scents. Results showed that the scent release should be more customisable [2].

3.2.4 Driving events

We can also consider the olfactory interface used in a research work [11] that we have already mentioned when talking about odour and driving events associations.

Authors used in their experiment pure essential oils (lavender, rose, lemon and peppermint). The participants in the first study were given (according to a given protocol) a jar with 5g of essential oil (or water). The jar was not see-through. They were supposed to smell the jar from a 2cm distance, one sniff a few seconds long. Short smelling was designed to prevent adaptation. Proper ventilation was also arranged. The second study included in this research used a different, automated approach, with a device located approximately 58 cm from the participants. Participants had headphones, so the sounds from the device were drowned out [11].

3.2.5 Olfoto

Another olfactory system was used in a study introducing the Olfoto tool. The study examined the effectiveness of text tags and smell tags when tagging photographs. Even though text tags were found to be more effective, smell tags also served significantly above chance. Authors used for their study small plastic cubes with an oil-based odour [13].

3.2.6 Directional Olfactory Display

Dong Wook Kim and Hiroshi Ando created an olfactory interface to be used in VR. In their research, they discuss previously presented olfactory interfaces. They say that some of them, using liquid-based scents, were not very durable and provided no spatial control. They wanted to improve their olfactory display to solve these issues. Their olfactory display was supposed to provide spatial control. Also, the aroma provided was supposed to be more durable. They presented a new solution - Micro-Aroma-Shooter. It was a small cube that used directional airflow to shoot a specific smell. The smell is being delivered to the user for a certain amount of time. The problem with aroma durability was solved using calcium silicate, which is a porous substance containing the aroma [14].

3.3 Olfaction analysis summary

We have considered the characteristics, advantages and disadvantages of our olfactory sense. From these pieces of information, we have concluded that using olfaction in interfaces for improving spatial orientation should be reasonable and valuable.

We can see that some scents are very suitable to use in olfactory interfaces for their characteristic effects. We mentioned a few scents in discussed studies. However, it might be helpful to have a much wider range of scents available for later olfactory interface design. We can also see that associations with given scents can play an important role.

As for olfactory interfaces, we are not aware of any olfactory interface used in spatial orientation improvement at this time. Studies mentioned above are more focused on olfaction as a tool for improving learning, event association, or relaxation. But these studies and their results are also very informative and essential for using olfaction in interfaces to improve spatial orientation for the visually impaired. And the orientation of visually impaired people is going to be our next topic to review.

Chapter 4

Orientation of visually impaired analysis

Globally, approximately 2.2 billion people have vision impairment of some kind; the majority of these people are older than 50 years [15].

But in spatial orientation, visual cues present the most informative sources [16]. After losing this efficient data source, spatial orientation might involve a lot of learning, practising, and accepting new approaches.

The spatial orientation of visually impaired people can bring significant challenges. With the growing number of visually impaired people worldwide [1], finding new effective aids in this area is becoming more and more essential.

4.1 Tools for improving spatial orientation

In this section, we are going to take a look at primary tools that help the visually impaired with spatial orientation. We are going to mention more common aids, like a white cane and a guide dog, and examples from less traditional - GPS-based, camera-based, and solar-based tools. We are going to name O&M training and its important terminology because this training can also be viewed as a tool for spatial orientation improvement.

4.1.1 O&M training and important terminology

Long and Giudice provide important information about visually impaired orientation and navigation. They mention the fundamental concepts of orientation. One concept is called *spatial updating*. This concept is about a relationship between the visually impaired person changing position and other objects' locations. While the person moves, they maintain awareness of how their distances and directions to their environment change. That is a fundamental skill for the visually impaired, and also a part of *O&M training* (where O&M stands for orientation and mobility) for visually impaired [16].

Another concept is about *frames of reference*. We can name two types - egocentric and allocentric frames of reference. Using an egocentric frame of reference, the person will describe their surroundings or route relative to their position. Objects around them will be left or right, depending on their perspective [16].

An allocentric frame of reference does not take a person's perspective and movement into account. Locations of objects depend only on each other. Learning to think from an allocentric perspective is also a part of O&M training. Using this allocentric reference frame might be more challenging but also more helpful for the visually impaired [16].

As visually impaired people learn new routes and places, they create mental representations of these places - *cognitive maps*. *"The term cognitive map is used to describe the way that people create and recall mental images of the distances and directions to places out of range of their perceptual systems"* [16]. This representation helps find detours and plan the routes [16].

Another important term in spatial orientation is a *landmark*. Landmark is a permanent sensory clue that can be identified easily. The traveller can be sure that the location of a landmark is stable [Hill and Ponder, 1976 as cited in 16].

We can distinguish *primary* and *secondary landmarks*. Primary landmarks are stable and hard to miss during travelling. On the other hand, secondary landmarks can be missed, but they are also stable [16].

Information points are similar to landmarks, but they are not unique and therefore can be present several times during the route. Both landmarks and information points provide necessary confirmations about going in the right direction and identifying locations along the way. The visually impaired person may integrate them into their cognitive map. [16]

For visually impaired people, it is essential to realize the presence of an orientation problem. They should be aware of it as soon as possible. They can spot this kind of problem if what they expect around them is different from reality. If this happens, they have to find out where they are and how to get back to the correct path. It might be harder to solve this problem if the person uses only an egocentric viewpoint [16].

There are three recognized strategies used to explore unfamiliar places: perimeter strategy, gridline strategy and reference point strategy [Hill and Ponder, 1976 as cited in 16]. Traveller using a perimeter strategy walks around a border of the given space and sequentially learns the attributes of the route. Using a gridline strategy involves a systematic search for landmarks. Finally, using the reference-point strategy, the traveller searches for landmarks. When they find one, they go back to where they started and then search for another landmark [16].

It was shown that people are more efficient in locating objects and estimating distance if they use more strategies (perimeter, gridline, reference-point) [Hill at al., 1993 as cited in 16].

After reviewing several studies about space exploration by the visually impaired, Long and Giudice draw two conclusions. First is that *"when an appropriate source of nonvisual information is provided, the spatial performance of individuals who are blind and that of individuals with vision does not differ"*, and second says that *"orientation is facilitated when people are allowed to learn new environments by free exploration, a finding that speaks to the importance of teaching search strategies"* [16].

We have mentioned the O&M training (and its fundamental terminology) that visually impaired people can take to improve their spatial orientation abilities. Next, we are going to mention some more material tools serving the same purpose, like white cane or guide dog. Finally, less known tools, for example, in the form of mobile applications or smart gadgets, are going to be considered.

4.1.2 White cane

The first tool that probably comes to mind when discussing the visually impaired spatial orientation is a white cane.

It is important to distinguish between a white cane and a cane with red and white bands. A cane with red and white bands signalizes a person with vision and hearing impairment [17]. A white cane without red colour signalizes a person with visual impairment.

This aid has several functions. First, the white cane signalizes to others that its owner has a visual impairment. Signalizing canes are shorter, around

90-110 cm. Second, it enables its user to detect and avoid obstacles in time. Third, it helps with a spatial orientation by detecting tactile characteristics of the environment. This kind of cane is usually long, around 110-140 cm. And finally, it can be used as a support while walking. In this case, the length depends on the user's height [18].

Of course, one type of white cane can fulfil several or all of these functions.

Philip Strong wrote: *"The white cane is not just a tool that can be used to achieve independence; it is also a symbol of the blind citizens in our society."* [19] He also mentions that the invention of a white cane claimed for himself James Biggs in 1921. This artist painted his walking cane white because he felt in danger from passing motorists and wanted to be more visible [19].

There were several attempts to make white cane more intelligent; one of these researches describes a white cane with sensors, audio (short messages), and haptic feedback (vibrations). If there is a stairway, the user is informed whether it goes up or down. It also can detect pits and obstacles [20].

Fundamentally all tools mentioned below are designed to use with a white cane. That only emphasizes the importance and wide usage of this aid.

4.1.3 Guide dog

Another aid in helping with spatial orientation and navigation is a guide dog. Some of our participants either had a guide dog at the time of our research or had owned a guide dog before. They used it alongside the (long) white cane. One of our participants mentioned that with the guide dog, she is more confident and has no trouble navigating even through complicated routes.

In a study [21], including six visually impaired participants, authors suggest eight themes regarding guide dog ownership:

- Improved mobility. Participants felt more confident and safe; they could also move faster.
- Guide dogs could provide companionship.
- Positive personality change. Participants felt more independent. They also experienced personal growth.
- Change of lifestyle. Of course, participants had to take care of their dogs, and with that came necessary time and money investments.

- Social magnet. Guide dogs attracted a lot of people, but also, other people tended to avoid them.
- Distractions challanges. Guide dogs sometimes were not able to avoid being distracted and acted not the way they should.
- Ignorance. Some participants had issues entering public places with the guide dog because dogs were not allowed to enter. Security guards were sometimes not educated about this rule exception.
- Pride. Participants were mostly impressed by their guide dogs' abilities.

These themes presented in [21] might seem overall positive. Of course, ownership of a guide dog (but also a dog in general) brings big lifestyle changes. How positive these changes are probably depends on how the dog and the owner match each other. After all, this aid will be around whether the user uses it or not and will probably require much more attention than other aids.

4.1.4 Tactile tools

We can also mention things like signs and descriptions in Braille that can help the visually impaired navigate. Unfortunately, they are not present in the environment very often.

Another tactile tool is a tactile map. In O&M training, tactile maps can be a very important tool [16].

We can also notice tactile elements on the street or in public buildings. They are usually lines, tiles or paving stones with raised or deeper features. These features help to guide or warn the visually impaired about some borders (in front of a pedestrian crossing or to know the safe distance from the train in the subway).

4.1.5 Sound beacons

Sound beacons are acoustic systems that help the visually impaired with an orientation by describing their environment. The user can activate beacons to hear the audio. In the Czech legislative, specific environmental situations (for example, being in front of escalators) have a particular sound assigned.

After the sound, there can also be a recording with a more detailed description of the situation (for example, which escalator goes which way) [22].

4.1.6 Smartphone applications

One of our participants mentioned using the GPS mobile application *Lazarillo*. He was surprised at how precise it is, and he found it very helpful. Lazarillo uses voice instructions to guide and navigate the user to the given location. Users can search a concrete location or select a category (for example, nearby restaurants). Users can use different means of transport. The application is free, and also extensively customizable [23].

This application is only one example of a mobile application for navigation of the visually impaired. We can expect there to be more of these applications, variating in functions, quality and prices.

4.1.7 Smart Gadgets

One of our participants mentioned that they would like to own *OrCam MyEye*.

OrCam MyEye 2 is a small gadget that can be attached to the glasses (picture 4.2) with magnets. The front part contains the camera and LED (to provide light if needed), the touch-strip on the side enables the user to control the device 4.1, the opposite side has small and strong magnetic plates and audio output in the back. Users can control the device by tapping or sliding the touch-strip and by making gestures with their hands [24, 25].

Figure 4.1: OrCam MyEye side view [26].

Figure 4.2: OrCam MyEye attached to glasses [27].

OrCam MyEye 2 has several functions that help users with spatial orientation and also other important tasks [24, 25]:

- It can read text from books, street signs, computer screens, etc.
- It can inform the user about people or objects in front of him.
- It can recognize people (faces). Users can choose to label people in order to hear the person's name next time it recognizes them.
- It can identify banknotes, colours, and objects that it has learned to recognize or objects stored in its database.
- It can inform the user about time and date.

Our participant has not bought this gadget because of its price, which is approximately 130 000 CZK [25].

Another gadget that can help with spatial orientation is the *Sunu Band* bracelet (picture 4.3), which might be confused with a smart-watch [28, 29].

Sunu Band uses vibrations to warn the user about nearby objects, which are detected using echolocation. The vibration's strength depends on distance - closer objects cause stronger vibrations. Understanding the vibrations takes a bit of practice. It has a touch-screen controlled by gestures and two buttons on the side. Users can connect the bracelet with a mobile application and use more functions - especially important is the navigation provided via sound messages. It also can function as an alarm or compass [28, 29].

The price is around 10 000 CZK [30].

Figure 4.3: Sunu Band [30].

4.2 Analysis conclusions

In this chapter, we have considered essential terminology regarding the orientation of the visually impaired. We have discussed the skills and concepts useful for effective spatial orientation and navigation.

Even though the technology is constantly evolving, smart gadgets (with representatives mentioned in this chapter) do not seem to be able to replace dominant tools like a white cane or a guide dog. White cane seems to be an irreplaceable tool, and new tools should not interfere with its usage. That is probably why mentioned tools are designed the way the user has free hands (or at least one hand).

Some of these tools might need a bit more practice for the user to control them efficiently, and some might be unaffordable because of the higher price.

No matter what technology we will use, making our future solution affordable (for individuals or institutions), useable with a white cane, and easy to control should be a priority.

Chapter 5

Olfaction in spatial orientation

We have discussed olfaction and spatial orientation of the visually impaired. Now, we are going to combine these topics and take a look at studies examining the relationship between olfaction and spatial orientation.

5.1 Usage of olfactory cues

Koutsoklenis and Papadopoulos presented a study that investigated the influence of olfactory cues on visually impaired navigation. The aim was to examine which olfactory cues the visually impaired use and how they use them and determine how valuable these cues are for wayfinding. The research was focused on the urban environment [31].

The study examined which olfactory cues visually impaired use for navigation. The resulting list consisted of cues like "Bakery", "Flower shop", "Sea", or "Fish shop" [31].

The participants also marked these cues according to their importance and usefulness. The most important cues mentioned were primarily cues that represented buildings (for example, "Restaurant", "Bakery", or "Supermarket") [31].

The participants also reported using the cues to determine an object's location (how far it is from them or where it is in the environment). The cues are also valuable for them as a confirmation that they found what they wanted. The participants further stated that the travel's purpose changes the attention towards the cues [31].

5.2 Smelling in stereo

We know that our eyes and ears can provide stereo input and give a sense of direction. We are used to listening to music in stereo, but can we also smell in stereo?

The study of Yuli Wu, Kepu Chen, Yuting Ye, Tao Zhang, and Wen Zhou provided findings that prove human ability to smell in stereo. Also, that humans can use these stereo cues to navigate without realizing it [32].

This is a finding that probably is surprising and unsurprising at the same time. We have two ears and two eyes, providing us with spatial pieces of information. But we also have two nostrils - why would there be two if it would not provide us with any spatial information? On the other hand, we do not actually realize what and how much we are smelling with the left or with the right nostril, so this stereo aspect stays somewhat hidden from us.

5.3 Tracking specific location

The experiment of Jacobs, Arter, Cook and Sulloway examined the spatial orientation of participants using the olfactory sense. The goal was to determine if humans can remember a specific location using just olfaction, then be relocated somewhere else (and become disoriented) and find the way back to the initial location [33].

Each participant tried to orient in the room in three different ways. First, only using his olfactory sense, then only using his vision and finally with no auditory, visual or olfactory information (also using nose clips) available [33].

Results described how much error there was between the actual start location and the location estimated by each participant. The average value indicating the error when using olfaction was 289 cm. When participants wore all the sensory covers, this value increased to 361,4 cm. These values show the estimation was more accurate with the olfactory sense involved. The results also suggest that the participants were able to track a specific location using just their sense of smell and odours around them (using information from two scents in the room) [33].

As the authors say: *"This evidence, however, is not a demonstration of true navigation but rather a demonstration that humans can use this sensory modality to map and reorient to a learned location"* [33].

5.4 Spatial representation

Zhang and Manahan-Vaughan presented a study that examines the creation of stable spatial representations from only olfactory sources in rats. Rats were placed in the box where each of the four quadrants was influenced by a different odour [34].

Their results showed that the rats were able to create stable spatial representations using only the olfactory cues from the space around them. The results also suggest that shuffling the odours' places caused the spatial representations to change and remap. The authors mention that: *"These data support that olfactory information can help to stabilize place field when other sensory modalities are not salient enough"* [34].

This experiment of Zhang and Manahan-Vaughan [34] might seem a bit related to the research of Jacobs, Arter, Cook and Sulloway [33] in its findings (of course, taking into account that in the first participated rats and in the second one humans). In both experiments, there was more than one odour; the odours were distinct and placed in specific locations in space. They both seem to suggest that olfactory cues alone might be sufficient enough to provide reasonable spatial information when other sensory cues are not available. That is a promising finding for our research.

5.5 Olfaction in spatial orientation summary

What is needed for a sense to be an efficient tool for spatial orientation? We can consider an analogy to the human sense of hearing. We need to hear sounds from the environment, distinguish them from one another, determine their volume, and recognize the direction they are coming from. Now, how olfaction seems to fulfil these criteria?

From the study [31] of Koutsoklenis and Papadopoulos, we can see that olfactory cues can be efficiently used as information points. Possibly in some cases, even as landmarks. In the urban environment, these points seem to be buildings of some kind — usually, the ones with typical smell.

The study [33] of Jacobs, Arter, Cook and Sulloway suggests that people can track a particular learned location using odours. That is a significant finding for using olfaction in spatial orientation.

Evidence that olfaction provides a stereo olfactory input used for navigating [32] is also very encouraging.

Finally, Zhang and Manahan-Vaughan's experiment [34] suggests that olfactory cues are enough to create a stable spatial representation of the environment. Even though this experiment was using rats, its findings are very informative and significant. But of course, this cannot be taken (fully) into account in the case of humans.

We can now go back to our question. We know that humans can smell odours, distinguish them from one another, evaluate their strength. And from the mentioned studies, we know that humans can perceive them in stereo [32] and use them to track a specific learned location [33].

These facts and reviewed findings of the studies above provide us with promising information about olfactory cues and their processing to use them as tools for improving spatial orientation.

Even though olfaction seems to play an important role in the process of orientation in space, after the analysis (see chapter 3), we do not know about any olfactory interface actively used to improve visually impaired people's spatial orientation.

There is not a sufficient amount of research done at this time to enable us fully explore the relationship between olfaction and spatial orientation in humans. However, mentioned studies give some interesting suggestions and pieces of information to consider.

Chapter 6

Design concepts

In this chapter, we are going to design a solution that will fulfil our target group's requirements. We are going to use the information we learned from our research, olfaction and olfactory interfaces analysis and analysis of tools for improving the spatial orientation of the visually impaired.

All of the presented designs have their advantages and disadvantages. Some are suitable for outdoor usage, some for indoors and some for both.

More research would be necessary to determine which of these design concepts is usable and which version is the best.

6.1 Design requirements

Giudice and Legge mention in their work that many navigational technologies have been made to assist visually impaired users. However, only a few are now actually used. There is a gap between how the navigational tools work in theory and practice, used by real users [35].

For this reason, we should clearly state the requirements that would be ideal to fulfil in our future solution design to ensure maximal usability. We are going to examine the needs from different points of view.

6.1.1 Target group requirements

There are several requirements our design should fulfil in order to be usable for our target group – visually impaired adults:

- The interface of our solution must be suitable for visually impaired users (considering mechanical knobs and buttons, appropriate feedback, Braille, no touch screen...).

- If we consider our target group, we should bear in mind that using auditory output could be interfering with crucial sounds from the environment. It might block out valuable and informative sounds. And in the worst case, it might even put the user in danger. Using mostly another type of output would be more appropriate.

  This hearing interference negatively impacting visually impaired peoples' navigation was also confirmed by our user research (see the end of section 2.2.3).

  Regarding this issue, olfactory cues are a perfect option. We can also consider combining them with tactile cues.

  However, using auditory output can be considered indoors. Also, it could be used as a supportive tool to provide additional information on demand. The problem of interference with the environment sounds could be partially solved by using bone conduction headphones.

- We have to remember that our users have while navigating at least one hand full because of using a white cane. White cane was an essential tool our participants reported to work with, and we should expect other visually impaired people to work with it as well.

  Also, some of our participants reported using a guide dog (along with the white cane). That means that they need both hands to operate these tools, and there is no room for anything else.

  Our solution should be ideally with hands-free control.

6.1.2 Requirements regarding olfactory cues

- We have to acknowledge the problem of adaptation [9] to an odour after a while.

- Olfactory cues are not always very durable. We should think about improving the durability or ease of refreshing and maintaining the odours. Olfactory cues should be stable.

- We should also consider possible environmental influence (for example, for an outdoor interface, the effect of wind).

- We should consider using more natural odours because we know that these odours were more pleasant for our participants in our research. Odours that are probably most suitable are presented in Table 2.1.

- The olfactory skills of our research participants were varying. The possibility of customising the strength of the olfactory cues would be ideal.

6.1.3 Other general requirements

There are also some more general rules that we should have in mind to create practical and usable design concepts:

- The final solution must be easy to learn.
- Our solution should provide customizability if possible.
- The solution should be financially accessible.
- The final solution must be easy to operate. If it is going to be wearable, it cannot be too heavy or enormous.
- For a wearable solution, the design must be fashionable. The users should not feel awkward or uncomfortable using the designed solution.
- The construction of our solution should be suitable for a given environment.
- The solution should be easy to maintain.

6.2 Design concept A: Scented watch

As we discussed in section 3.1, olfaction is closely connected to memory [4]. This design concept – a solution in the form of a watch – uses this fact. The solution (Figure 6.1) would look like a classic watch (of course, some specific adjustment for the visually impaired would be required), but it could be opened and filled with a specific odour (in the form of essential oil). The user could take their favourite odour wherever they like. When they want, they can push the button on the side of the watch and spray the odour towards their face.

This way, for example, the user could smell the odour on demand during the whole route (during the learning phase) and then go through the route again and use the smell, which may help them recall it better.

The button controlling the odour delivery sprays the odour through small air holes on the side. This way, the odour should aim at the user's face. The second button could be used for opening the watch to get to the inside part.

The inside part might be taken out from the watch to be filled with essential oil or washed. There might also be other buttons necessary to control the actual watch.

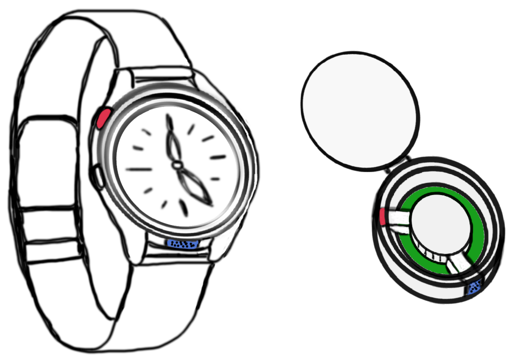

Figure 6.1: Sketch of the Scented watch design; the part sketched on the right is designed to be inside the watch. Green marks the space for the odour (essential oil). Blue denotes the air holes through which the odour is sprayed. The red colour marks the button for controlling the spraying of the odour.

This solution is not truly a navigational aid. It is more like aid for better memorisation. It can be used when learning difficult routes or places where the user is not often, and the smell might help him remember these places for longer.

It is unclear whether the effect on memorisation in the mentioned study [Holloway, 1998 as cited in 6] was caused explicitly by mint odour or if some different odour present during the learn and recall phase would have the same or similar effect.

For this reason, using the mint odour would be probably the best. But if the user does not like the odour, he can use whatever odour he likes.

It would be perhaps even desirable that the user can choose many different odours for different routes or different parts of one long route.

Advantages

- Customization. The user can choose whatever odour they like.
- Discreetness and fashionability. The solution looks like a watch – nothing unusual. The user can spray the odour while touching the watch (it seems like they check the time).

- No adaptation. Because the odour would be released on demand, there is practically no risk of adaptation to the chosen odour. The user would also probably move very soon after releasing the odour to continue.
- Washable. The part containing the odour can be taken out of the watch and washed. This way, the actual watch would not get into the water, and the odour part could be sufficiently cleaned.

Disadvantages

- The user has to use one hand to control the interface and probably change the position of the other hand with the watch to move it closer to their face.
- All the necessary electronics in this watch might be too big. It might be hard to guarantee that it still looks fashionable.

Adjustments

- It might also be desirable to use more odours so that they would be all available during the route. Although, there is probably not enough space for that (so the solution would still look fashionable).
- The solution doesn't need to be in the form of a watch. It could also be, for example, a bracelet.

6.2.1 Scenarios

Here we are going to mention some situations in which such a tool could be beneficial.

Scenario 1
The user has to go to the dentist. It is a route that they do not like. There are many turns close to each other. They make up a sequence that is hard to remember. The user has tried using navigation (application on their phone), but it was often not very precise, and the audio output was disturbing them – there are many pedestrian crossings where they need their hearing fully focused.

Scenario 2
The user needs to visit the local tax office. They visit it every year to submit their tax return. Because they go there only once a year, they struggle to

find the correct path every time. They always need to ask for directions, but the office employees are often unhelpful or even rude. Therefore the user would rather find the path to the tax return office on their own (also to be more independent). However, they sometimes fail to do so, knock on the wrong doors or even wait in the wrong waiting room.

6.3 Design concept B: Office odour guide

Our next design is not meant for personal use as the previous one. We wanted to focus on places where our research participants reported the most prominent issues – big open spaces.

Shopping malls vs offices. The most troubling for our participants were the shopping malls. However, at the moment, we have not chosen to design our olfactory interface for such a place for several reasons. The first one is that there are already plenty of olfactory cues in shopping malls that would interfere with our interface. The second reason is that the malls are too open-spaced – it would be difficult to place the odours efficiently in such an environment. It would be hard to deliver the odours in the right amount in the right direction to our users. This issue might be solved with a tool for more personal use. In conclusion, the olfactory interface efficiently functioning in such a problematic space would definitely need more research.

For this reason, we have chosen to focus on offices. They are smaller but also challenging for our participants. Moreover, offices are places where our participants had the least amount of associations with any odours. This is an excellent opportunity to introduce them.

General functioning. This olfactory interface would be installed in a building (post office, tax office...). There would be containers with specific odours placed in public places. The odours would be sprayed only if a visually impaired person went around them.

Odour activation. The odour delivery could be done in several different ways. The first way would be to use a specifically designed device (transmitter). The user would get the transmitter after entering the building or use their own. This transmitter would transmit a signal to the controllers of the odour devices in the building. When the delivered signal is close enough, the odour would be sprayed locally to the small area through which the person would be going.

Another way would be using some smartphone application that would replace the transmitter by transmitting a signal to Wi-Fi stations around the building. This way, the user's location to the nearest station could be detected, and the closest odour device(s) could be activated at a specific time.

The most suitable way, however, would probably be using a device the users are already accustomed to – a sound beacons controller. Using an adjusted version of the controller could on-demand activate the nearest odour device(s).

Odour arrangement. The placement of the odours could vary. One option might be assigning particular odours to specific doors (specific offices). Doors marked with specific odours would enable users to recognise the correct door discreetly, without the need to ask others or examine anything by touch while looking for descriptions in Braille. It could help to avoid entering the wrong office. The odours could be only detected close to the door, so they would not disturb anyone. They could also be placed on the door without the need for any devices that would deliver the odour.

Another option might be to place the odours uniformly around the building. As described in the study [33] mentioned in the previous chapter, humans were able to track (to some degree) a specific learned location using two olfactory cues placed in a room. Uniformly distributed odours could serve as tools for mapping someone's location and help to reorient.

Some alerting odours could also be placed nearby places where more attention is needed, such as stairways or unexpected obstacles.

We could also somehow combine these arrangements. More research would be needed to find out the most effective combinations to help our users the most.

An example of odour arrangement can be seen in Figure 6.2. Dots mark the placement of the odours. Red dots represent alerting odours that are placed in front of (unexpected) obstacles. In this case, they are nearby stairs, in front of chairs in a waiting room, and around a hallway column. These odours serve as a warning that the user should pay more attention to their surroundings. Other dots mark different odours chosen for the offices' doors. Ladies' room and men's room have different odours, but they could be very similar, representing the toilets in general.

Tool for memorization. If such a system were used as a navigational tool, we would encounter some problems.

Let us say, for example, that there would be two odours - lavender,

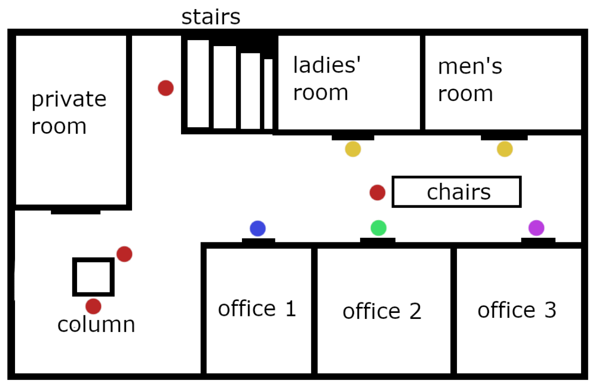

Figure 6.2: Design of odour arrangement for an office building. Dots represent odour placement.

which would mean ”go left”, and rose, which would mean ”go right”. If two visually impaired users went through the same space, the odour device would activate for both of them and spray the odours. The users would be confused about which odour is the correct one and why they smell both odours. They might even follow directions intended for someone else.

Furthermore, the user would have to somehow communicate where they want to go and what their target destination is. That would only increase their dependence on other people. I such a case, it would probably be much easier if the other person gave directions to the target destination directly.

All this considered, this system is not meant to be an actual navigational tool. As with the previous design, it should serve as an aid for better memorisation. Our participants mentioned that they have trouble in offices because they do not go there very often. This way, they may be able to remember the routes through the offices for longer, without the need to relearn them again and again.

Advantages

- There should not be a big problem with the adaptation of the odours. The odours would be sprayed only when the user was nearby. They would also not last for very long.
- If the controllers for sound beacons were used, the users would find it much more user-friendly since they are already accustomed to controlling these devices.

- The users would be able to use the odours discreetly. Other visitors, if they smelled some of these odours, would probably think of them as an effort of the employees to create a pleasant atmosphere.
- A version of this interface is hands-free. The other requires the user to use only one hand.

Disadvantages

- Proper ventilation might be needed.
- Maintaining all arranged odours in the building might be difficult.
- Other people could smell the odours. Primarily, it should be ensured that the odours do not bother the office employees.

6.3.1 Scenario

The user goes to the tax office every year. Finding the correct office in the building is a problem for them. They always forget the path by the time they need to use it again. They have to ask for directions, but usually, there are only other visitors who do not know the way and cannot help them. There are no description signs in Braille. Last time the user had tried to find the correct office by themselves but chose the wrong door. They felt embarrassed. After this negative experience, they even had trouble leaving the building.

6.4 Design concept C: Correcting necklace

Some of our participants described that the routes they do not like have many similar turns, and it is hard to know that one turned wrong. They usually find out too late.

Realising a navigational mistake is very important for the visually impaired, and even more to realise it as soon as possible. Also, after realising that mistake and trying to set it right, they need to know that they got to a point where they are no longer lost and can figure out what went wrong.

General functioning. We present a design concept that could help with warning the user about a wrong turn. The user would wear a necklace, which would contain two containers with odours. One odour would be pleasant, for example, rose odour, and one odour more alerting, for example, some citrus odour. The user can choose the odours in the necklace to their preference. They can fill them with essential oil selected.

The necklace would be connected to a smartphone navigational application. When it would happen that the user would go the wrong direction, the alerting odour would be released (sprayed). After correcting the direction, the pleasant odour would be released, so the user knows they are back on the correct way.

Description. Concept (see Figure 6.3) has a front part that looks like a big necklace. The look of the front part could vary, but it must be big enough to cover the mechanics on the back side. On the back side, there are two batteries, a controller for releasing the odours, two odour containers and a receiver for the signal from the smartphone application.

Usage. There are no audio messages, only olfactory messages. The necklace is meant to be used on the routes the users repeatedly go and do not need all the instructions. But it is intended for routes that cause users trouble. For example, there are too many similar turns close to each other, or too many people or too much noise. It might be used at places where the audio messages are difficult to hear or at locations where the users need to pay attention to their hearing.

We have not suggested using this necklace as a fully functioning navigational tool. It could be, for example, done in a way that one odour means ”go left now” and the other ”go right now”. But this would require probably much larger odour containers that would not fit the necklace. There would also be a higher risk of adaptation if the odours were released close too frequently.

Advantages

- It could help the user to recognise a navigational mistake soon.
- The front part of the necklace could be customised to fit the user’s preferences (however, the necklace would still be bigger than usual necklaces).
- The user would be warned discreetly.
- Odours could be chosen to the user’s preference.
- There would be no risk regarding the adaptation to the odour.

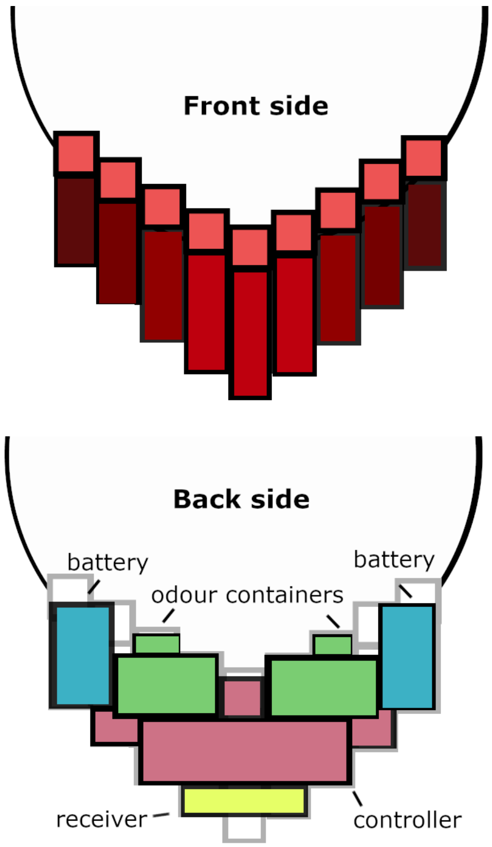

Figure 6.3: The design concept of the correcting necklace, front and back side.

- Hands-free control.
- The spraying of the odour could also be done to work on demand. The user could press a button (necklace subpart) to spray the odour. This way, the necklace could be used the same way as the watch in design concept A. It could be used this way indoors, where the navigation would not work correctly.

Disadvantages

- The technological part of this design might not be realistic. The electronics and other necessary components on the backside of the necklace might be too big to fit the necklace.

- The necklace might be too heavy or oversized and, therefore, uncomfortable.
- All these issues regarding heaviness or size might also cause the necklace to look unfashionable.
- This version is designed only for women. A different design would be required for men. It could be, for example, a longer triangular shape design that would be hidden inside a shirts' collar.

6.4.1 Scenario

The user goes to visit their grandmother every week. They do not like the route because it is complicated and full of non-perpendicular frequent turns. It is very monotonous. There are also obstacles, very often parked cars on the pavement. It happened many times that the user got lost, had to return and found out that they went a third of the route in the wrong direction. They tried to use audio navigation once, but it was very uncomfortable for them because there was a lot of traffic.

Chapter 7

Concept usability testing

From our three design concepts, we have chosen to further prototype, test, and develop **design B - Office odour guide**.

The reasons for this decision are following:

- the offices were the least connected to odours according to our research which gives us an excellent opportunity to introduce them there;
- because people do not visit offices very frequently, the effect of olfaction on memorization should be most beneficial there;
- it is the most user friendly of our designs in many aspects:
  - users do not need to carry any additional gadgets on them;
  - users are usually already familiar with using a sound beacons controller, which might be used after adjustments for controlling the odour devices;
  - users do not need to maintain the system;
  - users can take advantage of this design discreetly (there is no need to look for the odours like for tactile cues, users will immediately know the if odours are there);
- the odours might also brighten up the often stressful atmosphere in the offices.

7.1 Experiment design

We have designed our experiment to test chosen prototype and also to help us find answers to the following research questions:

1. Will participants notice new olfactory cues during their route?
2. How will participants use prepared olfactory cues?
3. Will participants consider prepared olfactory cues reliable and efficient?
4. Can olfactory cues be used sufficiently as landmarks in the navigation of visually impaired people?
5. Can olfactory cues be used to identify points of interest (POI)?
6. Will olfactory cues help participants to remember the route better?
7. Will participants be able to recognise the odours they smelled during the route?
8. Will participants find the olfactory cues pleasant?

7.1.1 Method

In our experiment, we are going to simulate an office environment. In the first part of the experiment, the participants are going to visit the office (it can be perceived as, for example, a post office building). Their task is going to be to visit one by one

- office number 1, where they get a form,
- office number 2, where they get a stamp on the form,
- finally, office number 3, where they hand in the form.

The participants are going to be told that they will probably revisit the office soon, and it would be helpful to remember the arrangement of the three offices in the building. Each office is marked with a corresponding odour, label in Braille and tangible number. The participants do not need to go inside the offices or carry around an actual form, only announce that they found the given office (in correct order).

Before the experiment begins, the participant is also told that everything they will perceive is stable in the environment (sounds, smells, furniture, music...). They are going to be informed that we have intentionally added some new landmarks to the environment, and all of them are permanent. We are going to tell them this information rather carefully. We do not want to tell them directly that the new landmarks are (only) olfactory cues. This note is there to help to ensure the participants are not going to ignore the odours as unstable and uncertain immediately.

After the first part follows an interview. The participants are going to go through their route again and describe what they perceived, how they estimated their location, how they recognised the right office etc.

The following second part also involves a visit to the same office building. However, this time, because of reconstruction, the offices are placed differently from the last time. The task is only to visit office number 1 and get a form there. The office doors are labelled the same way as in the first part. Pairs office number-odour are the same for both parts of the experiment. The participants are this time asked to think aloud from the beginning.

The simulation of reconstruction of the office building encourages the participants to use the odours for orientation. Placement of the offices is different, which means remembering the corridor layout and how offices go one after another will not be helpful for the revisit. However, the odours stay the same for corresponding offices, which presents the opportunity to find and identify the offices using the odours.

After the experiment, there is another interview with additional questions and an odour test. The participants are going to be given one by one six essential oils. Three of them were not used in the experiment, and the remaining three were the office odours. The participants are supposed to say the name of the odour (if they know it), how pleasant it is for them (on a scale from 1 to 5, 1 means very pleasant, 5 means very unpleasant), and finally, if they think the odour was present in the experiment or not. This test is there to discover how the participants remember the odours, if they can distinguish which odours they perceived and which not, and alternatively if they remember to which offices odours belonged.

7.1.2 Environment.

We want to provide as realistic conditions that represent an office environment as we can.

One of the sections (Figure 7.1) of our university building is suitable to simulate the office environment. In this section, there is a corridor with multiple doors on each side. These doors are going to represent the entries to our experiment offices. This building section is also suitable because there are no stairways that might endanger visually impaired users.

We can use another floor with a bit different structure to simulate a reconstruction of the offices in the second part of the experiment.

There are going to be three offices on the second floor and the same three offices on the fourth floor. The offices have assigned numbers (1, 2 and 3). On each floor, the offices are situated differently (Figure 7.1).

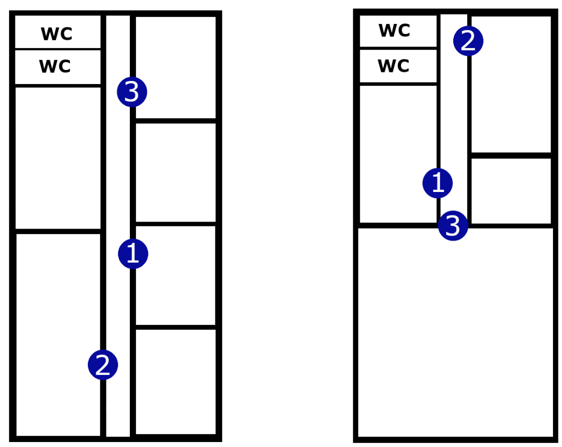

Figure 7.1: Arrangement of the offices on the second (left- offices before reconstruction) and fourth floor (right- offices after reconstruction).

7.1.3 Odour delivery.

For this prototype, we are going to use small wooden cubes soaked with given essential oil to simulate the odour devices from our chosen concept.

The first idea was to use kitchen sponges soaked with a few drops of the given essential oil. However, this alternative has not proved to be particularly useful for our purposes. The strength of the odour was either relatively weak or excessively strong, highly unpredictable and unstable. The odours would also easily mix soon.

The odour from wooden cubes is much more stable and durable. The number of cubes for each door was chosen according to a series of smaller experiments – 8 cubes for each office has given the best results regarding odour strength and durability. Also, it is optimal to begin the experiment approximately 10 minutes after preparation. However, odours seemed stable even after 30 minutes. The odour is noticeable from roughly 1-1,5 m distance from the cubes.

Because our chosen environment is essentially impossible to ventilate properly, running the experiment with no more than one participant a day to ensure consistency will be necessary.

On each office door is placed a net with wooden cubes soaked with essential oil. The net is placed on the office door roughly above the headline, so participants are less likely to touch it accidentally. Under the net, there is a number of the office distinguishable by touch. The number is there for participants who are not able to read Braille. But for those who can, there is also a label in Braille under the tangible office number. Discussed tools used to label and mark the office door are shown in Figure 7.2. The arrangement of these door elements is illustrated in Figure 7.3.

Figure 7.2: Tolls used to label and mark the office doors – tangible numbers, Braille labels, wooden cubes, essential oils, nets.

7.1.4 Odour selection.

For our experiment, we need to choose three odours that will mark entries to defined offices.

We discovered in our previous research which of our selected odours seem pleasant to our participants and which rather not (Table 2.1). According to these results, we have decided to use vanilla (office number 2), tree blossoms (office number 3) and citrus (office number 1) odour because they were

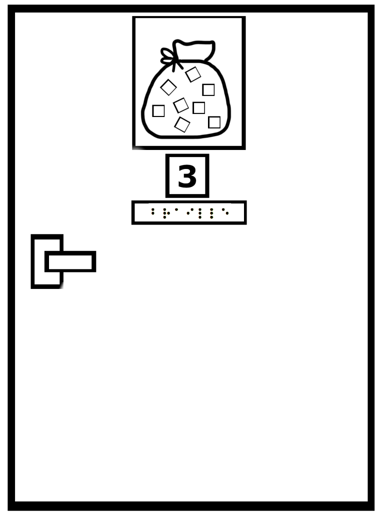

Figure 7.3: Office door arrangement. The wooden cubes are placed in a net set above the headline on a plastic background. Under the net is a tangible number and a label in Braille.

found the most pleasant. The pleasantness of these odours might enhance the often stressful atmosphere of offices. These three odours are also quite distinct, which might help eliminate the potential mixing of the odours in the corridor.

We are not going to use the forest odour. No essential oil which we have tried seemed authentic enough to represent the forest odour. These odours were too synthetic. And because we can see from our results that participants overall preferred more natural odours, choosing such an odour would be inappropriate.

7.1.5 Recruitment and participants

We recruited the participants via email.

In the screening process (via email and before the beginning of the experiment), we again excluded people with olfactory impairment, people with vision impairment present less than a year, and people who always use the help of others for navigating themselves. When asking about olfactory impairment, we also asked about hearing and sense of touch to hide the experiment's nature.

All our participants (Figure 7.4) were visually impaired adults with visual impairment lasting for more than five years. We recruited in total 7 participants, 4 women and 3 men.

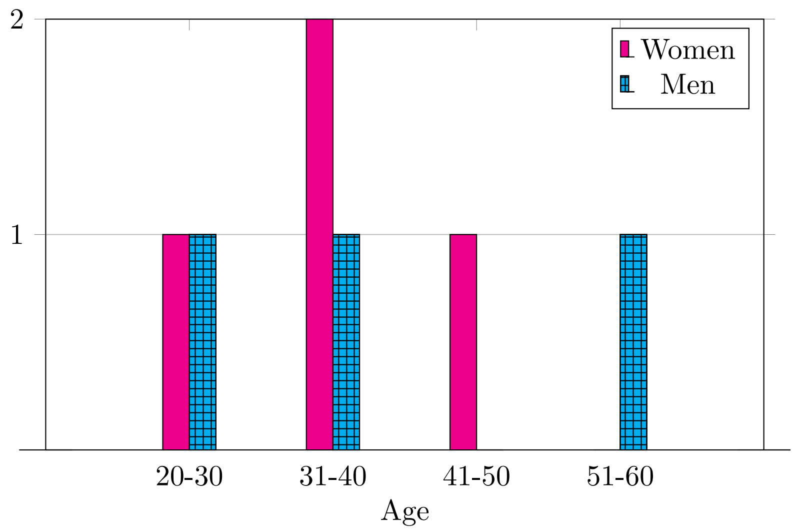

Figure 7.4: Overview of age and gender of participants of the experiment.

7.2 Results and discussion

In this section, we are going to examine the overall outcomes of our conducted experiment. Of course, these findings are only qualitative in nature due to a smaller number of participants. They serve to inform about interesting facts and provide valuable insights.

We are going to list all our findings from the experiment and use these findings to search for answers to our research questions. We are also going to discuss what we have observed.

Awareness of odours. One participant mentioned they noticed all tree odours in both parts of the experiment. The participants mostly noted one or several odours. Two participants noticed some odours, but they chose to ignore them.

One participant noticed the odour(s) yet did not realise it. This participant claimed they had not noticed the odours, but they realised they remembered the vanilla odour from the experiment during the odour test.

These findings answer our first research question: Will participants notice new olfactory cues during their route? To sum up, all participants noticed the odours to some extent.

It is essential to say the participants were not told explicitly that the odours were there and that they function as permanent olfactory cues marking the offices. The results might have been very different if the participants had known about olfactory cues ahead.

The experiment has been designed this way to see if participants notice the odours on their own. We also wanted to examine how they use the olfactory cues without us telling them their purpose.

More research is needed to explore how would participants function during the experiment knowing this information. Mainly, it could significantly limit the level of distrust in the olfactory cues (discussed in the next point).

However, without this information, participants also did well in noticing the odours, sometimes even unconsciously. This finding appears very optimistic, especially while considering varying olfactory skills people might have.

Distrust in (indoor) odours. Overall, the participants did not find the olfactory cues reliable. They mentioned that it is hard to trust and rely on them primarily because of their impermanence.

Some participants noted that if they knew they could rely on the odours, the odours would be helpful. One of the biggest obstacles in using the olfactory cues efficiently seems to be the deep-rooted tendency not to rely on the odours.

However, this distrust does not seem to be present outdoors to the same extent as indoors. Almost all participants mentioned they use olfaction to find shops on the street. They use the smell of the shop as a landmark or at least as an additional confirmation that they go correctly. They often noted that they would not think about using it indoors. One reason was that the odours could mix with naturally present odours in the environment. Alternatively, they mentioned that the indoor odours are not permanent, and they cannot know they will not disappear.

Participants' doubt in indoor odours appears justified. Indoor odours are often impermanent and easily influenced (fresh coffee, perfume, cleaners and others). The proposed concept also brings quite a unique approach to a navigational aid. None of the participants was used to this kind of approach.

Therefore, it would be necessary for future designs that users knew about the odour system in the offices and understood where the odours are. The users would have to know what to expect and that the olfactory cues are there permanently and intentionally.

It would also be sufficient to choose odours that are the least mistakable with natural indoor environmental odours.

The efficiency of olfactory cues. As for efficiency, the participants who were able to assess the usefulness of the olfactory cues in the experiment gave it the average value of 3 (on a scale from 1 to 5, 1 means very useful and 5 means completely useless).

The last two points answer rather negatively the third research question: Will participants consider prepared olfactory cues reliable and efficient?

The fact that the participants assessed the efficiency of olfactory cues as average might relate to the discussed distrust in odours. Also, the efficiency could significantly increase with higher prototypes and giving explicit information about the olfactory cues system to the users. However, we did not want to use any devices to spray the odours when participants moved around the offices. The experiment was meant to test mainly the heart of our concept. Also, spraying the odours would be hearable, and as mentioned, we did not want to alert the participants about the presence of the odours explicitly.

Olfactory cues usage. This point brings us to our second research question: How will participants use prepared olfactory cues?

Some participants did not use the olfactory cues. They had different reasons:

- they thought the odours are a natural part of the environment,
- they chose to focus primarily on tactile cues and, therefore, (knowingly) ignored the olfactory ones,
- or they did not think the odours could be meant as cues they should use.

From those participants who used the olfactory cues, they worked with them in several ways:

- three participants mentioned that the odours confirmed to them they are somewhere important where they are supposed to be,
- one of these participants used citrus odour to help them identify the location of the office in both parts of the experiment,

- one participant used the citrus odour as an additional confirmation that they found the right door.

We can also address our fourth research question: Can olfactory cues be used sufficiently as landmarks in the navigation of visually impaired people?

From our results, it does not seem the olfactory cues alone could be used sufficiently as landmarks. No participant used the odours solely to identify an office. However, some participants used it as additional information to confirm the location of an office (discussed in the next point), even though they mentioned later that they had had trouble trusting the odours.

We should note here that using the olfactory cues as landmarks was not our actual goal. In our initial user research, we learned that participants did not use olfactory cues in this way. As confirmed in the experiment, they used it more as information points or additional sources of information.

The participants who did not use the olfactory cues seemed to do so because of distrust or just out of habit. Even such a finding brings a positive fact – the system causes no obstacle for those users who decide not to use it.

Those participants who used the odours found the purpose of the cues in general as an additional confirmation that they are at some point of interest. These findings show that we might consider designing future prototypes mainly to function as a secondary confirmation working parallel with other aids, not trying to develop it as the primary orientation aid system.

Identifying points of interest. Our results indicate that the primary tool to identify the offices were the tactile cues on the door – Braille label and tangible number.

Most participants did not recognise any particular system in the odours. One participant noticed the system yet chose to ignore the odours and focus on tactile cues instead.

Nevertheless, as mentioned in the previous point, some participants used the olfactory cues as additional information to confirm the location of an office. If participants noticed that a specific smell belongs to a particular office in the first part of the experiment, they used this information to confirm the correct location of this office in the second part. (The citrus odour seemed to do the best job in marking its office.) This fact indicates the potential of olfactory cues usage to mark points of interest and seems to answer our fifth research question: Can olfactory cues be used to identify points of interest (POI)?

Varying olfactory skills. We can confirm the finding from our first user research – the participants had varying olfactory skills. These skills included naming the odours, noticing them, recognising them, remembering them and matching them with the offices.

In future prototypes, we might solve different olfactory skills issues with the customisation of our concept. For instance, the users could have the ability to choose how many times they want the olfactory devices to spray the odour.

Unintentional odour memorisation. More research is needed to explore the effect of olfactory cues on route memorisation. Therefore, our sixth research question (Will olfactory cues help participants remember the route better?) remains mostly unanswered. The experiment, however, indicates some interesting effects on memory as well.

It seems participants were able to memorise some odours unintentionally. One participant was sure they had not smelled anything, yet they confidently recognised one of the odours in the following odour test. Another participant said they only tried to remember the locations of the offices (in the first part of the experiment) and nothing else. However, in the second part, they recalled which odour marked office number 1. Another example is the participant who said they completely ignored the odours yet afterwards successfully identified two odours present in the experiment.

This finding is probably the most interesting one and also very promising. It seems that some participants did not have to pay attention to memorise some odours knowingly. Together with the general effect on memorisation, this effect, as mentioned, deserves more research, especially in the long term.

Odours' presence in the experiment. As stated in the previous point, the participants unintentionally remembered the experiment's odours without trying. They sometimes recognised more odours than they thought they remembered. Most often remembered was vanilla odour followed by citrus odour. Tree blossoms odour, on the contrary, caused the most trouble.

Other times, however, even though they noticed some odour, they could not recognise it during the odour test.

In Figure 7.1 are shown summarised results of all odour tests regarding odours presence in the experiment and participants' opinions about this presence.

Not counting the participants who were not able to decide, the total number of correct answers is 26 (84%), and the total number of wrong answers is 5 (16%). The participants, therefore, answered mostly correctly and were highly accurate in distinguishing which odour was present in the experiment and which was not. Moreover, in establishing which odours were not present in the experiment, were the participants 100% accurate. Of course, we have to consider that some participants did not notice the odours in general and therefore could have reported that some specific odour was not in the experiment. Although, the answer to our seventh research question (Will participants be able to recognise the odours they smelled during the route?) seems quite positive.

Odour name	**In experiment**	**Yes**	**No**	**No answer**
Lavender	no	0	**4**	3
Vanilla	yes	**6**	0	1
Citrus	yes	**4**	2	1
Strawberries	no	0	**6**	1
Cinnamon	no	0	**5**	2
Tree blossoms	yes	**1**	3	3

Table 7.1: Odour test results first summary. The first column represents the name of the odour. The second column tells if the odour was present in the experiment or not. The third column shows how many participants said the odour had been present in the experiment, and the fourth column how many participants said it had not been present. The last column represents the number of participants who were not able to decide. Correct answers are highlighted in bold.

Odours' pleasantness. Before the odour test, the participants were asked how pleasant they found the odours during the experiment. If participants noticed the odours during the experiment, they always assessed their pleasantness with value 1 as very pleasant.

The following evaluation took place in the odour test to assess how pleasant each odour was to the participant. In Figure 7.2 are shown summarised results of all odour tests regarding participants' opinions about odours pleasantness. Generally, the participants usually marked all odours as pleasant, with the worst average value of 3 for tree blossoms odour.

The vanilla odour seemed the most pleasant of the odours. Also, this odour was the one (correctly) most remembered from the experiment (Figure 7.1).

Interestingly, on the contrary, tree blossoms odour was hardly noticeable and memorable for the participants. It was the only odour that was essentially a mixture of different aromas. It was also evaluated as the least pleasant.

Odour name	Best mark	Worst mark	Average pleasantness
Lavender	1	5	2,71
Vanilla	1	3	1,71
Citrus	1	4	1,86
Strawberries	1	4	2
Cinnamon	1	4	2,14
Tree blossoms	2	4	3

Table 7.2: Odour test results second summary. The first column represents the name of the odour. The second column shows the best mark given in evaluation and the third column the worst (on scale from 1 to 5 where 1 means very pleasant and 5 very unpleasant). The last column shows an average result of how pleasant the odour was for the participants.

We can see that this data provides a confident, positive answer to our last research question: Will participants find the olfactory cues pleasant?

Tangible numbers. All participants appreciated the tangible numbers on the door and evaluated their usefulness with value 1 (very useful). Only one participant used both the number and the Braille for all offices. Two participants started with examining both and then continued with checking only the numbers. Three participants examined only the numbers and ignored the Braille label, even though they could read Braille. One participant also used only the numbers and was very excited about them because they were not able to read Braille. They mentioned that if somewhere are any tactile cues, it is usually only in Braille, and there are no other options for people who cannot read it. Tangible numbers were beneficial for everyone in this experiment. One participant even mentioned it might also be valuable for purblind people.

It would be very suitable to involve such tangible numbers as a part of future designs. That way also, more modalities would be applied.

Relationship with olfaction. There were no significant differences among participants who use olfaction for orientation extensively and those who use it occasionally and do not see it as an essential tool for orientation. Also, there seems to be no significant difference among participants who regularly use olfaction for orientation only outdoors or both indoors and outdoors.

Gender. There were no significant differences in noticing or remembering the olfactory cues among men and women in this experiment. We can only mention two facts. The first is that men had a high tendency to ignore the odours entirely even when they noticed them. The second one is that women were much more successful in naming the odours. They correctly named 54% odours. On the contrary, men named successfully 17% of odours.

Difficulties in offices. The participants mainly reported that they need to rely on the help of others when visiting the offices. One participant noted that they even try to avoid these visits. Two participants mentioned that they always inform themselves ahead but usually ask someone for help likewise. Two participants expressed their disapproval of the modern touch screens used nowadays in offices. Finally, four participants noted that there are usually no tactile cues for visually impaired visitors.

These answers only supported the idea to provide more assistance in the offices for visually impaired users.

7.3 Follow-up interviews

We have conducted additional follow-up research via phone calls with the participants of our experiment. We have interviewed three of our participants approximately two months after they participated. We wanted to know what information (regarding olfactory cues) they remember and find out possible associations with these memories.

Results

- All participants remembered which odours they had identified during the experiment.
- All participants mentioned at least four (out of six) odours they remembered from the experiment/odour test.
- The participants who noticed where the odours had been located during the experiment remembered this information in the interview.

- All participants found all odours pleasant and would want to be exposed to them again.
- All participants mentioned that the way they use olfaction in their day-to-day lives has not changed after the experiment.

The fact that the participants have not changed the way they use olfaction might not seem surprising. The participants are used to a particular habit of (not) using the olfactory cues, which one participation in an experiment appears to have no power to change.

The fact that the participants remembered the odours they had noticed during the experiment and mostly remembered the other odours from the odour test is quite favourable. Even though these are findings from only three participants, the potential of olfaction to improve memorisation of the routes seems to be there, waiting to be explored more.

Chapter 8

Website Design

To make our learnings accessible for a wide audience, we have decided to propose a design of a website. The website is going to have an educative purpose - to report our most interesting and important findings. We want to raise awareness about discussed topics and help employ olfaction in aids to improve the visually impaired's spatial orientation.

Delivery form. The website is going to present interesting and valuable facts to inform and educate the user. We also want the user to enjoy being on the website. The facts are going to be short with attractive titles, divided into consequent sections. The website is going to be minimalistic, with only one page. The user will scroll down to read more information. In the end, there is going to be a link to our research if the user wants to learn more.

Responsiveness. The electronic prototype is focused on desktop use (designed for resolution 1440 x 1024 pixels). Still, the final design is meant to be responsive and comfortably used on a tablet or mobile device.

Accessibility. In a final design, there will have to be an emphasis on accessibility elements. We want the final design to be accessible to as many users as possible. Mainly, it should be eligible for screen readers for visually impaired users.

Animations. Current prototype design has some illustrative animations set. We mainly wanted to show the core of the final design and the form in which our learnings could be delivered. Animations, in general, will have to be moderate, so the accessibility would not be jeopardised.

8.1 Scenarios

Let us propose some scenarios that could illustrate use cases of our website design.

Scenario 1: Manager of a post office installed on demand of the customers new ticket system controlled through a touch screen. He knows this system is not suitable for visually impaired visitors. He wants to make the post office available to them. However, the post office is due to a significant amount of visitors very loud and crowded place. Sound and tactile cues might not be sufficient enough there. He wants no learn about other alternatives he has to help improve the accessibility for visually impaired people.

Scenario 2: An owner of a hobby shop knows that visually impaired people have trouble finding her shop. The entrance is from the street, but there are several other entrances relatively close. She wants to do something to make it easier for them. She knows that visually impaired people always find the bakery across the street, even though it has a similar mistakable entrance. She immediately imagines the lovely smell of the bakery when she walks around it. She wonders if maybe a smell could help her visitors to find her shop.

Scenario 3: Office workers in a tax office are often in contact with visually impaired visitors who chose the wrong office. The office workers have Braille labels, but some visually impaired visitors do not read Braille. Sometimes they do, but they have trouble finding the labels. Office workers would like to install a system to help visually impaired people find the correct office, ideally silently, so they would not be disturbed so often.

8.2 Design Process

We quickly tested each prototype phase with a few participants and changed the design according to the findings.

Low-Fidelity Prototype. We started with a paper prototype (see Figure 8.1) of the website. There was a long paper representing the background of the page and slips of paper with the text on it placed on the paper. To "scroll down", the participant moved the background paper up.

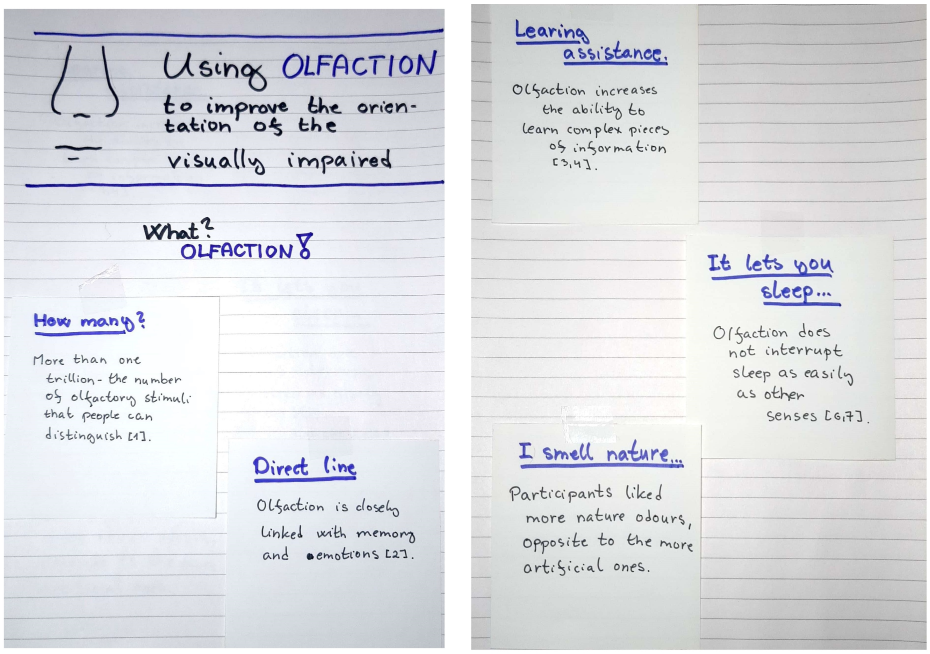

Figure 8.1: Part of a paper prototype.

The four usability test participants liked the content itself and found it very interesting. One participant said that it would be great to be able to skim more quickly through some facts without reading the whole text. Another participant mentioned that they do not know where to look first. Three participants agreed that they would like to learn more.

According to these results, we highlighted important words in the presented facts so that the users can skim through the page more quickly if they want. We also added arrows to guide the eye.

High-Fidelity Prototype. An electronic version of this website prototype (see Figures 8.2, 8.3) was created in the Figma tool [36]. The participants this time viewed the website design through a presentation tool of Figma on the desktop.

Three participants again liked the presented information and also appreciated the appearance of the page. One participant found technical issues with the animations, which have been corrected. Another participant mentioned that they would like to have a bit more colours there. All participants agreed that they would like to learn more about the research.

Figure 8.2: Part of an electronic prototype - sections transition.

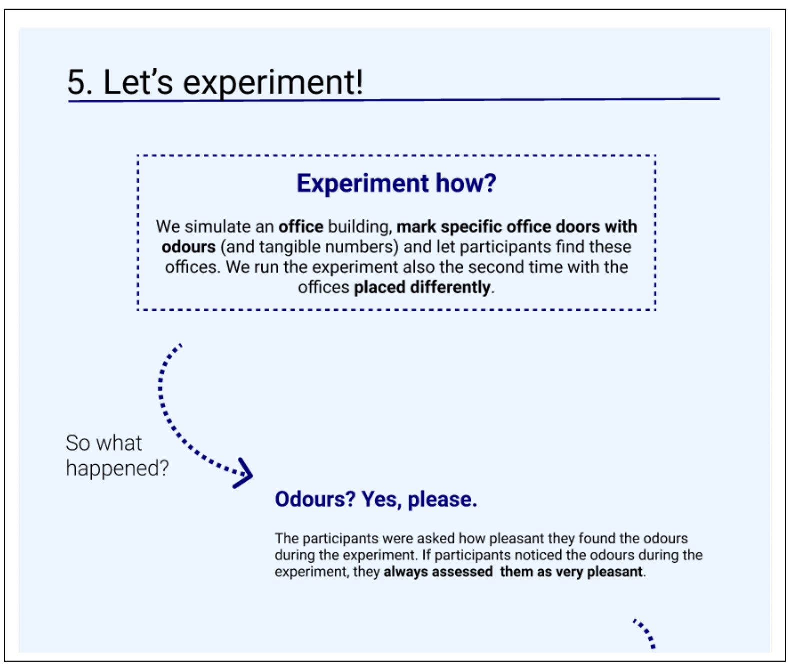

Figure 8.3: Part of an electronic prototype - section about our experiment.

From these results, we can see that our design prototype seems to be going in the right direction. Participants were interested in the presented information, and the delivery form appeared to be efficient. The design can always be extended or updated with more findings from future research works.

Chapter 9

Conclusions

Our goal was to propose an olfactory interface design concept to aid visually impaired users in spatial orientation tasks. To do so, we started with research and analysis of our target group - visually impaired adults. We conducted two research studies with the visually impaired to discover answers to our defined research questions. In the first one, we found, besides other things, the odour preferences of our participants, their odour associations, how they use olfaction in spatial orientation, and how they orient generally. In the second research, we explored some topics in detail to gain interesting qualitative insights. The results mainly showed that our participants have to often rely on assistance from others and have problems with large open spaces - especially shopping malls or office buildings. We also learned how the participants use olfactory cues.

We continued with the analysis of olfaction and olfactory interfaces. We learned about some critical advantages of olfaction like the close connection to memory [4] and positive effect on learning [6]. We also examined visually impaired users and the aids they use to gain a better understanding of our target group and their needs. This way, we could, for instance, recognise that our designs should work simultaneously with the aids the target group is already used to. Analysis continued with examining research on the role of olfaction in spatial orientation to learn how these topics correspond and if olfaction can be an effective tool for spatial orientation.

Based on our learnings and design requirements, we created several design concepts. We analysed them and discussed their properties, benefits and limitations with our target group in mind. We chose one design concept that had the most considerable potential to help our users - the Office odour guide. This concept presented a system of olfactory cues used in office buildings to navigate users to find desired offices. Creation of experiment design and prototype followed. The prototype used olfactory cues to mark the office doors in a simulation of an office building where participants looked for given offices and tried to remember their locations. We also conducted follow-up interviews mainly to find out if participants remember odours used in the experiment and if their usage of olfaction changed in any way after they participated. We presented our results and discussed them. The fundamental problem with olfaction usage in the experiment was participants' distrust in odours. However, other significant findings were that the participants overall could notice the odours, sometimes memorised them unintentionally, and used them often as additional confirmation. During the interview after the experiment, the participants again reported difficulties visiting the offices and their need for assistance there.

Finally, we proposed a website design focused on a broad audience. Website design summarises our findings and best practices to help employ olfaction as an aid in the spatial orientation of the visually impaired.

After this step, we believe our goal is met and that our research showed that olfaction could have its place in designing aids for visually impaired users. For future research, it would be desirable to continue testing higher prototypes (automated spraying devices instead of soaked wooden cubes). It would be beneficial to cooperate with a concrete office and use the prototype there and examine the effect on visually impaired visitors in the long term.

Bibliography

[1] Peter Ackland, Serge Resnikoff, and Rupert Bourne. World blindness and visual impairment: despite many successes, the problem is growing. *Community eye health*, 30(100):71, 2017.

[2] Judith Amores and Pattie Maes. Essence: Olfactory interfaces for unconscious influence of mood and cognitive performance. In *Proceedings of the 2017 CHI conference on human factors in computing systems*, pages 28–34, 2017.

[3] Mary A Carskadon and Rachel S Herz. Minimal olfactory perception during sleep: why odor alarms will not work for humans. *Sleep*, 27(3):402–405, 2004.

[4] Colleen Walsh. What the nose knows. *The Harvard Gazette* [online]. 27. 2. 2020 [cit. 2021-10-24].
Available at: `https://news.harvard.edu/gazette/story/2020/02/how-scent-emotion-and-memory-are-intertwined-and-exploited/`.

[5] Lucia F. Jacobs. From chemotaxis to the cognitive map: the function of olfaction. *Proceedings of the National Academy of Sciences*, 109(Supplement 1):10693–10700, 2012.

[6] M. Garcia-Ruiz, Samir A. El-Seoud, Arthur Edwards, Jihad Mohamad Alja'am, and Raul Aquino-Santos. Integrating the sense of smell in an educational human-computer interface. *Interactive Computer Aided Learning*, 2008.

[7] Caroline Bushdid, Marcelo O Magnasco, Leslie B Vosshall, and Andreas Keller. Humans can discriminate more than 1 trillion olfactory stimuli. *Science*, 343(6177):1370–1372, 2014.

[8] Jayant M Pinto. Olfaction. *Proceedings of the American Thoracic Society*, 8(1):46–52, 2011.

[9] Kaori Ohtsu, Junta Sato, Yuichi Bannai, and Ken-ichi Okada. Scent presentation technique of pulse ejection synchronized with breathing. In *2009 Ninth Annual International Symposium on Applications and the Internet*, pages 125–128. IEEE, 2009.

[10] Shannon Barker, Pamela Grayhem, Jerrod Koon, Jessica Perkins, Allison Whalen, and Bryan Raudenbush. Improved performance on clerical tasks associated with administration of peppermint odor. *Perceptual and Motor Skills*, 97(3):1007–1010, 2003.

[11] Dmitrijs Dmitrenko, Emanuela Maggioni, Chi Thanh Vi, and Marianna Obrist. What did i sniff? mapping scents onto driving-related messages. In *Proceedings of the 9th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, pages 154–163, 2017.

[12] Gayathri Mani. *Smells and multimodal learning: The role of congruency in the processing of Olfactory, visual and verbal elements of product offerings.* The University of Arizona., 1999.

[13] Stephen Brewster, David McGookin, and Christopher Miller. Olfoto: designing a smell-based interaction. In *Proceedings of the SIGCHI conference on Human Factors in computing systems*, pages 653–662, 2006.

[14] Dong Wook Kim and Hiroshi Ando. Development of directional olfactory display. In *Proceedings of the 9th ACM SIGGRAPH Conference on Virtual-Reality Continuum and its Applications in Industry*, pages 143–144, 2010.

[15] Blindness and vision impairment. *World Health Organization.* [online]. [cit. 2021-03-21]. Available at: https://www.who.int/en/news-room/fact-sheets/detail/blindness-and-visual-impairment.

[16] Nicholas Giudice and R.G. Long. *Establishing and Maintaining Orientation for Orientation and Mobility*, pages 45–62. American Foundation for the Blind, 3rd edition, January 2010.

[17] Červenobílá hůl. *LORM – Společnost pro hluchoslepé z.s.* [online]. [cit. 2021-03-21]. Available at: https://www.lorm.cz/pro-hluchoslepe/pohyb-a-orientace-hluchoslepych/cervenobila-hul/.

[18] Bílé hole - Kategorizace a názvosloví bílých holí. *Sjednocená organizace nevidomých a slabozrakých ČR.* [online]. [cit. 2021-03-21]. Available at: http://archiv.sons.cz/docs/bilehole/01.php.

[19] Philip Strong. The history of the white cane. *American Council of the Blind*, 2009. [online]. [cit. 2021-03-21]. Available at: `http://www.acb.org/tennessee/white_cane_history.html`.

[20] Rohit Sheth, Surabhi Rajandekar, Shalaka Laddha, and Rahul Chaudhari. Smart white cane–an elegant and economic walking aid. *American Journal of Engineering Research*, 3(10):84–89, 2014.

[21] Cindy Wiggett-Barnard and Henry Steel. The experience of owning a guide dog. *Disability and Rehabilitation*, 30(14):1014–1026, 2008.

[22] Majáčky - příklady frází. *Sjednocená organizace nevidomých a slabozrakých ČR*. [online]. c2012–2020 [cit. 2021-04-13]. Available at: `https://www.sons.cz/Majacky-priklady-frazi-P4007576.html`.

[23] Lazarillo. *LAZARILLO*. [iOS, Android], 2016. Available at: `https://lazarillo.app/`.

[24] SONS. O kameře OrCam MyEye 2 střízlivě a s nohama na zemi. *Tyflokabinet Praha*. [online]. 05.11.2018 [cit. 2021-03-25]. Available at: `http://www.tyflokabinet.cz/clanky/tecko/orcam`.

[25] OrCam MyEye. *GALOP, s.r.o.* [online]. GALOP [cit. 2021-03-25]. Available at: `https://www.galop.cz/orcam`.

[26] OrCam MyEye – detail vnější strany zařízení. *GALOP, s.r.o.* [online]. GALOP [cit. 2021-03-25]. Available at: `https://www.galop.cz/download/foto/OrCam150_web.jpg`.

[27] OrCam MyEye. *GALOP, s.r.o.* [online]. GALOP [cit. 2021-03-25]. Available at: `https://www.galop.cz/download/mainfoto/OrCam153_web.jpg`.

[28] Náramek Sunu Band: cestujte s důvěrou – 1. část. *Pélion – Vzdělávací portál o výpočetní technice pro zrakově postižené*. [online]. [cit. 2021-03-27]. Available at: `https://www.portal-pelion.cz/naramek-sunu-band-cestujte-s-duverou-1-cast/`.

[29] Náramek Sunu Band: cestujte s důvěrou – 2. část. *Pélion – Vzdělávací portál o výpočetní technice pro zrakově postižené*. [online]. [cit. 2021-03-27]. Available at: `https://www.portal-pelion.cz/naramek-sunu-band-cestujte-s-duverou-2-cast/`.

[30] Náramek SUNU. *GiebHelp s.r.o.* [online]. [cit. 2021-03-27]. Available at: `https://giebhelp.eu/sunu-naramek/`.

[31] Athanasios Koutsoklenis and Konstantinos Papadopoulos. Olfactory cues used for wayfinding in urban environments by individuals with visual impairments. *Journal of Visual Impairment & Blindness*, 105(10):692–702, 2011.

[32] Yuli Wu, Kepu Chen, Yuting Ye, Tao Zhang, and Wen Zhou. Humans navigate with stereo olfaction. *Proceedings of the National Academy of Sciences*, 117(27):16065–16071, 2020.

[33] Lucia F Jacobs, Jennifer Arter, Amy Cook, and Frank J Sulloway. Olfactory orientation and navigation in humans. *PLoS One*, 10(6), 2015.

[34] Sijie Zhang and Denise Manahan-Vaughan. Spatial olfactory learning contributes to place field formation in the hippocampus. *Cerebral cortex*, 25(2):423–432, 2015.

[35] Nicholas A Giudice and Gordon E Legge. Blind navigation and the role of technology. *The engineering handbook of smart technology for aging, disability, and independence*, 8:479–500, 2008.

[36] Figma. *Figma, Inc.* [Linux, macOS, Windows, Chrome OS], 2016. Available at: `https://www.figma.com/`.