Lost Everyday

Design for Developmental Topographical Disorientation

Thesis report

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Final thesis for the program
MSc. Design for Interaction,
from the Industrial Design Engineering
Faculty at the TU Delft.

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October, 2024

Acknowledgements

Before diving in, I would like to take a moment to express my heartfelt gratitude to the people whose guidance and support made this masters' thesis possible and a very enjoyable process throughout.

For the invaluable guidance, mentorship and patience throughout many conversations on how to gather my thoughts, I extend my deep appreciation to my supervisory team for their unwavering support. My TU Delft chair Marijke Melles who reminded me to keep looking at the big picture and whose design expertise was invaluable for this project. As well as, my TU Delft mentor Christina Schneegass, who was the first to jump on board and come with me to watch a lecture on spatial orientation. Even knowing that you would be away for a time in the project, that didn't stop you and still gave me all that enthusiasm. Which brings me to thank Tilman Dingler , who stepped in with a lot of great insights to make a real difference in this project.

To Ineke van der Ham, thank you for showing me the world of DTD and to see the world in a different perspective. For the trust and openness to see DTD from a less clinical point of view and for always being available when needed.

Overall, I would like to thank my parents Beatriz and Arnoldo for their love and encouragement today and always. There are no words to describe my gratitude and the joy I feel to have you so close while at the same time completing my master's abroad.

To all those who answered a survey, participated in my research or heard me talking repeatedly about maps and how the mind can envision the environment, I extend my heartfelt gratitude.

Taking a look back at these years, TU Delft and its professors expanded my understanding of design and all its possibilities. It has truly been a privilege to study here and I am very grateful for the opportunity I have to say that my Bachelors' preparation at the Costa Rica Institute of Technology prepared me really well for a Master's at TU Delft, which is why I think those professors deserve recognition as well.

Finally, to those friends who may be close or far, the experiences lived with you have brought me to this day and the completion of what I can say have been the best years of my study life. Specially the members of my volleyball teams, my board 6pack, the skunky gang, TUD Crew, and all the people who I had the privilege of getting to know as a TU Delft student. To those in Costa Rica: my family who I miss, mis Amibros and my friends, abracito de lejitos.

Abstract

This thesis explores design interventions for individuals with Developmental Topographical Disorientation (DTD) and others with weak navigational skills. *"DTD refers to the lifelong inability to orient in extremely familiar surroundings despite the absence of any acquired brain damage or neurological disorder" (Iaria & Burles, 2016)* This research focused on addressing the gap between allocentric navigation (map-based, provided by technology) and egocentric navigation (personal perspective), which many individuals with DTD struggle to translate effectively in their daily life.

The research goal was to explore how to better support individuals in bridging the gap between these two navigational perspectives. Interviews with students and recent graduates who self-identified as having poor navigational skills revealed low spatial anxiety, likely due to their reliance on GPS. Based on these interviews and navigation technology research, wayfinding guidelines were developed, emphasizing clear visual landmarks that simplify the cognitive translation between map-based and personal navigation.

A design concept was created which presents the directions to take in a landmark based map, with a song as a mnemonic aid to learn the navigation instruction. Focusing on how individuals use both allocentric and egocentric perspectives to navigate an evaluation with participants who self identify as not having good navigation skills, navigated a virtual environment using the concept. Results showed that while a multisensory approach can be useful, clear and simple visual cues, such as the selection of one specific landmark per decision point, are more effective in aiding navigation.

In conclusion, the study shows design guidelines to simplify the transition between allocentric and egocentric navigation, and to motivate the user to memorize the route rather than relying solely on technology or multisensory tools. It also highlights the need for greater awareness of DTD and offers insights into designing accessible, user-centered navigation tools.

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Preface

This master's thesis, part of the MSc. Design for Interaction program at TU Delft, explores how people interact with their environment to develop innovative, user-centered design concepts that are feasible, desirable, and viable. Focusing on Developmental Topographical Disorientation (DTD), the study emphasizes the need for empathy in understanding the challenges faced by those with cognitive navigation difficulties. For individuals with DTD, navigating everyday spaces presents significant challenges that affect their quality of life. Therefore, understanding how these users think and feel is critical to creating solutions that genuinely meet their needs.

In collaboration with Professor I. van der Ham from Leiden University, who specializes in spatial thinking in both real and virtual environments, this project draws on a combination of neurocognitive research and applied clinical insights. Her expertise provides a foundation for exploring DTD from a user-centered perspective, which has been less emphasized in existing research. By focusing on the lived experiences of individuals with DTD, this project seeks to bridge the gap between clinical understanding and practical design solutions that improve wayfinding.

The project also explores how technology, particularly auditory and interactive tools, could be employed to enhance navigational abilities. While GPS systems have become widely available, this research questions whether relying solely on such technology is enough. Instead, it aims to demonstrate how new approaches can support individuals with poor navigation skills in developing a stronger sense of orientation, empowering them to feel more confident and independent in their daily lives. Ultimately, the project seeks to improve not only the understanding of cognitive conditions like DTD but also the broader implications for design in accessible navigation systems.

Introduction

Everyday activities involve using our sense of orientation, such as navigating to work, the grocery store, or visiting friends. Typically, after visiting a place a few times, we can remember the route. However, some people struggle to remember routes even after multiple visits, not due to a poor sense of direction but because of an inability to form mental maps of familiar routes. This condition, different from getting lost in new or complex environments, is called Developmental Topographical Disorientation (DTD).

"Developmental topographical disorientation (DTD) refers to the lifelong inability to orient in extremely familiar surroundings despite the absence of any acquired brain damage or neurological disorder" (Iaria & Burles, 2016). DTD is an innate condition, meaning some people are born with it and have struggled with orientation throughout their lives without an obvious cause. People can also just have Topographical Disorientation, which is when the lack of mental imagery regarding navigation & orientation happens because of a trigger such as a stroke or advancing Dementia. Navigating and orienting oneself is an essential skill for daily routines, yet people with DTD face significant challenges. Many are unaware that their navigation difficulties stem from a specific condition.

Although the terminology is evolving, with DTD also being referred to as spatial dyslexia or spatial aphantasia, we will use the term DTD for simplicity. This lifelong condition affects how individuals navigate their surroundings, for which they need to develop coping strategies for everyday activities. Despite the prevalence of this condition, few people realize that there is a specific neurological reason behind their navigation challenges.

Through this research, it will be possible to better understand DTD, its impact on individuals, and to explore potential design interventions or tools that could aid those affected in improving their navigation skills.

Problem Statement

Developmental Topographical Disorientation (DTD) is a relatively recent discovery, and as such, there is a limited number of comprehensive studies and tailored solutions addressing the unique challenges faced by this user group. The available research tends to be clinical, focusing on extreme cases of DTD and overlooking the spectrum of individuals who may experience milder forms of the condition.

Regarding the scope of wayfinding design, little has been explored related to this condition. While some products and services for navigation are very functional for the general population, they often do not meet the specific needs of individuals with weak navigational skills in everyday wayfinding. This lack of support impacts their daily life, increasing a constant feeling of disorientation and limiting their independence in familiar environments.

However, the focus of this project is not on medical interventions or treatments. Instead, it is dedicated to designing technology that can enhance navigation for people with DTD in practical, everyday situations.

By adopting a user-centered design approach, this project aims to create accessible technological tools and strategies that improve wayfinding for individuals with weak navigational skills, as well as making research on DTD more accessible to the general public.
This project explores the experiences, challenges, and needs of individuals with DTD, with the goal of designing accessible, everyday technological innovations that empower them to confidently navigate both familiar and unfamiliar environments. Through this, the project hopes to empower individuals with DTD and make the research more approachable and relevant to everyday life.

Methodology

To understand DTD from a user centred approach and later applying that understanding to a design intervention, the project was divided in five stages split across two phases. The two general phases of the project are Research & Design.

For this, the expanded adaptation of the Double Diamond Framework for Innovation proposed by Design Council, originally in 2004, is used as a guideline for the process of this project. See the Further Reading Section of this document for a detailed description of the phases.

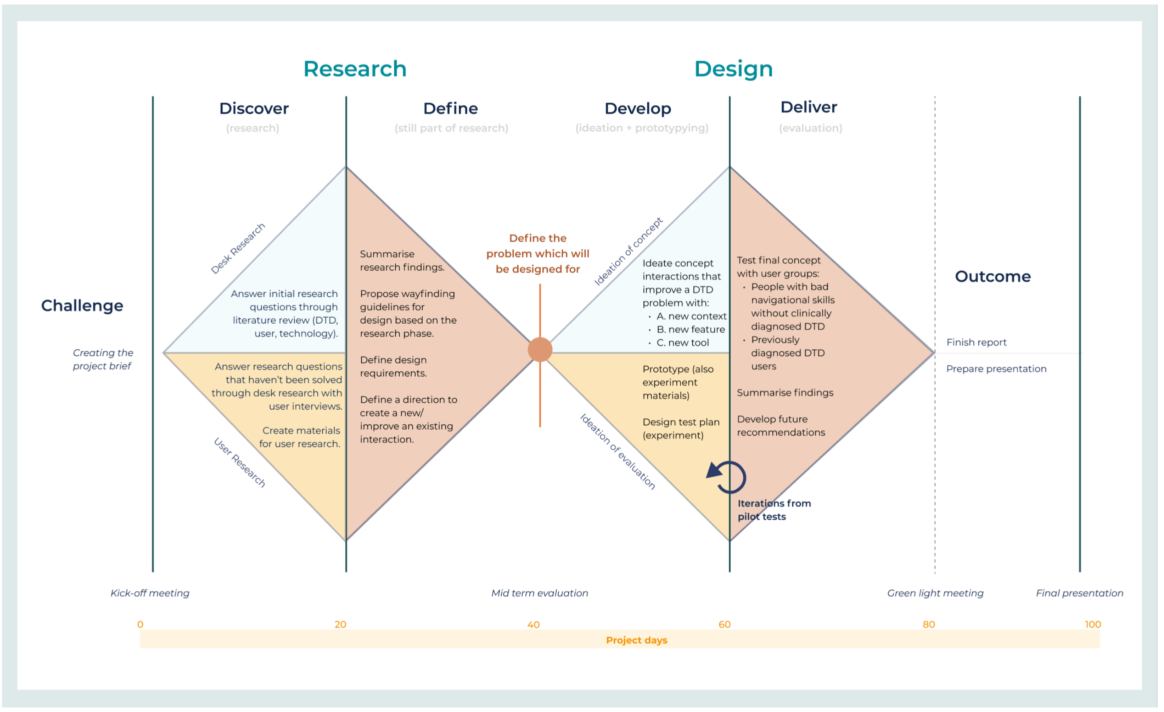


Figure 1. Methodology: Adaptation of Double Diamond Framework for Innovation

Adding on to it, the union point between Defining and Developing which is the definition of the problem that will be solved in the following stage. This expanded version also separates the Outcome from the Deliver stage, which better suits this project timeline as a final conclusion and reporting stage of this thesis.

1. Discover: Literature Review

1.1 DTD at a glance

a. Defining DTD

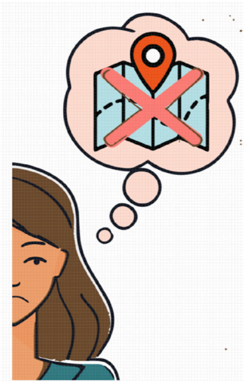
DTD is a relatively newly discovered condition, having less than 15 years since the first case was published by a team of Canadian researchers led by G. Iaria.

The first definition of DTD was previously referred to as *"a lifelong cognitive disorder characterized primarily by an inability to encode large scale environmental layouts" (Iaria et al., 2009).*

DTD is different since the people who experience getting lost in familiar surroundings have done it their entire life. They tend to have memories from their childhood or teenage years, usually when you start gaining some autonomy and start orienting on your own.

"Individuals with DTD get lost on a daily basis in familiar places, such as the neighbourhood where they have lived for their entire lives, or, in some cases, their own homes" (Iaria & Burles, 2016).

Not having a grasp of the spatial environment in an unfamiliar context such as a new city or a parking lot, is to be expected of most people. In individuals with average memory and spatial awareness, it can take a few times to generate a mental map of the surroundings because this usually requires repetitive exposure. Nonetheless, there is a group of people who are never able to form this cognitive map, which definition is described in figure 2 below.



"A cognitive map can be formed when an individual has gained configurable knowledge of an environment (understanding the location of landmarks in space with respect to each other) allowing the formation of a mental representation of the surrounding."

(Farran et al., 2015)

Figure 2. Definition of a cognitive map

In 2022, a group of researchers from the Department of Psychology of Sapienza University of Rome *"confirmed that the rate of occurrence of the disorder is not a rare condition; rather, it affects 3% of young people undermining their autonomy and ability to work away from family boundaries." (Piccardi et al., 2022).* This study analysed the presence of DTD in 1,698 young Italians and found this disorder in 3 % of their sample, specifically in a population in the ages between 18 to 35 years, indicating a possibility of a lot of people having it worldwide.

What makes a person qualify for having DTD?

According to *Iaria et al. (2014)* and subsequent research, DTD is defined by four main requirements:

1. Getting lost in extremely familiar surroundings
2. Experiencing the orientation problem consistently from childhood or adolescence (i.e. the stage at which we would expect and individual to begin independently navigating)
3. Reporting no brain injury or neurological condition
4. Reporting no other cognitive complaints* (e.g. attentional, perceptual, or memory issues)

*requirement for research study recruitment but not necessary for a DTD diagnosis

Since other cognitive conditions such as ADHD and Dyslexia can also affect cognitive mapping, with spatial orientation sharing the same mental connections, there is not yet a clear distinction whether the spatial disorientation of these people is a symptom of other cognitive disorders and not DTD exclusively. For this reason, when recruiting participants for a study on DTD, it is better to focus on people without additional cognitive complaints or mark down their presence for accurate data analysis.

How can DTD impact a person?

People with DTD (DTDers for short) often lead normal lives without realising they have a cognitive condition. Many assume they are simply bad at navigation, believing others face similar difficulties. It's usually not until they encounter someone with strong navigational skills that they begin to question their own abilities.

Earlier studies focused on extreme cases, where individuals seek professional help due to the significant impact on their lives. More recently there are general definitions of this condition with specific criteria to diagnose a person with DTD. These studies often still highlight severe impairments, but milder symptoms of DTD can go unnoticed for a person's entire life, as the condition has no obvious physical or personality traits.

"All individuals with DTD get lost in familiar environments, but the degree to which a given individual struggles with getting lost, as well as other related processes, varies between cases" (Iaria & Burles, 2020). Research, like this recent 10-year study of 1,299 participants, shows that DTD presents differently in individuals. For instance, some struggle to form cognitive maps, while others may excel in certain spatial skills but struggle with mental rotation tasks (understanding which direction "North" is). Or sometimes they are capable of navigating well but it just takes them a longer time to achieve the task. This variability suggests the need for a clearer spectrum of DTD severity, possibly in mild, moderate, and severe categories, to better understand and diagnose the condition.

It is important to acknowledge that individuals with DTD may not be aware that getting lost is an uncommon experience for the general population. As it has been noted in recent studies *"Despite difficulties in estimating distances and navigation, DTD participants report relatively low spatial anxiety. This suggests that people born with navigation problems experience less fear of getting lost." (Stofsel, 2024)*

DTDers have likely faced repeated situations of getting lost throughout their lives, leading them to develop coping mechanisms and strategies, such as focusing on landmark recognition, that make their navigational difficulties feel less problematic. Unlike those who acquire topographical disorientation later in life, DTDers may not view their lack of navigational skills as a major issue because they have learned to manage it over time. However, during critical periods of gaining independence, such as adolescence or early adulthood, there may have been significant stress related to getting lost, prompting the development of these coping strategies.

Additionally, DTD can take an emotional toll in self perception. This is further explain in the chapter 1.1.c. Living with DTD on page 21 of this report.

What daily activities do DTDers struggle with?

According to Iaria's latest study, the main difference between DTDers and a control group was "the ability to recognise and imagine familiar places, as well as succesfully differentiating between which side is their left and their right." Analysing the raw data of unpublished research of *I. van der Ham & M. Stofsel (2024).* , figure 3 illustrates a few other examples of activities that tend to be difficult for people with DTD.

These unpublished comments made by participants of that qualitative study have been rephrased to protect their privacy. They are still included in this literature review since they reflect the direct thoughts and feelings of people struggling with DTD. This is crucial for a user centered design approach such as this project.

Figure 3. Daily activities affected by DTD

All these activities are related to spatial orientation and navigation. In order to understand what people with DTD see in their mind instead of a map, first it is necessary to understand the basic cognitive elements of navigation.

Is DTD an exclusive cognitive condition?

It is also important to distinguish people with other cognitive conditions that impair them from having accurate navigational skills.

In the past, severe lack of spatial orientation, as seen in DTD, was believed to be part of conditions like Aphantasia and Agnosia. *Agnosia is a disturbance of perception characterized by the inability to recognize familiar objects, people, sounds, shapes, or smells, despite the absence of memory issues or basic sensory impairments (Perrotta, 2020).* Since Agnosia manifests in different ways, understanding DTD fully requires considering whether other neurological conditions might be the primary cause of spatial disorientation. Additionally, *individuals who experience both spatial and object imagery deficits often focus more on their object imagery challenges (Blazhenkova & Pechenkova, 2019)*, suggesting that someone struggling with another form of visualization deficit could also be affected by DTD.

Apart from focusing on object recognition, there are also varying levels of how vividly people imagine, where there is already a standard classification of visual vivid imagery. People visualize their thoughts on different levels, *"there are people with aphantasia or "aphantasics," who can't visualize at all. On the opposite end, are people with hyperphantasia or "hyperphantasics," who have an incredibly vivid imagination. Their imagination is so vivid that it's almost like they're really seeing it." (Aphantasia Network. n.d.)* This classification will be further explored in Phase 2: Design of this project.

"Most individuals with aphantasia can lead functional, ordinary lives, with many individuals realizing their imagery experience differed from the majority only in adulthood" (Bainbridge et al., 2021). Interestingly, recent research, like Keogh's and Pearson's 2018 study, found that while individuals with aphantasia were impaired in all measures of visual object imagery, they were not impaired in their spatial imagery. In fact, they rated their use of spatial imagery higher than a control group, even though this wasn't statistically significant *(Keogh & Pearson, 2018).*

Object aphantasia refers to the inability to visualize objects, whereas *spatial aphantasia refers to the difficulty visualizing spatial relationships and properties (Blazhenkova & Kozhevnikov, 2016).* This distinction is crucial because overlapping symptoms between different cognitive conditions can sometimes lead to confusing DTD with other issues.

Recent research by M. Stöfsel remarks that *"Although a possible relationship between DTD and aphantasia could be suggested from the literature, the study indicates that a strong overlap between DTD and aphantasia is unlikely." (2024).* For the purpose of this study, however, aphantasia will be considered a separate condition from DTD.

How can DTD be diagnosed?

“One important issue in diagnosing DTD is distinguishing these subjects from those healthy individuals with a ‘poor sense of direction’, who merely perform at the low end of the normal spectrum of navigational skills.” (Iaria & Barton, 2010). Similarly, it is crucial to differentiate DTD from other cognitive conditions that impair navigation abilities.

Individuals with DTD are often identified through self-reporting, recognizing their own difficulties with spatial orientation. Once they come into contact with a researcher or clinician, DTD may be formally diagnosed. One activity that indicates DTD is difficulty pinpointing familiar locations or for example, locating the entrance of a building once they are inside of it and it is out of sight.

“DTD can be diagnosed through a combination of clinical assessments, self-reported experiences, and specialized cognitive tests.” (Piccardi et al., 2022) Usually a diagnosis starts with an interview in which the individual describes their experiences with navigation and the impact that these have in their daily life.

Along with that there are questionnaires applied that can help quantify their subjective self perception of navigation and orientation. Examples of these that have been used for DTD diagnosis are the *Santa Barbara Sense of Direction Scale* developed by *Hegarty et al. (2002)* and the *Wayfinding Questionnaire* developed by *Montello et al. (2003)*.

Nonetheless, with subjective tests there are factors that may hinder the diagnosis process of DTD. *Van der Ham & Claessen* have noted that *“the emergence of navigation assistance options since the first report on DTD. Currently, many people have technological assistance available to them through smartphones and car navigation systems.” (2024)*

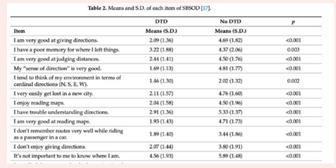
There are also specialized cognitive tests that can help an individual and clinicians identify symptoms of DTD, beyond just the subjective self-reporting from the individual. *“Neuropsychological tests can evaluate memory, spatial reasoning, and other cognitive functions to rule out other potential causes. Additionally, brain imaging techniques like MRI or fMRI may be employed to examine the structure and activity of the hippocampus and related areas involved in navigation. (Piccardi et al., 2022).*

Some of these neuropsychological tests can be perceived as games, but for people with spatial orientation problems they result a difficult task to be done. The most common form of these are virtual orientation and navigation tests, in which the participant needs to analyse an environment and answer questions about what was shown. The tests focus on mental rotation exercises, memorisation of landmarks, among other tasks that involve the visualization of a cognitive map.

Further explanation on the tools used for this study can be found in Appendix 1: Technology for DTD, of this report. But in summary, DTD can be diagnosed through the tools that are detailed in figure 4.

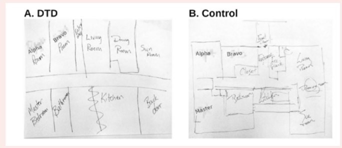
Subjective reporting of symptoms

A person recognizes that they have weak navigational skills or other people remark that they are getting lost frequently.



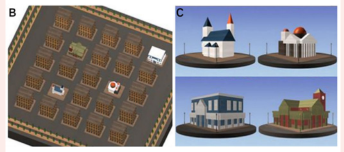
Questionnaires

Standardized questionnaires that quantify the self perception of navigational skills such as the Santa Barbara Sense of Direction Scale *developed by Hegarty et al. (2002).*



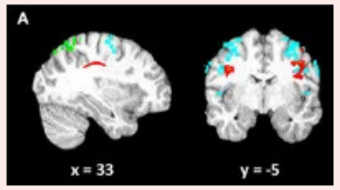
In person visualization tests

When asked to draw a map of their home or office, people with DTD don’t visualize proportions and instead they focus on the order of the rooms. The example to the left comes from research *published by Burles & Iaria, (2020).*



Virtual orientation & navigation tests

Online 3D environments have been created to asses the skills of spatial orientation. The example on the left is the Cognitive Map visualization test *applied by Burles & Iaria, (2020).* available at Gettinglost.ca.



fMRI brain imaging

Neurophysiological studies have been involved with showing differences when DTDers perform navigation tasks in computer-based testing. This is an example image of an fMRI imaging *applied by Rusconi et al. (2021).*

Figure 4. Tools currently used for DTD diagnosis.

Developing tools for diagnostic and defining the spectrum of DTD symptoms presents a great opportunity for development. However, due to the time and resources available for this project, as this would require a clinical study. Therefore, this study focuses on DTD as a condition with a wide range of symptoms and assumes that people with self-identified low navigational skills can be potential candidates for a DTD diagnostic.

b. Cognitive elements of navigation

Starting with the differentiation of spatial orientation which *"involves knowing where one is in relation to fixed or moving points"* vs spatial navigation that is the *"directed movement with an intended destination and requires knowledge of directions and locations" (Psathas, 1976).* In other words, a person needs orientation of where they are in order to navigate towards a destination.

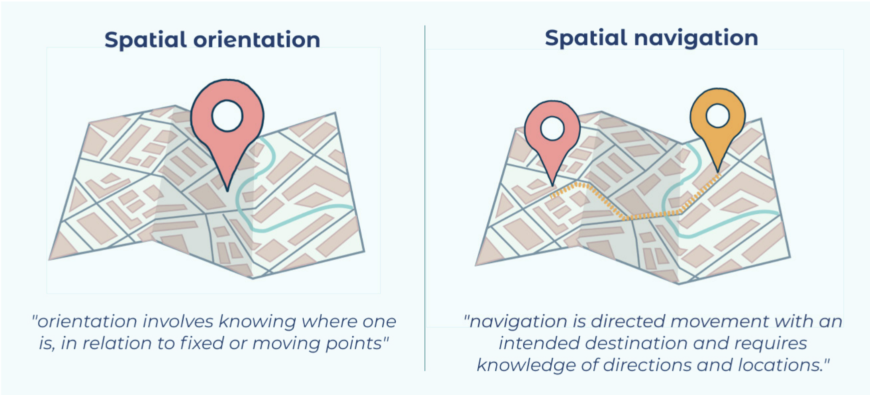


Figure 5. Definitions of spatial orientation and navigation. Adapted from (Psathas, 1976).

Being able to orient in the environment, as well as navigating to a specific destination requires the distinction of 3 basic elements: the object (here onwards referred to as a landmark), the landmark's location in space (and other surrounding objects) and oneself's position in relation to the landmark's position.

The same way that these 3 basic elements make spatial orientation possible, these can also be affected individually and create difficulties in wayfinding. *"DTD group shows a distinct navigation profile, with weaknesses in route knowledge, path overview knowledge and location knowledge. In contrast, landmark recognition is found to be a strength." (Stöfsel, 2024).*

According to the framework presented by Claessen & van der Ham in 2016, these are the main types of navigation impairments that people with DTD can struggle with:

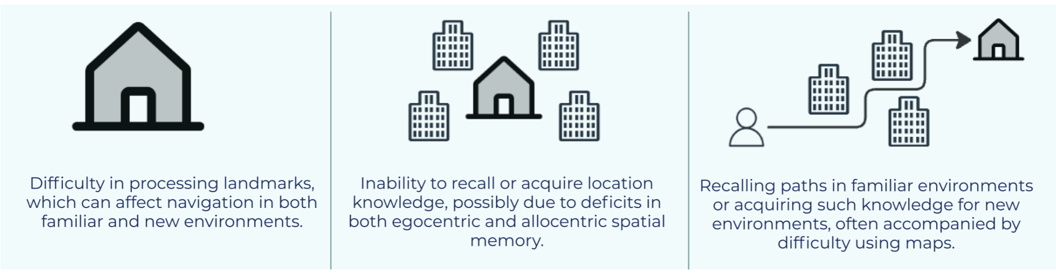


Figure 6. Types of navigation impairments. Adapted from (Claessen & van der Ham, 2017).

How is navigation seen?

Once having defined the basic elements of navigation, meaning "what" do we see, then we can explore "how" do we see those elements in our head when we think of navigation. There are 2 types of perspectives when you need to find your way.

1. **Egocentric view**, in which you see a landmark's position corresponding to yourself, as if seeing it in first person view.

2. **Allocentric view** in which you see a landmark's position corresponding to the position of other landmarks.

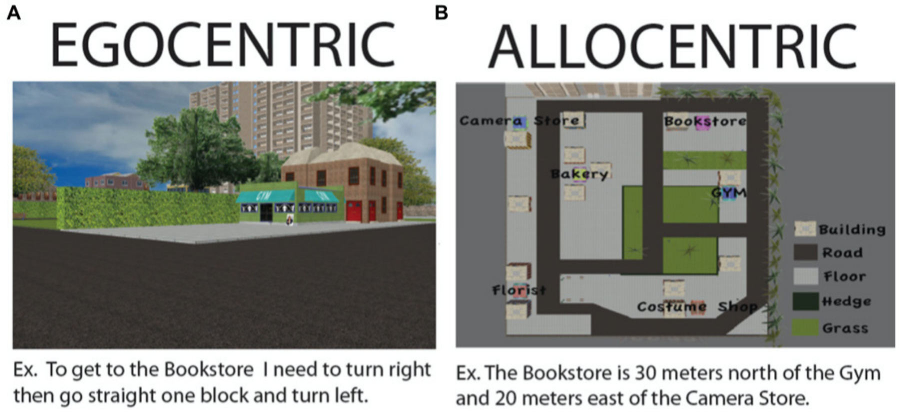


Figure 7. Representation of Egocentric vs Allocentric views. Created by (Burles, F. & Iaria, G., 2020)

Egocentric navigation tends to be easier to remember since it is the direct view from our own perspective. Allocentric, on the other hand, requires the cognitive task of translating a landmark's position into a mental representation of a map, as well as, doing mental rotation tasks to fit those in its correct position corresponding other previously analysed landmarks. A combination of both perspectives of navigation create the shape of the cognitive map, with one of the two being more dominant depending on the task to solve.

Egocentric perspective is used more in the memorization of landmarks, as well as orienting oneself in the current space. An allocentric representation is used mainly when calculating distances between landmarks and when making navigation decisions between landmarks. Nonetheless, "pure" cases of using one of the viewpoints independently from the other are not very likely since *"while we identified situations in which an allocentric representation might dominate, such as when participants make judgments involving relative distances or directions of objects to each other, egocentric* *representations still serve as important anchors and cues in solving these tasks". (Ekstrom, Arnold & Iaria, 2014).*

From this same study an example is given of how a navigation task that would normally be solved using an allocentric representation, might be solved using an alternative egocentric strategy, such as the one described in figure 8.

Allocentric strategy	Alternative / Egocentric strategy
"when arriving at a landmark, or viewing it from a certain distance, we could remember that our destination is positioned between this landmark and another one, sitting about 2/3 of the way from the 2nd landmark and at a 30° angle from the first one."	*"when arriving at a landmark, or viewing it from a certain distance, we could also remember, based on our past experience, that our goal is present 50 and 30° to the right of our current position."*

Figure 8. Egocentric vs Allocentric strategies. Adapted from (Ekstrom, Arnold & Iaria, 2014).

Seeing how an egocentric viewpoint is the direct representation of the seen environment, whereas an allocentric viewpoint involves the task of making a cognitive map and tasks that usually would be solved allocentrically can also be solved egocentrically, people with DTD tend to have a better developed egocentric sense of orientation compared to an allocentric one.

According to *van der Ham & Claessen (2017) "DTD is specifically linked to impaired allocentric location knowledge, and path survey knowledge. Nonetheless, landmark knowledge is largely intact".* Meaning that DTD affects the recognition and memorization of the spatial location of multiple landmarks in an environment, but it doesn't affect the ability to recognize and memorize the landmarks themselves.

Further explanation of these navigation related cognitive tasks can be found in Appendix 1 along with the representation on the Leiden Navigation Test.

c. Living with DTD

As previously described in "How can DTD impact a person?" section of this report, people with DTD struggle with activities that require navigation every day. Nonetheless, the perceived struggle is not as big as with people who suddenly develop topographical disorientation because of a brain injury or another condition, because DTDers have had their entire lives to develop coping strategies. Plus, since it is a very subjective condition, then people have no point of comparison and therefore do not feel like something is missing.

There are moments, though, in which the impact of DTD can be felt strongly, specially when others depend on that person for navigation. Additionally, there are multiple occasions in which a direct comparison of ability can be made with people with good orientation skills, which can lower the self esteem or perception of intelligence of the DTDer.

The emotional impact of DTD

Analyzing the emotions of people with DTD not only can justify the need of creating more awareness about DTD as a widespread condition, but also it can provide insight into the specific pain points that can be addressed with a design solution. Figure 9 illustrates the emotional connotation of thoughts of people with DTD from unpublished research of *I. van der Ham & M. Stöfsel (2024).*

*"When we had tests like that at school, **I felt really ashamed.** They'd show a sheet full of circles, signs, and symbols, and ask us to copy it. I would just hand in a blank page.*

*"**It used to make me really sad**, because it was a constant reminder of what my brain couldn't do something that seemed so simple for others, and that everyone had an opinion about."*

*"**I'm disappointed in myself.** No one else seems to have a problem with it, but I can't do it, and I just feel bummed that I'm like this. You know, I can't find it, and others can."*

*"It's a burden because it **makes me feel very stupid**. The fact that I, that I just can't orient myself and Google Maps has to go everywhere."*

Figure 9. Quotes related to the emotional perception of DTD from research by Stofels & van der Ham (2024).

Even though DTDers reflect having less spatial anxiety than others, still there is a negative perception of having DTD and the burden it creates in everyday navigation. This can affect the self confidence and perception of intelligence of these individuals. Do people who grew up with access to a GPS at all times have the same perception? This is further explored in the User Research section of this report.

Exploring problems of people with DTD

From the analysis and literature review, and specially from the qualitative insights provided by the yet unpublished research from Stöfsel and van der Ham, the following problems of having DTD are self-perceived by DTDers. These problems are shown in figure 10 below in a problem-tree structure, and were further analyzed to identify possible themes that can be explored more in depth on this project.

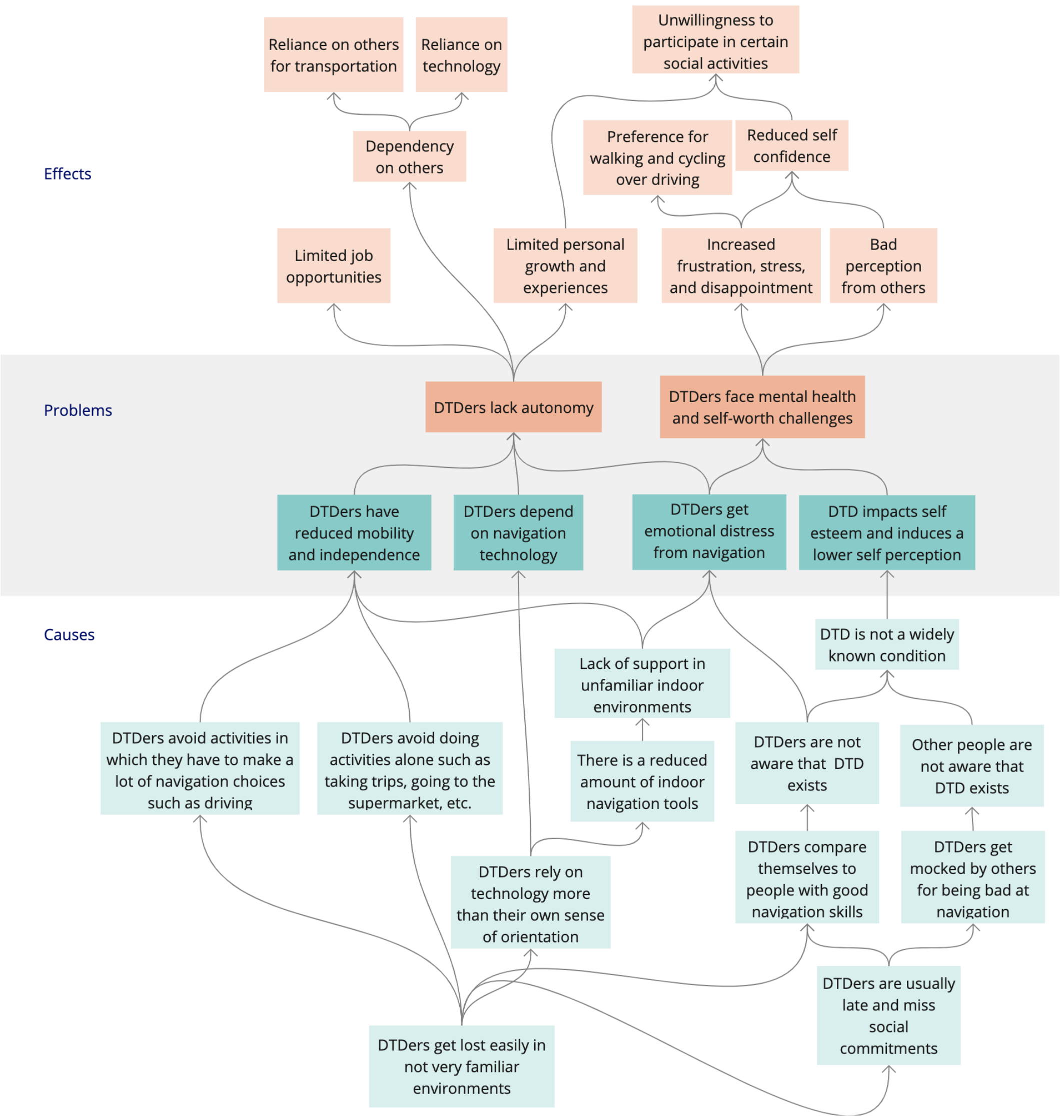


Figure 10.Problem tree diagram on the effects of DTD in daily life from unpublished data from Stofels & van der Ham (2024).

From this, the following problems can be extracted: (1) lack of autonomy, (2) lack of awareness about DTD from others, (3) self confidence challenges, (4) insufficient signage in the environment and (5) inaccuracy of navigation systems. These are further used as the specific research questions to explore in the interviews of this project.

How do people deal with DTD?

As DTDers can't rely on allocentric reasoning for daily navigation, they tend to use alternative strategies as can be see in back in figure 8. Recent publications exemplify how *"DTD participants often emphasized their specific focus on remembering landmarks to maintain route awareness " (Stöfsel, 2024).* From the unpublished data of the interviews by the *van der Ham research group*, a few coping strategies can be noted as a way to deal with DTD on a daily basis. Apart from other coping strategies seen on figure 11, nowadays because of the accessibility of navigation technology embedded on a smartphone, the most used strategy is relying on technology for daily navigation and orientation.

Avoidance

Avoid situations in which the DTDer needs to travel or lead others.

Examples:

- Not driving unless necessary
- Working from home
- Not going on trips alone
- Inviting friends over for dinner instead of going to them

Rely on someone else

Choosing to be surrounded by people that are good at navigation

Examples:

- Following crowds
- Travel in group
- Have a partner or friend that is good at navigation
- Calling that person in case of emergency

Preparation

Preparing their route prior to the journey

Examples:

- Planning 30 mins to in case they get lost
- Visualising the route on a map
- Studying the important landmarks
- Writing down names of streets
- Writing down left-right directions

Use of technology

Use of GPS for daily activities

Examples:

- Using maps, GPS and IPS for orientation in space
- Following the route provided by the system
- Following the simplest route shown even though there might be a faster one

Figure 11. DTD coping strategies interpretation from unpublished data from Stofels & van der Ham (2024).

Can spatial orientation be trained with the use of technology?

Currently there are a few tools that aim to train and improve spatial navigation, although it is yet unclear whether it is possible to train an ability for which the necessary basic mental processes are not present. The most recent developments based on technology are the use of 3D virtual environments to improve a person's ability to form and recall mental maps. These immersive simulations provide a safe and controlled setting for individuals to practice navigation skills. With the remark that most of them have been tested only with non DTD subjects. Additionally, advancements in augmented reality are being explored to offer real-time, context-sensitive guidance to enhance spatial orientation in real-world environments.

For example, *McLaren-Gradinaru et al. (2020)* developed a 12-day training protocol which consists of assessing the participants' navigational skills before the training with a behavioural assessment including the Santa Barbara Sense of Direction Scale. Then a week 1 training performing the designed training program 45mins per day for 5 consecutive days with 2 days of rest before repeating that training for week 2. Finally, the behavioural assessment would be repeated at the end to compare scoring.

As can be observed in figure 12, the designed training program consisted in participants navigating through interactive 3D spaces, completing tasks that challenge various aspects of spatial orientation, such as wayfinding and landmark recognition. The program featured progressively difficult tasks, real-time feedback, and regular assessments to monitor progress. It also included training in cognitive strategies, such as using visual landmarks and memorizing routes.

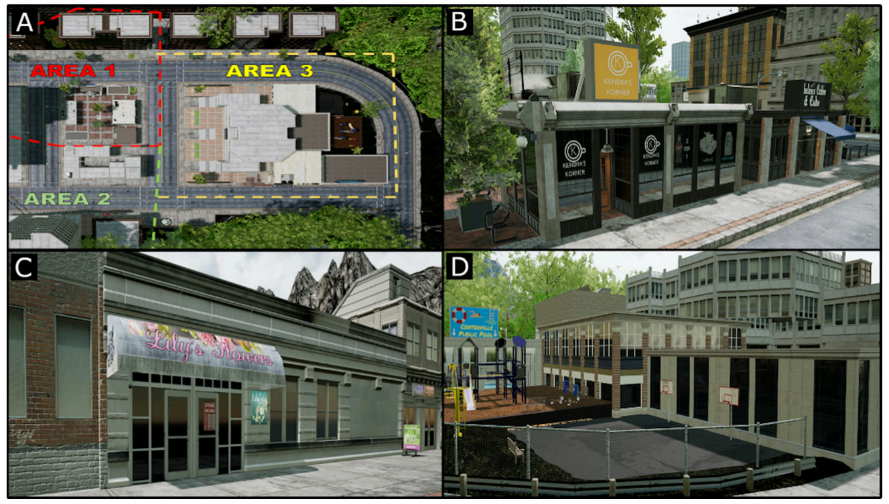


FIGURE 4 | Different views of the virtual town "Centerville." **(A)** Image showing how the training environment is split into three distinct areas. **(B)** Example buildings from Area 1, designed to be rustic with lots of colorful details making the buildings stand out. **(C)** Example buildings from Area 2, designed to be more industrial with gray colors making the buildings blend together. **(D)** Example buildings from Area 3, designed to be more modern and introduce more complex landmarks such as playgrounds, pools, and parking lots.

Figure 12. Training environment created by McLaren-Gradinary et al. in 2020.

"The results of this study confirmed the feasibility of the training program and suggested an improvement in the ability of participants to form mental representations of the spatial surrounding." (McLaren-Gradinaru et al., 2020)

Nonetheless, this study was only tested with non DTD subjects that can succesfully form a cognitive map of their environment. So, the success of a training program with people with DTD still needs to be verified as the feasibility of training a skill that does not exist in the brain. It might be that only the training of alternative strategies, such as landmark recognition, is possible.

DTD at a glance - Key Insights:

- Spatial navigation is typically developed through repeated exposure to an environment, but individuals with DTD fail to develop this ability despite normal intelligence and no other cognitive impairments .
- People with DTD often do not realize they have a condition due to the subjective nature of navigation difficulties and the lack of a direct point of comparison with others .
- Navigation involves two perspectives: allocentric (map-based) and egocentric (personal view). People with DTD often struggle with allocentric navigation, or more specifically interpreting what they see into a mental map.
- People with DTD navigate using landmarks, and they develop coping strategies over time, but still face challenges when learning new routes and when navigation problem solving is necessary. DTD has a direct emotional toll on self confidence and perception of intelligence.

1.2 Wayfinding Design

a. Navigation technology

Throughout history, humans have found creative ways to improve navigation, mostly by relying on their sense of sight. Early explorers used the stars and constellations to guide them across vast oceans, forming mental maps and being able to picture spaces even when the environment changed at different times of the day. The invention of the compass later provided a reliable tool for direction, allowing people to develop maps and charts that translated a mental map into a graphic representation. According to *Ishikawa and Montello (2006), "external aids like maps and compasses allow individuals to externalize their spatial knowledge, thus improving navigation in unfamiliar areas."* These maps, filled with landmarks and important features, have always been crucial for navigation.

Today, with GPS technology, things have evolved even further. As *Montello et al. (2003) note, "while GPS provides accurate, real-time directional guidance, it diminishes the reliance on internal cognitive maps and spatial learning."* GPS systems on smartphones and other devices offer real-time guidance with detailed, turn-by-turn instructions, reducing the need for people to rely on their mental maps.

With new advancements like augmented reality (AR) and virtual reality (VR), wayfinding technology has taken another leap, letting users develop better spatial awareness and improve their navigation skills in lifelike, controlled environments. In a study by Dey et al. (2018), it was found that *"AR-based navigation systems improve spatial awareness by embedding navigational information directly into the user's perception of the real world, reducing cognitive load and enhancing spatial memory."*

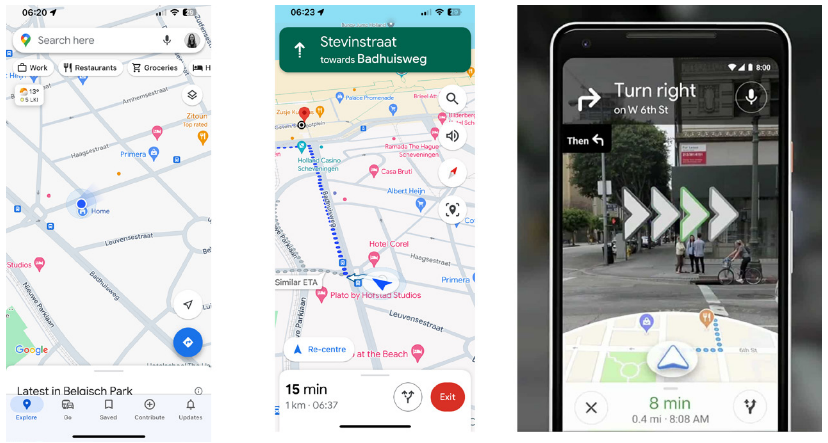


Figure 13. Google Maps as an example of a GPS tool with both allocentric and immersive egocentric representations.

Despite the assistance provided by modern navigation technologies, all people including DTDers still need to make cognitive translations to interpret maps and directions displayed on screens and apply them to the real-world environment. While these tools reduce the burden of decision-making, they rely heavily on users' ability to process visual information. For DTDers, this dependence on visual input presents a significant challenge, highlighting the importance of creating more inclusive navigational tools that go beyond visual cues and are adapted to diverse cognitive needs.

What type of support do current navigation/wayfinding aids give?

Current navigation and wayfinding aids offer different levels of support on making navigation decisions. The following classification was defined for the technology benchmarking done for this research:

Automatic systems provide complete guidance, giving step-by-step instructions that users follow without having to make any navigation decisions. An example of this is a GPS system in a car, where the device dictates every turn and the driver simply follows.

Semi-automatic systems offer tools and options but require the user to make decisions at each step. A hiking app that suggests multiple trails based on user preferences is an example, allowing the hiker to choose their path.

Manual systems present the environment without specific instructions, leaving all navigation decisions to the user. Traditional paper maps fall into this category, as they provide a visual representation of the area, requiring the user to interpret the map and decide on their route independently.

Additionally, navigation aids for the visually impaired, such as tactile maps or audio guidance systems, considering **alternative ways of navigation** such as haptic and hearing aids.

Such is the example of innovative concepts such as "Wayfinding fashion" which indicates where a user must turn through the use of vibrations in different body hemispheres. In figure 14 are some examples of Wayfinding Technology and their corresponding classification based on decision automation. All the products studied for this overview can be found on Appendix 2.

Figure 14. Examples and classification of Wayfinding technology

Do automatic wayfinding systems hinder spatial knowledge acquisition?

Automatic wayfinding aids reduce the need for users to develop mental maps, as they primarily rely on following the instructions from the navigation system. While this can be beneficial for individuals with DTD or low navigational skills, can also decrease spatial knowledge acquisition and problem solving skills when the system is unavailable. ***Brügger, Richter & Fabrikant (2019)*** found ***"that participants using systems with higher levels of automation did not acquire enough spatial knowledge to reverse routes without errors",*** as higher automation discourages cognitive engagement in navigation tasks. In contrast, groups interacting with a system with a lower level of automation had a more strategic approach with the displayed tools and invested more cognitive effort in actually learning the route. The study from ***Brügger, Richter & Fabrikant (2019)*** highlights how users, even those without navigation difficulties, tend to minimize decision-making if they are allowed by the system.

Ultimately, wayfinding systems should encourage users to interact with their environment to foster spatial knowledge. This is crucial for individuals with low navigation skills to create mental maps and for people with DTD to develop effective coping strategies.

b. Existing Wayfinding Guidelines

The branch of design, as a discipline, that explores how people navigate their environment and get spatially oriented is called Wayfinding Design. The term wayfinding has been around since 1960s as ***"way-finding, the strategic link is the environmental image, the generalized mental picture of the exterior physical world that is held by an individual. This image is the product both of immediate sensation and of the memory of past experience, and it is used to interpret information and to guide action." (Lynch,1960)***

Similarly, the elements that compose wayfinding have been defined across various sources, as can be seen in figure 15. These definitions will be used further in this project.

Elements of wayfinding design

Paths: *Paths are the routes or channels along which people travel. They are the most frequently experienced elements in an environment and are crucial for organizing space and guiding movement. (1)*

Districts: *Districts are medium-to-large sections of the city that have a recognisable identity. These areas are perceived as having some common, identifying character and are critical for orientation. (1)*

Nodes: *Nodes are strategic focal points where paths converge or where there is a concentration of activities. These points serve as anchor points for navigation. (1)*

Landmarks: *Landmarks are external reference points that help with orientation. They are physical objects that stand out from their surroundings and are easily recognisable from a distance. (1)*

Signage: *Signage provides written or symbolic information to aid in navigation. Effective signage is clear, visible, and placed at decision points where wayfinding decisions are made. (2)*

Maps: *Maps provide an overview of an area, showing paths, landmarks, and other key elements of the environment. They are a crucial tool for planning and navigation. (4)*

Technology: *Technology includes digital tools like GPS and mobile apps that assist with navigation, offering real-time information and interactive maps. (5)*

1: (Lynch, 1960) 2: (Passini, 1992) 3: (Mollerup, 2013) 4): (Montello, 2004) 5): (Kray, 2003)

Figure 15. Definitions of the elements of wayfinding design.

The problem is that wayfinding has always been based of from the fact that all people can create a mental map of their environment and remember it correctly. This is seen in definitions of wayfinding such as a ***"key objective in wayfinding design, ..., is to enable each person to form a mental map of a site or environment, so the clearer physical layout of a site, the clearer those mental maps will be. (Calori & Van den Eynden, 2015).***

Wayfinding guidelines for accessibility

From the Queensland University of Technology in Australia, R. Apelt, J. Crawford and D.J. Hogan proposed Wayfinding design guidelines considering inclusive design and the principles of Universal Design. The complete list in Appendix 3 offers a very complete checklist that includes recommendations for spaces in which people with varying languages, and various levels of physical abilities can navigate through a physical environment.

A summary of the most important factors considered in these guidelines can be observed below. While these guidelines are mainly targeted towards physical spaces, they serve as a good parting point for wayfinding guidelines to be applied on technology.

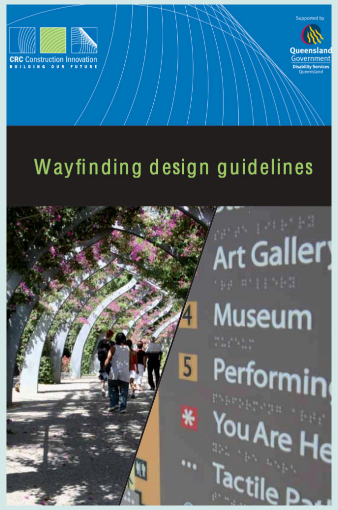


Figure 16. Cover of the Wayfinding design guidelines by Apelt, R. , Crawford. J., and Hogan, D.

[shown for illustration purposes only]

Wayfinding design guidelines (Apelt, Crawford & Hogan, 2007)

1. Analyze **access points** considering the physical and aesthetic characteristics of the building or site.

2. **Divide large-scale sites into distinctive smaller zones** while maintaining connectivity and a sense of place.

3. **Organize zones with a logical and rational structure** through a well-devised zonation plan.

4. Provide frequent **directional cues, especially at decision points**, for clear navigation in both directions.

5. Ensure **decision points are logical, obvious, and directly related to the space, with clear sequencing and grouping of message signs.**

6. Design a **flexible and memorable naming protocol** using culturally diverse names and symbols.

7. Use a consistent, logical naming protocol for master-planned places like hospitals or educational institutions.(*Ensure alpha-numeric coding systems are consistent, such as "building B, level 3, room 7."*)

9. Incorporate multiple languages or pictograms into the naming protocol.

10. Ensure **signs are physically placed, installed, and illuminated for all users' visibility and accessibility**.

Even though these guidelines are mostly focused on the design of the physical environment, their application reduces the cognitive load on the environment and therefore making navigation easier for people with DTD as they emphasize clarity, simplicity, and accessibility. For example, dividing large sites into smaller, logical zones with frequent, clear directional cues minimizes cognitive overload, while logical and obvious decision points help prevent disorientation. Flexible and memorable naming protocols, consistent alpha-numeric systems, and the inclusion of multiple languages or pictograms strengthen the orientation through the visual sense. Lastly, ensuring that signs are visible, accessible, and well-placed is critical for users who rely heavily on signage from the environment to orient themselves.

Wayfinding for dementia considers how to design for people who can't create a mental map.

People with dementia have similar wayfinding difficulties since they ***"may encounter great difficulty in retrieving a mental visual image of a place that they cannot see, rendering them unable to generate, maintain, and use a cognitive map." (Marquardt, 2011).*** Marquardt, after reviewing existing studies of wayfinding for people living with dementia, proposed the following design guidelines, which have been summarized below.

Wayfinding for dementia guidelines (Marquardt, 2011)

No need for new or higher skills:

Navigation should not require complex skills like reading signage. Floor plans should be simple and clear, with geometrically straightforward rooms.

Allow visual access and overview:

People with dementia cannot mentally represent unseen spaces, so all relevant areas should be visible. Design should allow residents to see their entire immediate environment.

Reduce decision making:

Layouts should guide residents intuitively without requiring them to make choices.

If directional changes are necessary, incorporate meaningful reference points. Use differences in size, shape, color, and lighting to distinguish rooms with similar functions.

Increase architectural legibility:

The purpose and function of spaces should be clearly communicated through their size, materials, and furnishings. Distinctive, memorable places promote better spatial orientation and wayfinding.

While these guidelines are specifically tailored for wayfinding in nursing homes, they can also be a guiding point for adaptations to existing wayfinding strategies for the general population, making them more accessible for people with DTD. Unlike people living with dementia, people with DTD do not have impaired logic or reasoning abilities and can live highly functional lives with normal or high IQs. Their shared challenge lies in visualizing a mental map of their environment.

Consequently, while they could benefit from some simplification, it is not necessary to completely eliminate navigation decisions or overly simplify their environment, as they can still adapt and develop effective navigation strategies. The "reduction of decision making" can be directly beneficial for people with DTD if meaningful reference points are used as landmarks, and therefore easier to remember.

Wayfinding strategies for fast-paced environments offers guidelines for efficient navigation decisions.

The Wayfinding strategy of the NetworkRail of United Kingdom provides additional guidelines that can benefit people with low navigational skills, especially in places where decision points need to be efficient and people are usually in a hurry.

NetworkRail (2020) defines "Decision points are locations where the passenger make a wayfinding decision". From this strategy, the following recommendations can be useful to apply in wayfinding systems that need to be adapted for people with DTD and low navigational skills, as well as people with normal navigation skills.

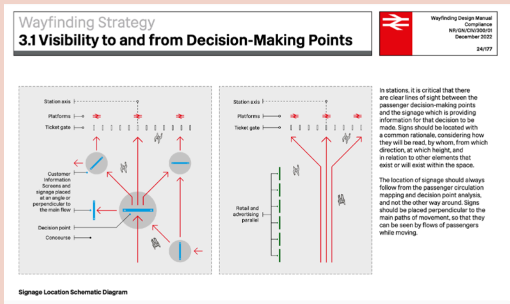


Figure 17. Signage Location Schematic Diagram developed by NetworkRail (2020).

Strategic positioning of signage:
Overhead signs should be visible from a distance of 4-6 meters and positioned to minimize neck strain. Eye-level signs should be readable from 1-2 meters, placed so passengers can read them without breaking their pace.

This is further detailed in Figure 17.

Digital wayfinding as a complementary tool:
Digital navigation aids should support, not replace, traditional methods. While useful, they can fail, so combining both digital and traditional signage ensures inclusivity and reliability.

Principles of Wayfinding Design by NetworkRail UK (2020).

Decision points in transient spaces:
Decision points occur in high-traffic areas where movement is fast, so it's important to design these spaces to prevent passengers from stopping, which could create bottlenecks.

Signage placement near decision points:
Signs should be placed as close to decision points as possible, taking into account natural movement patterns and available mounting locations.

Avoid combining advertisements with wayfinding:
Advertisements should not be placed where they might distract from or obscure wayfinding signage, as this reduces clarity and visibility.

Maintaining flow and preventing congestion: Decision points should allow passengers to make quick, intuitive choices to keep traffic moving. Clear signage and intuitive layouts reduce the need for passengers to stop and think, ensuring smooth movement.

As people with DTD struggle with making fast paced decisions, in a context such as cycling and driving, these guidelines directly apply to improve the wayfinding experience of DTDers. The Principles of Wayfinding Design developed by NetworkRail in 2020 can directly translate into principles for the design of wayfinding technology as well.

After reviewing various guidelines proposed by different sources, it became clear that no single framework exists that comprehensively integrates all the necessary guidelines for designing wayfinding systems adapted to current technology, while also considering the specific needs of individuals with low navigational skills, such as those with DTD. Although several studies address aspects like automation, user engagement, and spatial knowledge acquisition, a unified set of recommendations that considers modern navigation technologies alongside the challenges faced by people with low orientation skills is lacking.

Moreover, there is a significant research gap regarding the specific actions and contextual needs that individuals with DTD and low navigational skills would require from products and services to follow these guidelines effectively. This gap underscores the importance of conducting user research with real users to gather insights on their behaviors, challenges, and needs in real-world scenarios. By doing so, it is possible to better understand the practical steps necessary to design navigation aids that not only adhere to existing guidelines but are also tailored to the specific cognitive and spatial challenges of these users.

Wayfinding Design - Key Insights:

- Wayfinding technology can be classified by the level of support they give to the user to make navigation decisions, in automatic, semi-automatic and manual.
- Wayfinding Design explores how people navigate their environment and get spatially oriented. Terms such as landmarks, decision points or nodes, as well as signage were defined.
- Wayfinding traditional tools like GPS and digital maps heavily rely on visual input. This makes it easier for people with DTD, who rely heavily on the visual sense. But if the navigation aid is not available, then the person can't easily make navigation decisions.
- Existing wayfinding design is based on the assumption that users can form mental maps, which does not apply to individuals with DTD. Universal Design principles, wayfinding for cognitive impaired people (like Dementia) and fast paced environments were explored to make wayfinding more accessible.

2. Discover: User Research

2.1 DTD in young adults

a. Research objective

After an initial literature and previous research review, and since DTD is a relatively new condition, an opportunity to gain new knowledge was discovered. As discussed in the literature review, sufficient research has been made for specific cases of DTD and recently published articles that generalise the symptoms of DTD have helped define the main qualities of a person with DTD.

These studies help set a basis of the feelings and impediments that people with DTD can feel daily. But these insights were gathered from a large sample of participants.

Do people that have grown up with the aid of technology for navigation have the same difficulties in terms of wayfinding?

This led me to the goal of finding out how much can DTD affect younger adults through the following research questions:

What is the influence of lifelong weak navigational skills on the daily experiences of young adults aged 20 to 30, and

how can this understanding inform the development of wayfinding guidelines tailored to technology design for individuals with Developmental Topographical Disorientation?

In order to research this, interviews were conducted with students and recent graduates of the TU Delft. These were screened for presence of DTD symptoms following the criteria set by *Burles & Iaria et al. (2016) in their study "Behavioural and Cognitive mechanisms of Developmental Topographical Disorientation"*. Since not only people with DTD can suffer from poor navigational skills, as well as this research having reduced accessibility to clinically diagnosed DTD people, the sample included people who self identified with lifelong low navigational skills, which is one of the requirements to be diagnosed with DTD. In the interviews the following themes are explored as secondary research questions:

- Perception of autonomy
- Impact on daily life
- Emotions related to wayfinding
- Dependence in navigation technology
- Pain points in wayfinding

b. Method

Target Group

Due to proximity to the target group and because of DTD's high probability of being in 3% of the population, the target group consisted in:

- TU Delft students or recent graduates
- Between 20-30 y.o.
- That self identified as having weak navigational skills
- That fulfil the selection criteria set by Burles & Iaria. (2020) via a screener which is detailed below.

Recruitment and screening of participants

In order to recruit participants for this initial research, an invitation was sent internally through personal connections from the TU Delft. This message prompted people to fill in the questionnaire if they identified struggling with navigation in the following examples:
"I often get lost easily", "I depend way too much on google maps", I struggle remembering where places are located in a map", "I can feel overwhelmed in places like parking lots and shopping centers".

These examples were more general than only people with DTD to attract them into filling in the screening questionnaire. From this prompt, 44 people filled in the screener questionnaire and from this sample 14 people seemed to qualify for a follow up interview. The interview sample ended up being of 9 participants from the target group described above (5 women and 4 men).

The screener developed specifically for this project, which is fully explained in Appendix 4, had the following selection criteria:

- **Having experience getting lost/feeling disoriented: with 4 or 5 on a scale of 1 never and 5 always.**
- **Getting lost in their own neighbourhood, finding their way to rooms they have previously been before inside of a building, getting lost inside of their home and/or remembering where stores are in the city that they have visited before.**
- **Having always found navigation difficult and it is not something recent.**
- **Have memories of getting lost in since their childhood or teenage years, when they would start being independent enough to make navigation decisions.**
- **Not having had any previous neurological damage such as a concussion, tumour, etc.**

*** Since a clear connection hasn't been yet established, other cognitive impairments such as dyslexia, aphantasia and ADHD were not excluding factors for screening. Nonetheless, participants with presence of such were noted as an additional remark.**

c. Research Set Up

Participants were first provided with a sensitizing booklet prior to the interview, giving them enough time to observe their navigation behavior on both a weekday and a weekend day. They were encouraged to reflect on their decision-making processes regarding navigation, particularly focusing on the visual cues they used and moments that triggered navigational decisions. Taking pictures was suggested to capture these instances. Figure 18 shows the activities of the sensitizing booklet.

Weekday/Weekend Activity:

After each day, participants selected one activity they found most challenging in terms of navigation, mapping out the trajectory in self-defined steps. The aim was to explore what they considered important for spatial orientation. They were prompted to reflect on whether they checked a map, changed transportation modes, encountered new areas, or relied on landmarks or street names. For each step, they documented how they navigated, their transportation mode, the difficulty of the task, and their emotional response, using stickers to express their answers.

At Home Map Activity:

Participants were also asked to draw a map of their apartment and reflect on whether they had ever gotten lost indoors. This exercise aimed to translate their known environment into a mental representation and offer insight into potential signs of DTD.

Stickers Page:

The provided stickers served as prompts, particularly for emotions, which were left vague to encourage participants to explain their feelings in more detail. For concrete concepts like transportation, predefined options were provided to simplify the task and reduce cognitive load.

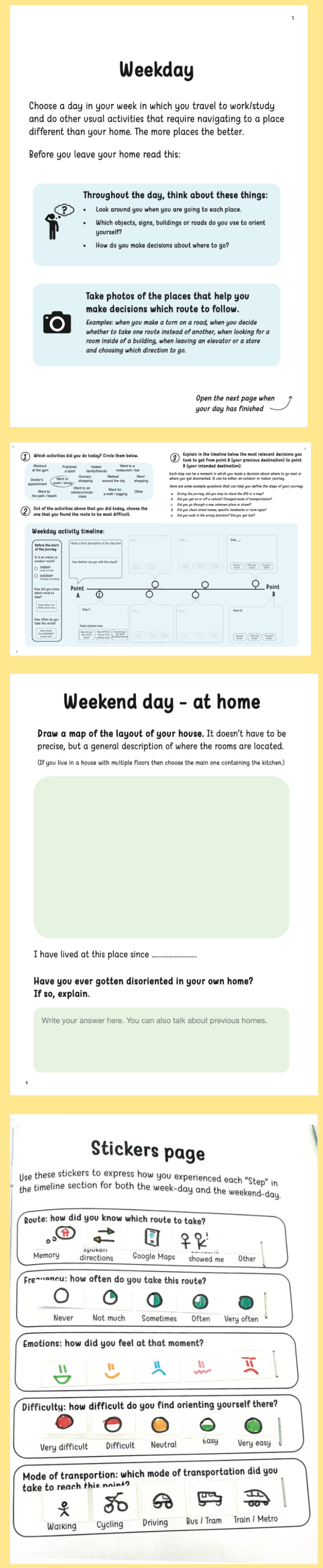


Figure 18. Pages of the sensitizing booklet

Interview

The semi-structured interview consisted of 3 parts:

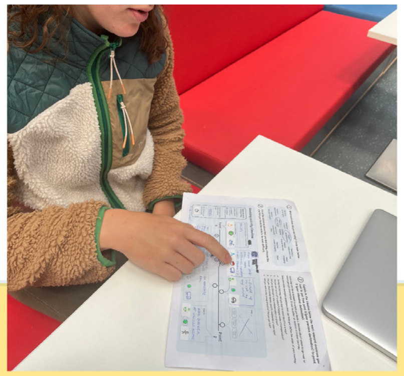
- Explaining their experiences with the help of the previously filled sensitising booklet.
- If questions from the discussion guide hadn't been answered yet on their own initiative, probe on the specific themes detailed in Table 1.

Theme	Objective	Question(s)
Impact on daily life	What are the main daily activities in which DTD can affect a person?	• Which activities did you do and which one did you choose for the exercise? • Why did you choose this one specifically to map out?
Pain points in Wayfinding	What are the gain and pain points of a journey in which DTD can affect the individual?	• How did you decide which were the steps taken for your chosen route? • What sample question did you use the most to decide the steps of the journey?
Emotional impact	Do people with low navigational skills also have the same emotional effect as DTDers?	• How did you feel at each specific step? What do you think caused those emotions? • Probe about the emotions chosen in the booklet for each step, get a specific name for each emotion sticker • How has the perception from others about your navigation skills affected your self perception?
Autonomy	How autonomous do they feel in their daily life, compared to DTDers?	• Did you do this trip alone or accompanied? • How do you feel about navigating alone, without companionship from another person or technology?
Dependence of technology	What is their current dependence on technology?	• How much do they rely on Google Maps for their daily navigation? • What other technology do they use as navigational aid? • What is their type of technology do they use the most? Possible levels: automatic navigation, semi automatic navigation, manual navigation

Table 1. Discussion guide for interviews

- Complete a navigation test to verify the possibility of them having DTD. The navigation test used was developed by van der Ham et. al. from Leiden university in collaboration with the UMC Utrecht. This test is a combination of a Wayfinding Questionnaire, focused in subjective navigation complaints, and the Leiden Navigation test which provides insight in which specific navigation tasks the participant can struggle with. This test is *"a brief, yet comprehensive tool to assess navigation ability in minutes and to detect potential navigation impairment in clinical populations and experimental settings." (van der Ham, et al., 2020).* See Appendix 1 for the navigation test explanation.

Figure 19. Interview phases



Explain sensitising booklet

Follow up questions

Navigation Test

2.2 Results

a. Sensitizing booklet

Although some participants were initially sceptical about the sensitizing booklet, worrying it might be too time-consuming or difficult, they engaged with it thoroughly and provided detailed responses without needing follow-up questions. Most participants chose to describe outdoor journeys they had not done before, despite the activity's objective of focusing on familiar routes. This helped identify key decision points, as using tools like GPS for unfamiliar journeys required participants to memorize the map and develop strategies to remember the route. As one participant remarked, **"I used Google Maps to pick up a package, but I had to remember the street turns after checking it."**

The dual timeline activity for weekday and weekend journeys gave participants the chance to map both frequent and unknown routes. Examples included picking up packages, grocery shopping, traveling to sports centers, visiting less-frequented cities, and navigating Utrecht Central Station, which two participants mentioned as particularly challenging.

Cycling was the most common mode of transport since these activities occurred in the Netherlands. Although more emphasis could have been placed on taking photos of specific decision points, the activity still provided valuable insights.

Mapping their homes wasn't particularly difficult for participants, as many lived in small, shared apartments or studios. Most described feeling confident in their orientation at home. However, one participant demonstrated an interesting cognitive strategy by focusing on larger objects and their relation to the room's perimeter, rather than the room itself: **"I think of the wall behind the couch first, then visualize the window on the wall behind it."** This suggests a potential distinction between perimeter-based versus room-based mental mapping.

Figure 20. Insights from the Sensitizing Booklet

b. Interviews

A total of 9 interviews were done. Nonetheless one of those was with participant, who even though considered themselves as bad with navigation, was actually good at it and would even go hiking on their own. This also gives good insights towards the mental mapping abilities of people with slightly better navigational skills and less navigation anxiety.

The interviews provided qualitative insights in the following themes:

Daily activities affected by DTD or low navigational skills:

The participants in this study, mostly adults younger than 30 living in the Netherlands, reported that their daily activities were not significantly affected by their navigational challenges compared to other cases analyzed, such as those in van der Ham's research group.

For outdoor navigation: This could be attributed to their regular use of GPS apps like Google Maps and 9292 for nearly all their outdoor journeys. They heavily depend on these technologies for direction. One participant noted, ***"I can't even imagine the world without Google Maps" (Participant 5).***

- Walking was generally considered manageable since participants could take their time to consult maps, though there were issues with the GPS detecting their precise location: ***"I have to walk a few steps just to figure out where the blue dot is moving" (Participant 1).***
- Cycling, however, required participants to navigate without much immediate access to technology, as they tended to hold their phones for directions despite legal risks: ***"I knew that there would not be any police coming anywhere, so I just held my phone in my hands, but I already got a fine for that" (Participant 6).***
- Driving: While driving is not common among this group, it was considered easier compared to cycling due to the ease of comparing the road with the virtual map on the GPS system, whether its on the car's multimedia or on their phone.

For outdoor navigation: While the participants express feeling less lost indoors, some environments, like hospitals, are considered harder to navigate due to unclear signage or confusing layouts. Indoor landmarks tend to be elevators, service desks and access doors. It was expressed that when different floors have colors that helps distinguishing them, but a legend must be visible at decision points.

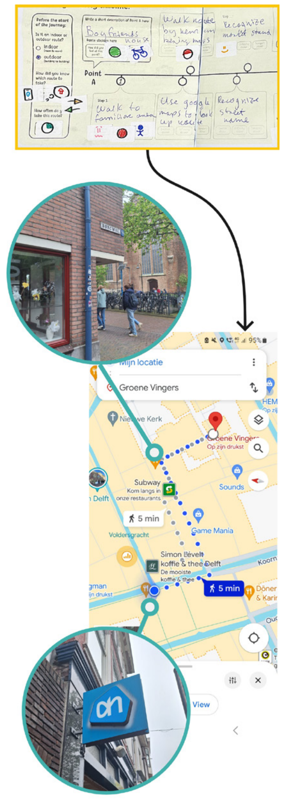


Figure 21. Qualitative insight from interview

Pain points of a journey in which weak navigational skills and/or DTD can affect the person

Mismatch between the real environment and the description: Discrepancies between the actual environment and the descriptions provided by navigation tools can be confusing.

Depending on technology for confirmation: Participants often feel the need to "give up" and check their phones for reassurance when uncertain about directions.

Inadequate proximity of signage points: Signage points that are too far apart can cause confusion and missed directions. ***"If the signs are too far then I think that I probably just didn't see one." - Participant 6***

Deviation from routine: They prefer to park their bike in less popular areas to ensure they find a spot in a zone they know, even if it's less convenient.

Unforeseen route blocks: Unexpected obstacles on the route can cause significant stress and inconvenience. ***"I hate going off the route, I passed my bike underneath the fence just to keep going through." - Participant 1***

Confusion with redundant paths: Encountering two different paths that seem to lead to the same destination can be confusing and disorienting.

Not being in control: The automatic rotation feature of Google Maps can be frustrating and lead to disorientation.

Figure 22. Illustration of anecdotes told by the participants

Emotions related to DTD and/or low navigational skills

Participants in this study recognized their poor navigational skills, often trusting technology and environmental cues over their own intuition. As one participant noted, ***"I trust the signs more than my own intuition" (Participant 6).*** However, negative emotions regarding their navigation difficulties were not frequently observed. When participants did experience disappointment, it was generally tied to their memory performance, particularly when they struggled to remember more than three previously encountered instructions.

Critical moments of stress or panic, similar to those experienced by individuals with DTD, were reported in situations with heightened time pressure or when unexpected navigation decisions had to be made. These moments were particularly stressful when others were dependent on their actions. In such cases, participants expressed feelings of guilt or responsibility if their navigational mistakes led to others becoming lost. While this sense of guilt is not unique to individuals with poor navigation skills, it was noted that these individuals tend to internalize blame more quickly, as they already perceive themselves as "bad at navigating." Participant 8 mentioned, ***"I feel bad if we get lost because it is my fault".***

Social comparison also played a role, especially when others suggested more efficient routes. Though participants were occasionally teased by others, this did not significantly impact their self-esteem. As highly educated university students and recent graduates, they did not equate poor navigational skills with lower intelligence. As another participant remarked, ***"I don't see myself as dumb, I'm in university, so I'm still smart enough" (Participant 3).***

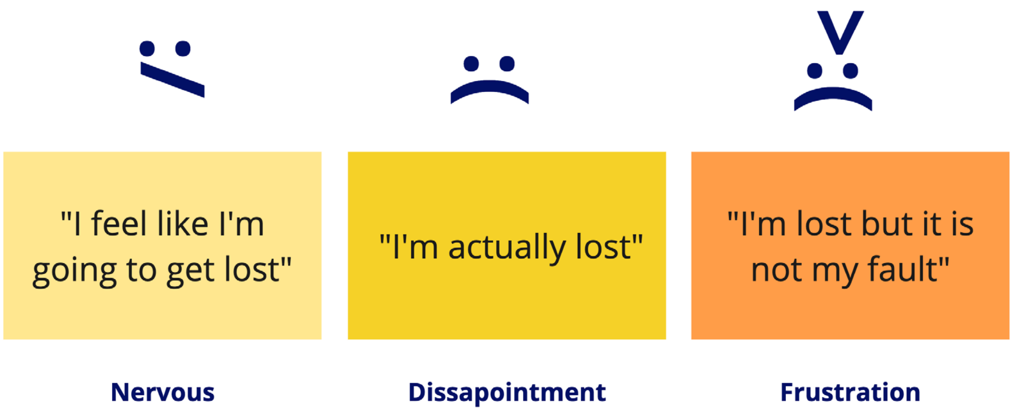


Figure 23. Classification of emotions towards wayfinding by a participant

Autonomy in wayfinding and navigation

In terms of autonomy, the participants generally felt independent but acknowledged that this autonomy was reliant on technology. Known environments were are not perceived as a risk for getting lost. As Participant 9 mentioned, ***"You can't get fully lost in a city, you can always ask someone for directions."***

However, reliance on familiar routes was more common under time pressure, even if they weren't the most efficient. Several participants shared that they enjoy exploring new routes and even being lost on purpose if they had time, as it allowed them to explore new areas: ***"We did a scavenger hunt in school and you had to take a picture at every church, that still helps me remember where to go" (Participant 8).***

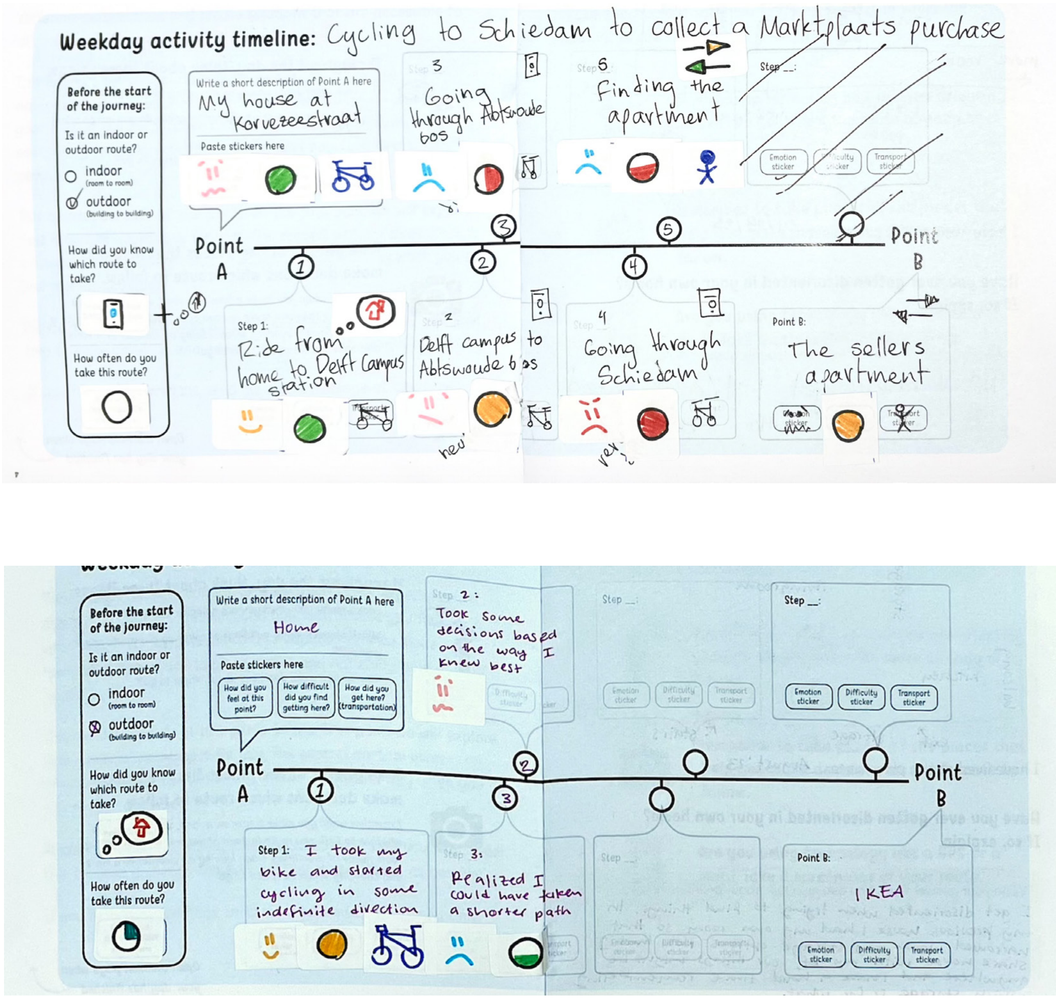


Figure 24. Comparison of booklets filled by different participants.

Dependence on technology

All participants demonstrated high dependence on navigation technologies like Google Maps for their daily outdoor journeys. They also mention the combination of various navigation apps to fulfil different navigational tasks. Nonetheless they do express not wanting to depend on technology for simple routes. One participant mentioned, ***"Why did I have to use Google Maps if it was only 2 streets?" (Participant 2).***

While auditory navigation cues were available, they were often inaccurate at decision points: ***"I have tried this with my earphones and listening to the sounds, but it doesn't work like that. It's too early or too late to take the two meters" (Participant 3).*** Most participants preferred using visual cues and often consulted their phones for reassurance, even for simple routes.

They also preferred manually rotating the map to align with their direction: ***"I need to have it in front of me and the same direction I am looking towards" (Participant 8).***

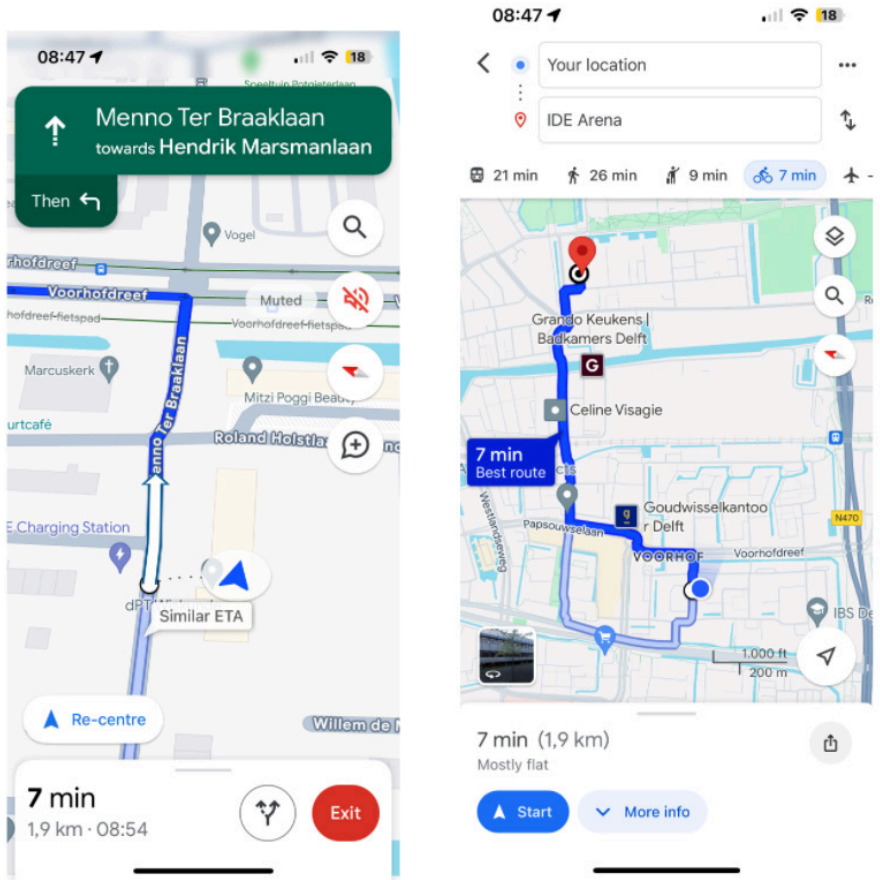
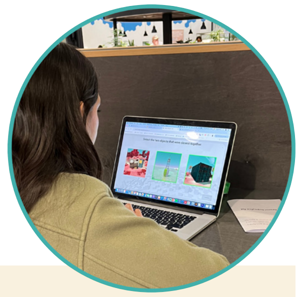


Figure 25. Participants of the study remark being highly dependent on navigation technology such as Google Maps.

b. Navigation test

The results of the Wayfinding Questionnaire and the Leiden Navigation Test can provide an indication of Developmental Topographical Disorientation based on the participants' performance on specific tasks.



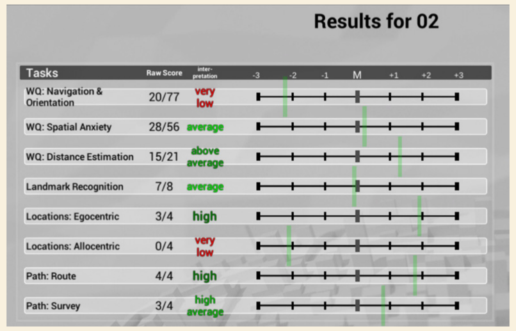


Figure 26. Results from WQ and LNT

The subjective report of navigational complaints in the Wayfinding Questionnaire (WQ) usually highlight a low perception of their own skills in estimating distances and their ability to orient and navigate. Spatial Anxiety usually tends to be low, which translates to a high score indicating that the participant is confident in navigation.

Because of the lack of visualization of a cognitive map, people with DTD tend to rely on landmark memorization for daily orientation. In the LNT, higher scores on Landmark Recognition and Location: Egocentric, are expected compared to lower scores on the rest of the tasks. This can be interpreted as the participant relying mainly on its own perspective to navigate the environment. The translation from an egocentric to an allocentric point of view is usually where DTD participants struggle. The overview of the score for this target group can be seen in Table 2.

Task	P1	P2	P3	P4	P5	P6	P7	P8	P9	Average Score
WO: Navigation & Orientation	-3 very low	-2,2 very low	-3 very low	-1,2 below average	-0,9 low average	-3 very low	+0,1 average	-1,2 below average	-0,9 low average	-1.70 below average
WQ: Spatial anxiety	+1,3 above average	-0,1 average	+2,9 very high	-0,2 average	+0,3 high average	+2,9 very high	+0,8 high average	+0,9 high average	+2,9 very high	1.30 high average
WQ: Distance estimation	-1,7 below average	+1,3 above average	-2,3 very low	-1,1 low average	+1,6 high	-1,5 below average	-0,8 low average	+0,8 high average	0 average	-0.41 low average
Landmark recognition	-0,2 average	-0,2 average	+1 high average	-0,2 average	-0,2 average	-1,2 below average	-0,2 average	-1,2 below average	-1,2 below average	-0.40 low average
Locations: egocentric	-1,3 below average	+1,9 high	+1,6 high average	-0,4 average	-1,4 below average	-0,4 average	-0,2 average	-0,4 average	-0,4 average	-0.11 average
Locations: allocentric	-1,2 below average	-2,1 very low	-1,5 below average	-1,2 below average	-1,2 below average	-1,5 below average	+0,7 high average	+1,8 high	+0,4 high average	-0.64 low average
Path: Route	+1,8 high	+1,8 high	+1,8 high	-0,2 average	-1,2 below average	+0,8 high average	-0,3 average	+0,8 high average	-0,3 average	0.56 high average
Path: survey	+0,9 high average	+0,8 high average	+0,8 high average	-0,2 average	-0,2 average	+0,8 high average	-0,3 average	-1,2 below average	-1,4 below average	0.00 average
Total	-0.43 average	0.15 average	0.1625 average	-0.5875 average	-0.4 average	-0.3875 average	-0.03 average	0.0375 average	-0.1125 average	-0.18 average

Table 2. Discussion guide for interviews

2.3 Discussion of Results

The qualitative research shows that people with low navigational skills experience similar impacts as those with DTD, but younger, highly educated individuals feel less negative impact on their self perception as low navigational skills is not seen as a detriment to intelligence. Due to their reliance on navigation technology, their exposure to daily disorientation and spatial anxiety seems to be reduced, which seems to lead to a higher perceived autonomy.

There is a very high dependence on navigation technology.

The participants rely heavily on GPS-based applications like Google Maps for route guidance, time estimation, and public transportation updates. This dependence, while convenient and reassuring, raises concerns about its long-term effects on navigational skills and autonomy, suggesting a need for interventions balancing technological support with skill development in navigation.

Due to their reliance on technology, their autonomy is sufficient to successfully perform navigation and wayfinding activities.

Technology, especially tools like Google Maps, provides participants with a sense of autonomy in navigating both familiar and unfamiliar environments. They feel fully autonomous using these tools but acknowledge varying degrees of autonomy without them. Activities such as cycling or even hiking are often undertaken with initial technological assistance, highlighting technology's role in maintaining autonomy.

The emotional impact of their wayfinding skills is significantly lower compared to people with DTD.

The participants' reliance on navigation technology mitigates the emotional impact of their poor navigational skills. They do not experience significant spatial anxiety or lowered self-esteem related to navigation abilities, unlike people with DTD who tend to experience higher anxiety and rely on coping strategies such as avoidance.

The impact in daily life of having low navigational skills varies significantly per person and the complexity of their environment.

The impact of low navigational skills varies significantly among participants, influenced by individual strategies and environmental complexity. While technology reduces the overall impact, challenges remain in activities requiring memory of multiple instructions. Indoor wayfinding poses fewer challenges, with participants finding it easier to ask for help in enclosed spaces.

2.4 Conclusion

Navigational aids must align closely with the immediate environment to be truly effective, especially for people with DTD who rely heavily on memorizing landmarks due to their difficulty visualizing cognitive maps. A mismatch between expected and actual states of landmarks, caused by seasonal changes, weather conditions, or obstructions, can lead to significant disorientation. To address this, navigation aids should offer **clear descriptions that are easily identifiable in both map-based (allocentric) and real-world (egocentric) views.** Following the wayfinding design guidelines proposed here, more inclusive navigation systems can be designed for people in all sections of the navigational skill spectrum. Frequent wayfinding cues in the physical environment and adaptable information layers based on user preferences are crucial.

By providing sufficient information for decision-making, without overwhelming the user and blending wayfinding elements into the environment, we can enhance navigation effectiveness and reduce reliance on technology. From these findings, it is possible to create a framework of guidelines that comprehensively integrates all the necessary guidelines for designing wayfinding systems adapted to current technology, while also considering the specific needs of individuals with low navigational skills, such as those with DTD.

User Research - Key Insights:

- From the literature, the following question was still unanswered " What is the influence of lifelong weak navigational skills on the daily experiences of young adults aged 20 to 30, and how can this understanding inform the development of wayfinding guidelines tailored to technology design for individuals with Developmental Topographical Disorientation?". User research was done to answer it.
- Interviews with young adults revealed a high reliance on GPS technology, with varying impacts on autonomy. However, younger participants did not perceive poor navigation as negatively affecting their intelligence.
- The reliance on technology provides autonomy but seems to reduce spatial knowledge acquisition. Future wayfinding systems should integrate both technological support and opportunities for cognitive engagement

3. Define

3.1 Redefining the problem

a. Adjusting the scope

Based on the insights gathered from the user research, DTD is not a great impairment or cause for anxiety in university students / recent graduates. Nonetheless, it was also learned that this target group also highly struggles with the mental rotation task of converting a map in an allocentric view, into decisions that need to be made in an egocentric view and vice versa.

The most popular products on the market, such as Google Maps, have developed version to translate these two views, but users either (1) not know them (2) don't want to dedicate time into watching every step and remembering it (3) they still do not understand them. An example of this view can be observed in figure 27.
So how can the design of technology for navigation be more usable?

For this, **the following chapter builds on the insights gathered from the literature review and introduces specific design guidelines tailored for a more inclusive wayfinding system.** This framework aims to provide practical suggestions to ensure that navigation tools accommodate the needs of individuals with weak navigational skills, those with Developmental Topographical Disorientation, and possibly users with other cognitive impairments.

Furthermore, a design concept is ideated to innovate on navigation technology and later tested with the same target group to observe if the applied insights from the user research phase were succesful.

The general goal of this project remains to improve not only the understanding of cognitive conditions like DTD but also the broader implications for design in accessible navigation systems.

b. Design Goal

Based on the insight that people with DTD tend to struggle with translating maps into the real 3D environment, the following design goal has the potential to aid in the definition or Wayfinding Guidelines and later guide the design of an intervention that improves the inclusiveness of navigation technology.

Bridging the gap between map-based perspectives (allocentric view) and real world experiences (egocentric view) by using engaging technology that stimulates spatial orientation skills and empowers users with weak navigational skills and possibly DTD so they don't depend on technology for daily navigation.

Figure 27. Design Goal.

c. Interaction Vision

As inspiration to develop concepts to fulfil that design goal, an interaction vision was ideated in which the navigation system should feel like a guided tour experience. In this analogy, the navigation system acts as a tour guide, offering users the choice to either closely follow detailed guidance or step back and explore autonomously. As seen in figure 28, the user will feel guided, informed and committed to retain that newly learned information from a system that is entertaining and accurate but still allows autonomy from it.

This flexible approach ensures that users feel supported but not overwhelmed, allowing them to engage at their own pace. The system should make learning about one's environment feel like a fun and rewarding process, rather than a stressful task.

System attributes:

Entertaining — *__Entertains__ the user and captures their attention*

Accurate — *Provides __accurate__ information at the precise time*

Allows user autonomy — *Allows __autonomy__ to the user for them to choose whether they want this or not*

User attributes:

Guided — *The user feels like they are being __accurately guided__ to their destination*

Committed — *The user feels __committed__ to retain that gained information*

Informed — *The user feels like they are __learning__ something they didn't know*

Figure 28. Interaction Vision.

3.2 The Wayfinding System

a. Overview

Based on the general wayfinding guidelines previously explored in the literature review and the discussion of the results from the interviews done, new wayfinding guidelines are proposed to design navigation systems that are apt for people with low navigational skills and people with DTD.
As outlined in the literature review, four key sources were examined to develop these guidelines. The purpose of combining these sources was to create a comprehensive approach to a wayfinding system, incorporating inclusive design principles, accessibility considerations, technological advancements, and the specific needs of individuals with low navigational skills.

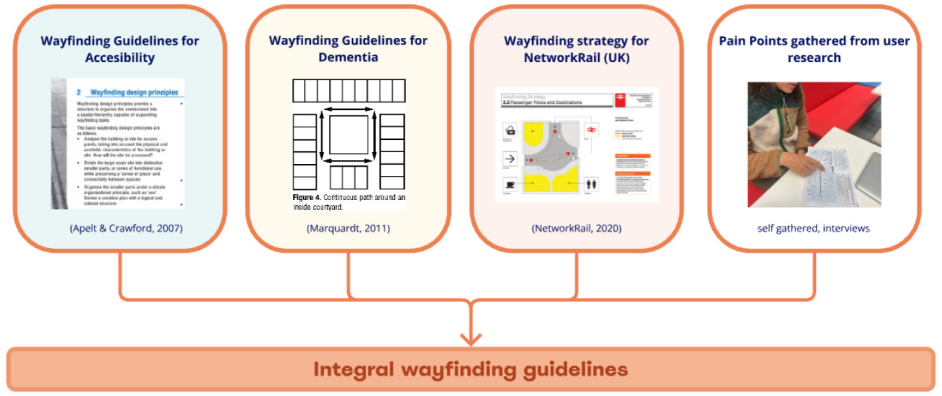


Figure 29. Sources for Wayfinding System.

The guidelines provide a comprehensive framework for designing an effective navigation system that integrates environmental factors, wayfinding elements, representation systems, and user interaction to support individuals with low navigational skills, such as those with DTD, in navigating their surroundings with greater autonomy and confidence. The structure of the framework can be observed in figure 30.

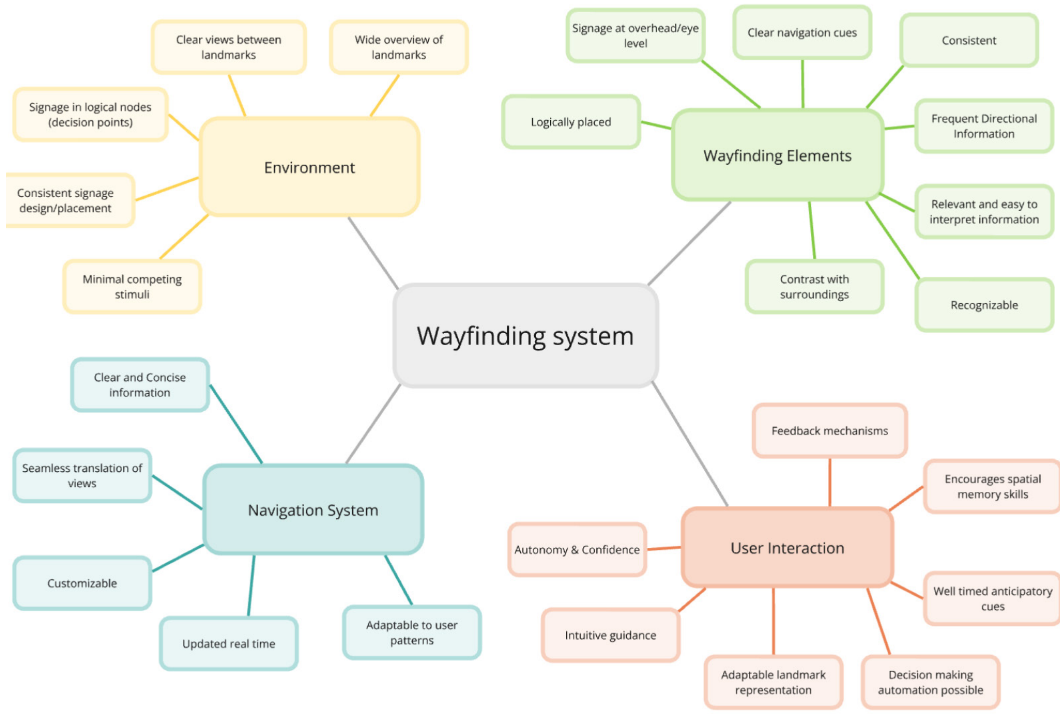


Figure 30. The Wayfinding System

The system consists of 4 elements: the environment, the wayfinding elements, the navigation system (also called the representation) and how the user should interact with them. All elements in the wayfinding system can also be observed as a whole in figure 31.

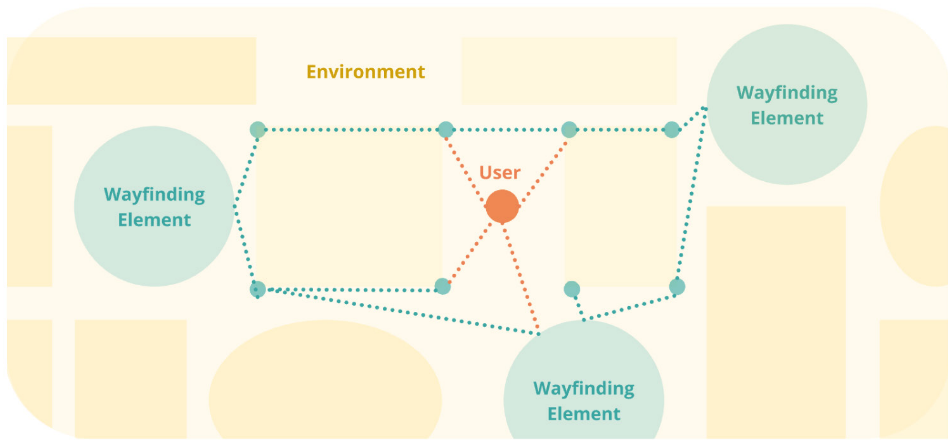


Figure 31. Illustration of the Wayfinding System

b. Guidelines per element

Environment (physical space)

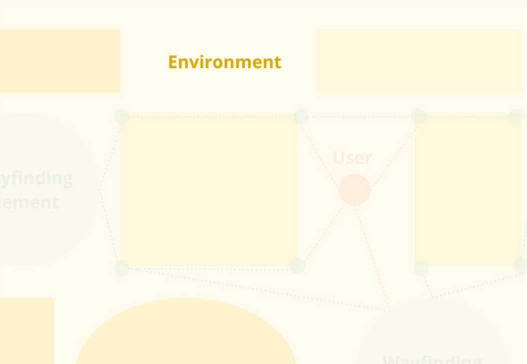


Figure 32. Illustration of the Wayfinding System: Environment

The physical environment consists of all the elements in the immediate surroundings of the user, including buildings, streets, sidewalks, street crossings, stoplights, and other objects such as advertisements. It should minimize competing stimuli and offer clear views between landmarks, logical decision points, and wayfinding elements to facilitate smooth navigation. Signage and cues must be consistent and positioned strategically at decision points and access points, ensuring users can easily transition between allocentric and egocentric views with accurate orientation.

#	Summary	Guideline	*Example*	Origin
E1	Reduce competing stimuli	**Physical space should not have too much competing visual & auditory stimuli.**	*Advertisements should not be placed in positions where they will visually obstruct, obscure, or distract from, station wayfinding or signage*	[Marquardt] [NetworkRail] [Symmonds]
E2	Big overview	**Physical space should be designed to have big overview between landmarks, allowing the user to oversee their entire immediate environment.**	*All places relevant to them should allow for visual access, and it should be possible for them to oversee their entire immediate living environment*	[Marquardt]
E3	Clear decision points	**Physical space should offer wayfinding elements at key nodes and obvious/logical decision points of navigation with clear signage.**	*Signage should be placed before the decision needs to be made and not right at the same spot*	[Apelt, adaptation]
E5	Access points	**Physical space should clearly distinguish access points.**	*Showing a clear access point in and another access point out of each section. Ex: Having a title of the building that is visible from the closest public transportation stop.*	[Apelt]

Table 3. Wayfinding Guidelines for DTD: Environment

Wayfinding Elements

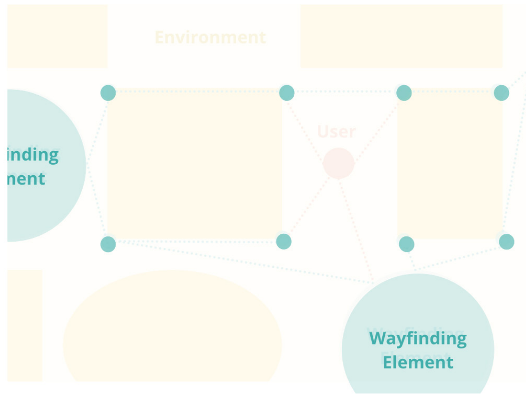


Figure 33. Illustration of the Wayfinding System: Elements

Wayfinding elements refer to objects and markers that help guide users through a space, such as signage, landmarks, or visual cues in the environment. These elements must be recognizable, contrasting with their surroundings, and offer consistent and progressive directional cues to prevent confusion. Signage should be positioned at eye-level and overhead, displaying only the most relevant information in a clear and standardized manner to guide users efficiently.

#	Summary	Guideline	*Example*	Origin
W1	Precision of navigation cues	**Wayfinding elements such as signage should indicate navigation cues precisely, meaning pointing to the correct direction at the correct place.**	*If a street has a turn and it keeps the same name, then the sign should reflect that or be doubled to indicate continuity*	[self, interviews]
W2	Landmarks should be recognizable	**Wayfinding elements and landmarks (buildings, streets, natural elements) should have recognizable permanent features that contrast with the immediate surroundings such as name, color, size.**	*Signage elements are designed with bold, contrasting colors to make them stand out against the neutral tones of the background.*	[Marquardt]
W3	Landmarks should be reliable	**Ensure longevity of landmarks. Avoid using places as reference points that have high possibility of changing. Update directions to always have the accurate landmark.**	*Do not use fashion stores unless assured longevity.*	[Apelt, adaptation]
W4	Consistent style	**Wayfinding elements should be consistent in style and distance between them.**	*People will start wondering if they are actually going the right way if the signage is not placed in consistent distance*	[Apelt]
W5	Progressive disclosure of information	**Wayfinding elements should progressively disclose information as it is needed to avoid the user forgetting essential information along the way.**	*Signage should only show 4 titles at most*	[NetworkRail]
W6	Clustering of information	**Wayfinding elements should cluster information based on position and similarity**	Information should be clustered in primary secondary and tertiary levels of information. For an airport this can be: first level: entrance, elevators, information, parking, special assistance.	Paul Symonns
W7	Placement of signage	**Signage should be placed at or close to decision points, considering user flows.**	*overhead signs, typically read from a distance of 4–6 meters, should be placed where passengers can comfortably view them without excessive neck strain. Eye-level signs, best viewed from 1–2 meters away, should be installed where users can easily read them without breaking their stride*	[NetworkRail]
W8	Symbology should be logical	**Symbology & naming protocol of signage must be logical, with clear sequencing and grouping of information and relation to the physical space.**	*Ensure alpha-numeric coding systems are consistent, such as "building side north, level 3, room 7."* *Using colors or metaphorical elements to designate zones is highly recommended, as long as the user has a connection to it or it has been clearly explained to them.*	[Apelt adaptation]

Table 4. Wayfinding Guidelines for DTD: Wayfinding Elements

Representation / Navigation System

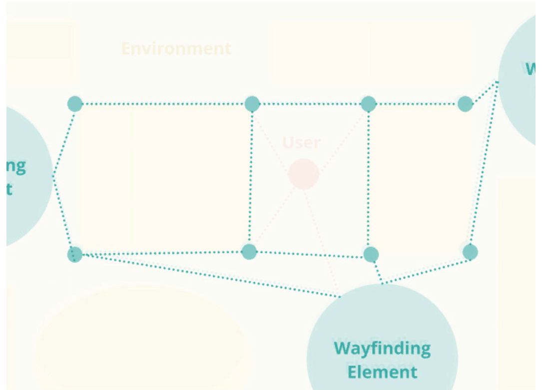


Figure 34. Wayfinding System: Navigation system

The representation or navigation system includes any digital or physical tools that display a representation of the environment or the navigation instructions to take, such as maps, GPS interfaces, or augmented reality systems. The system must ensure a smooth translation between egocentric and allocentric views, reflecting the real-time state of the environment and providing users with segmented, customizable information. It should offer personalization features, such as interface customization and feedback options, allowing users to tailor the system to their needs and navigation patterns.

#	Summary	Guideline	*Example*	Origin
S1	Egocentric to Allocentric translation	**Representation of the physical space should offer egocentric to allocentric view translations, with an indication of the orientation of the user in the physical space.**	*Ex: Static maps should show the "you are here" and then be oriented front view according to the same cardinal points as the map*	[self, interviews]
S2	Matching orientation	**The cardinal orientation of the representation should match the current one the user has.**	*In an interactive map the first view should be with the first street straight*	[self, interviews]
S7	Avoid initial mental rotation tasks	**Mental rotation tasks should be avoided as a first step to understand the translation between the allocentric and the egocentric view.**	*Avoid showing the map in a different rotation than what the user is facing at the moment*	[self, interviews]
S3	Matching state of landmark	**Current physical state of a landmark should match in both views of this translation (egocentric - allocentric).**	*Maps should show the current status of each landmark, indicating whether it's undergoing maintenance.*	[self, interviews]
S6	Indication of location	**The system should indicate where the user is currently located in the representation and the physical space.**	*Like the blue dot in Google Maps or the "you are here" in maps*	[self, interviews]
S9	Interpretations adapted to users mental map	**The representation should offer different types of interpretations to fit the users' mental representation.**	*for example, instead of saying 1km radius it can be said 10min walking radius*	[self, interviews]
S5	Information presented in segments	**The information shown in both views should be segmented in levels of detail and only show the most relevant information for navigation first.**	*Visual elements that correctly show the aesthetic of the environment, with a special attention to natural elements, are highly encouraged. Ex: Green areas show that there is a park besides without showing all the detail. But trees on the side of the street can be shown in more detail.*	[NetworkRail]
S4	Eye-Level representation	**Egocentric view of representation should show representation of landmarks as seen at eye level.**	*Do not show photos of landmarks from a drone view*	[self, interviews]
S8	Location of wayfinding elements	**The precise location of the wayfinding elements should be shown in the representation.**	Where to find the wayfinding elements should also be shown	[self, interviews]
S10	Consideration of user navigation patterns	**The system should consider user navigation patterns and define key nodes such as decision points according to that.**	*Decision points are located in transient spaces characterised by fast-paced movement, where it is important to deter passengers from stopping and creating bottlenecks in circulation space.*	[NetworkRail]

Table 5. Wayfinding Guidelines for DTD: Navigation System

#	Summary	Guideline	*Example*	Origin
S13	Reaffirmation of correct path	**Reaffirmation that the user is on the correct path is encouraged.**	*It is better to be redundant with signage than less than needed*	[Apelt]
S14	Reduce unnecesary decision making	**Reduce unnecessary decision making.**	*For special populations, show multiple routes but already a recommendation.*	[Marquardt]
S15	Levels of decision automation	**Provide levels of decision-making automation.**	*Let the user decide how much they want automated or if they want to train their memory*	[self, interviews]
S16	Inform impact of information	**The system should provide the user with additional information over the impact on the route in case a decision needs to be made.**	*If multiple options are shown to reach the same spot, the difference (or advantage) between them must be clearly communicated, but the user makes the decision. Ex: Show in one sentence "shortest route" vs "simplest route".*	[self, interviews]
S17	Feedback from user	**Allow user to give feedback over the information and recommendations provided by the system.**	*Provide rating system for routes and level of automation*	[self, interviews]
S18	Visual autonomy	**The user should not need to see the representation visually in order to remember the route to take, system should offer alternative representations for navigation.**	*Provide cues that are easy to remember.*	[self, interviews]
S20	Easy correction of mistakes	**If the user deviates from the set navigation path they should be able to easily identify the mistake and be offered a solution to correct it.**	*Offer solutions to get back on track or self adjust to a new route from that point onwards*	[self, interviews]

Continuation Table 5. Wayfinding Guidelines for DTD: Navigation System

User interaction

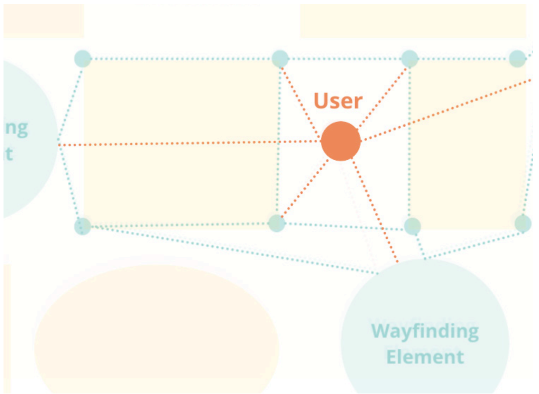


Figure 35. Wayfinding System: User interaction

This user interaction refers to the ways in which a person engages with the navigation system or environment to find their way, such as choosing routes or responding to cues. Users should interact with the navigation system through adaptable decision-making options, anticipatory cues, and feedback mechanisms that empower them and reduce dependency on visual aids. The system should encourage spatial memory training while offering intuitive support and reassurance at critical points to foster autonomy and confidence in navigation.

#	Summary	Guideline	*Example*	Origin
U1	User feels informed on time	**The user should be informed about an upcoming decision point, with accurate distance so that the user sees the decision point but still has enough time to make the decision.**	*User can decide how soon they want the navigation cue*	[Apelt, adaptation]
U2	User feels reassured	**The user should be reassured that they are going in the right direction and warned if not.**	*It is better to be redundant with signage than less than needed*	[Apelt]
U3	Intuitive guidance	**The user should feel led intuitively and not be required to choose from different options to plan a route.**	*If a floor plan typology that features changes in the direction of the circulation system is the only design option at a site, a meaningful reference point should be incorporated.*	[Marquardt]
U4	User feels in control	**Users should feel in control of their interaction with the representation.**	Ex: *Add an option to prevent self orientation of the map on the device.*	[self, interviews]
U5	User controls amount of information	**The user should be able to choose how much information is presented.**	*Do not show commercial ads in critical moments for navigation.*	[self, interviews]
U6	Empowered decision making	**If a user must make a navigation decision they should feel empowered to make it.**	*To be defined how.*	[self, interviews]
U7	Encourage of spatial memorization	**The user should be encouraged to train their spatial memorization skills. This does not mean that they are required to use a mental map to navigate every time.**	*Make it a gamified experience*	[self, interviews]
U8	Reduced dependency on system	**The user should not feel dependent on the representation to remember the route to take.**	*Provide cues that are easy to remember.*	[self, interviews]

Table 6. Wayfinding Guidelines for DTD: User interaction

b. Case Study: Google Maps

In order to verify that the proposed interaction guidelines are grounded in current technical capabilities, a review was done of one of the most popular existing navigation tools, such as Google Maps. The aim was to identify how well Google Maps has developed concepts around these guidelines and where could there be room for innovation.

Focusing on one of the most pressing topics of the user's given feedback about navigation, was the translation of the provided allocentric view (map) into the decision points that need to be taken in an egocentric point of view.

Allocentric to Egocentric translations

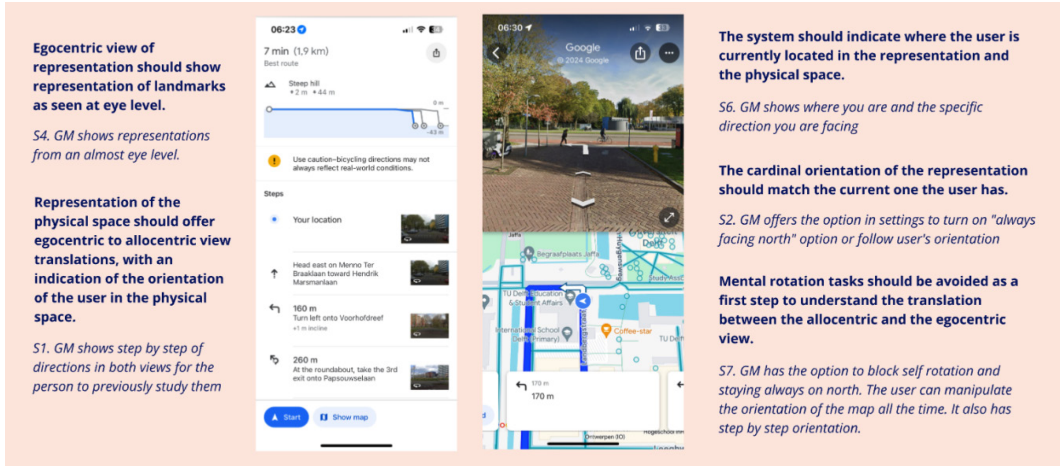


Figure 36. Google Maps Case Study of proposed guidelines: Allocentric to Egocentric translations.

Google Maps offers features that align with each of the accessibility traits highlighted in the guidelines. A detailed comparison of these features can be found in Appendix __. Since the guidelines were shaped by user feedback from qualitative research, where they shared their experiences with Google Maps, it raises an important question:

Adapting to the user's mental map

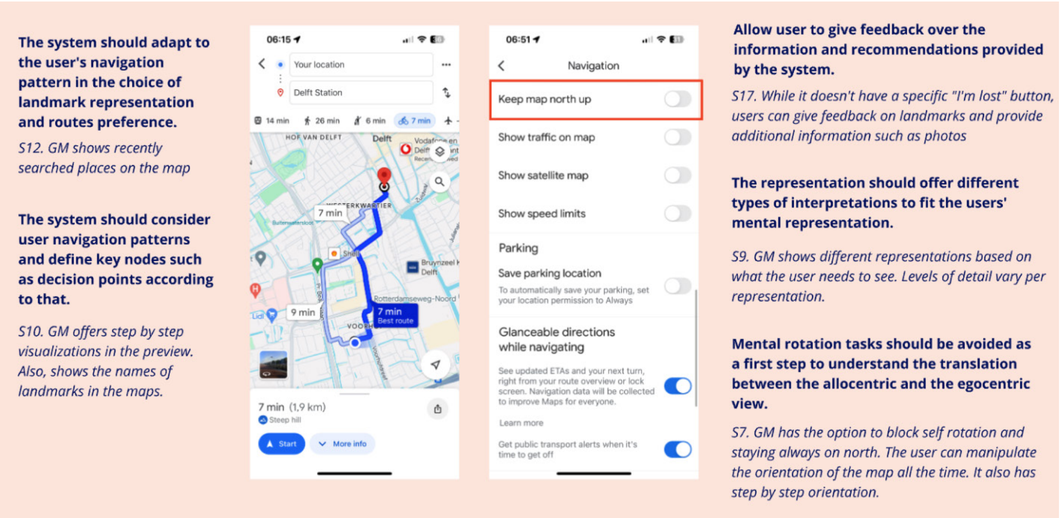


Figure 37. Google Maps Case Study of proposed guidelines: Allocentric to Egocentric translations.

if these features are already in place, why aren't users engaging with them?

The Wayfinding System - Key Insights:

- The wayfinding system consists of environmental elements, wayfinding aids, representation systems (maps), and user interaction
- Each element in the wayfinding system should focus on offering clear, progressive directional cues and logical decision points. Signage and navigation aids must be adapted for both allocentric and egocentric navigation
- A case study of Google Maps was conducted to evaluate how well its features align with the proposed wayfinding guidelines. Although Google Maps provides detailed guidance, users often do not engage with its full capabilities

3.3 Design directions

a. New interactions

Having defined the interaction guidelines for people with low navigational skills, it was easy to already think of a few new interventions/features that could be applied to navigational aids in order to make them more inclusive. These new features could improve how much a person can remember of the route and also motivate them to use the navigational aid less by using gamification elements.

Here are a few examples of different modes/features that could improve retainability. A specific "context of use" was chosen as a starting point for the ideation of an intervention.

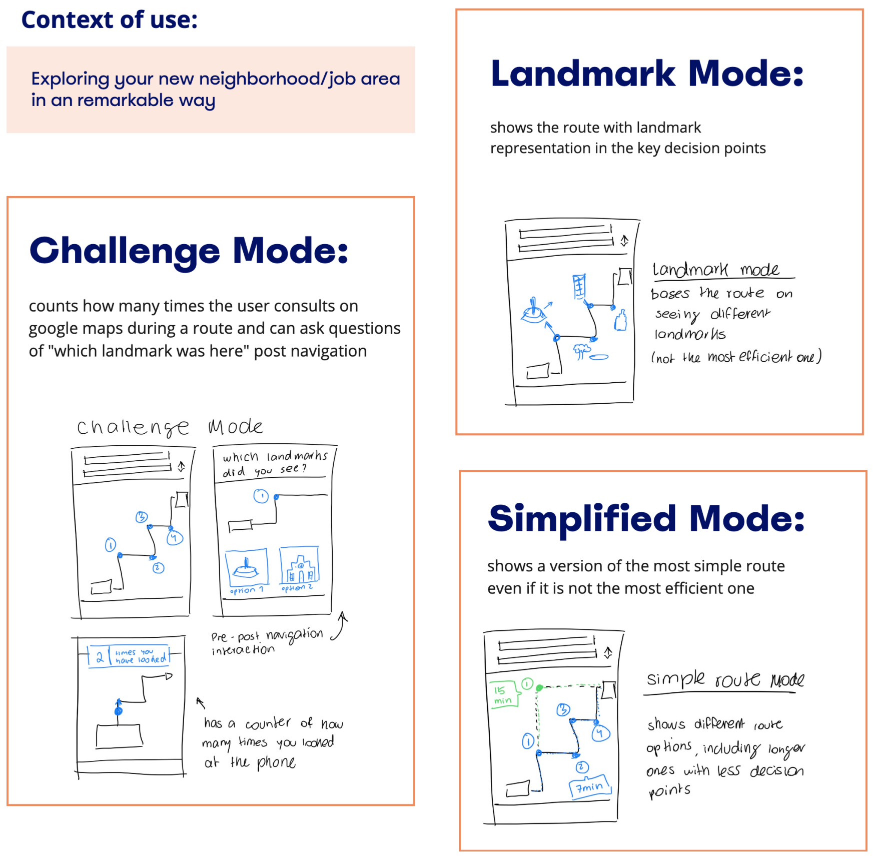


Figure 38. Ideation on navigation interactions

Nonetheless, these features were the result of an initial brainstorming directly after the Case Study was done. They still rely mainly on the visual sense by showing the landmarks they need to remember. The design space could be further explored, which is why more concepts were further developed.

4. Develop

4.1 Design Concept

a. Ideation

First Ideas

Having defined the interaction guidelines for people with low navigational skills, it was easy to already think of a few new interventions/features that could be applied to navigational aids in order to make them more inclusive. These new features could improve how much a person can remember of the route and also motivate them to use the navigational aid less by using gamification elements.

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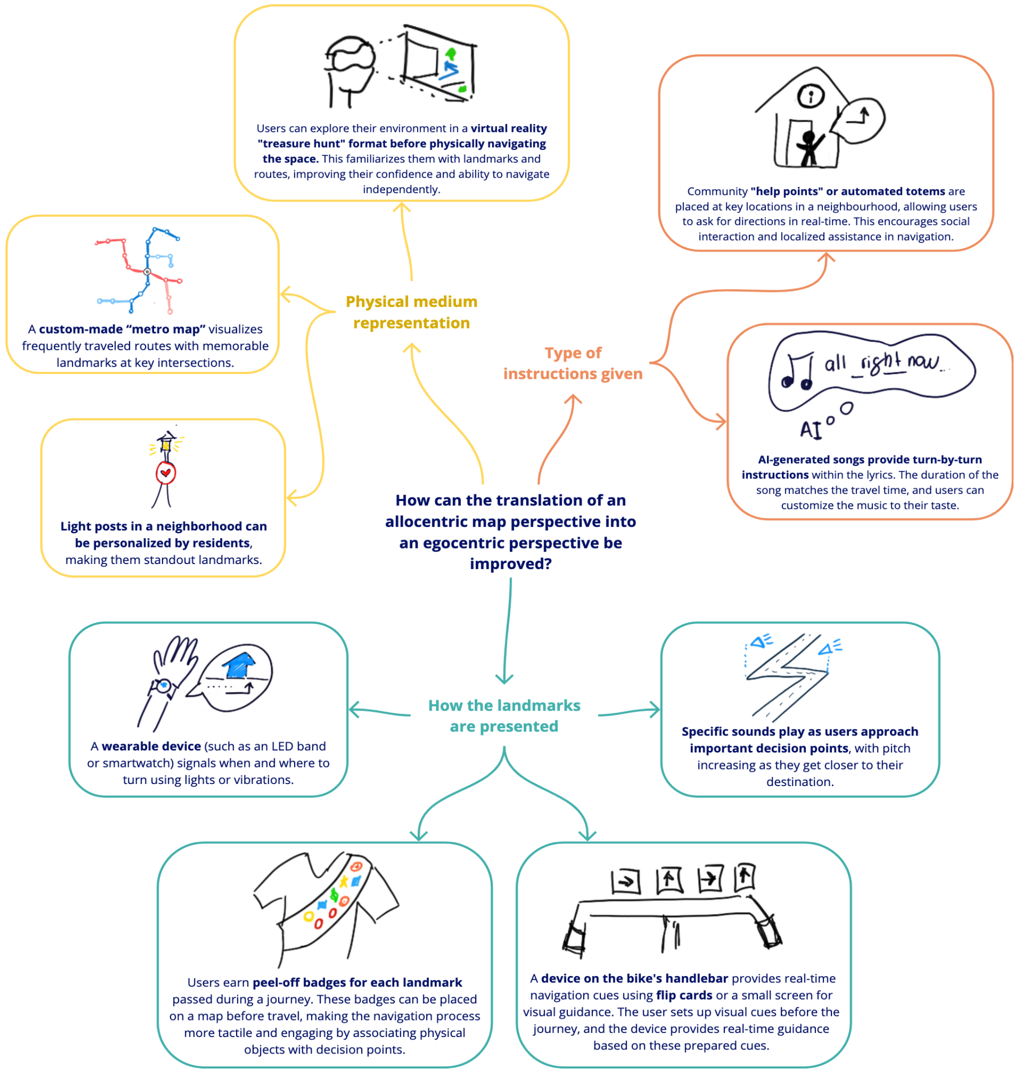
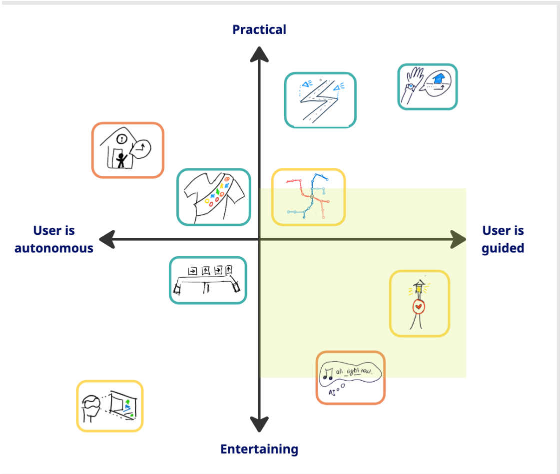


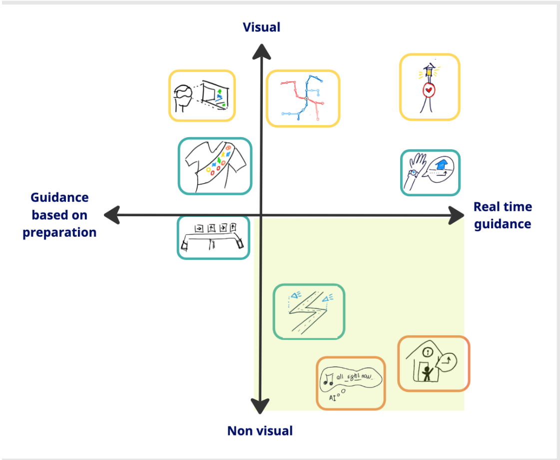
Figure 39. Brainstorming first ideas

Clustering Ideas

The previous concept ideas were clustered based on the attributes from the interaction vision, such as the level of user autonomy they promote, their entertainment value, and their reliance on technology. This allowed for a clearer understanding of which solutions would be most effective in engaging users while fulfilling the design goal of fostering independence in navigation.

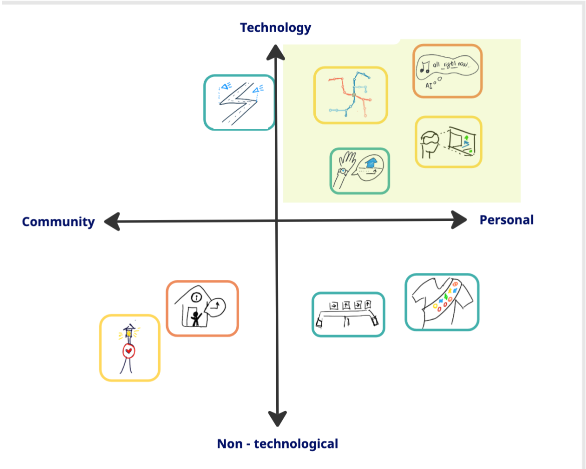


The first cluster has as the most desirable attributes that the system is "entertaining" and that the user "feels guided". This is in line with the interaction vision as a tour guide analogy. Nonetheless, the practicality of the system is important so that it is easy and convenient for the user to use it and therefore increase the motivation.



The second cluster focuses on highlighting the different types of representation the system can have.

Ideally, the user will feel guided even when they are already on the road and will not depend only on remembering a visual representation. Although, guidance based on preparation could also be interesting to propose as a concept if users are motivated to spend additional time.



This third cluster, although less relevant, is to align the ideation process with the goals set from the beginning of this project. Creating technological innovation will follow the current design tendencies and providing personalization to the user can adapt the system to their own needs.

Figure 40. Idea clustering

Highlighting the differences

From the previous clustering, it became clearer how the ideas differed between them. This differentiation provided another opportunity to further develop design concepts that adapt to the user needs.

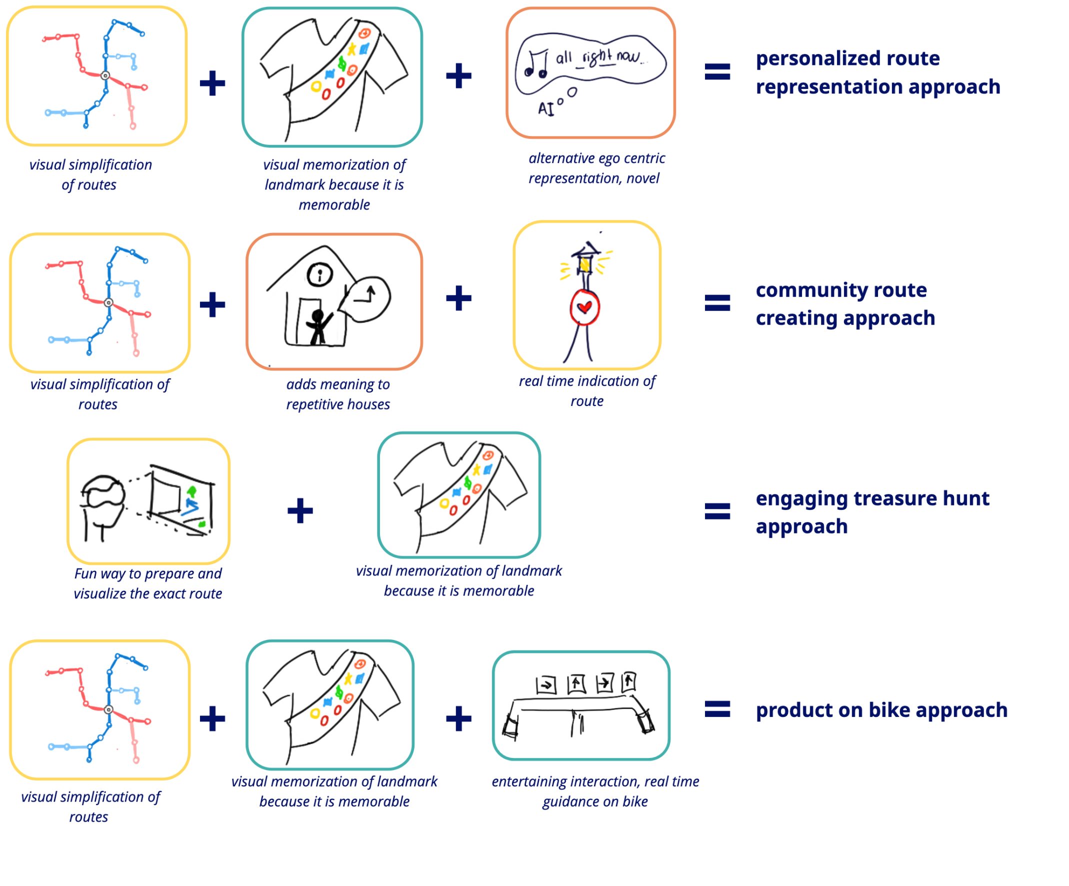


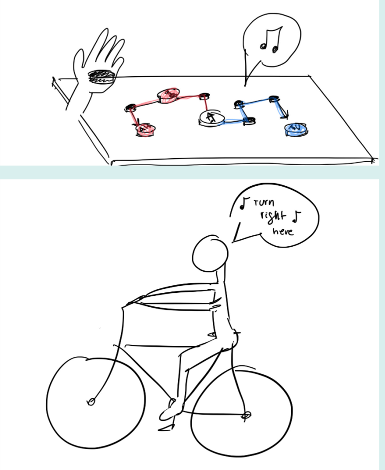
Figure 41. Developing the first concepts

These four opportunities provide the design directions to be developed in the following section. These approaches will be further detailed and evaluated to formulate the design concept.

Design Concept Approaches

The concepts developed represent various approaches to a navigational aid system. Each concept was then analyzed in greater depth, focusing on how closely they align with the attributes outlined in the interaction vision. Here are 4 design approaches:

1. Personalized route songs

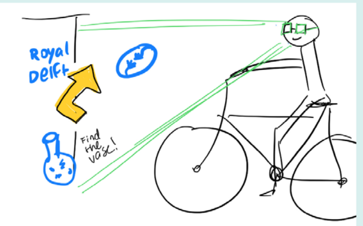


A system that generates personalized songs with embedded navigation instructions based on a customizable "metro map" of frequented routes and landmarks. The songs guide users while the map provides a visual representation of their environment.

Entertaining:	●●●●○	Songs can be adapted to the music taste of the user and new songs can be created.
Accurate:	●●●●●	If lyrics play at the precise decision point and describe landmarks.
User Autonomy:	●●●●○	Connection between ego - allo views User can listen to it at any moment.
Guided:	●●●●●	User is guided the whole time, real time guidance
Informed:	●●●●○	Lyrics of the song describe the landmark and give instructions, the system informs of possible routes
Committed:	●●●●○	If songs are entertaining the user will want to listen to it again and retain the information gained

Figure 42. Concept 1 Personalized route songs

2. Engaging treasure hunt

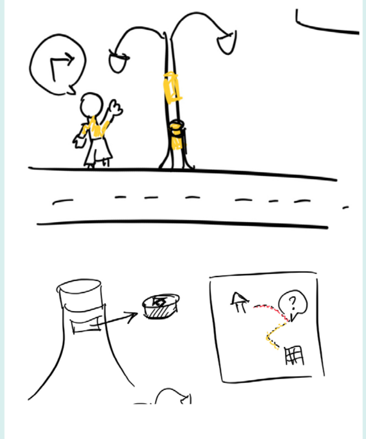


A system that lets users virtually explore their environment in a treasure hunt format, allowing them to familiarize themselves with landmarks and routes before navigating in real life.

Entertaining:	●●●●●	Different quests can be created per route, challenging and highly entertaining
Accurate:	●●●○○	System must have ready a lot of tasks to create an interaction with most frequented places
User Autonomy:	●●●○○	No real time directioning, depends on memory of the user
Guided:	●●○○○	User is only guided prior to the experience or at the moment but the user must be willing to spend more time
Informed:	●●●●○	The system informs about specific points and strategies to remember where those points are through a game
Committed:	●●●○○	If the experience is fun then the user will want to repeat it, can't take too much time so that it is still efficient

Figure 43. Concept 2 Engaging treasure hunt

3. Community route creation

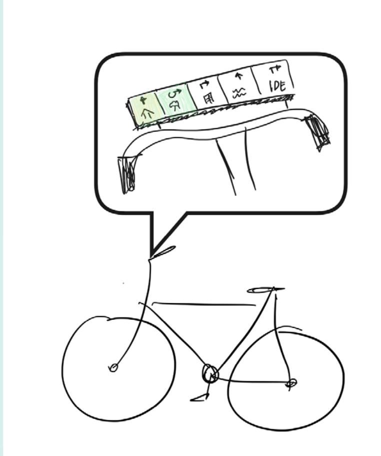


A system where community members contribute to route creation by customizing light posts, adding help totems, and setting up "ask for directions" points. This creates a collaborative navigation network.

Entertaining:	●●●●○	It can be entertaining to talk to people around the neighbourhood
Accurate:	●●●○○	Depending on the the style of giving directions of the person or totem
User Autonomy:	●●○○○	User must remember the directions given
Guided:	●●●○○	User is guided during critical decision points
Informed:	●●●●●	User learns information about the city but also about who lives there.
Committed:	●●○○○	User will want to create connections with the people who give directions, more time consuming

Figure 44. Concept 3 Community route creation

4. Navigational device on bike



A system that can be bike-mounted device with flip blocks that shows navigation instructions and landmarks. Users prepare the flip blocks before their journey, setting up visual cues for each decision point. Alternatively, a screen for the bike that shows the landmarks and next navigation instructions.

Entertaining:	●●●○○	User can have a gamified experience in the bike
Accurate:	●●●●○	Yes but depending mainly on the level of detail given in the instructions
User Autonomy:	●●○○○	Different playing modes and levels available, easy explains all points and hard challenges the user's memory
Guided:	●●●●●	User is guided the whole time, real time guidance
Informed:	●●○○○	More of a find the place interaction rather than learning about the spot
Committed:	●●●○○	If the interaction is fun then the user will want to keep using it, the system should be detachable to avoid robbery but easy to mount so the user actually does it

Figure 45.Navigational device on bike

Each concept demonstrates varying strengths across the attributes. For example, the "Personalized route songs" concept is more autonomous and guiding, while the "Engaging treasure hunt" is highly entertaining but low on providing guidance. Meanwhile, "Community route creation" emphasized commitment and user interaction, and the "Navigational device on bike" provided a unique blend of both physical and digital navigation aids, excelling in user autonomy but with moderate accuracy depending on its setup.

b. Evaluation of ideas

To assess the potential of each proposed concept, two evaluations were done with a Weighted Score technique (Van Boeijen et al., 2013) were employed. This allows for an objective evaluation of how well the concepts fulfilled the attributes defined in the interaction vision and also the interaction guidelines proposed in the last chapter. Each concept was scored on a scale of 1 to 5 based on how well it performed against each attribute/requirement. It is worth noting that this evaluation was done to aid in choosing a design concept. These approaches, if further developed could have probably fulfilled the requirements and scored higher based on the set attributes.

Weighted score - Attributes

	1. Personalized route songs	2. Engaging treasure hunt	3. Community route creation	4. Navigational device on bike
Entertaining:	4	5	4	2
Accurate:	5	3	3	4
User Autonomy:	4	3	2	3
Guided:	5	3	3	5
Informed:	4	4	5	2
Committed:	4	3	2	3
Total:	26	21	19	19

Table 7. Weighted Score - Attributes

The Weighted Score analysis clearly highlights that the personalised route representation approach outperforms the other concepts. While other concepts, such as the engaging treasure hunt approach, score highly in entertainment, they fall short in critical areas like accuracy and guidance, making them less practical for everyday navigation.

Weighted score - Interaction Guidelines

#	Summary	Guideline	1	2	3	4
S1	Egocentric to Allocentric translation	**Representation of the physical space should offer egocentric to allocentric view translations, with an indication of the orientation of the user in the physical space.**	5	3 (relies on external help)	4	3 (real time visual instructions)
S2	Matching orientation and landmarks	**The cardinal orientation of the representation and current physical state of landmarks should match between allocentric views given and current egocentric view the user has at that moment.**	3 (a song might not describe the landmark with enough detail)	3 (since it relies on locals they might describe it differently)	3 (more time intensive to create which means updated views may not be frequent)	4
S7	Avoid initial mental rotation tasks	**Mental rotation tasks should be avoided as a first step to understand the translation between the allocentric and the egocentric view.**	4	2 (no real time guidance)	4	3 (users will still need to interpret the directions)
S6	Indication of location	**The system should clearly indicate the user's current location and the precise position of wayfinding elements in both views.**	5	3 (decision point descriptions might not be accurate)	4	4
S9	Adaptation to User Navigation Patterns	**The system should consider user navigation patterns, adapting representations and routes to the user's mental map.**	4	3	3	2 (system follows preset routes, offering limited adaptation to unique user preferences)
S5	Information presented in segments	**The information shown in both views should be segmented in levels of detail and only show the most relevant information for navigation first. It should be announced with enough anticipation to assist navigation (when it is visible on the horizon but with enough time to anticipate the decision point.)**	5	3 (no real time guidance so all info is given at once)	4	4
S4	Eye-Level representation	**Egocentric view of representation should show representation of landmarks as seen at eye level.**	4	3 (since it relies on locals they might describe it differently)	3	4
S10	Consideration of user navigation patterns	**The system should consider user navigation patterns and define key nodes such as decision points according to that.**	4	3	3	2
S13	Reaffirmation of correct path	**The system should provide reassurance that the user is on the correct path.**	5	3 (info points should be able to indicate that they are in the wrong path)	4	4
S20	Easy correction of mistakes	**If the user deviates from the set navigation path they should be able to easily identify the mistake and be offered a solution to correct it.**	5	3 (community support might not be available at all times)	4	3 (system might not recognise errors quickly)
S14	Reduce decision making complexity	**The system should reduce unnecessary decision-making by simplifying navigation tasks and provide levels of automation based on user preferences.**	4	3 (community guidance might be more complicated)	3 (treasure hunt requires more tasks than just navigation)	2 (user needs to interpret the landmark badge)
S18	Visual autonomy	**The user should not need to see the representation visually in order to remember the route to take, system should offer alternative representations for navigation.**	4	4	2 (Heavy reliance on visual cues)	2 (Heavy reliance on visual cues)
S16	Inform impact of information	**The system should provide the user with additional information over the impact on the route in case a decision needs to be made.**	3 (song would need to have alternative lyrics)	4	5	2 (there is no space to show additional info.)
S17	Feedback from user	**Allow user to give feedback over the information and recommendations provided by the system.**	4	5	4	3 (limited opportunity for user feedback)
	Total score:		59	45	50	42

Table 8. Weighted Score - Interaction Guidelines

This analysis based on the system guidelines as requirements hints that the Personalized Route Representation concept is the most comprehensive solution. This concept excels in critical areas such as Egocentric to Allocentric Translation, Indication of Location and Elements, and Error Recovery, making it a well-rounded choice for users with low navigational skills. It balances automation, autonomy, and user engagement, offering personalized guidance while minimizing cognitive load.

c. Concept choice

Personalized route song generation

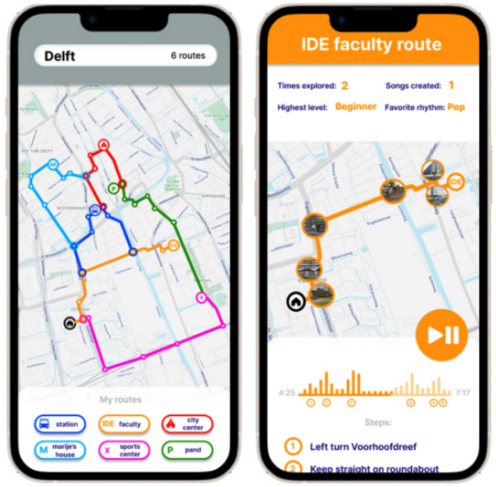
After the previous selection of a concept, the "Personalized Route Songs" concept was chosen to be further developed. A specific user case was defined as the context to have a starting point for the design and specify the interaction.

The context:

Exploring a new route on your neighbourhood / new place of work, by bike.

With the house / workplace as starting point, the system creates a route with a specific color for every frequented place.

Routes can be made longer by adding landmarks, but they remain using memorable landmarks as decision point spots. Each dot represents a landmark.



The system generates a song with lyrics that indicate the decisions that need to be made and the landmarks that need to be located in order to take them.

The system will create the songs based on the musical preferences of the user so they will enjoy listening to it along the ride.

Figure 46. Design Concept

System attributes:

- Provides **accurate** information at the precise time
- Allows **autonomy** to the user for them to choose whether they want this or not
- **Entertains** the user and captures their attention

User attributes:

- The user feels **committed** to retain that gained information
- The user feels like they are **being accurately guided** to their destination
- The user feels like they are **informed** about something they didn't know

User - system interactions

Table 9 outlines the general phases of the user journey for the Personalized Route Representation concept, which generates tailored audio navigation through music. It details how the user interacts with the system from the moment they input their frequent destinations to the completion of their journey, with a focus on minimising cognitive load and enhancing navigation enjoyment through an immersive and intuitive experience.

Phase	User action	System action (front end)	System automation (back end)
As soon as the user moves to a new home / starts a new job	The user inputs their base point and places they will start going to and from reguglarly	The system asks for the home of the user and most frequently visited places.	• The system starts creating routes to and from these places. • The system should calculate the amount of time it takes from the starting point to the destination.
User is planning the journey to a nearby destination by bike (3 -15 mins)	The user can choose: • the mood they are in • the level of difficulty (amount of instructions given) • the genre they want to listen to • the voice they want the lyrics sang • colour of the route • points of reference	The system creates a song based on the written directions where they need to turn (for every decision point) and can stay instrumental or play different lyrics when there are no decisions that need to be taken.	The system incorporates that song into a route and it creates a new route in the map
User previews the route to take and landmarks to look out for	User learns the landmarks they need to look out for	The system visually highlights the landmarks and important points on the route.	The system matches visual cues with auditory landmarks in the song, ensuring consistency.
During the journey	The user cycles with headphones on (low volume so it is still safe)	• System is safely stored in bag or pocket while the user cycles • System plays the generated song with the directions embedded in the lyrics	The system detects the user's pace and adjusts the tempo of the song to match (faster or slower). • If the user stops, the song pauses until they resume moving.
Destination has been reached	User inputs feedback on the route lyrics generated and their accuracy.	The system notifies the user that they have arrived at their destination with a final confirmation lyric or sound. The system requests feedback of the generated song. If gamified: system opens post navigation game.	The system records the journey, offering feedback and options to customize future trips based on this experience.

Table 9. User - System interactions

Conclusion

This concept could fulfil the set design goal and motivate the user to remember better the navigational decisions that need to be made, regardless whether they have DTD or not. Nonetheless, looking back again at the set design goal, there is a problem. In order to allow user autonomy from the system, the user must not fully rely on it to know/remember all the navigational decisions to be made. Which is why the dilemma with this concepts lies on whether the user should be motivated to learn the lyrics of the song with the instruction well before going physically on the route.

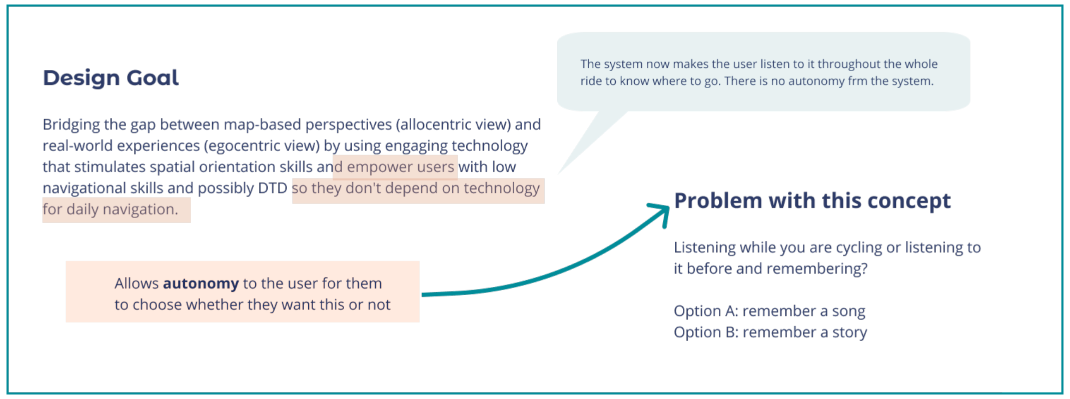


Figure 47. Reflection on the alignment between the Design Concept and the Design Goal

As mentioned earlier, individuals with DTD often rely on memorizing landmarks to navigate, especially after encountering them a few times. But what if they could familiarize themselves with these landmarks in advance? Could this lessen their dependence on real-time navigation? Considering that most current GPS tools are visually focused, could a new approach that integrates auditory cues prove just as effective in translating navigational decisions from a map-based (allocentric) view to the real-world (egocentric) perspective, where decisions are actually made?

To answer the previous questions, memorization strategies were studied and are explained in the following chapter.

Design Concept - Key Insights:

- The ideation process focused on innovating for navigational retainability and traceability, for individuals with DTD through the integration of both auditory and visual aids.
- The chosen design concept involves using a song to help users remember navigation instructions. This concept was based on the idea that familiar melodies can be tied to specific wayfinding decisions, enhancing memorability.

4.2 Development & Prototyping

a. Further research on memorization strategies

Mnemonics

People use certain tricks in order to remember concepts, terms, a sequence, or daily tasks. These "tricks" are called mnemonics. *"A mnemonic is an association between the information that needs to be recalled and information that is more easily recalled, specifically, information that has previous ingrained meaning, such as personal or humorous information (Soanes et al. 2006)."*

Most children learn in school songs that would help remember the order of terms, or the parts of the body, numbers in a foreign language, etc. Mnemonics are widely applied in current education with various methods. Here are 3 methods that were explored as a basis for this design concept.

1. Peg method

This method is the most likely the one you have encountered in modern education. The peg method is *"mnemonic technique used to enhance memory by associating information with a set of pre-memorized "peg words" that are easily recalled. Each peg word corresponds to a number and serves as a mental "hook" to which new information can be attached." (Higbee, 2001)*

- one = bun
- two = shoe
- three= tree
- four = door
- five = hive
- six = sticks
- seven = heaven
- eight = gate

In the case of memorizing navigational instructions it could prove useful to associate the navigational instructions to the rhyming elements of the peg method. For example:

One is a bun: First, turn right at the residential building. A giant bun on top of the building can be imagined or residents carrying buns to emphasize that it's a residential area.

Two is a shoe: Next, take the second exit at the roundabout. Visualize a giant shoe at the second exit of the roundabout, guiding you to take that exit"

2. Musical Mnemonics

The phenomenon of using the same melody for different sets of lyrics, like with the "ABCD song" and "Twinkle Twinkle Little Star," is a great example of how musical mnemonics work. Our brains are capable of associating different verbal content with the same melody due to a few key cognitive processes.

This is possible because these two songs are learned in different contexts. Familiarity with the context (learning the alphabet vs. a nursery rhyme) plays a role in how easily the brain can separate the lyrics.
Wallace (1994) noted that familiar melodies used in mnemonic techniques increase the ease of recall because the brain processes familiar auditory structures more efficiently.

Musical mnemonics are not only for children. They have been studied to establish if they have the potential of improving working memory in adults, with and without cognitive impairments. As *Derks-Dijkman et al., (2023) studied that rhythm significantly improved working memory performance in both cognitively unimpaired young adults and older adults, supporting the idea that rhythmic mnemonics can enhance recall by chunking information in a structured way.*

A similar and promising effect was studied in individuals with cognitive impairments such as Alzheimer's Dementia. The literature review suggests that *"Music may function as a temporal scaffold, thereby selectively directing attention, and thus reinforce and facilitate learning and memory." (Derks-Dijkman, Schaefer, & Kessels, 2024).*

This shows that musical mnemonics is a promising direction for people with DTD and people with low navigational skills as well. That review also provides a formula to create a successful musical mnemonic aid:

Musical stimulus + verbal material + personal aspects = remembering

Musical mnemonics for navigation

Coming back to the scope of the project, using musical mnemonics for navigation is not a new concept. Aboriginal cultures from Australia still preserve to this day the concept of "Songlines".

Victorian Aboriginal Heritage Council (2016). notes (as cited in Green, 1989) "Just like the GPS in your car gives you directions as to when and where to turn, Aboriginal people coded the directions for travel in a continuous song that was chanted as you went along."

Option A: remember a song
Option B: remember a story

The previous dilemma from the set design goal can be combined with this concept.

Figure 48. Illustration of Aboriginal Songlines related to navigation.

Songlines are sang stories with landmarks of the route, so they knew that they are going in the right direction.

Songlines involve using dramatic story songs that First Nations people began creating long before the written word as a mnemonic and spiritual system to navigate Australia's harsh terrain: they would do so by singing the songs as they walked across the land. (Cultural Heritage, 2023).

They would detail a story that took place linked to geographical features. Such as a how a warrior made a canoe out of a tree, referencing that the traveller must encounter a tree with a scar the size of a canoe. This is a direct reference of a cognitive map based on landmarking.

These songs, which also define groups and laws and impart cultural values, have been passed down from one generation to the next over thousands of years. (Cultural Heritage, 2023).

In summary, this concept of aboriginal Songlines can be translated into a modern day style of navigation, incorporating the auditory sense in a more engaging way than just listening to the directions spoken outloud by the voice of the GPS. This is the main inspiration for using musical mnemonics to help individuals with DTD improve spatial recall without relying on visual maps.

b. Creating a mnemonic aid for navigation

This phase aims to explore whether the use of musical mnemonic aids can improve the retainability and traceability of navigational instructions, particularly for individuals with low spatial orientation skills, such as those with DTD. Nonetheless, as the visual sense is still predominant, even in people with low navigational skills, the concept will merge the visual representation and the auditive mnemonic aid, so the user can use both mechanisms to remember the routes better.

Apart from the visual translation of an Allocentric to an Egocentric representation that is incorporated to the design concept, such as the example shown in figure 49, the directions given by the system will be shown in a mnemonic based structure.

What facilitates remembering directions more for people with low orientation skills, a musical mnemonic aid or a visual aid?

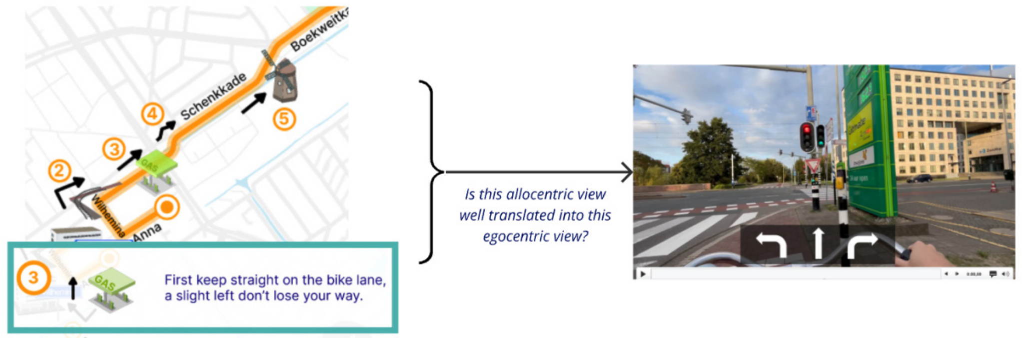


Figure 49. Allocentric to egocentric representation of the design concept

1. Initial Prototype: Story-Based Mnemonic

The starting point to create a Musical Mnemonic Aid, was first choosing a memorable melody alongside an interesting story to go along with it.

In the first iteration, the focus was on creating a story-based mnemonic, where participants would remember navigational instructions through a coherent narrative linked to landmarks. Using storytelling techniques inspired by the Aboriginal Songlines concept, which links stories to geographical features. For the melody, the starting point was thinking of which songs where the most memorable, and the result was children's songs. The chosen melody was Yankee Doodle, a familiar tune known (to me, the designer, from my childhood) used in the popular children's show

"Barney". Even after years of not listening to it, both the melody and lyrics still remained in my memory.

However, it was soon realized that this approach required too much cognitive effort, as participants would've had to remember long, detailed narratives for just one route.

2. Second Prototype (first iteration):

To simplify the memory load, the story-based mnemonic was transformed into shorter verses set to rhyme and with the specific length of melody. The rhythmic and repetitive nature of the song made it a good candidate for enhancing memorability. However, during testing, it was discovered that the chosen melody "Yankee Doodle" was not as well-known among European participants. Its limited cultural relevance meant it did not provide the familiar mnemonic scaffold needed for effective recall across a wider audience, especially in Europe.

The melody was changed to a universally recognized tune—Twinkle Twinkle Little Star/ABCD. This melody is known across cultures and already associated with multiple sets of lyrics (both the "Twinkle Twinkle" song and the alphabet song, ABCD). The advantage of this melody was that it allowed participants to easily remember the tune without needing additional cognitive effort, enabling them to focus on the new navigational lyrics.

Additionally, using a well-known melody meant that participants would not need to learn anything new; they could simply focus on the lyrics.

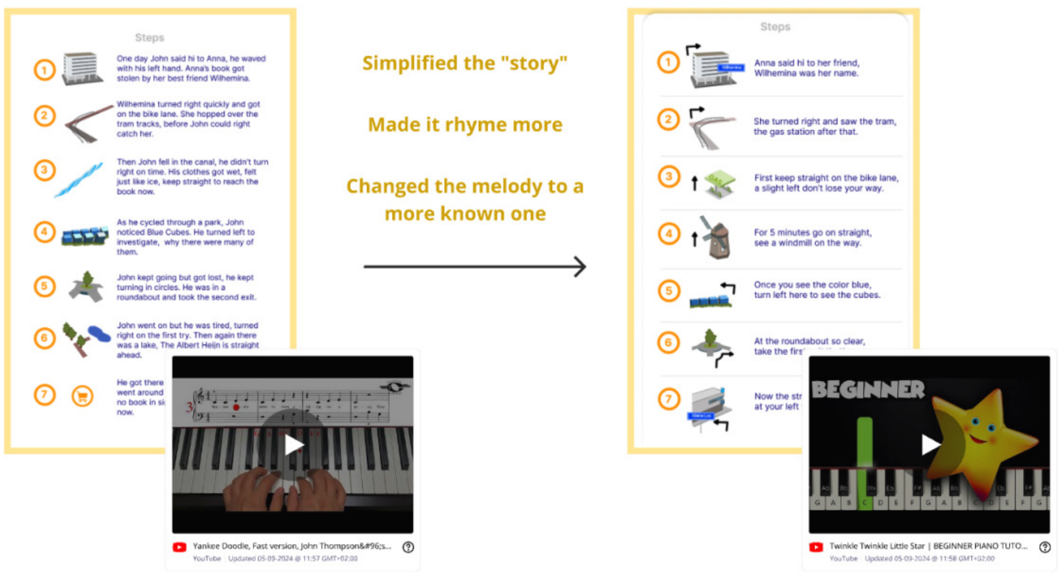


Figure 50. Iteration on the musical mnemonic aid.

System: Navigational aid

The system consists of two navigational elements for memorization:

Figure 51. Navigation aid.

The first is an **allocentric representation (a map)** that shows egocentric views of specific landmarks where navigational decisions need to be made.

The second element are the **steps, or navigational instructions** for the decisions that need to be taken at that specific landmark. They follow the same order and depending on the version in which they are presented have a rhyming lyrical structure.

Two versions were developed of the verbal navigational aid for each route:

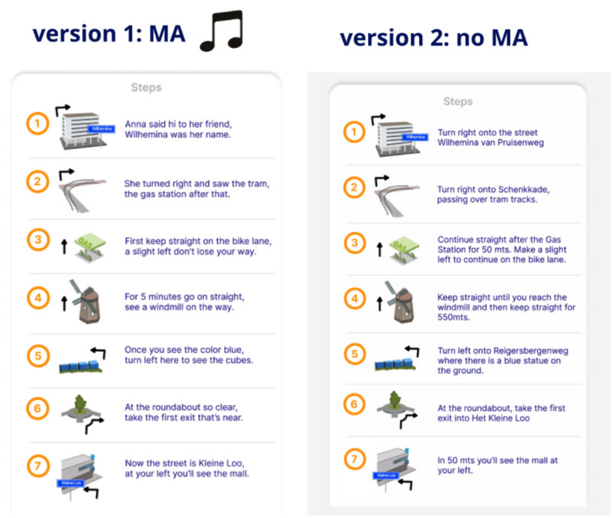


Figure 52. Versions of the musical mnemonic aid for navigation

Version 1 (with Musical Mnemonic Aid): This version includes an abstract version of the verbal directions accompanied by a musical mnemonic. The melody helps to reinforce recall by integrating key actions and landmarks into the rhythm or lyrics of the song. Participants listen to the song as they navigate, which is designed to support memory retention by providing cues through auditory stimuli.

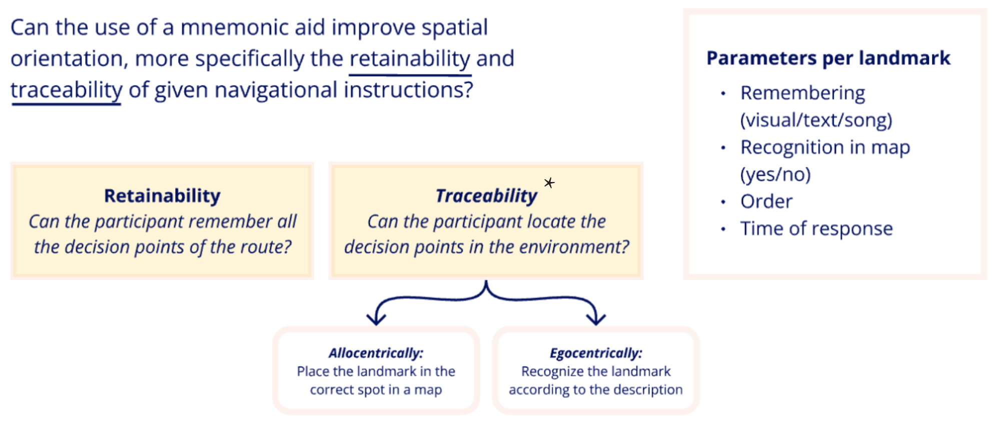
Version 2 (without MMA): This version presents the same route instructions purely in textual form, without any accompanying music. Participants must rely on written directions and visual representations of the route, which is the traditional approach to navigation.

Both versions provide information such as street names, landmarks, and turn-by-turn instructions, with one incorporating a musical element to see whether it enhances memory.

b. Testing mnemonics for navigation

In order to test if the proposed concept could have a positive impact, an experiment was done to evaluate the effect of mnemonic aids in navigation.

For this, the following research question was determined:



*Further in this project traceability is also referred to as landmark saliency.

Figure 53. Research question for the experiment.

Exploring the possibilities of testing musical mnemonics for navigation

To systematically explore how musical mnemonics could aid navigation, a framework was developed that considers both retainability (the participant's ability to remember decision points) and traceability (the participant's ability to locate decision points in the environment).

For retainability or saliency, factors such as the order of instructions, the medium (spoken, written, or auditory), and the type of visual representation were examined. For traceability, both egocentric and allocentric perspectives were considered, assessing how well participants could place landmarks on maps or recognize landmarks from descriptions.

By listing the different possibilities of variables that could be useful, mediums, and objectives, this table outlines all potential ways to evaluate whether musical mnemonics could enhance spatial navigation. This exploration can be observed in Figure 54.

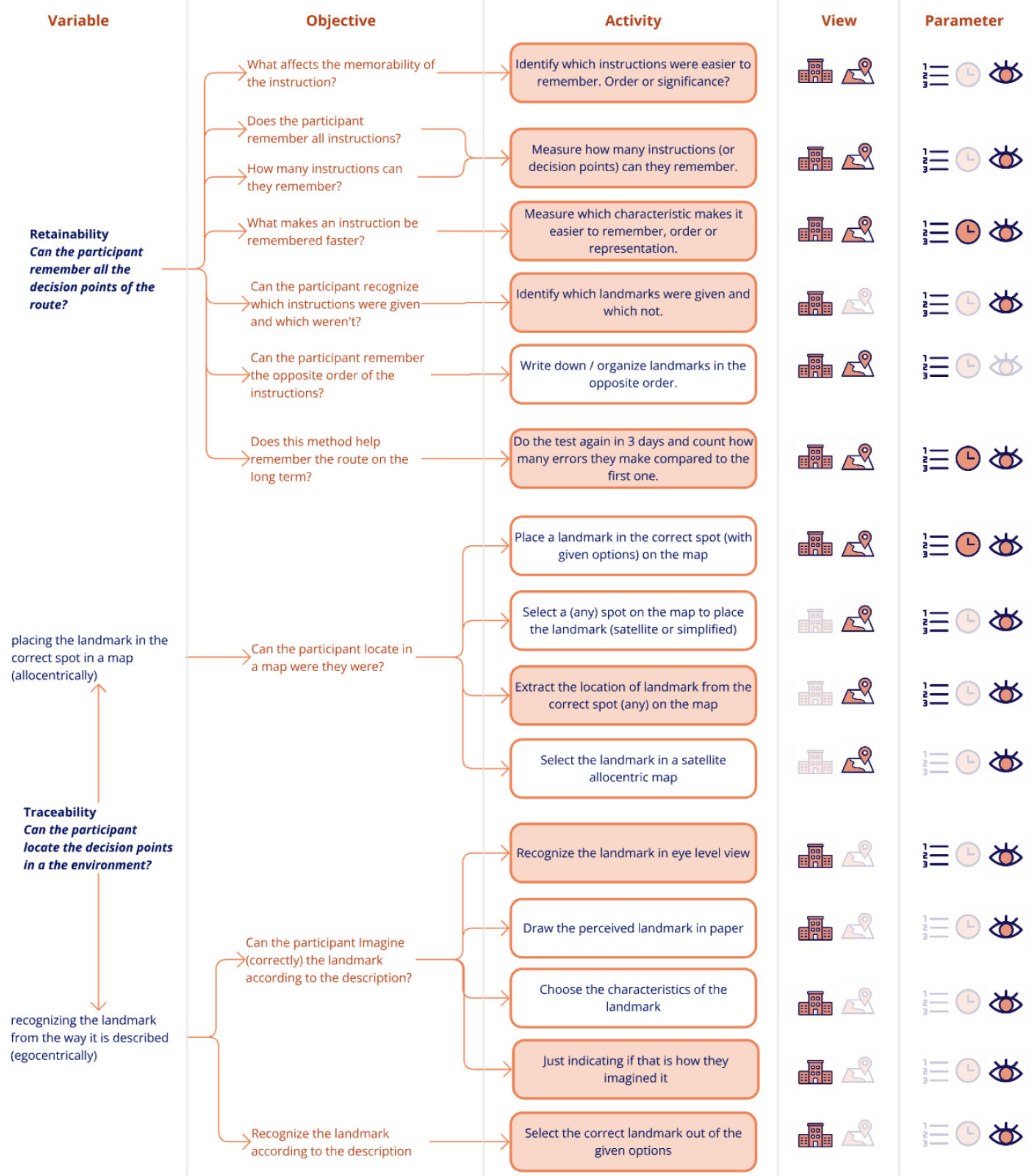


Figure 54. Activity & Objective exploration for the experiment on navigation aided by mnemonics.

Evaluation material: Virtual environment (the routes)

In order to test the effect of the mnemonic aid in a controlled environment, a virtual environment that simulates real-world routes being cycled was created. The virtual environment offers two different routes that participants must complete using the provided navigational aids. This immersive experience allows to measure how effectively participants can follow instructions in a controlled but realistic setting. Ideally a 3D virtual reality environment would have been created, but in the time and scope allocated for this project, it was adapted using a recording of a journey on the bike.

An overview of a route distribution is illustrated in figure 55.

Figure 55. Overview of a route visual representation and it's virtual test environment.

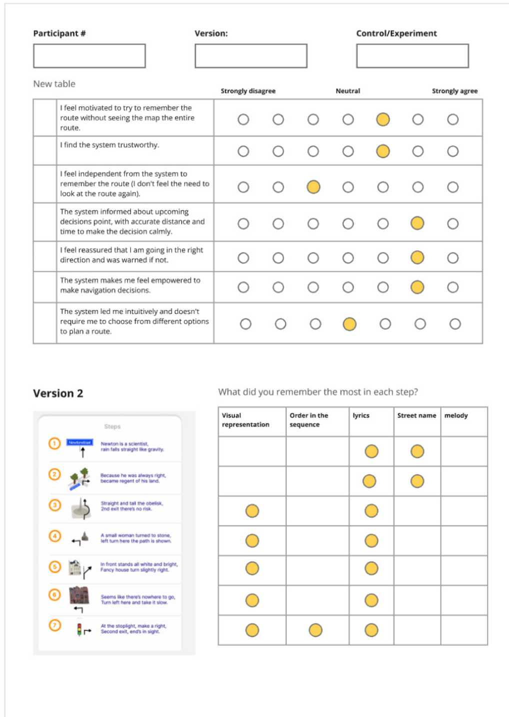
Both routes were recorded in residential areas of non popular neighbourhoods to avoid having a bias in participants because they already knew the area. The map representation was tampered in the non transited area so that it would be even less recognisable, by adding large park areas that don't really exist. But the video recording wasn't tampered, so all the navigation decisions correspond with the map representation.

For both routes a total of 6 landmarks needed to be remembered but in reality, up to 15 decisions need to be made in order to reach the correct landmarks. Each of these decisions has to be made when an alternative street is available on the map. If the participant would take the wrong decision, that is immediately perceived as the virtual environment only shows the correct path taken. Adding the alternative routes would have been ideal to notice "when does the participant realise they made a navigational mistake?". Nonetheless, this is out of the scope of the current experiment and would have required greater time to develop.

Evaluation material: Subjective perception

After completing the routes, participants are asked to fill out evaluation materials designed to measure their memory performance.

This evaluation focuses on two main outcomes: retainability (the ability to remember key decision points along the route) and saliency (the ability to recognize and act upon landmarks and cues in the virtual environment).


Participant # | Version: | Control/Experiment

New table

		Strongly disagree			Neutral			Strongly agree
	I feel motivated to try to remember the route without seeing the map the entire route.					●		
	I find the system trustworthy.					●		
	I feel independent from the system to remember the route (I don't feel the need to look at the route again).			●				
	The system informed about upcoming decisions point, with accurate distance and time to make the decision calmly.						●	
	I feel reassured that I am going in the right direction and was warned if not.						●	
	The system makes me feel empowered to make navigation decisions.						●	
	The system led me intuitively and doesn't require me to choose from different options to plan a route.				●			

Version 2

What did you remember the most in each step?

Visual representation	Order in the sequence	lyrics	Street name	melody
		●	●	
		●	●	
●		●		
●		●		
●		●		
●		●		
●	●	●		

The participant has to fill a form for each route. These materials assess:

Subjective evaluation: Participants rate their experiences using a Likert scale, answering questions about how well they trusted the system, felt independent from it, and whether they were reassured that they were following the correct route.

What participants remembered most: Categories include visual representation, order in the sequence, lyrics (for the MA version) or words, street names, and melody.

Figure 56. Subjective evaluation form

c. Pilot + Iteration

Pilot

A pilot study tested the use of the melody "Twinkle Twinkle Little Star/ ABCD" with shorter, rhyming verses to aid a DTD participant's navigation. The verses referenced key landmarks or decision points and aimed to be concise and memorable, utilizing the familiar melody to help chunk the navigational steps.

Figure 57. Pilot test

This approach proved particularly useful in environments that lacked distinct visual landmarks. Although the participant still made errors, they found the mnemonic aid surprisingly helpful in anticipating decisions based on the melody. However, feedback highlighted that the test routes were too memorable due to unique landmarks like windmills and colorful statues. To better challenge the participant, the routes were revised to include more typical, less memorable residential streets. The lyrics were also adapted to include creative and humorous elements, helping participants recall steps in otherwise mundane environments.

Changes from pilot:

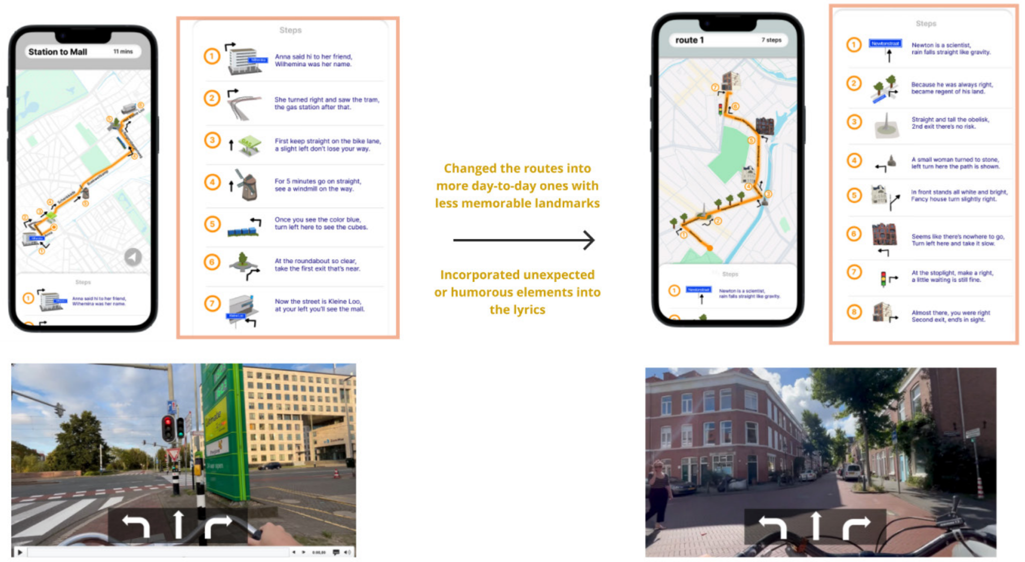


Figure 58. Changes to the prototype after pilot testing.

d. Final Prototype

In summary, the final prototype provided an effective balance between memorability and usability, leveraging a familiar melody and creative lyrics to improve navigational performance for individuals with low spatial orientation skills.

- The MMA version integrates **short, rhyming verses with a universally recognized melody—Twinkle Twinkle Little Star/ABCD**—to enhance memory recall.
- The non MMA version shows the **steps to take just as commonly used navigational aid like "Google Maps"** would show them.

If the participants manage to still remember well enough the route, it might be because the mnemonic aid doesn't have a significant effect in improving the retainability and traceability of routes such as this one. Also, since already a more descriptive visual description of the landmark is given, thanks to its graphic representation of an eye level view, it is also possible that just that intervention is already enough to effectively translate an allocentric map view to the egocentric decisions that need to be made while navigating.

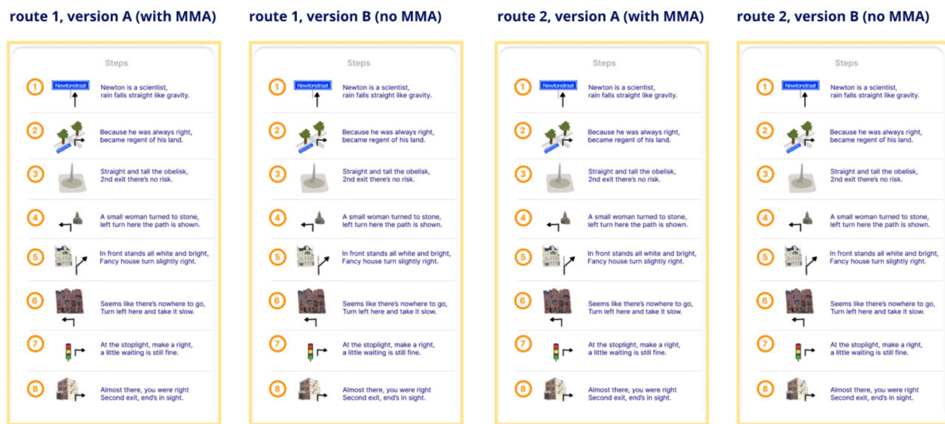


Figure 59. Final prototype of the mnemonic aid for navigation.

Prototyping - Key Insight:

- After pilot testing, it was evident that simple, rhyming and unexpected lyric choices worked better for users. As a result, the routes were adjusted to reflect more realistic, everyday street environments.

5. Deliver: Evaluation

5.1 Experiment Set Up

a. Method

The experiment compares two versions of navigational aids:

1) Version 1 (with MMA): one incorporating a musical mnemonic aid (MMA) to the visual system and includes directions accompanied by a musical mnemonic. The melody is linked with key actions and landmarks, designed to chunk information and reinforce memory through auditory cues.

2) Version 2 (no MMA): This version presents the same navigational steps in written format, without any musical accompaniment, relying solely on textual and visual cues.

The core objective is to determine if adding a musical stimulus enhances participants' ability to remember and follow the given navigational instructions. Participants were shown the route on a virtual map and guided through a simulated environment. The virtual environment served as a testing ground to immerse the participants and simulate real-life navigation scenarios.

Control group & randomization

As seen in the diagram of figure 60, participants were allocated a version of the experiment to achieve a within subjects approach (AB, CD). Each participant does the two versions of the prototype, one without a MMA and the other with a MMA. Half of the group does route 1 with MA and the other route 2 with MA.

- Group AC-BD gets first route 1 without MMA and then does route 2 with MMA.
- Group AD-BC gets first route 2 without MMA and then does route 1 with MMA.
- Group BC-AD gets first route 1 with MMA and then does route 2 without MMA.
- Group BD-AC gets first route 2 with MMA and then does route 1 without MMA

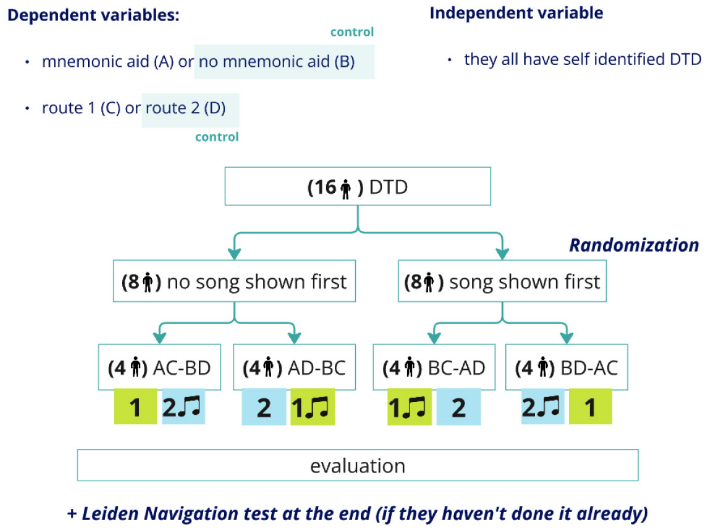


Figure 60. Distribution of participants .

Target group & Recruitment process:

Both the target sample of participants and the recruitment process were the same as the first phase of this project.

The target group consisted in 16 participants which are:
- TU Delft students or recent graduates
- Between 20-30 y.o.
- That self identified as having weak navigational skills
- That fulfil the selection criteria set by Burles & Iaria. (2020) via a screener previously explained in section 2 of this report.

Possible limitations of this approach that were taken into consideration:

Choosing a within subjects approach instead of a between groups one, allowed to draw significant conclusions with less participants and less risk of confounding variables to affect the study. Nonetheless, using this approach also has the following limitations.

- **Memory Overload and Complexity:** Participants need to remember two distinct routes, which can cause cognitive overload and memory interference, leading to confusion between the two sets of instructions. This may make it harder for participants to accurately recall each route's directions.
- **Carry-Over Effects:** Completing one route may influence how participants perform on the second route. For example, strategies or landmarks remembered from the first route may carry over to the second, affecting the ability to measure the unique impact of the mnemonic aid.
- **Fatigue:** Navigating two routes back-to-back could cause participants to become fatigued, which can reduce their engagement and cognitive performance. Fatigue may result in poorer performance on the second route, making it harder to assess the true effect of the mnemonic aid.
- **No Forward and Backward Testing with MMA:** The study does not test participants on the same route both forward and backward using the mnemonic aid. This limits the ability to assess whether the mnemonic aid is effective for both forward navigation and retracing steps, which is common in real-world navigation.

The effect of these limitations is severely reduced by the randomization of which version the participants performs first and adding an additional control route as part of the test.

b. Materials

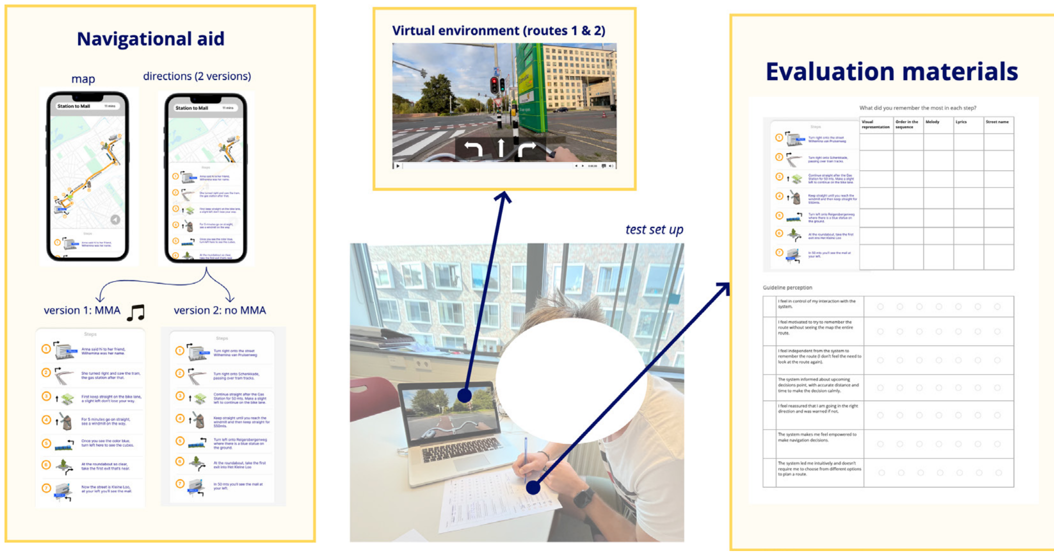


Figure 61. Created materials for this experiment.

As illustrated in figure 61, the materials used for the experiment are structured around two key components: the prototype of navigational aids and the evaluation materials, designed to asses how participants retain and trace navigational instructions.

c. Hypothesis

Based on the observations of the pilot test, the following are the expected results to come out of this experiment:

- In the versions without MMA there will be more errors and more time spent per landmark.
- MMA Lyrics will help the participant "guess" better what the next landmark can be.
- Even if the MMA helps, participants will rely more on the visual representation of the landmark than the mnemonic.
- Participants might be sceptical about remembering the directions with "twinkle twinkle".
- Street names will be ignored (because you can't see them in the video).
- The time spent remembering will equal the level of difficulty perceived.
- The system will not be perceived as trustworthy because it doesn't correct your mistakes.
- The user will not want to spend additional time learning the song, so having the option to "listen as you go" adapted to a rhythm/music genre they like will be more useful than a children's song.

5.2 Results

In this preliminary results section, the analysis is structured to provide a clear and detailed breakdown of participant performance and navigation behavior across various decision points in the routes. Each route is discussed with attention to both the navigational errors made and the elements that contributed to successful decision-making.

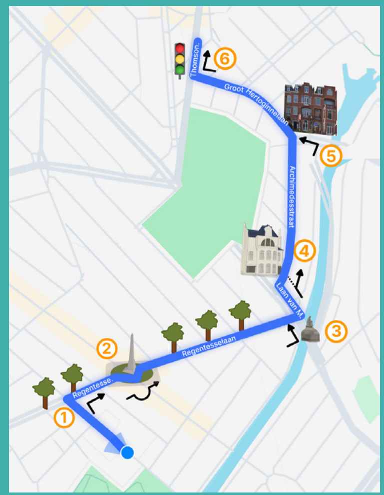
The first section highlights the key insights from each decision point, supported by participant remarks and observations.

Following this, a detailed timeline of navigation provides context on the sequence of actions participants took, focusing on performance at each critical step. In this way, the results outline both the successes and challenges in navigational aids, such as the use of Musical Mnemonic Aids (MMAs), and how elements like landmarks, song verses, and visual cues influenced the overall navigation experience.

Finally there is a description of the observations/comments made by the participants on each step adding to the qualitative value of this experimental approach.

Figure 62. Results of route 1.

Route 1: Regentesse



Duration: 5 minutes
Total decision points: 14, with 6 key steps (instructions) that required remembering due to a change in direction or obstacle.
Overall performance:
16 out of 224 possible errors. Participants made an average of 1.06 errors with a deviation of 0.84. This is fewer than expected.
The combination of this route being instructed without the MMA and having done it as the second route in the experiment resulted in no errors made.
Most salient landmarks:

- **Roundabout (Step 4):** Highly contrasting with its environment, making it memorable.
- **White House (Step 8):** A distinct object that also stood out visually.

Main insights:

- **Musical Mnemonic Aid (MMA):** Participants with the song-based navigation aid made fewer mistakes on the instructed steps, but made more errors at other the other non-instructed decision points.
- **Overshadowing Effect:** In cases like the White House, participants often forgot what followed immediately after a highly salient landmark.
- **Creation of a mental map:** Participants seemed to remember well the general route on the map and that gave them the tool to "guess" where they needed to go if they didn't remember the instruction. This indicates a notion of egocentric orientation that was not expected in the design of this experiment.

Navigation error distribution

Timeline of navigation

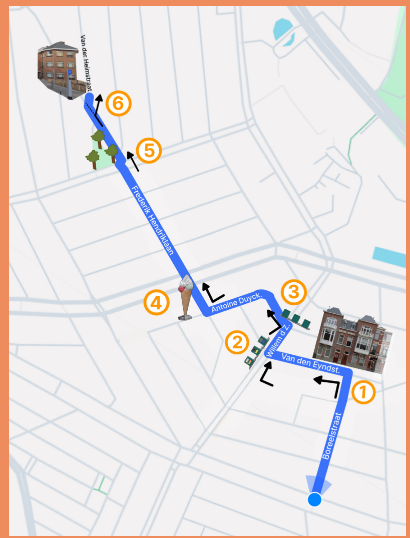
Remarks & Quotes per step

	1	2 (right)	3	4 (straight)	5	6	7
Observation	Participants focused mainly on the size of the street to decide not to turn here.	The size of the street and the alignment of the trees were the main indicators. Even though they remember the word "king" from the song verse "the king is always right", they didn't associate it with "Regentesselaan", which caused errors.	The visual representation and the song verse/written instructions were very memorable. "Obelisk" is not a commonly used word so it improved the saliency of the landmark.	The previous step and this one are seen as one action. Mistakes were made in the step before only because it is more of a square than a roundabout so the dimensions seemed like taking the first exit was going straight.	Most participants remembered to keep going straight until they see the next landmark. One mistake was made because the person completely forgot what was after the roundabout.	Same as last step. No mistakes were made.	Here some participants could already see a bridge or the stoplight (which was mentioned in the written instructions). They mostly anticipated turning left but still were waiting to encounter the small statue of a woman.
Comments from participants	• "Waiting for the boulevard"	• "King doesn't say anything to me" • "I feel like this is the street becasue there are trees"	• "Roundabout with obelisk, although this roundabout is not an actual circle"	• "It does help that it said 2nd turn because I would have gone straight"	• "There was water on the map, so go straight until the water"	• "I dont see anything so still straight"	• "I think still straight because of the traffic lights at the end"

	8 (left)	9 (right)	10	11	12	13 (left)	14 (right)
Observation	Because the statue was at the other side of the street and it was small in size from the point of view in which the decision to turn left, most participants except for 2 didn't see it. This caused a lot of confusion and participants expressed that it affected their remembered order. The sung instructions were remembered well because "stone woman" was mentioned.	The visual representation of the house was very similar to its real version. This was a good landmark choice because it is a big, stand alone object that contrasts with its immediate environment. Participants also remembered well the sung instructions.	Because the last step was very memorable, it might have overshadowed this next step. Most participants remembered that they needed to go left at the brown house, but either 1) the visual representation was not clear enough or 2) there are many similar red brick houses which makes it not distinguishable.	After the shock of the last step most participants took reflected on the fact that red house landmark was not so early. Some started thinking of the map and recalled that it was continuing straight until it was not possible anymore because of the landmark.	Since it is the same action as the previous step, and could also see the T intersection at the end of the road then they were more confident on continuing straight. Still 2 participants made a mistake because there were still a lot of red houses around that looked like the one of the visual representation.	As the landmark before the last it is expected that participants would get confused on the direction to choose. Some participants mentioned remembering the map to make the decision rather than the instructions (going right would mean going back to the area full of water).	Some participants had fully forgotten the last step (probably because there was a already a stoplight in the way on step 8). But still most managed to make the correct decision. It was mentioned that because crossing the street seemed like a more difficult action then they would have probably remembered it so right is the path of least resistance. The choice of wording traffic light vs stop lights is interesting.
Comments from participants	• "Here it says laan van meerdervoort, I dont see the statue"	• "Stone woman should be before this but maybe I missed it" • "The fancy house looks like the image so now a slight right"	• "There are a lot of red houses" • "Was it the first one? Im just guessing now"	• "I lost one image of what I'm looking for and then the rest is gone" • "Another brown house" • "One of the steps said until you can't anymore"	• "This looks like the brown house" • "Go straight until you can't no more"	• "I remember these houses but I anticipated them differently" • "Can't go straight, should not go right"	• "I honestly thought I was done, I don't remember this street" • "What was it at the traffic lights?"

Figure 63. Results of route 2.

Route 2: Frederik



Duration: 5 minutes
Total decision points: 15, with 6 key steps (instructions) that required remembering due to a change in direction or obstacle.
Overall performance:
21 out of 240 possible errors, with an average of 1.31 errors per person and a deviation of 0.97. This is fewer than anticipated, showing that participants generally performed well.
Most salient landmarks:

- **Ice cream shop (Step 8):** The most memorable due to its association with a familiar and enjoyable concept (eating an ice cream) and its strong contrast with the surrounding environment.
- **Trash bins (Steps 5 and 6):** The trash bins were recalled as one decision point by participants due to the repetition in the object but noting the difference in color and navigation direction.

Main insights:

- **Use of egocentric navigation:** As seen in Route 1, some participants relied on a general sense of the route and map, which was not anticipated in the experiment design. This allowed them to make educated guesses about their next move, even when they didn't remember specific instructions.
- **High reliance in order:** In the early steps (Steps 2 and 3), a small number of errors were made due to participants not correctly remembering when the first landmark would appear, which would distract them from the order they were remembering and therefore forgetting the next steps.
- **Musical Mnemonic Aid:** The presence of the MMA was very impactful on reducing mistakes at the last step because the sang instructions warned specifically about not taking the first slight right. Nonetheless the same amount of mistakes were made in the last step even with the MMA because they were focusing on the landmark of the park that was only mentioned in the sung instructions.

Navigation error distribution

Timeline of navigation

Remarks & Quotes per step

	1	2	3	4 (left)	5 (right)	6 (left)	7	8 (right)	9	10	11	12	13 (straight)	14	15 (right)
Observation	The first decision point was after 4 steps which is why continuing straight was easy to remember for most participants. The only error occurred because one participant focused too much on learning the instructions and didn't spend enough time reviewing the map, leading to uncertainty about how many streets to pass before the first landmark.	The presence of (other) trash bins on the side of the street added some confusion, but participants who remembered the order of the landmarks knew this wasn't the correct step for a turn.	In this decision point the landmark becomes visible at the end of the street so it is easier to anticipate. One mistake was made because seeing the landmark, even from far, prompted the user to already turn. The other mistake was made from the same participant who made the mistake on the step before.	All participants took the correct decision and turn left at the T junction. A few said that they recognized the building, but most decisions were taken because of the general direction of the route. Here the Street Name was visible so 2 participants indicated they used it to locate themselves and 3 of them said they remembered the lyrics/written instructions.	Most participants indicated that they remembered this step and the next one as one. This because the landmark is the same object (trash bins) with a clear difference (one has colors and the other doesn't) and opposite directions. The first bins had no mistakes, nonetheless 2 participants made a mistake in the second set of bins. One mistake was made because one participant forgot there were 2 sets of bins and the other mistake was because the participant remembered more the words than the visual of the map. One participant ignored the written instructions and didn't know they were trash bins and just referred to this landmark as the "three small blocks with colors" and got both right.		This decision point is where the road is curved so it makes a turn without a decision needing to be made. But right after this turn there is a possibility to go left, which caused one participant to forget if they had already turned left and therefore made a mistake. Most participants were already thinking of the following landmark.	Most participants easily remembered the ice cream statue, likely because it stood out from the environment and triggered associations with ice cream, engaging their memory of an enjoyable activity. However, two participants missed the statue entirely, focusing on the size and appearance of the street instead.	For this and the following steps there is one shared instruction which is to stay straight for 5 streets. When phrased in a sung instruction "Frederik is so very long" the saliency was noted. Most participants mentioned that the street was long even if they didn't remember the name of the street.	Here participants were more curious to find the sign with the street name in the virtual environment. Because the signs are placed parallel to the point of view of the virtual environment they only had a second to look at it sharply which is the participants did not see the street sign.	Some participants expressed that they were already not remembering the instructions or the shape of the map. Despite these comments, no mistakes were made and the confidence level was at its maximum.	In this step, participants used an indirect landmark (a park visible on the map and only mentioned in the sung instructions) as a reference point. Many continued straight until they saw the park, showing they remembered the sung instructions. While no mistakes were made, participants were less confident compared to the previous step.	Here a sort of green area is visible, which some participants associated with a park. The size of the road also was used as reference to make the decision, since the instructions said "slight right, this four way crossing was too big to follow the instruction.	This step proved to be the most challenging due to an intersection that matched the landmark description, except for a difference in distance from the previous step and a different brown building. Five participants made mistakes by taking a slight right turn, but those with the sung instruction, "not the first after the park," avoided this error. There were no errors in this step from the version with the MMA.	Participants who made a mistake in the previous step corrected themselves here. However, another five participants continued straight instead of turning, as they were overly focused on the park. They expected a more formal park, whereas the virtual environment showed a smaller green area. Given that this step followed several straight decisions, these errors were anticipated.
Comments from participants	• "no house yet so continue straight"	• "I already went past some bins so that is confusing because it is not yet" • "are those the bins I need?"	• "it is that building after the car but it is still far" • "trying to remember the building I saw"	• "not from the song but from the map" • "this is the building" T reference "until no more"	• "bins right, bins left" alternating • "this is a big street so gives more the vibe where I need to move"	• "I see both bins decision as one" • "bins with no color" • "I see the bins, did I have to go left or right?"	• "this was the bend that was not a decision point" • "I expect to go left without choosing" • "I dont see the ice cream so I just continue straight"	• [does not see ice cream] "right at some point, do I see Frederik?" • "ice cream right" • "straight at the ice cream"	• "I remember blue sign with F but not the whole name" • "very long way, not remember the name"	• "Also not a decision in the map, after ice cream there was frederik is so long" • "I do see a long street name but that is not the one we were talking about"	• "I'm just continuing straight until I recognize something because I dont know" • "I don`t remember" "past 4 gets difficult" • "Feels like we are going in circles"	• "I already forgot what is after" • "still no park"	• "Is this the park?" • I know I have to look for trees but there are a lot of trees • "not fully clear but I remember slightly to the right so it is not something big"	• "this might be the house, is this the slight right?" • "not the first I remember from the instructions"	• "I was wondering if this is a park, I missed it" • "yes remembered the VR but didn't recognize it in the video" • "don't remember what the building looked like"

5.3 Results & Discussion

This section outlines the findings from the navigation experiment conducted across two distinct routes: Regentesse and Frederik. As detailed in the prior chapter, participants were introduced to navigation steps either via written instructions or through a song-based mnemonic format. They were then tasked with navigating a virtual environment where they encountered several decision points, some directly tied to the provided instructions and others designed to observe whether participants would mistakenly confuse them for official steps. These instructed decision points required memory recall due to directional changes or the presence of obstacles.

To mitigate bias and account for cognitive load, participants were divided into groups and exposed to different combinations of route versions with both written and sung instructions presented in varying orders. This approach was intended to prevent potential carry over effects that might influence their performance when learning two sets of navigation instructions within a short time.

Comparison of performance between routes:

Participants performed very similar in both routes. The mean number of errors for Route 1 ("Regentesse") was 1.06 per participant, with a standard deviation of 0.84. For Route 2 ("Frederik"), the mean was slightly higher at 1.31 errors per participant, with a deviation of 0.97.

As shown in figure 64, fewer errors were made during the second route for both Regentesse and Frederik, irrespective of the presence of the Musical Mnemonic Aid (MMA). This was anticipated, as participants were already familiar with the process. While introducing a practice route might have provided additional preparation, its impact is uncertain, as it could have caused carry over effects, influencing performance in the actual test routes.

An equal number of errors (7) were observed on instructed steps when Route 1: Regentesse included MMA and when Route 2: Frederik featured MMA and was presented second.

Several factors contributed to the navigation errors:

- In both routes, highly salient landmarks caused an "overshadowing" effect, leading participants to forget subsequent steps after encountering these prominent landmarks.
- After the fourth landmark (decision point 9 or 10), participants' retainability of further landmarks decreased. Many reported that they were already anticipating the final landmark, which reduced their ability to retain the fifth step.
- The metaphors used in the sung instructions were not always effective. For instance, the phrase "Here the king is always right, he is the regent of his land," meant to reference Regentesselaan, was less useful because the street sign for Regentesselaan was not easily visible, preventing participants from making the association.

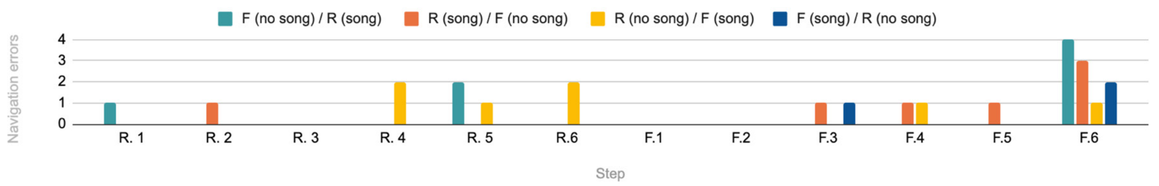


Figure 64. Navigation errors made in instructed steps of both routes, divided by order of randomization of routes.

Note: because the presence of the MMA greatly affected if an error was made in the Route 2: Frederik in the instructed step 6, the decision points 14 and 15 of this route are seen as the combination of step 6.

Saliency of navigation elements (per participant):

Although the sample size consists of 16 participants, several patterns can be observed in Table 10, which shows the levels of saliency distributed per participant rather than per step, particularly related to the level of vivid visual imagery.

Participant code	E_7	E_1	E_3	E_4	E_16	E_9	E_12	E_5	E_8	E_10	E_11	E_6	E_13	E_14	E_15	E_2
WQ (x/77)	28	20	33	20	33	33	28	36	31	34	37	33	41	20	27	36
LNT egocentric (x/4)	0	3	3	1	1	1	1	1	1	1	0	0	2	2	2	2
LNT allocentric (x/4)	1	0	3	1	1	2	4	4	2	4	2	0	4	4	4	4
VVIQ test classification	A - phanta stic	Hypo- phanta stic	Hypo- phanta stic	Phant astic	Phant astic	Phant astic	Phant astic	Phant astic	Hyper - phantas tic	Hyper- phantas tic	Hyper- phantas tic	Hyper- phantas tic	Hyper- phantas tic	Hyper- phantas tic	Hyper- phantas tic	Hyper- phantas tic
Visual representation saliency	**25%**	**50%**	**75%**	**33%**	**75%**	**42%**	**50%**	**75%**	**92%**	**75%**	**50%**	**75%**	**75%**	**83%**	**50%**	**67%**
Map visualization saliency	**42%**	**25%**	**8%**	**50%**	**8%**	**42%**	**58%**	**67%**	**100%**	**25%**	**42%**	**42%**	**67%**	**25%**	**58%**	**0%**
Street name saliency	8%	0%	0%	0%	8%	17%	0%	8%	8%	0%	17%	33%	0%	8%	8%	8%
Written instructions saliency	0%	0%	0%	33%	50%	0%	0%	33%	67%	50%	0%	67%	67%	83%	33%	0%
Sung instructions saliency	**33%**	**33%**	**50%**	**0%**	**0%**	**17%**	**33%**	**67%**	**100%**	**33%**	**50%**	**33%**	**17%**	**50%**	**0%**	**50%**
Order saliency	75%	42%	92%	75%	83%	8%	33%	67%	17%	67%	42%	83%	0%	33%	25%	100%
Mistakes made total (x/29)	1	3	2	3	1	6	3	4	1	1	3	3	3	1	1	3

Table 10. Saliency of navigation elements per participant distributed in order of visual vividness of their imagination.

Participants with highly visual memories (hyperphantastics) tended to recall the visual representation of landmarks associated with navigation decisions more effectively. All hyperphantastic participants indicated that they relied on the visual representation for over 50% of the decisions made.

Additionally, hyperphantastics were more likely to recall the written instructions compared to other phantastic groups, with an average of 43% recall among hyperphantastics, in contrast to 23% for phantastics, and 0% for both hypophantastics and aphantastics.

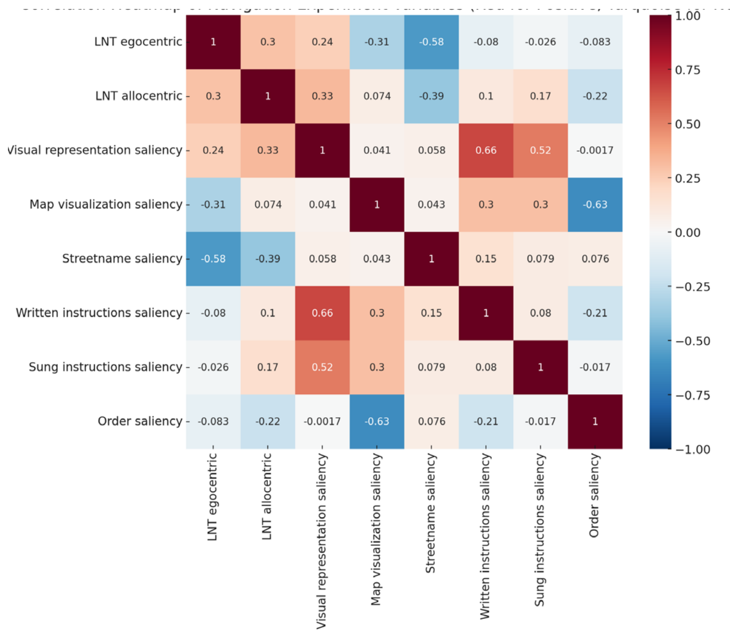
In comparison, participants with lower levels of vivid visual imagery (aphantastics and hypophantastics) did not recall the written instructions at all. Instead, these participants relied more heavily on the sequential order of landmarks and instructions. This reliance is evident in the combined 69% saliency score for low vivid visual imagery participants, compared to 53% for phantastics and 46% for hyperphantastics.

Hyperphantastics, in particular, demonstrated a stronger reliance on street names for navigation, using the combination of visual and textual information to enhance their spatial awareness.

In contrast, hypophantastics were less inclined to use the general line of direction from the map as their primary navigational tool. Instead, they relied more on direct landmarks and other cues. Due to the limited number of aphantastic participants (only one in this study), further research is required to explore their specific navigation strategies and tendencies.

The correlational heatmap in figure 65 revealed several key findings related to navigation performance. Participants made fewer navigation errors when they effectively remembered sung instructions (correlation of -0.54) or written instructions (-0.48), with a slight advantage for sung instructions. A better recall of visual representations was also associated with reduced mistakes (-0.42), indicating the importance of clear visual cues.

Correlation heatmap of Navigation Experiment Variables



Red for negative correlations (more occurrences)

Blue for positive correlations (less occurrences)

Figure 65. Correlation heatmap of Navigation Experiment Variables

For participants with lower Visual Vivid Imagination and stronger egocentric navigation, street names were not helpful (-0.58), while map visualization had a small negative correlation with errors (-0.33), suggesting limited effectiveness.

Unexpectedly, Order saliency shows a weaker positive correlation with mistakes made (0.32), indicating that relying on the order of landmarks might not have been as effective in preventing errors as other aids. This makes sense because those participants who scored higher on the Leiden Navigation Test's egocentric navigation task have more probability of having DTD and therefore they rely more on the Order saliency than the map visualization saliency, because they can't visualize a mental map.

In contrast, participants who performed well on allocentric tasks (Leiden Navigation Test) made fewer mistakes, supported by a weak negative correlation (-0.11), highlighting their reliance on map-based cues.

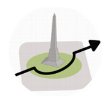
These insights suggest that visual and mnemonic aids (sung and written instructions) were more effective at reducing navigation errors than reliance on the order of landmarks or map visualizations. But, the saliency of the navigation elements can be highly related to the levels of egocentric and allocentric navigation, meaning that the effectiveness varies based on the participant's navigation style.

Of the 16 participants, only 4 reported that they did not rely on the map and instead navigated solely based on the recognition of landmarks and the sequence of instructions. This indicates that, for the majority, the map played a crucial role in navigation, highlighting the importance of both visual cues and the structure of the map for successful route planning. The reliance on landmarks and ordered instructions alone was less common, underscoring the limitations of this strategy without the additional support of a map. All participants indicated reliance on the visual representation of landmarks to some degree, which reinforces the importance of distinct and easily recognizable landmarks in navigation tasks.

Saliency of navigation elements (per route step):

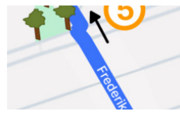
The following ranked list, from most to least salient, reflects the impact of each element on the participants' ability to navigate the route successfully. A distribution per step is illustrated in Figure 66. More in depth analysis is available at Appendix 7.

1. **[VR] Visual representation:** The participants consistently relied on the given visual representation of the landmark that was given prior to start the navigation.

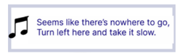


2. **[O] Order:** Participants used the sequence in which landmarks would appear to guide their navigation, and more distinctively the order of cardinal direction that needed to be taken (ex. left, right, right)

3. **[Map] Map visualization:** Most participants were able to remember the "blue line" and the shape of this in combination with the size of the streets and other indirect landmarks such as green areas and canals of water.



4. **[L] Lyrics:** The sung instructions helped participants recall specific landmarks but were less effective for remembering directional changes.



5. **[W] Words**: Written instructions were somewhat useful but less impactful than visual or auditory cues, with some participants not relying heavily on them or even completely ignoring them.

6. **[SN] Street names:** Less frequently used, as participants often missed or overlooked street signs. (the virtual environment also didn't allow to stop freely whenever a street sign was encountered. When used, street names provided confirmation but were generally less memorable. The first letter or a specific name are more memorable.

7. **[Melo] Melody:** The least salient element, as the few participants that indicated actively using the melody for navigation did it only at the beginning of the routes.

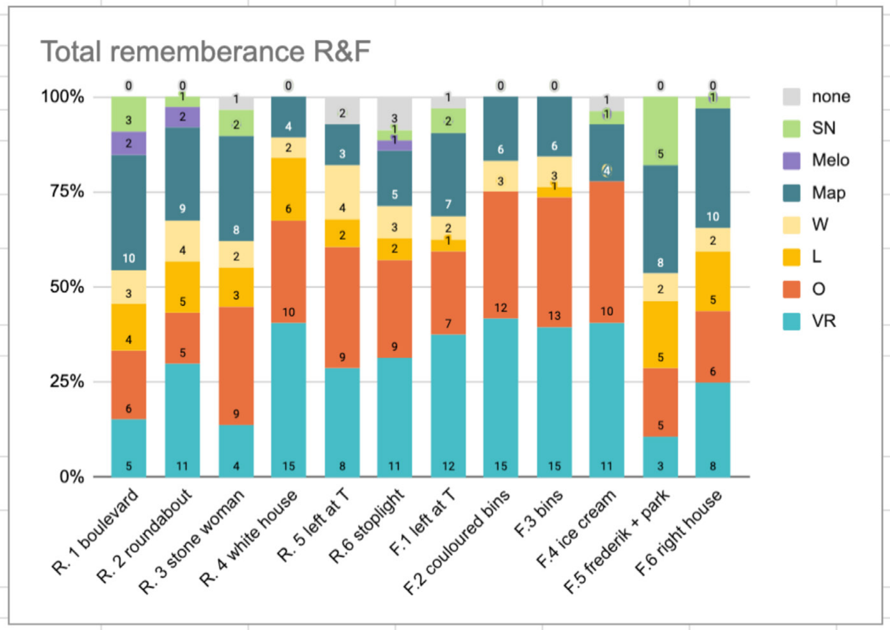


Figure 66. Saliency of Wayfinding elements

Impact of the Musical Mnemonic Aid :

Phrasing the instructions for each step in a song verse format enhanced the participants' ability to retain landmark information. However, this approach did not demonstrate a similarly clear effect on their ability to recall the corresponding directional changes. Notably, participants did not comment on a discernible pattern in the phrasing of the sung instructions. Specifically, verses associated with right turns typically concluded with a rhyming word on a high note, while those for left turns ended on a lower note.

Figure 67. Rhyming tone of mnemonic aid.

Analogies or metaphors related to street names proved useful as prompts for recalling instructions, provided that the street sign was visible. Street names were particularly effective because they could be associated with the cardinal orientation of the street itself, offering an additional navigational cue.

Figure 68. Comparison of saliency of Words vs Lyrics

Although the presence of the Musical Mnemonic Aid (MMA) combined with visual representations slightly improved the traceability and retainability of instructed steps, it did not reduce the overall number of navigation errors. These errors primarily occurred at non-instructed decision points.

In figure 68, an example of which version of an instruction was remembered the most, either in a song verse format or as written instructions.

Another example of this is the phrase "Frederik is so very long" functioned as an effective mnemonic, helping participants mentally count how many times to continue straight. Its rhythmic and repetitive nature reinforced the concept of a long, uninterrupted stretch, aiding spatial awareness and making it easier for participants to anticipate the next decision point.

Similarly, "not the first after the park" acted as a direct warning, increasing the step's memorability by highlighting a potential mistake. By signalling the need for extra attention after passing the park, this instruction heightened participants' focus and helped them avoid turning too early, making it both practical and easy to recall.

Subjective evaluation on interaction principles

Since this was an experimental study rather than a finalized concept or product, the focus was not on achieving the maximum possible scores in each category, but rather on gaining insights into participants' subjective experiences and feelings when using a musical mnemonic aid (MMA) for navigation decision points, and make independent decisions.

From the table 11, the scores from the Likert scale reflect the participants' responses collected during the evaluation after each route, providing insights into their subjective experiences with and without the Musical Mnemonic Aid (MMA).

With MMA	E_1 (R)	E_2 (R)	E_7 (R)	E_9 (R)	E_3 (R)	E_8 (R)	E_4 (R)	E_5 (R)	E_6 (R)	E_13 (F)	E_10 (F)	E_14 (F)	E_15 (F)	E_11 (F)	E_16 (F)	E_12 (F)	average	rounded
I feel motivated to try to remember the route without seeing the map the entire route.	1	3	1	0	3	-2	0	1	-2	3	2	2	-3	2	2	2	**0.9375**	**1**
I feel in control of how I interact with the system and how this responds to me.	0	-1	-2	2	0	1	-2	0	0	3	0	1	-1	-3	2	2	**0.125**	**0**
I feel independent from the system to remember the route (I don't feel the need to look at the route again).	-1	0	-1	-2	-1	1	-2	1	3	2	1	-2	-3	0	-1	2	**-0.1875**	**0**
The system informed about upcoming decision points, with accurate distance and time to make the decision calmly.	1	-1	2	1	1	2	0	3	0	3	-1	1	-2	0	-2	1	**0.5625**	**1**
I feel reassured that I am going in the right direction and was warned if not.	1	1	-3	-3	1	-1	-1	-3	0	2	2	-2	0	2	-2	0	**-0.375**	**0**
The system makes me feel empowered to make navigation decisions.	1	2	-1	0	0	1	1	0	0	3	2	1	1	1	1	1	**0.875**	**1**
The system led me intuitively and doesn't require me to choose from different options to plan a route.	0	1	-3	2	2	1	1	3	0	3	2	0	2	3	2	0	**1.1875**	**1**

Without MMA	E_1 (F)	E_2 (F)	E_7 (F)	E_9 (F)	E_3 (F)	E_8 (F)	E_4 (F)	E_5 (F)	E_6 (F)	E_13 (R)	E_10 (R)	E_14 (R)	E_15 (R)	E_11(R)	E_16 (R)	E_12 (R)	average	rounded
I feel motivated to try to remember the route without seeing the map the entire route.	1	3	1	-1	3	-2	2	3	2	3	2	2	-3	2	2	1	**1.3125**	**1**
I feel in control of how I interact with the system and how this responds to me.	-1	0	-2	0	0	2	-1	0	2	3	1	0	-2	-3	2	2	**0.1875**	**0**
I feel independent from the system to remember the route (I don't feel the need to look at the route again).	-2	1	0	-2	-2	0	-2	3	-2	3	-1	-2	-1	-3	0	-2	**-0.75**	**-1**
The system informed about upcoming decision points, with accurate distance and time to make the decision calmly.	1	1	1	1	2	2	2	2	-3	2	1	2	1	-3	1	1	**0.875**	**1**
I feel reassured that I am going in the right direction and was warned if not.	1	0	1	-3	1	0	-1	-2	-2	3	2	-1	-2	1	-2	0	**-0.25**	**0**
The system makes me feel empowered to make navigation decisions.	1	2	-2	0	2	2	1	1	0	3	2	1	0	2	1	1	**1.0625**	**1**
The system led me intuitively and doesn't require me to choose from different options to plan a route.	0	2	0	1	3	1	2	2	-2	3	2	1	2	3	2	-2	**1.25**	**1**

Table 11. Likert scale scores of subjective evaluation over interaction principles.

Motivation:
With the MMA, participants felt motivated to remember the route without consulting the map, scoring an average of 0.9375, showing good usability. However, without the MMA, motivation increased slightly, with a higher average score of 1.3125, indicating that participants found the system easier to use and relied more on their own recall when the song was not present.

Independency from the system:
The low score for independency without the MMA reflects participants' tendency to feel somewhat reliant on external aids like maps or visual cues during navigation, even in the absence of a musical mnemonic. Without the MMA, participants scored -0.75 on feeling "independent from the system to remember the route," indicating that despite the lack of an auditory aid, they still felt tied to the system for guidance, rather than fully trusting their own memory or decision-making skills.

Control and Feedback:
In terms of control, participants felt less in charge of their navigation with the MMA, reflected by a low score of 0.125, likely due to reliance on auditory cues. In contrast, without the MMA, participants felt marginally more in control, scoring 0.1875, though both versions scored relatively low, indicating room for improvement in fostering user autonomy in both setups.

Empowerment:
The MMA system made participants feel reasonably empowered to make navigation decisions, scoring 0.875. However, without the MMA, empowerment increased slightly, with an average score of 1.0625, suggesting that participants felt more confident and autonomous when they were not relying on auditory instructions.

Navigation Efficiency:
With the MMA, participants found the system to be intuitive and helpful in informing them of upcoming decision points, scoring 0.5625 for decision point clarity and 1.1875 for intuitive guidance. Without the MMA, these scores were higher, at 0.875 for decision points and 1.25 for intuitive guidance, indicating that participants found navigation more straightforward and efficient when they relied on their spatial memory rather than auditory prompts.

Importantly, the relatively low scores in certain areas, such as control and feedback, do not necessarily indicate a failure of the system but highlight areas where the musical aid changed the way participants interacted with the navigation system. These results suggest that while the MMA helped with route recall, it may have slightly reduced participants' sense of autonomy, as they became more reliant on the auditory cues. Thus, the experiment was designed to explore how musical mnemonics could support navigation in specific ways, rather than serve as a fully optimized solution for every aspect of the user experience.

Overall, the non-MMA version scored higher across all aspects, demonstrating that participants felt more motivated, in control, empowered, and navigated more efficiently without the song cues, while the MMA version was helpful but slightly reduced user autonomy.

Ultimately, these findings provide an important foundation for understanding how mnemonic aids could be integrated into future navigation systems, while leaving room for further refinements that could balance the use of such aids with user autonomy and control.

5.4 Experiment conclusions

Improving the translation between an allocentric map perspective to real environment egocentric perspective can be highly improved just by showing a better visual of a selected landmark that needs to be identified. Focusing on one very noticeable object and simplified instructions. Adding a musical mnemonic aid did not cause a significant improvement in both the traceability and retainability of landmarks.

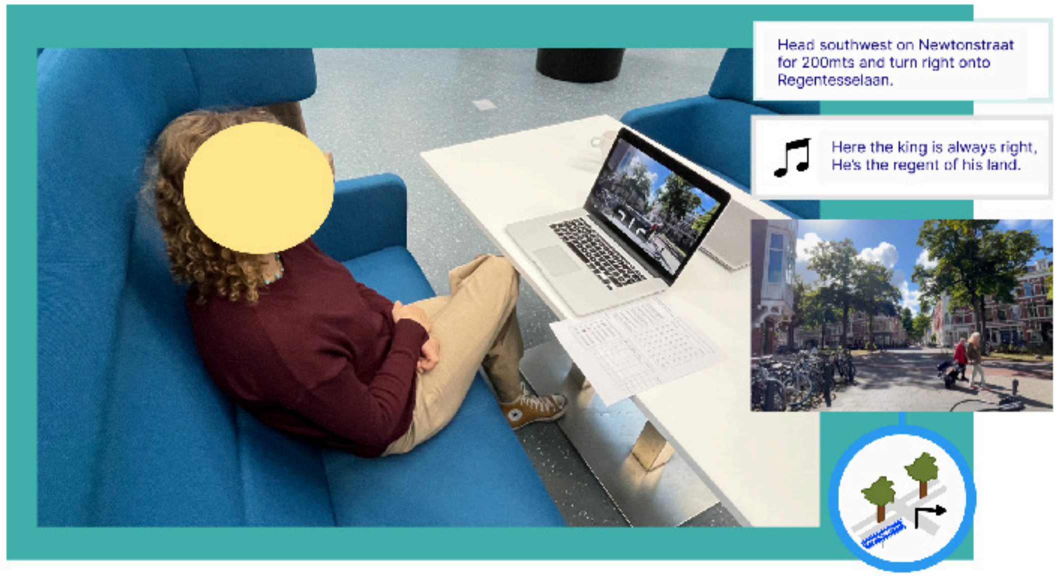


Figure 69. Experiment overview.

Mnemonic Aid for Spatial Orientation
The use of the Musical Mnemonic Aid (MMA) showed mixed results regarding spatial orientation. While the MMA improved the recall of landmarks (retainability), it did not have the same effect on remembering directions (traceability). The aid helped participants better guess upcoming landmarks based on the lyrics, but their ability to associate those landmarks with the correct directional changes was less consistent. The aid's impact was mainly seen in reducing mistakes during key steps but was less effective at non-instructed decision points.

Saliency / Retainability
Participants demonstrated a strong ability to remember decision points with the help of the MMA, especially for highly memorable landmarks like the "roundabout" or "ice cream shop." The presence of the mnemonic aid enhanced their recall of specific features, though the "overshadowing effect" showed that overly memorable landmarks sometimes caused participants to forget subsequent steps. Overall, retainability was better when landmarks were linked to strong visual or auditory cues.

Traceability
Traceability, or the ability to locate decision points in the environment, was somewhat lower with the use of the MMA. Participants often struggled to link the mnemonic with precise directional changes. This suggests that while the MMA made

recalling landmarks easier, it was less effective at helping participants pinpoint their location and next action. They relied more on visual and spatial memory when it came to choosing directions.

Cognitive Load

The experiment revealed that participants experienced a greater cognitive load when the MMA is present, causing more navigation errors. Despite learning two sets of instructions in a short time, participants adapted to the different routes, showing that the overall load of the experiment (using a 5 min route with 15 max decision points) is achievable. Participants made fewer mistakes as they became more familiar with the process, indicating that cognitive load decreased with experience. For this experiment carry over effects were observed, both positive and negative. The cognitive load of remembering a second route after already having learned another route before was mentioned as difficult, although there was not a significant effect observed in the amount of mistakes.

Hypothesis and Assumptions check

Most of the points mentioned in chapter 4 were shown as correct hypothesis, except for the following.

1. **More errors without MMA:** Contrary to the hypothesis, participants did not consistently make more errors without the MMA. The results showed that the adding an MMA increased the cognitive load and therefore the participant had more to focus on. The non-MMA version allowed participants to rely more on visual and spatial memory, which helped reduce mistakes in some cases.
2. **Lack of system feedback impacting trustworthiness:** The hypothesis that the system would not be perceived as trustworthy was partially confirmed. Participants felt that without corrective feedback when they made a mistake, the system seemed less reliable, though the absence of feedback did not significantly impact their overall performance.
3. **Reluctance to learn the song:** Participants did not express a strong desire to learn the song in its entirety beforehand, specially because in general they would not spend time learning the route before and would just glance the map once and then glance it again everytime that is needed. They favored an approach where they could "listen as they go." A more personalized or engaging musical genre might have made the process more appealing, but this was not tested in during this experiment.

5.5 Design Implications

After the insights from the experiment there is a more integral perspective of the type of mental map and navigation strategies from a DTD and low navigational skills point of view. It is now known that providing a visual representation of a specific element as a landmark improved the saliency of the decision points of the route.

This in contrast of the current approach which shows the entire environment and leaves it to the user to find something to place their focus on and remember what to do there. Taking a look back at the proposed design guidelines from chapter 3, the following guidelines in table 12 are improved and further specified to show landmarks in the most salient way.

Designing the navigation system

#	Most prevalent navigation element	Summary	Guideline	*Example*
S1	Map, Instruction	Egocentric to Allocentric translation	**Representation of the physical space should offer egocentric to allocentric view translations, with an indication of the orientation of the user in the physical space.**	*Maps should show the surrounding structures (buildings or walls) as a direct or indirect landmark for orientation.*
S2	Map	Matching orientation	**The cardinal orientation of the representation should match the current one the user has.**	*Maps should show real-time the "you are here" element, and then the map should be oriented by default facing the system's current distribution of the environment and not necessarily North to South orientation.*
S6	Map, order	Indication of location	**The system should indicate where the user is currently located in the representation and the physical space.**	
S7	Map,	Avoid initial mental rotation tasks	**Mental rotation tasks should be avoided as a first step to understand the translation between the allocentric and the egocentric view.**	*Avoid showing the map in a different rotation than what the user is facing at the starting moment of the journey*
S3	Visual Representation (VR) of landmark	Matching state of landmark	**Current physical state of a landmark should match in both views of this translation (egocentric - allocentric).**	*Maps should show the current status of each landmark, indicating whether it's undergoing maintenance.*
S9	Map, instructions, VR of landmark	Interpretations adapted to users mental map	**The representation should offer different types of interpretations to fit the users' mental representation of the route and preferred method of saliency.**	*for example, instead of saying 1km radius it can be said 10min walking radius*
S5	Map, instructions, VR of landmark	Information presented in segments	**The information shown in both views should be segmented in levels of detail and only show the most relevant information for navigation first.**	*The map should show the landmark and this landmark needs to be chosen as the most salient element in the environment.* *The system can distribute the instructions so that landmarks are split in blocks.*
S4	VR of landmark	Eye-Level representation	**Egocentric view of representation should show representation of landmarks as seen at eye level.**	*The VR of landmark should show it from an eye level view and size should equal the size of the landmark as seen from the point in which the decision needs to be made.*
S11	Instructions, VR of landmark	Appropiate announcement of decision points	**Anticipation of decision points should be announced once the decision point is visible on the horizon but with enough time to anticipate the decision point.**	*Ideally Landmarks should be visible with enough time to anticipate the decision that needs to be taken. The placement of the landmark should hint the direction that needs to be decided on.*
S8	Map,	Location of wayfinding elements	**The precise location of the wayfinding elements should be shown in the representation.**	*The precise location of the chosen landmark should be shown, indicating the precise side of the street and height in which it is.*
S10	Instructions, map	Consideration of user navigation patterns	**The system should consider user navigation patterns and define steps including either the most familiar to the user, easier to recognize or the least decision points possible.**	*The path of least resistance is chosen in which it is more intuitive to guess where to go. If a user goes through a specific landmark often, then this landmark should be included as much as possible in other routes.*
S12	Map, instructions	Adapt to user	**The system should adapt to the user's navigation pattern in the choice of landmark representation and routes preference.** **System should provide levels of decision-making automation and reduce unnecessary decision making.**	*The system should offer the easiest route with least instructions to remember, the fastest route and the one with most memorable landmarks. The most efficient route should be a combination of the fastest and least decisions that need to be made.*
S13	Instructions	Reaffirmation of correct path	**Reaffirmation that the user is on the correct path is encouraged.**	*Provide routes that have less possibility to make navigation errors. Avoid complicated intersections and streets without signage.*
S20	Instructions	Easy correction of mistakes	**If the user deviates from the set navigation path they should be able to easily identify the mistake and be offered a solution to correct it.**	*Offer solutions to get back on track or self adjust to a new route from that point onwards*
S18	Instructions	Visual autonomy	**The user should not need to see the representation visually in order to remember the route to take, system should offer alternative representations for navigation.**	*Provide landmarks and instructions that are easy to remember and identify. Routes should follow the path of least resistance when possible avoiding unnecessary crossings of streets and complicated intersections.*
S17	Instructions, Map, VR of Landmark	Feedback from user	**Allow user to give feedback over the information and recommendations provided by the system.**	*The user should be able to indicate if the instruction or landmark was easy to remember, the difficulty of the route and report differences between the system instructions and the real time environment.*

Table 12. Updated Wayfinding Guidelines: Navigation System.

Choosing a salient route:

Users with low navigational skills will prefer to go through easy routes with few decision points or those that have landmarks that they already know the route to and from well. Places like the home, supermarket, workplace, center square of the city, specific stores, historic monuments and a public transportation station are good starting points for landmarks.

If users are in a hurry they will choose the most know route, even if it is not the quickest.

When users are not in a hurry then they are open to explore more scenic routes with memorable landmarks as long as they are easy to remember and the route still feels efficient.

As mentioned in chapter 3, navigation systems should offer at least: the easiest route option, a most memorable option and the most efficient route using previously known places.

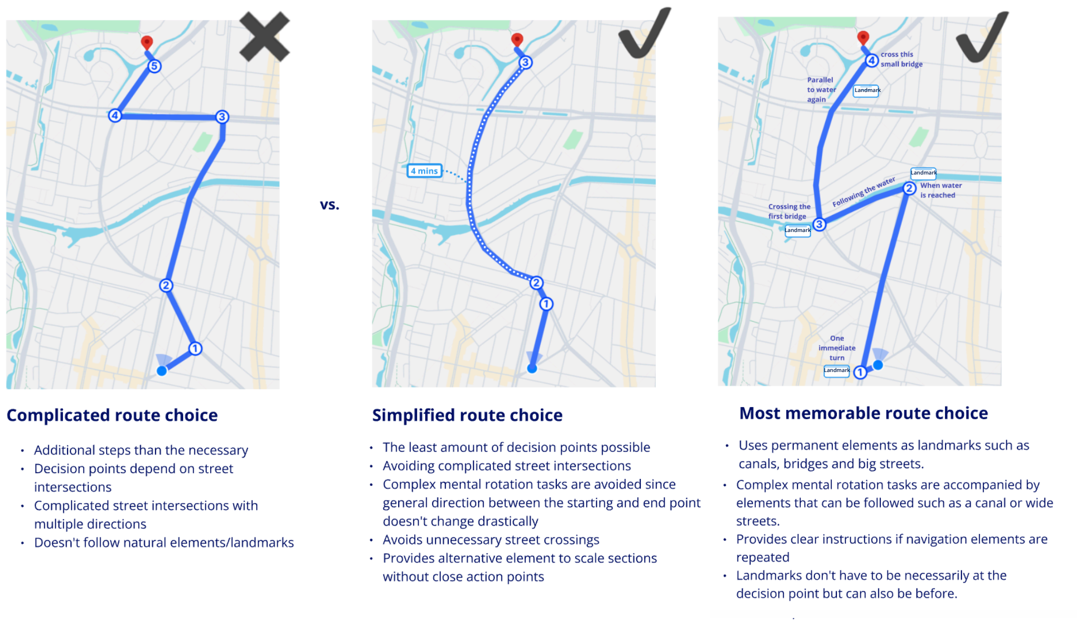


Figure 70. Classification of ideal routing for easy Wayfinding.

For longer routes, the user will choose to divide it in sections and first learn how to get to one place that seems reachable, a checkpoint, without a navigation aid and once that place is reached they will learn the new route towards the next checkpoint. The ideal checkpoints should be already known destinations for the user.

Choosing a salient landmark:

An ideal landmark for visual representation is one that is highly distinct and contrasts strongly with its surroundings, making it easy to retain in the memory and recognize in the environment.

An acceptable landmark can blend more subtly into the environment but still offers enough differentiation, like a bridge or a row of trees, a row of trash bins, a specific store or temporary elements such as the ice cream cone statue that is outside to show that the ice cream shop is open. Although, those not permanent ones must be taken chosen carefully to ensure it is actually in place when needed.

In contrast, a poor landmark is one that lacks distinctiveness or is easily confused with its surroundings, such as a generic brown brick house surrounded by other brown bricked houses. Or, a hard-to-see / far away statue, which can lead to confusion and navigation errors.

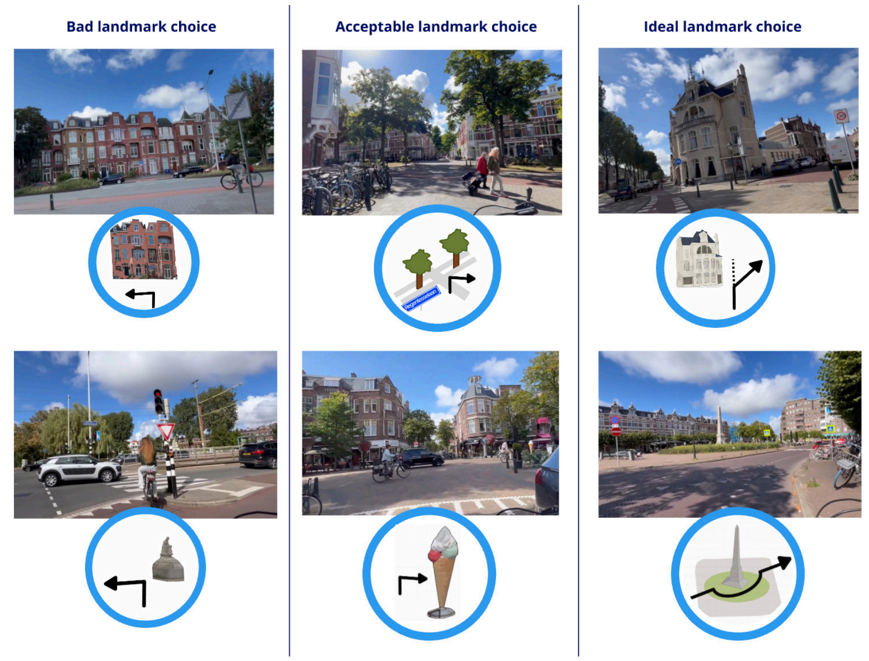


Figure 71. Classification of ideal landmarking for easy Wayfinding.

Using natural elements as landmarks is effective only when there is a clear, distinguishable alignment that participants can easily interpret from both an egocentric and allocentric perspective. For instance, the presence of a tree-lined boulevard provided a useful spatial cue, as the alignment of the trees offered a consistent visual pattern. Similarly, trees were beneficial when used to indicate a park, where the distinctive boundary between the park and surrounding streets served as a reliable landmark. However, in cases where the trees lacked a unique arrangement or context, participants struggled to use them effectively as navigational aids.

The final destination should also be shown as a landmark so the user knows what to look out for.

Choosing a salient instruction:

Primary instructions should be only about decision points with specific changes in direction. There can also be secondary instructions which reassure the user that they are indeed in the correct path.

For users with DTD and low navigational skills, using allocentric references such as North and South do not bring as much orientation value as direct references of their egocentric position (left and right of their current position).

Street names are only used as a wayfinding element in 3 situations:

- **Decision point landmark:** when there are no other more salient landmarks with enough contrast at the decision point
- **Final destination saliency:** if the user is looking for the final destination which involves a street name and number
- **Reassurance:** When the route goes along a street for a long time and the user had multiple chances to see the street sign.

If users have to learn street names to complete their route, they will only choose to remember one or two street names alongside other landmarks. This depending on the length of the route of course, longer routes might require to learn more street names, but as mentioned before longer routes will most likely be split into sections by the user. If split into sections the maximum amount of streets that should be remembered is one or two per section.

Street names can be shown as a landmark, bringing emphasis to the first letter of the name. Details such as whether it is a street, avenue or way are not necessary. For example, in the context of the Netherlands if a street name is "Delftselaan" or "Delftseweg", user will most likely remember the word Delft but not specifically the type of street unless those two options are within close distance to each other and a navigation decision needs to be made depending on that information.

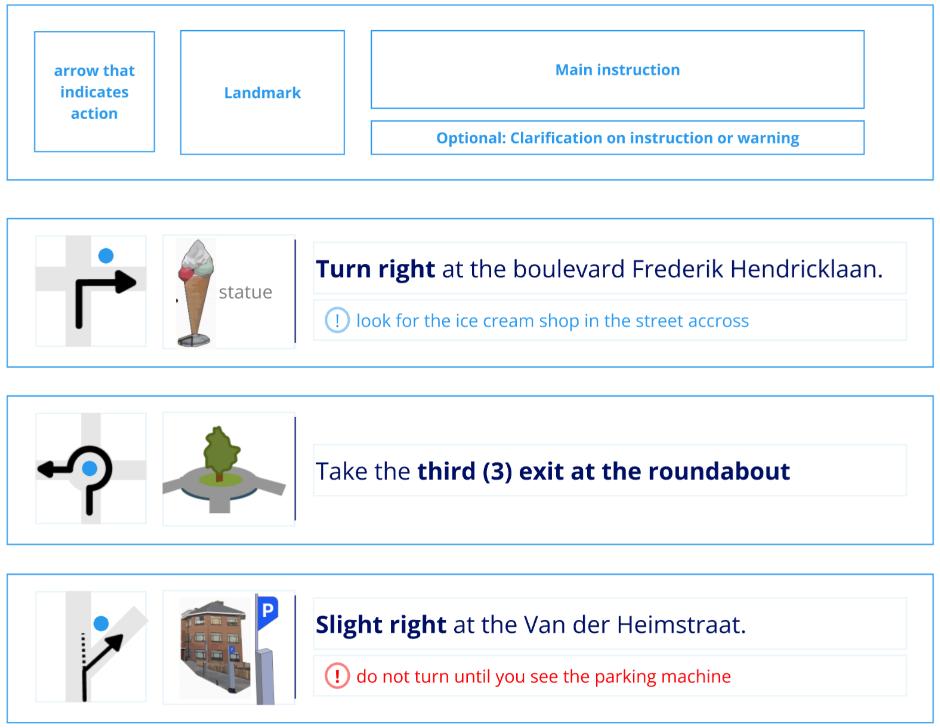


Figure 72. Classification of ideal instructions for navigation.

6. Outcome

6.1 Conclusions on the project

This project provided a deep dive into "how do people navigate?" and more specifically, the daily navigational challenges faced by people with Developmental Topographical Disorientation, but also, those who consider themselves not good with navigation. From an initial exploration of the clinical topic of DTD, to the development of design guidelines, this project aimed to bridge the gap between navigation technology and the real-world environment for all those users who face difficulties with spatial orientation.

Through interviews, an experiment, and the design of a wayfinding framework, the study has highlighted the ways in which people navigate their environments, indoors as well but mostly outdoors. While, also bringing attention to the cognitive processes that underlie these interactions.

As this work has shown, effective navigation goes beyond just technological solutions. It's about creating systems that empower individuals to feel confident and independent, even when the surroundings are difficult full of houses that look all the same or buildings with endless corridors. Overall these are the general conclusions of the entire project:

- **The original focus on Developmental Topographical Disorientation (DTD) was broadened to include individuals who self-identified as having low navigational skills.** This adjustment not only made it easier for participant recruitment but also raised awareness about DTD among a wider audience. Many participants were able to recognize that their navigational challenges did not reflect a lack of intelligence. By expanding the scope of the study, it became possible to develop inclusive design guidelines aimed at creating accessible wayfinding systems for a diverse range of users.

- Even though DTD is not a high risk condition, **there are still multiple moments of distress caused by the inability to orient in the environment,** and even financial consequences if the person gets caught by the police for using the phone while cycling. The efficiency of fast paced environments represent an extra stress factor for those with DTD and others as well. The best example of this is at hospitals, known for having complicated layouts, where every minute makes a difference.

- Even though the second half of this study primarily focused on outdoor navigation, the findings have significant implications for indoor wayfinding. The emphasis on clear instructions and visually distinct landmarks could benefit users navigating complex indoor environments. **The guidelines proposed can also translate to indoor wayfinding**, although it would be useful to develop a specific set for indoor wayfinding. Design based on these insights can help individuals, both with DTD and without, to better orient themselves.

- The research also **broadened the understanding of the mental maps formed by individuals with DTD**, and it hints at revealing a spectrum of navigational abilities even though there isn't much literature available yet on a specific classification of navigational abilities.

- Future Co-creation sessions with individuals who have weak navigational skills or DTD could provide **valuable insights into which elements are easiest to remember and why**. This would contribute to the design of future wayfinding systems better tailored to this population.

- Additionally, **raising awareness about DTD has been a key outcome of the study**, empowering both individuals and designers to address navigational challenges with more inclusive tools.

- Since DTD and spatial aphantasia are relatively new areas of research, scientific developments progressed alongside this study. **New findings, particularly the possible correlation between levels of visual imagery and navigational proficiency, prompted necessary adjustments to the methodology.** These findings highlight the need for further research into how visual imagery influences navigation strategies, especially in processing visual and auditory cues. This could provide a basis for designing personalized navigation aids tailored to cognitive profiles.

- Creating Wayfinding Guidelines specifically tailored for people with DTD or weak navigational skills proved to be a challenge since wayfinding happens in all kinds of environments with multiple routes daily, and personalizing each decision point would demand considerable effort from developers and motivation from users. While AI could help by adapting routes to user preferences, **participants did not express a strong desire to pre-study routes, indicating a potential barrier to motivate the strengthening of navigational skills.**

6.2 Limitations

1. Lack of Awareness of Developmental Topographical Disorientation (DTD): A major limitation was the public's unfamiliarity with DTD, potentially affecting participants' understanding of the study's goals and navigation aids' relevance. Since DTD is a relatively novel research area, new findings, such as the connection between visual vividness imagery and DTD, were integrated halfway through, limiting their consideration in early phases of the study.

2. Clinical Approach to DTD: The study's controlled, clinical setting, though useful for isolating variables, did not fully capture the real-world navigation challenges faced by individuals with DTD. Factors like spontaneous route changes and environmental distractions, crucial for understanding mnemonic aids' effectiveness, were not replicated in the virtual environment.

3. Recruitment Challenges: Recruiting participants was difficult, resulting in a small, homogeneous sample that did not fully represent a broad range of navigation abilities or cognitive profiles, limiting the generalizability of the findings.

4. Virtual Environment Prototyping: The use of a 2D video-based environment restricted participants' ability to engage with street signs, which would have required a 3D VR setup. However, prototyping VR technology within the time constraints was not feasible.

5. Time Constraints: The project was constrained by limited time, which affected the development of the virtual environment and the overall length of the study. A longer timeline could have allowed for more iterations, participant training, and follow-up assessments.

6. Scope of Prototyping: The experiment's narrow focus on a specific set of routes limited its ability to capture the wide range of real-world navigational challenges. This also restricted the exploration of alternative designs for the MMA system, such as using different musical genres or customized auditory cues.

6.3 Recommendations

1. Specify when using the Wayfinding Questionnaire which questions should be answered from the perspective of "using a GPS".
2. For an iteration of the experiment:
    a. Repeat the navigation of the routes in the virtual environment, 3 days after (without showing the navigation system the second time) to see how many decision points are accurately remembered, simulating that you are learning the route to go somewhere close in your new neighbourhood that you will frequently go to.
    b. Incorporate a task that is doing the learned route "in reverse" to see how the "order" as a navigation element is affected.
    c. Test with an older and younger sample population, emphasizing the difference between those who have learned to navigate without a constant GPS and those who almost never experience navigating on their own without GPS.
    d. Adapt the experiment to indoor navigation of a complex environment such as a hospital, airport or shopping center.
    e. Have the participants draw what they remember after being exposed to the navigation system and the virtual environment, to see what type of mental map is created after the exposure of the route.
    f. Create routes with varying degrees of cognitive load (e.g., a simple grid layout versus a more winding, irregular path) to examine how MMA influences decision-making under different levels of navigational complexity.
    g. Test the traceability and saliency of landmarks in different situations, such as with a change of weather or even at night.
    h. Go out into the real world. Do the experiment but instead of using a virtual environment have participants navigate a real-world version of the route to compare how well they transfer knowledge from a virtual environment to reality. This would help gauge the effectiveness of VR training in real-life scenarios.
3. Research the impact of cultural differences on landmark recognition. Conduct cross-cultural studies to determine how individuals from different cultural backgrounds recognize and prioritize landmarks, and how these insights can inform more inclusive navigation system designs.
4. Facilitate co-creation sessions with people with DTD and low navigational skills to identify what type of landmarks are the most salient to them and to create routes based on their own navigation and coping strategies.
5. Municipalities and City makers should promote local artists to create art (especially statues and murals) on objects that could work as a navigational landmark so citizens depend less on seeing their phones while cycling to look at the map.

6.4 Reflection

1. Lack of Awareness of Developmental Topographical Disorientation (DTD): A major limitation was the public's unfamiliarity with DTD, potentially affecting participants' understanding of the study's goals and navigation aids' relevance. Since DTD is a relatively novel research area, new findings, such as the connection between visual vividness imagery and DTD, were integrated halfway through, limiting their consideration in early phases of the study.

2. Clinical Approach to DTD: The study's controlled, clinical setting, though useful for isolating variables, did not fully capture the real-world navigation challenges faced by individuals with DTD. Factors like spontaneous route changes and environmental distractions, crucial for understanding mnemonic aids' effectiveness, were not replicated in the virtual environment.

3. Recruitment Challenges: Recruiting participants was difficult, resulting in a small, homogeneous sample that did not fully represent a broad range of navigation abilities or cognitive profiles, limiting the generalizability of the findings.

4. Virtual Environment Prototyping: The use of a 2D video-based environment restricted participants' ability to engage with street signs, which would have required a 3D VR setup. However, prototyping VR technology within the time constraints was not feasible.

5. Time Constraints: The project was constrained by limited time, which affected the development of the virtual environment and the overall length of the study. A longer timeline could have allowed for more iterations, participant training, and follow-up assessments.

6. Scope of Prototyping: The experiment's narrow focus on a specific set of routes limited its ability to capture the wide range of real-world navigational challenges. This also restricted the exploration of alternative designs for the MMA system, such as using different musical genres or customized auditory cues.

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Appendix 1:

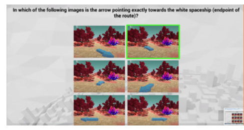
Technology for DTD diagnostics.

Leiden Navigation test

This navigation test was developed by a team of scientists from Leiden University and UMC Utrecht led by van der Ham, et al., to detect navigational cognitive impairment through the analysis of underperformance in navigational and orientation tasks compared to 11887 subjects with no evidence of navigation impairment. This test compares the results divided by age, sex and educational level achieved. After watching a first person perspective of a person walking in an unknown environment, the participant has to answer the questions shown below:

Landmark recognition

Assesses the ability to process, store and recognize relevant landmarks in the environment. This ability is vital for orientation and navigation in both familiar and unfamiliar environments.

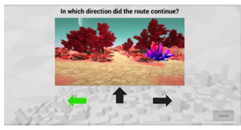


Location - egocentric

Concerns the ability to point to the endpoint of the route standing at the location of a particular landmark. In this way, knowledge of the relative positions of landmarks is measured based on the perspective from the route itself. This ability is realted to sense of direction.

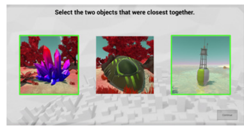
Location - allocentric

Concerns the strategy to find the way by using a mental map of the environment (from a bird's eye view). This subtest addresses to what extent the participant is able to indicate the positions of relevant landmarks within a map of the environment.



Path - route

A particular strategy for navigation is to remember specific routes. In this respect, it can be helpful to remember information about the actions (i.e., left, straight ahead, right) that are required at a particular landmark. This subtest is concerned with measuring this ability.



Path - survey

Measures the knowledge of how location are connected realtive to each other within the environment. This ability relies on having a mental map and is important for having a sense of direction. While Location - allocentric is about relative locations of landmarks, Path - survey concerns the paths which connect these locations.

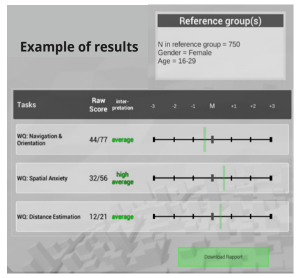
The results of this test can show an indication of Developmental Topographical Disorientation based on the results of specific tasks. Higher scores on Landmark Recognition and Location - egocentric compared to lower scores on the rest of the tasks can be interpreted as the participant relying mainly on its own perspective to navigate the environment. The translation from an egocentric to an allocentric point of view is usually where DTD participants struggle.

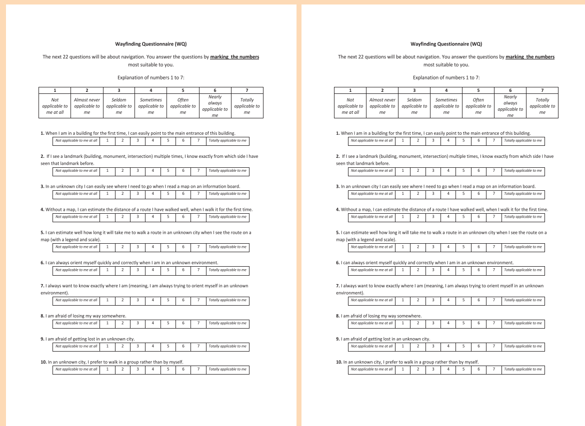
Wayfinding Questionnaire

Originally developed by ____ in 2019 to assess the subjective navigation complaints on stroke patients, this questionnaire allows the detection of navigational difficulties by self report. This clinically validated tool allows a possible detection of DTD based on the participant's self evaluation.

The Wayfinding Questionnaire measures 3 subscales:

- **Navigation & Orientation:** Measures the participant's subjective estimate of their ability to navigate (find their way around) and orient.
- **Spatial Anxiety:** Measures the participant's subjective degree of tense and anxious feelings experienced when navigating in both familiar and unfamiliar environments.
- **Distance Estimation:** Measures the participant's subjective ability to estimate distances, a specific ability that can contribute to accurate navigation.





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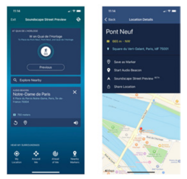
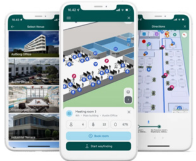
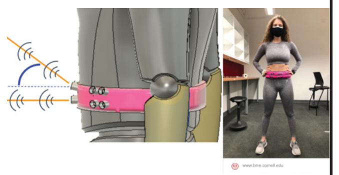
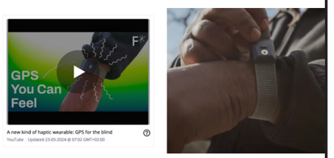
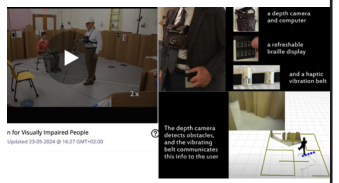
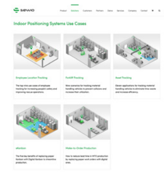
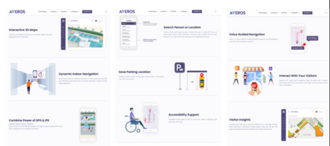
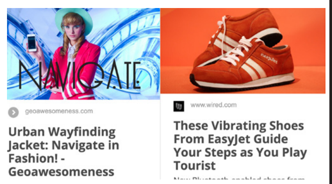
Appendix 2:

Wayfinding technology.

Product name & image	Description	Type of support provided	Reference
 WeWalk smart cane	The smart cane project is designed to assist visually impaired individuals with navigation through features like enhanced obstacle detection via haptic feedback and an intelligent AI voice assistant. It offers efficient route planning, integrates public transportation data (via Moovit), and provides low-vision mapping, while also incorporating information about neighborhood landmarks to improve interaction with the surroundings.	Automatic, semi automatic, manual	https://wewalk.io/en/product/
 Aira	A service connects visually impaired users with agents who assist in navigation via video calls, providing visual interpreting to make visual information accessible. Agents verbally describe, explain, and navigate in real-time for blind or low-vision users, offering essential guidance through verbal communication. This service enables visually impaired individuals to access critical visual details and navigate environments more effectively.	Automatic	https://aira.io/
 Microsoft soundscapes	A mobile app offers audio cues to help visually impaired users navigate. Features include a 2D street preview, user-placed beacons, and modes like "Around Me" and "Ahead of Me" to identify nearby points of interest. It connects to wireless earbuds with a gyroscope for real-time orientation and provides proximity alerts to landmarks. The app also gives information on local activities along the route, enhancing the navigation experience.	Automatic, semi automatic, manual	https://www.microsoft.com/en-us/research/product/soundscape/
 OpenStreetMap	OpenStreetMap is a place for mapping things that are both real and current - it includes millions of buildings, roads, and other details about places. You can map whatever real-world features are interesting to you. What it doesn't include is opinionated data like ratings, historical or hypothetical features, and data from copyrighted sources. Unless you have special permission, don't copy from online or paper maps.	Manual	https://www.openstreetmap.org/
 Bitlab	Blitab is an Android tablet with a smart Braille surface, featuring 14 rows of 23 6-dot Braille cells. It allows users to read maps in Braille, while the bottom portion operates as a regular Android screen for apps. Equipped with Wi-Fi and Bluetooth, Blitab offers a unique way to interact with both tactile content and digital applications, providing inspiration for accessible navigation technologies.	Manual	https://www.perkins.org/resource/blitab-android-tablet-14-row-braille-display/
 Touch Mapper	Touch Mapper is a different way of showing navigation but not a navigation device itself, only for inspiration A 3D representation of the street	Manual	https://touch-mapper.org/en/
 TomTom	TomTom GPS devices and software that provide real-time traffic information and route guidance for drivers, cyclists, and pedestrians. It also offers digital maps, location-based services, and navigation solutions for mobile apps, automotive, and enterprise use.	Automatic, semi automatic	https://aira.io/

Product name & image	Description	Type of support provided	Reference
 MapsPeople	MapsPeople has 2D & 3D maps of indoor spaces, only on request by an organization, it doesn't direct where to go.	Manual	https://www.mapspeople.com/mapsindoors
 Pointr	Pointr provides 2D and 3D indoor maps on request from organizations, offering precise navigation within indoor spaces. Their solution uses Bluetooth Low Energy (BLE) technology for an accurate "blue dot" navigation experience, which requires minimal user setup and is scalable.	Semi automatic	https://www.pointr.tech/solutions/location-based-services/indoor-positioning
 Visation (biomedical student project)	Wearable navigation band for the blind, university student project	Automatic for object detection Manual for orientation	https://www.bme.cornell.edu/spotlights/wearable-navigation-device-blind
 Wearworks	Haptic app and armband for the blind. Vibrates when the user deviates from the direction, only works outdoors	Automatic	https://www.youtube.com/watch?app=desktop&v=yj7kZQbOQlc
 MIT navigation device for the blind	Vibrates when the user is facing an obstacle, from the MIT Computer Science and Artificial intelligence lab	Automatic for object detection Manual for orientation	https://www.youtube.com/watch?v=R6Pjbk-9w2Jk
 Sewio	Sewio indoor visualization system (beacons) 2D & 3D maps of indoor spaces and objects in it (with movement tracking), only on request by an organization,	Semi automatic	https://www.sewio.net/indoor-location-tracking-and-positioning/
 Averos Navibees	Averos Navibees, indoor navigation system. 2D & 3D maps of indoor spaces and the movement within, only on request by an organization, it does direct where to go	Semi automatic	https://averos.com/solutions/navibees/
 Geocaching	Real world treasure hunts. Usually rely on maps but sometimes have alternative ways of directing users towards a destination.	Semi automatic	https://www.geocaching.com/blog/2018/03/what-is-geocaching/
 Wayfinding Fashion	Bluetooth enabled clothing with haptic feedback to give directions. Urban wayfinding jacket and vibrating shoes from EasyJet .	Automatic	https://geoawesome.com/urban-wayfinding-jacket-navigate-fashion/ https://www.wired.com/2016/05/easy-jet-sneakairs-smart-shoes/

Appendix 3:

Wayfinding guideline analysis.

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se

From the Queensland University of Technology in Australia, R. Apelt and J. Crawford proposed Wayfinding design guidelines considering inclusive design and the principles of Universal Design. This list offers a very complete checklist that includes recommendations for spaces in which people with varying languages, and various levels of physical abilities can navigate through a physical environment.

While these guidelines are mainly targeted towards physical spaces, they serve as a good parting point for wayfinding guidelines to be applied on technology.

Wayfinding design guidelines (Apelt & Crawford, 2007, 4)	**Adaptation towards wayfinding technology design**
1. Analyze access points considering the physical and aesthetic characteristics of the building or site.	1. Ensure app or website entry points are user-friendly and visually appealing, providing clear access to primary functions and features.
2. Divide large-scale sites into distinctive smaller zones while maintaining connectivity and a sense of place.	2. Segment digital content into smaller sections while maintaining logical connections, ensuring users can easily navigate through large amounts of information.
3. Organize zones with a logical and rational structure through a well-devised zonation plan.	3. Implement intuitive information architecture in digital platforms.
4. Provide frequent directional cues, especially at decision points, for clear navigation in both directions.	4. Use navigational aids like breadcrumbs and arrows at key points.
5. Ensure decision points are logical, obvious, and directly related to the space, with clear sequencing and grouping of message signs.	5. Design clear, contextually relevant options for seamless navigation.
6. Design a flexible and memorable naming protocol using culturally diverse names and symbols.	6. Use memorable, culturally relevant names and symbols in interfaces.
7. Use a consistent, logical naming protocol for master-planned places like hospitals or educational institutions.	7. Maintain consistent labeling across all digital systems.
8. Ensure alpha-numeric coding systems are consistent, such as "building B, level 3, room 7."	8. Implement clear alpha-numeric coding for easy identification and retrieval.
9. Incorporate multiple languages or pictograms into the naming protocol.	9. Support multiple languages and universal icons on digital platforms.
10. Ensure signs are physically placed, installed, and illuminated for all users' visibility and accessibility.	10. Design visible, accessible digital signs and notifications.

Wayfinding for dementia considers how to design for people who can't create a mental map.

People with dementia have similar wayfinding difficulties since they **"may encounter great difficulty in retrieving a mental visual image of a place that they cannot see, rendering them unable to generate, maintain, and use a cognitive map." (Marquardt, 2011).** Marquardt, after reviewing existing studies of wayfinding for people living with dementia, proposed the following design guidelines:

No need for new or higher skills.
The navigation of the floor plan of a dementia-friendly setting should not require higher skills, such as reading and interpreting signage. A simple, clear layout of the floor plan and well-defined, geometrically simple rooms are structural prerequisites to successful orientation and wayfinding in nursing homes.

Allow visual access and overview.
Because of the degeneration of their brains, people with dementia cannot mentally represent spatial situations that they cannot see directly. Therefore, all places relevant to them should allow for visual access, and it should be possible for them to oversee their entire immediate living environment.

Reduce decision making.
People should be led intuitively and not be required to choose from different options to plan a route. If a floor plan typology that features changes in the direction of the circulation system is the only design option at a site, a meaningful reference point should be incorporated. Further, to identify and locate rooms with a similar meaning or function, distinctions in size, shape, color, and lighting must be articulated.

Increase architectural legibility.
The function of rooms and other spaces, as well as the behavior that is expected and appropriate there, can be made clearly legible by means of size, proportion, materials, and furnishings. In this manner, distinctive places that can better be memorized and located are created, thus promoting residents' spatial orientation and wayfinding.

While these guidelines are specifically tailored for wayfinding in nursing homes, they can also be a guiding point for adaptations to existing wayfinding strategies for the general population, making them more accessible for people with DTD. Unlike people living with dementia, people with DTD do not have impaired logic or reasoning abilities and can live highly functional lives with normal or high IQs. Their shared challenge lies in visualizing a mental map of their environment. Consequently, while they could benefit from some simplification, it is not necessary to completely eliminate navigation decisions or overly simplify their environment, as they can still adapt and develop effective navigation strategies.

Considering wayfinding strategies for fast-paced environments offers guidelines for efficient navigation decisions.

The Wayfinding strategy of the NetworkRail of United Kingdom provides additional guidelines that can benefit people with low navigational skills, especially in places where decision points need to be efficient and people are usually in a hurry.

NetworkRail (2020) defines ***"Decision points are locations where the passenger make a wayfinding decision".*** From this strategy, the following reccomendations can be useful to apply in wayfinding systems that need to be adapted for people with DTD and low navigational skills, as well as people with normal navigation skills.

Decision points are located in transient spaces characterised by fast-paced movement, where it is important to deter passengers from stopping and creating bottlenecks in circulation space.

To maintain the flow of movement and prevent congestion, it is crucial that these decision points are designed to facilitate quick, intuitive decisions. Clear, visible signage and intuitive layout designs help passengers make choices on the go, reducing the likelihood of stops that disrupt the overall flow.

Signage should be placed at decision points or as close to the decision point as possible, taking into account the user flows and mounting points available in the space

For maximum effectiveness, signage must be strategically positioned to align with natural user movements and sightlines. Their strategy reccomends that overhead signs, typically read from a distance of 4–6 meters, should be placed where passengers can comfortably view them without excessive neck strain. Eye-level signs, best viewed from 1–2 meters away, should be installed where users can easily read them without breaking their stride. A more specific description of how early a decision point should be announced depending on the size of the signage can be further found in their strategy (page 49).

Advertising cannot be combined with wayfinding on the same sign. Advertisements should not be placed in positions where they will visually obstruct, obscure, or distract from, station wayfinding or signage

The clarity and effectiveness of wayfinding signs must not be compromised by commercial interests. Combining advertisements with wayfinding information can lead to visual clutter, reducing the visibility and readability of crucial navigational aids.

While digital wayfinding has an important role to play, it cannot be relied upon as the only method for finding your way.

Digital tools, such as apps and interactive maps, offer dynamic and personalized navigation assistance. However, these technologies are not foolproof and can fail due to technical issues or lack of access. Therefore, they should complement, not replace, traditional wayfinding methods. Combining digital and traditional methods can create a inclusive wayfinding system that enhances the user experience for everyone.

Appendix 4:

Screener for participant recruitment.

Screening survey

Questionnaire

Do you experience difficulties orienting and finding your way, or remembering where certain places are located? *

Never 1 2 3 4 5 All the time

- ○ 1
- ○ 2
- ○ 3
- ○ 4
- ◉ 5

Which are situations you find difficult to orient yourself and navigate the environment?
Or, that you depend heavily in the use of navigation tools like Google Maps.
Please select all that apply. *

- [x] Walking in your neighbourhood (or it took you a long time to get used to it)
- [ ] Walking in an unknown city
- [ ] Using public transportation
- [ ] Driving
- [ ] Cycling in the city/countryside
- [ ] Finding your bike/car in the parking lot
- [ ] Trying to find a room you have never visited before inside of a building
- [x] Going to a room you have visited before inside of a building.
- [x] Inside of your home
- [ ] Remembering where things are located in the supermarket
- [x] Remembering where a store/cafe you have visited before is located in the city
- [ ] Finding your way in shopping malls / hospitals / public buildings

Have these difficulties changed over time? *

- ○ Yes, I have only felt it recently.
- ◉ No, I have always found navigating difficult.
- ○ I have never felt difficulties

How old were you when you first became aware of, or concerned, about your orientation skills? When you started thinking that maybe navigation is not as easy for you than for others. *

- ◉ Since I was a kid, I have at least a memory of getting lost in a familiar environment.
- ○ Since I was a teenager, I remember getting lost all the time, even in familiar environments.
- ○ Only recently I have started noticing that I don't navigate as easily as others.
- ○ I feel like I have good navigation skills and don't get lost as often.

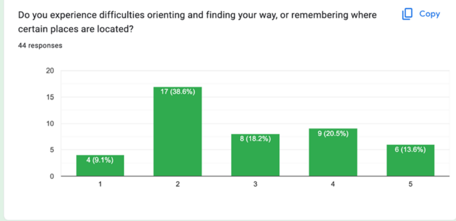
Are you aware of having any brain damage, brain malformation, or brain tumor? Concussions also apply *

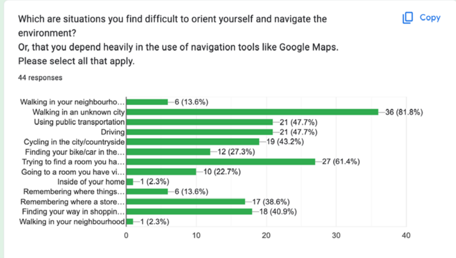
- ○ Yes, I have had previous neurological damage
- ◉ No, I haven't had previous neurological damage

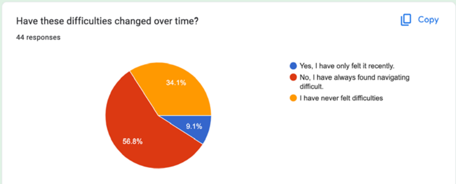
Do you have any neurological condition or cognitive disorder including colorblindness, dyslexia, dyscalculia, aphantasia, ADHD, prosopagnosia? Write down below the condition or just "no" if you don't have any. *

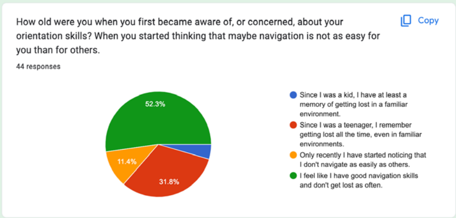
Your answer

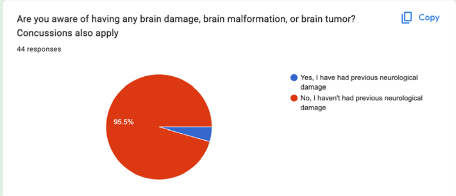
Summary of results

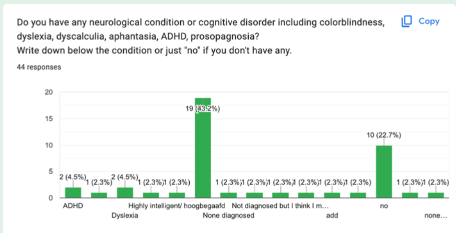












Appendix 5:

Consent Form

Informed Consent Form

You are being invited to participate in a research study titled Wayfinding Design for Developmental Topographical Disorientation. This study is being done by Sofia Brenes from the Industrial Design Engineering Faculty of the TU Delft in collaboration with researchers in cognitive psychology from Leiden University.

This research aims to understand the navigation challenges faced by individuals that self identify as having low navigational skills, and those with Developmental Topographical Disorientation (DTD), and to develop design guidelines for wayfinding systems to better support these individuals. The outcomes of this study will contribute to future research and designs in cognitive neuropsychology and wayfinding.

This study consists of two research phases with participants. The first is exploratory research about wayfinding experiences and the second testing the usability of a new designed wayfinding interaction. Today we are only going to do the first part.

Participating in this study will take you approximately **from 45 to 60 minutes** to complete. The data collected will be used for publication, application, and teaching purposes. We will be asking you first to test the prototype created for the experiment which involves getting a navigation aid and then performing a route with that aid, later do a virtual navigation test and lastly a visual imagery test.

To the best of our ability, your answers in this study will remain confidential. We will minimize any risks by ensuring that personal data will be anonymized, securely stored, and only accessible to the research team. Your contact information will only be accessed by the graduating student and will only be kept for the duration of this project. Your anonymous data will be published in the TU Delft repository. If you do not wish to remain anonymous you can indicate it below.

Your participation in this study is entirely voluntary and you can withdraw at any time. You are free to not answer any question you do not want to.

If you have any more questions, you can contact the lead researcher:

Sofia Brenes Piza

TU Delft - Faculty of Industrial Design Engineering- MSc. Design for Interaction
Landbergstraat 15
2628 CE, Delft

Informed Consent Form – Part 1. Wayfinding experiences with TU Delft students

	Yes	No
1. I have read and understood the study information dated [__/__/____], or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.		
2. I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.		
3. I understand that taking part in this study involves a. Testing the navigational aid prototype which involves memorizing a route and navigating a virtual environment. [15mins] b. Taking a virtual navigation test. *The results of this test are not an official medical diagnosis of my navigational skills and should not be interpreted as such. [10mins]* c. *Taking a visual imagery test. The results of this test are not an official medical diagnosis of my navigational skills and should not be interpreted as such. [5mins]* d. Talking about your personal experiences with navigation and spatial orientation in an interview with the lead researcher.		
4. I understand that the session will take approximately 40 to max 60 minutes. The project will end on 25/10/2024 but the publication of results might extend until 31/12/2025.		
5. I understand that taking part in the research also involves collecting personal information such as navigation experiences in my hometown, current neighborhood or other past memories - this information does not have to be given. The researcher will anonymize my information removing personally identifiable information such as my name, last name, and contact information.		
6. I understand that only the research team has access to my contact information and this will be destroyed when the project results are published.		
7. I understand that taking part in the research also involves talking about personal experiences and posible sensitive topics such as the emotional impact of challenges faced with navigation. This is voluntary and you do not need to share if you don't want to.		
8. I understand that my de-identified data will be archived in the TU Delft repository for future research and teaching, with restricted access. The data can also be accessed by researchers from Leiden University with expressed permission granted by the lead researcher of this project.		

Voluntary consent	Yes	No
I agree that photos and videos can be taken of me during the experiment.		
I agree that my real name (only the first name) can be used for quotes in research outputs.		
I would like to participate in further following research on wayfinding and navigation.		

Signatures

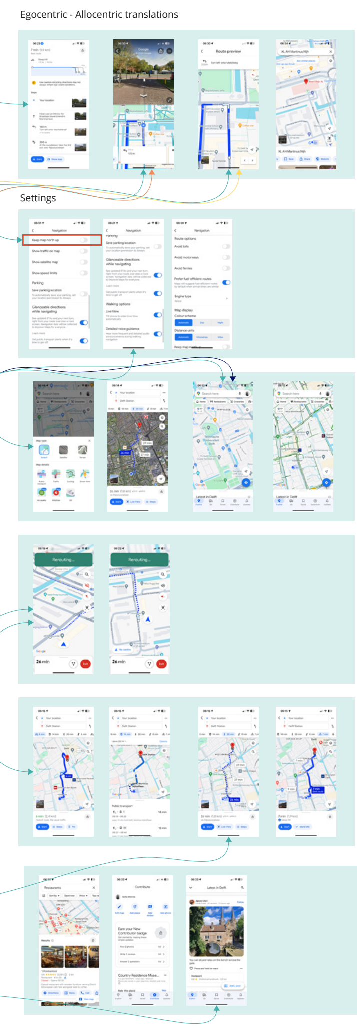
Name of participant [printed] Signature Date

Appendix 6:

Extension of case study Google Maps

New table

Theme	#	Summary	Guideline	*Example*
Representation / Navigation System	S1	Egocentric to Allocentric translation	**Representation of the physical space should offer egocentric to allocentric view translations, with an indication of the orientation of the user in the physical space.**	GM shows step by step of directions in both views for the person to previously study them
	S2	Matching orientation	**The cardinal orientation of the representation should match the current one the user has.**	*GM offers the option in settings to turn on "always facing north" option or follow user's orientation*
	S7	Avoid initial mental rotation tasks	**Mental rotation tasks should be avoided as a first step to understand the translation between the allocentric and the egocentric view.**	*GM has the option to block self rotation and staying always on north. The user can manipulate the orientation of the map all the time. It also has step by step orientation.*
	S3	Matching state of landmark	**Current physical state of a landmark should match in both views of this translation (egocentric - allocentric).**	*Not fully done: show the current status of each landmark, indicating whether it's undergoing maintenance.*
	S6	Indication of location	**The system should indicate where the user is currently located in the representation and the physical space.**	*GM show where you are and the specific direction you are facing*
	S9	Interpretations adapted to users mental map	**The representation should offer different types of interpretations to fit the users' mental representation.**	*GM shows different representations based on what the user needs to see. Levels of detail vary per representation.*
	S5	Information presented in segments	**The information shown in both views should be segmented in levels of detail and only show the most relevant information for navigation first.**	*GM changes the level of detailing shown depending on how zoomed in the map the user is.*
	S4	Eye-Level representation	**Egocentric view of representation should show representation of landmarks as seen at eye level.**	*GM shows representations from an almost eye level.*
	S8	Location of wayfinding elements	**The precise location of the wayfinding elements should be shown in the representation.**	*GM doesn't show wayfinding elements per se such as street signs but it does show the physical appearance and location of certain landmarks.*
	S10	Consideration of user navigation patterns	**The system should consider user navigation patterns and define key nodes such as decision points according to that.**	*GM offers step by step visualizations in the preview. Also, shows wayfinding as store signs in the maps.*
	S11	Appropiate announcement of decision points	**Anticipation of decision points should be announced once the decision point is visible on the horizon but with enough time to anticipate the decision point.**	?
	S12	Adapt to user	**The system should adapt to the user's navigation pattern in the choice of landmark representation and routes preference.**	*GM shows recently searched places on the map*
	S13	Reaffirmation of correct path	**Reaffirmation that the user is on the correct path is encouraged.**	*GM shows the distance between the user and the desired path.*
	S20	Easy correction of mistakes	**If the user deviates from the set navigation path they should be able to easily identify the mistake and be offered a solution to correct it.**	*GM shows an alternative way as soon as the user deviates from the recommended route*
	S14	Reduce unnecesary decision making	**Reduce unnecessary decision making.**	*If desired, the user can just follow the instructions (visual and auditive) without making decisions.*
	S15	Levels of decision automation	**Provide levels of decision-making automation.**	*GM offers different settings of how often do you want to hear navigation cues.*
	S18	Visual autonomy	**The user should not need to see the representation visually in order to remember the route to take, system should offer alternative representations for navigation.**	*GM has auditive cues for navigation.*
	S16	Inform impact of information	**The system should provide the user with additional information over the impact on the route in case a decision needs to be made.**	*GM shows the timing of each route but doesn't show "shortest route" vs "simplest route". Relies on the visual. In navigation settings there are options such as "avoiding tolls" and "avoiding ferries".*
	S17	Feedback from user	**Allow user to give feedback over the information and recommendations provided by the system.**	*While it doesn't have a specific "I'm lost" button, users can give feedback on landmarks and provide additional information such as photos*



Appendix 7:

Additional comparisons of data.

Figure 67. Wayfinding Element Saliency, comparison between routes.

Additionally, a direct comparison is made between Routes 1 and 2 in Figure 67.

- **Visual Representation (VR):** In Route 1, participants relied less on visual cues when the song was present, especially with difficult landmarks like the stone woman. In contrast, Route 2 saw more consistent use of VR, though the bins song and street signs were less effective.
- **Order and Sequencing:** Route 2 had stronger reliance on order, especially with the bins landmark, while Route 1 suffered from an "overshadowing" effect after the fancy white house, causing participants to forget the next step.
- **Words vs. Lyrics:** Lyrics were more effective in Route 2, where phrases like "Frederik is so very long" and "not the first after the park" helped guide participants. In Route 1, confusing metaphors led to mistakes, and lyrics were not as helpful for remembering landmarks.
- **Street Signs:** Route 1 struggled with confusing street signs, while Route 2 improved saliency by using the street sign for Frederik more effectively.
- **Map Visualization:** Both routes benefited from map visualization, with Route 1 using it to navigate street sizes and Route 2 leveraging it to visualize landmarks not in the instructions, like the park.

Overall, Route 2 had stronger results in order and visual representation, while Route 1 struggled with unclear lyrics and landmark retention in the map compared to the virtual environment, became an additional reference point even though it wasn't part of the instructions.

In summary, while both routes presented challenges, Route 2 (Frederik) was more successful in terms of order and visual representation, while Route 1 (Regentesse) struggled with lyric clarity and landmark retention. Both routes see improvements when the map is used as reference but they both suffered errors from the overshadowing effect of salient landmarks and confusion caused by the visual landmarks and metaphors in the MMA.