Narrating the route: route memorability in navigation instructions augmented with narrative—results from a user study

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Abstract

From oral histories to mnemonic devices, humans have an excellent ability to remember object sequences and their relationships inside of narratives (Baddeley 1999). In pedestrian wayfinding, remembering landmarks and their relationships is considered key to learning routes (Denis et al. 2014). This research explores whether augmenting verbal route instructions with a narrative increases the memorability of a route. Narrative theory is applied as a framework to develop narrative-based navigation instructions, which were tested in a field study (N = 18). After learning a route, participants recalled the route verbally, completed a photo-based landmark sequencing task and discussed their answers. One week later, a route recognition task and a second photo-based landmark sequencing task was completed online. Results show few significant differences between the two groups when compared quantitatively. However, during interviews, the narrative group repeatedly cited the narrative when remembering the route. The results suggest that incorporating narratives into route directions can be further explored, and that some novel direction types may not be well-measured using quantitative methods. This research confirms the prowess of landmark-based instructions to facilitate route memory, contributes to the growing body of work augmenting landmark-based route directions with detailed information, and further encourages designers to consider alternate route communication methods.

Keywords— narrative, pedestrian wayfinding, route memorability, field study

1 Introduction

Wayfinding is the "planning and decision making" of navigation (Montello 2005, p. 257). While finding one's way, new spatial information is continuously gathered and processed, termed spatial knowledge acquisition (Siegel & White 1975). This new knowledge adds, updates, and refines one's mental representation of the environment, known as a cognitive map (Lynch 1960; Vanclooster et al. 2016). As wayfinding is a complex task and users do not always have existing or accurate knowledge about the environment (e.g. when in a new neighborhood), users often rely on mobile navigation applications like Google Maps, Apple Maps, or Baidu Maps (Ishikawa et al. 2008; Löwen et al. 2019; Vanclooster et al. 2016). Routing information in mobile navigation applications is usually presented in the form of a mobile map, accompanied by verbal navigation instructions (text or audio). Verbal information is given as an action ("turn"), a direction ("left") and a distance ("in 200 meters") (Rehrl et al. 2010). Street names are also frequently used. These metric turn-by-turn directions allow users to reach their destinations very efficiently, but at a cost: this type of information is detrimental to spatial knowledge acquisition (Ahmadpoor & Smith 2020; Brügger et al. 2019; Ishikawa 2019; Ishikawa et al. 2008; Krukar et al. 2020; Löwen et al. 2019).

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In response to this finding, research has focused on how a route is communicated to a user, particularly pedestrians, as well as what type of route information is given. Pedestrians are a particular use-case of navigation systems, as the type, detail, and quantity of information they require about a route are different from that of car drivers (Gartner et al. 2011; Millonig & Schechtner 2007). Given these considerations, Gartner et al. (2011) encourage the exploration of "novel interface techniques facilitating both navigation and spatial knowledge acquisition" for pedestrians. This has been taken on by some researchers in the field (e.g. Anacta et al. 2017; Huang et al. 2021; Krukar et al. 2020; Wunderlich & Gramannn 2021). Only some projects, however, have gone beyond simple landmark-based turn-by-turn directions (e.g. "turn right at the church"). However, simplicity in wayfinding directions does not always correlate with better spatial knowledge acquisition (Krukar et al. 2020). In fact, findings suggest that additional information may facilitate spatial knowledge acquisition, despite adding complexity to the instructions (Gramann et al. 2017; Krukar et al. 2020).

Meanwhile, narratives, or the telling of stories, are one of the primary tools that humans use to convey information about our experiences in the world to each other. Narratives have a particular power in human memory; a well-told story is easy to remember. In fact, organizing information into a narrative has a positive effect on memory compared with listed or otherwise unorganized information (Baddeley et al. 2015; Crowley 2018; Reisberg 2010). Existing schemata, or peoples' "long-term structured representations" of knowledge previously learned about the world, may allow people to organize incoming information into a pre-existing structure, relating new information to previously learned information in their own way (Baddeley et al., 2015, p. 139; Crowley 2018). The more meaningful detail given to the new information, the easier it is to be related in a schema (Bartlett & Kintsch 1995, as cited in Baddeley et al. 2015).

Additionally, organizing incoming information in a visual way may help invoke stronger memories of narratives as we imagine real or fictional situations. Objects that are imagined interacting are much more likely to be successfully recalled than objects that are not imagined at all, or even imagined simply side by side (Baddeley 1999; Reisberg 2010). Furthermore, the more odd, interesting, or vivid the situation is, the more likely it is to be remembered, though only if in contrast to other, less odd, situations (Wollen et al. 1972, as cited in Reisberg 2010). The concept of vividness in navigation instructions has already been tested in Tom and Tversky (2012). Building off of Tom and Denis (2004), who found that landmarks arebetter remembered than streets when they are described vividly, Tom and Tversky (2012) found that routes with vivid landmarks or street names were remembered much better than routes with less vivid landmarks and street names. Participants recalled more streets and landmarks and were more correct in placing them on a map when they received a vivid instead of a basic description. Incorporating navigation instructions into a narrative might provide more avenues for a user to connect with the physical world through their own already existing schemata, and increase the visual imagery of the instructions, further aiding memory.

This research explores a novel, non-metric form of route directions for pedestrians, with the goal of supporting incidental spatial knowledge acquisition. Specifically, the research investigates if blending a narrative with route directions affects route memorability by acting as an additional source of information that the user can rely on when remembering the route. In order to identify whether the augmentation of verbal route instructions with a narrative can be used to increase the memorability of a route for pedestrians, two main research questions are addressed:

1. What are the fundamental components of a narrative and how can they be implemented in navigation instructions?

2. Does augmenting navigation instructions with a narrative increase the memorability of aroute? This will be specifically addressed with the following sub-questions:

Shortly after navigating, as well as one week later...

2.1. is the route more accurately recalled?

2.2. is the sequence of two given landmarks better remembered?

2.3. are users more confident in their memory of landmark sequences?

This research explores a novel way of communicating a route, and its effects on memory. In order to narrow the scope, the research centers on route knowledge acquisition, specifically route memorability. Memorability is "the quality of being easy to remember or worth remembering" (Merriam-Webster 2022). Following Denis et al. (2014), this will be measured by how accurately a route is remembered.

The following sections outline related work, and present the fundamental components of narrative, where the term is defined in detail. This analysis is then used to design the navigation instructions. Then, the instructions are tested in a user study, and the results are presented. The paper concludes with a discussion of the findings.

2 Related work

2.1 Narrative and location

While incorporating a narrative into mobile navigation aids for outdoor use is novel, narrative itself is not new to cartography. This is not surprising, given that place, described by Pearce (2008) as "space shaped by experience" and narrative are closely related (p.17). Narrative setting, where story events occur, is essential to narrative; descriptions of place build a new world, the story world (Herman 2010). Narrative and cartography have supported each other in different ways. Narratives have been augmented by a user's location, termed 'locative fiction,' both outdoors (see Paay et al. 2008) and indoors (e.g. museum narratives, see Wolff et al. 2014), or even by a user's gaze (see Kiefer et al. 2020). Cartographers have also used narrative as a framework for visual design (e.g. Roth 2021), as well as a way to analyze the process of mapmaking itself (Caquard & Cartwright 2014). Narratives have been strengthened and supported by maps (e.g. Indigenous histories or maps of fictional worlds) (Roth 2021), and maps have also been supported by narratives. Here, the work of Pearce (2008) is particularly interesting, arguing that narrative provides an additional opportunity to convey a sense of place in maps.

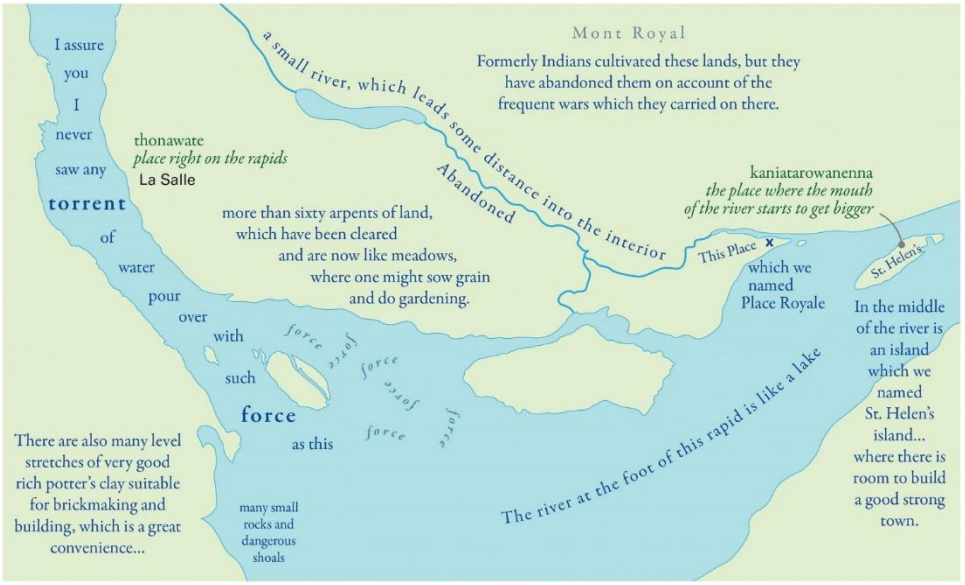


Figure 1: Hermann and Pearce (2008)'s map They Would Not Take Me There; People, Places, and Stories from Champlain's Travels in Canada, 1603–1616, published by the University of Maine Canadian-American Center. Words from Champlain's narrative are in blue, while words from a fictional narrative by Indigenous people from the area imagined by the authors are shown in green (Pearce & Hermann 2010). Used with permission from the University of Maine Canadian-American Center, ©2008 Canadian-American Center, University of Maine.

One example is the way Hermann and Pearce (2008) augment their map *They Would Not Take Me There; People, Places, and Stories from Champlain's Travels in Canada, 1603–1016* (Figure 1) with multiple narratives. They incorporate both words written by Champlain himself, using the words to describe the landscape and the journey (blue Garamond). They also include an imagined narrative from Indigenous people of the region to avoid the voicelessness of Indigenous people that so many maps of the journey perpetuate (green Garamond) (Pearce & Hermann 2010; Roth 2021). Here, narrative gives the map reader

additional information that encourages a deeper understanding of place and context than a traditional historical route map (where "specific route locations for a historical figure [where was he, when?]" are the goal) (Pearce & Hermann 2010, p. 34). In this way, the narrative acts as both a primary data layer for the map, as well as a visualization tool to deepen the readers understanding of the space. This manner of layering narrative into maps has not yet been explored as a method of route communication in outdoor wayfinding, which is of interest given the impact narrative can have on an audience's sense of place and memory (Baddeley 1999; Crowley 2018; Pearce 2008). The following sections will outline how a narrative was incorporated into landmark-based route directions and the results on memorability of the route.

2.2 Acquiring spatial knowledge during wayfinding

Various theories exist regarding how humans encode spatial information into their cognitive map. As cited in Kim and Bock (2021), Siegel and White (1975)'s influential theory posits that overall spatial knowledge acquisition occurs in three separate stages: landmark knowledge, route knowledge, and survey knowledge. Landmark knowledge is knowledge about discrete attributes of an object or scene in the environment (Ishikawa & Montello 2006). These attributes are referred to as salience, the property that makes a landmark distinct from its surroundings. Landmarks may be visually (e.g. a bright yellow building), cognitively (e.g. post office), or structurally salient (e.g. a park in a prominent, accessible location in the environment) (Raubal & Winter 2002, Yesiltepe et al. 2021). Route knowledge is the sequence of landmarks and direction choices that must be made to reach a destination. Survey knowledge is seen as the most complex level of spatial knowledge acquisition, and is an overall internal representation of the environment, a map-like representation which is properly scaled and allows for shortcuts and new routes (Ishikawa & Montello 2006; Kim & Bock 2021). More recent studies indicate that these knowledge types are likely acquired in parallel (Ishikawa & Montello 2006; Kim & Bock 2021; Krukar et al. 2020), and thus, tests of spatial knowledge acquisition in recent wayfinding studies often include measures of survey, route and landmark knowledge. This study focuses specifically on route knowledge acquisition, and therefore focuses on methods that measure route knowledge, though it is expected that users will acquire all three types to some degree. Additionally, because their importance as reference points in the environment, people rely heavily on landmarks when recalling a route, meaning that assessments of route knowledge often rely on landmarks as well (Daniel et al. 2007; Denis et al. 2007; Denis et al. 2014; Tom & Denis 2004).

2.3 Landmark-based navigation

In response to the findings in the last decades that GPS-based navigation leads to poorer spatial knowledge acquisition, many scholars have offered solutions to adapt mobile tools to increase the spatial knowledge acquired when using them. The most prominent finding is the influence of landmarks on the acquisition of spatial knowledge. Landmarks are of critical importance to wayfinding; they act as anchors in the landscape, both globally and locally (Richter & Winter 2014, Denis et al. 2007; Gärling & Golledge 2018; Lynch 1960; Wunderlich & Gramann 2021), and are relied upon to connect parts of a route (Denis et al. 2014).

Michon and Denis (2001) found that verbal route descriptions by users tended to include many references to landmarks, especially at points where an action must take place, or in moments of uncertainty (multiple options possible). Further research by Raubal and Winter (2002) proposed enriching route directions with local (on-route) landmarks, and developed an automatic extraction method to choose landmarks that should be incorporated into directionsalong a route. Tom and Denis (2004) found that memory for routes was better when participants received route information referring to landmarks instead of referring to streets. In a follow-up study however, Tom and Tversky (2012) found that better memory was more dependent on whether the names of streets or landmarks were high in mental imagery than whether a street versus landmark was used in the directions. This study suggests that it may not necessarily be that the landmark is more memorable, but that landmarks inherently provide more description than street names.

Wunderlich and Gramann (2021) found in multiple experiments that navigators had improved landmark and route knowledge when using landmark-based navigation instructions compared to metric instructions,

while Löwen et al. (2019) found that incorporation of local landmarks supported users' acquisition of route knowledge, but global landmarks supported users' acquisition of survey knowledge. Wang and Ishikawa (2018) found that landmark-based navigation instructions were especially helpful for people with a poor sense of direction (SOD).

User satisfaction is also higher when using landmark-based navigation. Ross et al. (2004) found that instructions including landmarks had a positive impact on navigation efficiency and user satisfaction. Rehrl et al. (2010) compared voice instructions enhanced with landmarks to metric directions and found that while performance was similar between the two, user confidence was significantly higher in the group navigating with landmark-enhanced directions. Taken together, these studies indicate that even if some types of landmark-based instructions do not improve efficiency, the increase in spatial knowledge acquisition as well asuser comfort is an important contribution towards human-centered navigation systems.

2.4 Beyond simple landmark-based instructions

Furthering the development of route directions to facilitate spatial knowledge acquisition, some recent research has investigated how additional information can be layered on top of basic route directions. Gramann et al. (2017) found that providing personal and impersonal facts about landmarks at decision points decreased navigation errors, increased the number of landmarks remembered, and improved sketch maps when compared with standard navigation instructions. Furthermore, the additional information did not increase cognitive load (Gramann et al. 2017). However, the standard navigation instructions did not mention landmarks, while the augmented instructions did.

In an attempt to investigate whether survey and route knowledge could be communicated simultaneously to the user, Krukar et al. (2020) studied differences between turn-by-turn, 'spatial chunking,' and 'orientation' instructions, also incorporating landmarks. Spatial chunking, proposed by Klippel et al. (2002), is where instructions are broken down into "cognitively logical chunks," or comprehensible pieces that mimic how humans communicate (e.g. "go through the park"), and do not necessarily mention every decision point (Krukar et al. 2020, p. 1). The orientation instructions, designed by Anacta et al. (2017), included survey-level information, in addition to route information (e.g. "go around the city center towards the church, then go through the park") (Krukar et al. 2020, p. 6). Importantly, results indicated that even though augmenting landmark-based instructions with additional information increased the length and complexity of navigation instructions, the information significantly improved pedestrians' acquisition of survey knowledge without affecting acquisition of route knowledge (Krukar et al. 2020). They further conclude that their more-complex orientation instructions provided more meaning to the users, facilitating their memory (Krukar et al. 2020).

Importantly, these studies provided extra information to the user within the directions, increasing the complexity of the directions in addition to increasing acquired spatial knowledge. They demonstrate that some additional information may give the user more opportunity to derive meaning out of the instructions, thus making them more memorable (Krukar et al. 2020). These findings not only support Gartner et al. (2011)'s suggestion that pedestrians have the ability to take in more detailed information, but also that this additional information can be beneficial in supporting spatial learning.

In summary, researchers have established the prowess of landmark-based navigation systems to communicate a route to a user, supporting the user's memory of the route. Furthermore, some have found that layering additional information onto the instructions can increase the route knowledge acquired while navigating, despite increasing complexity. One avenue yet unexplored is weaving a narrative into the directions to increase memorability.

3 Fundamental components of narrative

3.1 Defining narrative

In response to the first research question, properly defining the term narrative is necessary, though it is no easy task. As Roth (2021, p. 84) describes, narration and storytelling are so "fundamental to the human experience that the terms are often not defined in the literature." In cartography, the terms *story* and *narrative*

are often used interchangeably, however narratologists clearly distinguish the story, or the raw events that occurred, from the narrative, the telling of these events. To create a set of wayfinding instructions incorporating a narrative, definitions of narrative are analyzed to determine the main components, that is, the necessary 'base units' required to craft a narrative. This follows Herman (2002), who sees narrative not only "as a discourse genre and cognitive style," but also as a "resource for writing" (p. 1, as cited in Doloughan 2011). The following section outlines the historical and modern definitions of the term and the resulting fundamental components included in many definitions.

3.1.1 Historical framework

In narratology, the study of narrative, whole book sections or chapters are often devoted to the topic of defining narrative (e.g. "Defining narrative," Ryan [2005] and "Towards a definition of narrative" Ryan [2007]). There are, however, some central tenets in the field on which many of these definitions are built. Many of these arise from a classical narratological approach, forwarded by scholars such as Seymour Chatman, Roland Barthes, and Vladimir Propp (Toolan 2001).

Within this work, and stretching to more modern attempts at defining narrative, there is broad agreement on the dualistic nature of narrative, that it consists of two principal parts (there are a few exceptions, see e.g. Bal 1985, as cited in p. 12 of Toolan 2001). These two parts can be considered the what and the way of a narrative (Abbot 2007; Chatman 1978; Herman et al. 2005; Toolan 2001). The what of narrative is often referred to in English as 'story,' and the way as 'discourse,' (Chatman 1978; Herman et al. 2005; Toolan 2001).

Story is the "basic unshaped story material," and is often further broken down into events (actions and happenings) and existents (characters and setting) (Chatman 1978; Herman et al. 2005; Toolan 2001, p. 15). Chatman (1978, p. 37) notes that story on its own is an abstract representation; any attempt to tell the story "already entails the selection and arrangement performed by the discourse." Without the telling, through dance, text, speech, or other mediums, the events and existents remain unexpressed.

Bringing the raw story material into the world then requires the discourse. Discourse refers to "the means through which the story is transmitted" and refers to how the events that occurred are conveyed to narrative's audience (Chatman 1978, p. 9). It can also be thought of as a 'version' of the story: each teller of the story will create a different narrative via their use of discourse, which includes not only the medium that is used to transmit the story elements (e.g. dance, text, painting), but also the chosen order in which they are arranged (Toolan 2001).

While there seems to be general agreement on what makes up the story of a narrative, exactly what the discourse must consist of is less clear in earlier works (Abbot 2007). More recently, scholars have put forth various attempts at concrete, cohesive definitions of narrative in general, which can be used to better pinpoint the fundamentals of narrative.

3.1.2 Modern definitions

Recently, scholars have built upon this dualism and attempted to develop a brief, cohesive definition of narrative. Toolan (2001)'s definition is an oft cited one-sentence example:

> A narrative is a perceived sequence of non-randomly connected events, typically involving, as the experiencing agonist, humans or quasi-humans, or other sentient beings, from whose experience we humans can 'learn' (p. 8).

Toolan (2001) further summarizes the three defining features of narrative in his own definition as: sequenced or interrelated events, foregrounded individuals, and crisis to resolution progression (as the frequently preferred sequence of events).

Similar to Toolan (2001), Ryan (2005) defines narrative as follows, adding that the mental states and events are important as well. The definition additionally incorporates space:

- Narrative involves the construction of the mental image of a world populated with individuated agents (characters) and objects (spatial dimension).
- This world must undergo not fully predictable changes of state that are caused by non-habitual

physical events: either accidents (happenings) or deliberate actions by intelligent agents (temporal dimension).

- In addition to being linked to physical states by causal relations, the physical events mustbe associated with mental states and events (goals, plans, emotions). This network of connections gives events coherence, motivation, closure, and intelligibility and turns them into a plot (logical, mental, formal dimension) (Ryan 2005, p. 4).

The Routledge Encyclopedia of Narrative Theory also presents this definition, but additionally notes that some stories may become narratives, while some may only "possess narrativity" (Herman et al. 2005, p. 347). Chatman (1978) and Ryan (2005) also argue that narratives can possess different degrees of narrativity, or the amount that they incorporate the different fundamental elements of narrative, and some may focus more one or another element. Partially to address this, Ryan (2007, p. 29) later proposes that instead of an explicit definition, narratology benefits from a "fuzzy-set" definition of narrative; namely one that "allows variable degrees of membership, but [is] centered on prototypical cases that everybody recognizes as stories." To Ryan (2007, p. 29), a definition should consider:

1. Narrative must be about a world populated by individual existents.
2. This world must be situated in time and undergo significant transformations.
3. The transformations must be caused by non-habitual physical events.
4. Some of the participants in the events must be intelligent agents who have a mental life and react emotionally to the states of the world.
5. Some of the events must be purposeful actions by these agents.
6. The sequence of events must form a unified causal chain and lead to closure.
7. The occurrence of at least some of the events must be asserted as fact for the story world.
8. The story must communicate something meaningful to the audience.

This "fuzzy-set" definition of fundamental elements of narrative allows for greater flexibility in which works are considered narratives (better incorporating works such as painting, performance art, sculpture, etc.), while excluding categorically non-narrative pieces (such as weather reports) (Ryan 2005, 2007). It also allows for certain works to be 'more narrative' in regards to some parts of the fuzzy definition, and 'less narrative' in others.

3.1.3 Identifying the fundamental components

Taking the above modern and historical definitions, a summary of essential components of narrative can be generated, summarized in Figure 2. Overall, narratives are raw story material (story) coupled with the telling of said story (discourse). The first key part of the story material is the existents, consisting of characters and setting. Characters must be individuated (Ryan 2005, 2007) or sentient (Toolan 2001). Setting is the "place and collection of objects against which [a character's] actions and passions...emerge" (Chatman 1978, p. 138).

The second key part of story is the events. These are actions (things that characters do) and happenings (things that happen to them) (Chatman 1978), some of which must be purposeful (Ryan 2007), and should not be fully predictable (Ryan 2005). These events should be connected non-randomly (Chatman 1978; Toolan 2001), or "form a unified causal chain and lead to closure" (Ryan 2007, p. 29).

In the discourse of the narrative, these events should be ordered in some way by the author. It is this order that then effects the causal links of the events (Chatman 1978). Both Ryan (2005, 2007)'s and Toolan (2001)'s definitions include sequence; that the selected order of events matters to the overall narrative. In *the Cambridge companion to narrative* Bridgeman (2007, p. 57) adds, "the order in which events are presented in the text is...crucial to our temporal experience of narrative." Talking about events that happened in the past can lend background information to characters and setting, allowing new information to be revealed about the story (Bridgeman 2007). Flashing forward, on the other hand, can generate suspense or brief anticipation, useful tools for keeping readers engaged (Bridgeman 2007). Finally, the order in which the audience receives the story events can completely change the outcome of the narrative.

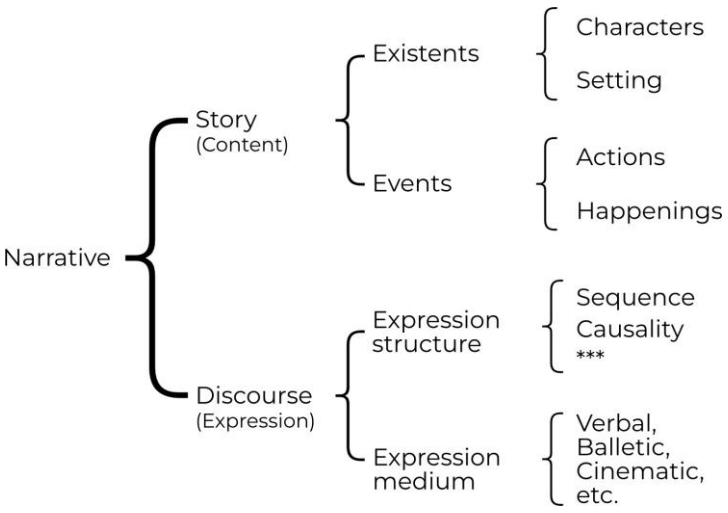


Figure 2: The two main components of narrative, story and discourse, are broken down further into events and existents, and expression medium and structure. The asterisks denote that sequence and causality are not the only two considerations for the writer of a narrative but were identified in this research as the most central. Figure adapted from Chatman (1978) based on Abbot (2007); Bridgeman (2007); Ryan (2005, 2007); Toolan (2001).

The order of events in turn effects the causal relationships of the events. Causality is a central requirement for narrative, dating back to Aristotle (Chatman 1978). A classic example of causality is from E.M. Forster:

1. The king died and then the queen died.
2. The king died and then the queen died of grief (Forster 1927, as adapted by Chatman 1978).

Chatman (1978) argues that the first sentence is simply a report, while the second is a narrative, because of the causal connection between the deaths. This causality is not always explicit. Human minds "inveterately seek structure:" if two seemingly non-related events are presented, we will automatically assume they have a relationship with the overall structure of the narrative (Chatman 1978, p. 45). In this way, the first sentence example above can also be considered a narrative, although the causal relationship is much weaker.

Finally, the narrative must be expressed in some way. This is implied in both Toolan's and Ryan's 2007 definition: narratives "must communicate something...to the audience" (Ryan 2007, p. 29), "from whose experience we humans can 'learn"' (Toolan 2001, p. 8).

In summary, it is possible to identify from the literature the primary components to include when developing a narrative from the literature, in response to the first research question. It was determined that a narrative should consist of existents, including characters in a setting, and of events, including actions that the characters take and happenings that occur to them that result in a transformation and that are not predictable. These events must be causally related and purposefully sequenced, and expressed in some way. Section 4.1.1 details the design of narrative instructions for this research, which are tested in a user study.

4 Methods

To test the memorability of navigation instructions augmented with narrative, two sets of route

instructions were designed and tested in a wayfinding study, one containing directions augmented with a narrative ("narrative instructions") and a control set with the same landmarks mentioned in the narrative instructions ("landmark instructions"). This section first explains the approach adopted for the design of the route directions and for each phase in the user study. Then, the details of the user study, including participants, materials, and procedure are discussed. Finally, the data analysis is discussed.

4.1 Methodological approach

4.1.1 Design of route directions

While designing narrative instructions for wayfinding, two primary requirements were followed. First, the narrative instructions are ultimately navigation instructions, and should thus follow standard design practices to ensure smooth navigation from one point to another.This included providing explicit actions at relevant landmarks (Denis et al. 2007; Klippel et al. 2002), using landmarks on the same side of the path as the turning direction (Klippel & Winter 2005; Röser et al. 2012), and using landmarks that had good visibility as they were approached (Yesiltepe et al. 2021). In a few cases, however, it was necessary to flout these suggestions in order to better knit together the story events. Second, the instructions should be augmented by a narrative that contained the identified foundationalelements of narrative already explained in Section 3.1.3. An excerpt of the resulting route directions can be seen in Table 1. An overview map of the route in Figure 5 is shown for reference.

State-of-the-art wayfinding instructions already share some characteristics of narrative. Most clear are actions, sequence, and setting. Directions are suggested actions: they provoke movement with a purpose. These actions are ordered: mixing the order of the directions completely changes the outcome of the navigation. Wayfinding takes place in a certain setting: the information the user receives is directly related to the physical location they are navigating. Additionally, the directions must be communicated in some way to the user, and the mode of this communication can vary. Weaker in wayfinding instructions, however, is explicit causal relationships between the actions and explicit existence of a character (and their transformation).[2]

Excerpt of route directions designed for the study

Landmark	Narrative
6. Turn right at the *pink houses*.	When they reached the *pink houses,* they turned right. Famously in 1855, a resident threw dozens of pink roses from the balcony in protest of the construction of the first public toilet. Oh, how Strauss missed politics.
7. Enter the *park* and turn left at the *table tennis table*	When Strauss entered the *park*, there were two table tennis players fighting in the dust. Some people hate to lose, Strauss thought. He turned left at the *table tennis table.*
8. Exit the *park* left	"Wait!" One of the players ran up to Strauss, panting. "They are voting to separate our district into two! Exit the *park* left and go see for yourself!"

Table 1: Excerpt of navigation instructions provided in the landmark and narrative conditions. Landmarks are highlighted in italics. Numbers refer to the direction number. The complete directions can be seen in Appendix A.

It is here in the connections of events to each other, and their connections in turn to the physical world, that narrative could provide a useful tool for memory of a route (Baddeley 1999; Reisberg 2010). Furthermore, providing a user additional information that they can already relate into their own existing 'schema' could help them relate to the information, more so perhaps, if the narrative provides vivid mental imagery along the route. For this reason, Johann Strauss, expected to be recognizable name to

[2] A weak causal relationship might be said to exist: turning onto "Bridge street" might be impossible without first crossing the bridge, for example, but this seems a stretch. Additionally, the user could be considered a character, but there is no guarantee of transformation, nor is navigating a non-habitual event.

most participants living in Vienna, was selected as the main character, and the narrative instructions were designed with a particular focus on providing strong causal relationships between narrative events that occurred to Strauss, with physical locations linked to these events, using imagery that was as vivid as possible.

Feedback about the directions was solicited from four non-participants, three of which were non-native speakers of English, to assess the clarity, audio quality, and word choice of the instructions. It was important that non-native speakers review the directions, as the participant group was expected to be international. The narrative instructions were tested against a control group in a user study, the methodological approach of which is outlined in the following sections.

4.1.2 Verbal generation of route directions

Used to assess users' internal representation of a route, participants are asked to verbally explain the route to the researcher as they remember it (Daniel et al. 2007). Verbal generation was chosen here instead of sketch maps, as it was hypothesized that more information about *why* a user remembered the route would emerge in verbal form. In addition, as Denis et al. (2014) note, verbal spatial information is particularly sensitive in capturing and conveying landmark-related information, which is important because landmarks play a central role in conveying route information (Daniel et al. 2007; Denis et al. 2007, 2014; Tom & Denis 2004). Denis et al. (2007) note, however, that "while verbal recall provides a clear answer to the question of the memorability of instructions, it does not give any real indication of the participants' understanding of the overall spatial structure of the route" (Denis et al. 2007, p. 39). As route memorability is the main focus of this study, this was not considered an issue. However, the task was combined with two other assessments to offer more comprehensive results.

4.1.3 Landmark sequencing tasks

Photo-based landmark sequencing is a method recognized as a measure of route knowledge (Denis et al. 2014; Kim & Bock 2021). As Denis et al. (2014) notes, "remembering the relative position of landmarks along a route is a critical component of navigational memory." Similarly,this research uses the method to assess the users' understanding of the sequence of scenes along the route. In Kim and Bock (2021), users had to select the three intersections in order that they had seen on a route, repeated for each of the three routes they had walked for a total of nine potential points, which were then used in a variance analysis with sketch maps. In Denis et al. (2014) and Daniel et al. (2007), 28 photo pairs were presented to the user and the total number of correct answers were averaged within each group. Analysis for the two photo sequencing tests in this research followed the method of Denis et al. (2014) and Daniel et al. (2007), but the overall number of photo pairs was reduced.

Where Denis et al. (2014) used all possible pair combinations, the photo pairs used in this study were carefully chosen based on two criteria: relatedness in either the physical world or in the narrative, and physical distance to each other. Photos of all landmarks except the starting and ending points (white palace and brown door) were considered as candidates for the photo task. Two photos were paired if they possessed either a strong causal relationship in the narrative or were closely related in physical appearance.

Three pairs which were considered to have strong causal links in the narrative were used in the first photo sequencing task (Phase 2b) and three pairs were used in the second photo sequencing task (Phase 3b). A table showing the pairings can be seen in the appendix. Likewise, three pairs considered related in physical appearance were used in Phase 2b and three in Phase 3b. Which pairs each group received was decided via a second criterion.

The second criterion was based off of literature on the symbolic distance effect. Originally studied on symbols, the symbolic distance effect is "the fact that making judgments about two items is easier when these items are more distant from each other in a given dimension," (Denis et al. 2014, p. 288; Moyer & Bayer 1976, as cited in Denis et al. 2014). The effect has also been seen in photo sequencing tasks: Denis et al. (2014) found that response times for photo sequencinggreatly decreased as the distance between a pair of given landmarks increased. For this reason, each potential photo pair was given a code of far if one photo was five or more landmarks away from the other. Using this rating, the pairs were distributed into the two phases as evenly as possible. Because the route was short and the start and end points

were excluded, each phase received only two far landmarks.

4.1.4 Route recognition tasks

Route recognition tasks (also referred to as "cued-recall tasks" or "route direction tasks") have been used as a measure of how well the user remembers which action takes place at a particular point along the route. Routes can be thought of as a linked sequence of turns, which depend heavily on the landmarks cuing the turns (Huang et al. 2012b; Münzer et al. 2006; Tom & Tversky 2012; Tversky & Lee 1999). The user's ability to recall what action to take at a certain point is regarded as a measure of the user's understanding of the route. In the literature, the method has been applied mostly as a photo task (Huang et al. 2012b; Münzer et al. 2006; Wunderlich & Gramann 2021). In this research, the method was adapted into an online text task and combined with a landmark sequencing task. Users needed to select the correct direction, which had been removed from the text (route recognition), as well as select which landmark came next (sequence of landmarks). Given previous findings on confidence and landmark-based auditory navigation instructions, confidence was measured after the photo sequencing tasks and the route recognition task (Rehrl et al. 2010).

4.2 User study

To test the memorability of the narrative instructions, a user study in Vienna, Austria was completed. Participants navigated a route using audio instructions. The following sections describe the participants, materials, and procedure of the user study, as well as the resulting data analysis.

4.2.1 Participants

18 volunteers (8 female) participated in the study. 77% had a background in cartography; most were students at the Technische Universität Wien, and all participants were between 18 and 44 years old. Participants understood at least B1 English, could hear and see, and consented to participation via an informed consent form after the experiment was explained. Additionally, a payment of 7€ was offered upon completion of the study.

Participants were divided into two groups based on equal gender balance, with one group receiving the landmark control directions (n = 10, female = 5), and one receiving the narrative directions (n = 10, female = 5). Unfortunately, one participant dropped out of the landmark group due to illness and one did not complete the second survey within 24 hours (n = 8, female = 3). Ages and professional background were well-distributed between the landscape and narrative groups. As a group, the landmark condition was slightly more familiar with the study area than the narrative group, but still most participants fell into the categories of "completely unfamiliar" and "unfamiliar." It is important to note that two participants in the landmark group, both of whom had near perfect recall on every task in the study, mentioned independently that they train their memory frequently and like memory games.

4.2.2 Materials

A route of 800m with nine changes in direction was selected along the border of the 4th and 5th districts. The route was close enough to the university that students could reach the starting point easily, but in a neighborhood that was not too close to be well-known to participants. It was also desirable to have short city blocks that allowed for more turns over a short distance. Additionally, the location should not be overly 'rich,' as rich environments have been found to increase memorability for landmarks (Denis et al. 2014).

13 landmarks were chosen for their usefulness for navigation of the particular route, visual or semantic salience, and potential to be incorporated into a narrative. Street network data from Open Data Österreich was used to map the landmarks and the route (StadtWien 2021).

Participants received a laminated simple paper map of the route during navigation. A recording of the navigation instructions was played via Bluetooth from an iPhone SE (3rd generation, Apple) held by the researcher to over-ear headphones (Flagship ANC, Status) worn by the participant. Surveys were completed on a laptop (2015 MacBook, Apple), and interviews were recorded using an iPhone SE (3rd

generation, Apple). Interview audio was transcribed using Otter (Otter.ai).

4.2.3 Procedure

The procedure of the study is broken into three phases: Phase 1: Learning, Phase 2: Verbal generation of route directions and first photo task and Phase 3: Route recognition and secondphoto task. Figure 3 shows an overview of the phases.

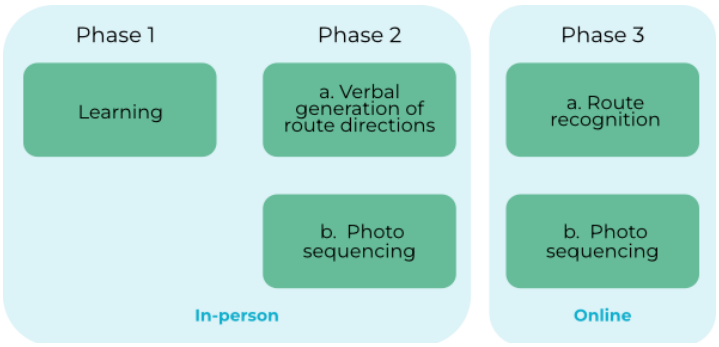


Figure 3: Overview of the three phases of the user study. Phases 1 and 2 were completed in person, while Phase 3 was completed one week later online

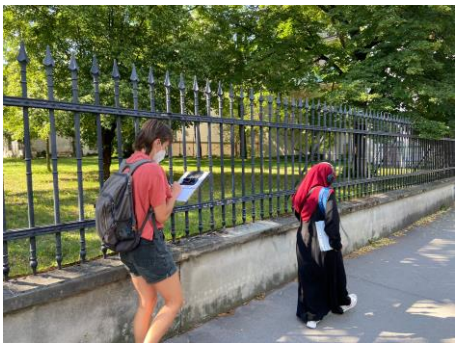


Figure 4: Demonstration of the wayfinding portion of the learning phase.

Phase 1: Learning

The first task was an assisted wayfinding task following Wunderlich and Gramann (2021), using audio navigation instructions controlled remotely by the researcher. While a few early studies found that audio-based navigation did not lead to increased spatial knowledge acquisition over paper maps (Huang, et al. 2012a; Münzer et al. 2006), audio instructions have the advantage that they do not interfere with visual attention, and have been recently found successful when used with landmarks (Krukar et al. 2020; Wunderlich & Gramann 2021; Wunderlich et al. 2022, see also Janarthanam et al. 2013). Each participant was met near the starting point, and provided with a route map inside of a small bag (simplified version of the map seen in Figure 5 with only the street network and route in blue) and headphones. Participants were instructed that they would receive audio navigation instructions through the headphones, but that they could use the paper map if they needed to. If further clarifying questions were asked, they were told to imagine their phone with a map was in their pocket that they could look at if something was unclear. These instructions were purposefully slightly ambiguous so as not to sway the user towards or away from using the map. A brief audio test was completed, which allowed the participant to adjust the volume on the headphones.

After answering any questions, the participant was led to the starting point and the navigation portion began. A recording of the audio directions was played via headphones to the user. Upon hearing the first direction, the participant began the route. The researcher followed behind, playing the navigation instructions slightly before each action to be taken. Figure 4 shows a demonstration of the wayfinding in progress. Upon reaching the end of the route, the participant was congratulated and was led to a nearby table to complete the next phase.

After reaching the interview location, the participant filled out a brief demographic survey and completed a computerized version of the Santa Barbara Sense of Direction Scale (SBSOD) from Hegarty et al. (2002), a self-reported measure of people's sense of direction. People "scoring higher on this scale do better on the tasks of wayfinding and spatial orientation that require an accurate configurational understanding of the environment" (Ishikawa 2019, p. 200). For this research, the survey was adapted into a five-page online survey with three questions per page. Format and layout were maintained as closely as possible, but it is possible that adapting the survey to the online format could alter the results.

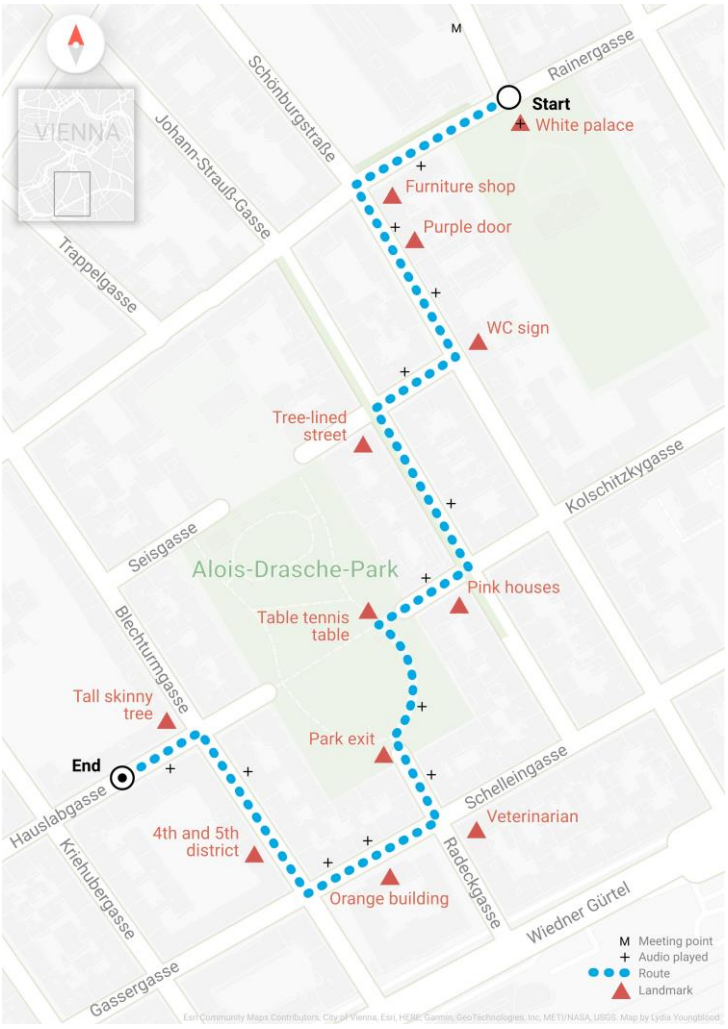


Figure 5: Overview map of the route and surrounding area. Participants met the researcher at the "M" in the far north of the map. The + symbol denotes at approximately what points the audio was played. Map by the author.

The survey took about five minutes to complete, and was completed between the learning phase and Phase 2a to introduce a slight delay in recall.[3] During this time, the recorder was set up by the researcher. Upon completion of the survey, the participant was told that audio recording would begin. This concluded Phase 1.

Phase 2a: Verbal generation of route directions and interview

Audio recording began with a scenario similar to that described by Brügger et al. (2019) and was followed by a semi-structured interview. Participants were told that they had lost their keys along the way, but a friend was meeting them at the park, so they were asked to describe the route to the friend over the phone. Based on their route description, follow-up questions were asked to better understand how a participant remembered some elements of the route better than others and to clarify any responses. The tone of the interview was casual and conversational. Participants also had the opportunity to fill in any missing route segments as they thought more about their experience. If the participant omitted part

[3] Remembering routes is affected by primacy and recency effects, two phenomena found in the recall sequential lists (Hilton et al. 2021). Items at the beginning and end of the list are more likely to be remembered than items in the middle (Baddeley 1999; Reisberg 2010). Introducing an active delay, where the user is occupied with some other task, can reduce this effect (Reisberg 2010).

of the route, they were prompted with a turn or landmark that they had mentioned, and asked if they remembered what came after that. If they were unable to remember, the next landmark was told to them and they were again asked if they remembered what followed. As a final question, each participant was asked if they wanted to add any further comments or memories. This concluded the interview section and recording continued for Phase 2b.

Phase 2b: First photo sequencing task

Participants were presented with printed photos of scenes seen during the walk. The photos were presented in pairs, with six total pairs, for a total of 12 photos. The order that the two photos were shown to the participant was random, but the first 10 participants received pair one, then pair two, and so on until pair six, while the last eight participants received pair six first, then pair five, and so on until pair one. This was to ensure that any patterns were not due to the ordering of the pairs.

Participants were asked to order the photos from left to right, placing the scene that they remembered seeing first on the left, and the one that came afterwards on the right. A brief training phase with two dummy objects and two dummy photos ensured that they understood the task. Every time the participant ordered a pair, they were asked why they were able to remember the order. Errors in the photo pairs were recorded. To measure confidence in the photo sequencing tasks, phases 2b and 3b concluded with a 5-point Likert scale question *On a scale from one to five, how confident are you in your photo answers?* This concluded the in-person phases of the research.

Phase 3a: Route recognition

One week after completing the first phase, participants received an email with a link to complete an online survey. The survey consisted of a new task designed to assess participant's route recall. The task was a combination of two methods in the literature: landmark sequencing and route recognition. The theoretical importance of these two tasks has already been explained in Sections 4.1.3. and 4.1.4.

This phase of the survey was designed to evaluate participants' memory of each action presented at a landmark and the sequence of landmarks. The route directions were divided into three sections, and then presented out of order. The first question set was about the middle of the route, the second question set about the end of the route, and the third question set was about the beginning of the route. The participant was prompted with the route directions they had received, but with the actions (turns or other) blanked out. First, they needed to select the correct action for each blank in the provided instructions. Then they needed to select which action and landmark came next from a list of four options.

The participants who were originally in the landmark condition received landmark instructions and the participants originally in the narrative condition received narrative instructions. The instructions were the same as the original, edited slightly to remove any obviously revealing information that situated the user in space. For example, the question including the seventh instruction (see Table 1, Section 4.1.1.) omitted the first half of the first sentence "When Strauss entered the park," starting directly instead at "There were two table tennis players fighting in the dust…" After completing the first section of the online survey, Phase 3b, the second photo sequencing task, was presented.

Phase 3b: Second photo sequencing task

The second task in the online survey phase was identical to the in-person photo pairs test but adapted to the online survey. Each photo was labeled "A" or "B." Here, participants needed to select photo "A" if they saw that scene first, or photo "B" if they saw the scene in "B" first. Participants confirmed that they understood the task via a training pair.

Six photo pairs were presented, different pairs from Phase 2b. 10 of the 12 photos had been seen in the first photo task, and two were new. As in the first task, the first 10 participants received pair one, then pair two, then pair three, and so on, while the rest of the participants received the pairs in reverse order. Additionally, for the last eight participants, the labeling of the photos was reversed, so that photo

"A" in pair one became photo "B" and vice-versa. Again, this was to limit any bias in the presentation order of the photos within the group. Again, at the end of the task, the user indicated how confident they were in their photo answers. Finally, the participant was thanked and the research was completed.

4.3 Data analysis

4.3.1 Learning (Phase 1)

Demographic information was reviewed for the groups and is summarized in Figure A.1 in the appendix. SBSOD scores were analyzed following recommendations by Hegarty et al. (2002),with scores reverse-coded so that all scores for the 15 questions could be averaged for each participant. Therefore, a score of one would correspond to a poor SOD, and seven to a good SOD (Hegarty et al. 2002).

4.3.2 Verbal generation of route directions (Phase 2a)

Interview audio was transcribed, and transcripts were checked for clarity. The participants' descriptions of the routes were rated by the researcher into one of three categories: "good," "fair," and "poor." The rating method is based on a similar method used in Denis et al. (2014) and Daniel et al. (2007). Both of these studies, however, only present the percentage of routes ranked as "good." Here, three categories were created. Table 2 shows the criteria for the categories.

In cases of ambiguity, the researcher looked further into the interview to understand whether the participant clarified or further developed their expression of the route. Some participants gave a route description that was missing a segment, but immediately after completing the description filled in the hole on their own initiative as more memories came back. The researcher included these in the assessment of the route quality only if the user brought up the missing segments themselves.

Ratings of the route descriptions

Rating	Description
Good	• Route is near perfect; if followed, directions will easily bring the listener to their goal. • Very few mistakes in either indication of direction or description of landmarks. • All or almost all parts of the route are discussed.
Fair	• Route is OK; if followed, directions will lead user generally in right direction but may have to consult a map. • Some mistakes in either indication of direction or description of landmarks • Most parts of the route discussed, although some short segments may be missing
Poor	• Route is poor; unable to be followed in some or all places, listener very unlikely to reach goal. • Many mistakes in either indication of direction or description of landmarks. • Large segments (> 3 or more turns) may be missing

Table 2: Shows the criteria for rating the user-generated route descriptions.

4.3.3 Photo sequencing tests (Phases 2b & 3b)

The two photo sequencing tests each produced four different groups for data analysis: one narrative group that had received image pairs one through six (NAR16), one narrative group that had received image pairs six through one (NAR61), one landmark group that had receivedimage pairs one through six (LM16), and one landmark group that had received image pairs six through one (LM61).

For each phase, the number of correct photo pairs was added up for each participant. For example, if a participant had gotten five pairs correct, they received a score of five. The highest possible score

was six. The scores from the two landmark groups were tested for significant difference between groups using the Kruskal-Wallis test (KWt), a one-way Analysis of Variance (ANOVA) on ranks for non-parametric data sets. If the differences were not significant, the two landmark groups could be combined and analyzed together, as well as the two narrative groups. Significance was then tested between the resulting two groups. The same procedure was done for both the first (2b) and second photo sequencing test (3b).

In the first photo task (Phase 2b), each participant was asked "Why do you remember it that way?" after sequencing each photo pair (six answers per participant). This qualitative data was analyzed based on themes emerging from the answers. In the second photo task (Phase 3b), each participant was asked just once after sequencing all photos "In general, how did you remember all of your photo answers? Did any information in the instructions help you remember your answers?" Similarly, emergent themes are analyzed.

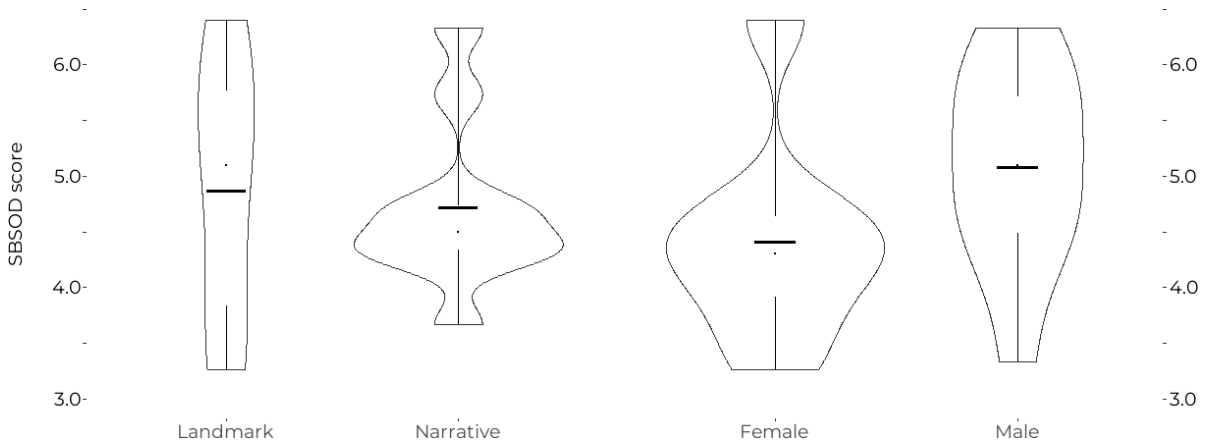
4.3.4 Route recognition (Phase 3a)

The number of correct answers was added up for each participant. Averages were then calculated within each group. There were 12 total questions; therefore, the highest possible score was 12. Averages for each group were computed, and significance was tested between the two groups.

5 Results

5.1 Phase 1: Learning

All participants successfully reached the destination with ease. Only two participants needed to be corrected during navigation, both in the landmark group. The overall SBSOD score for all participants was 4.78 (SD = 0.962, highest possible = 7). The SBSOD scores were similar in the two groups: the landmark group had an average score of 4.87 (SD = 1.21) and the narrative group an average score of 4.71 (SD = 0.772) (Figure 6a). The SBSOD scores were additionally grouped by gender and analyzed: females had a lower average score of 4.41 (SD = 0.938) compared to males with an average of 5.08 (SD = 0.917) (Figure 6b). Overall average scores and the difference between male and female participants are consistent with the literature (Huang et al. 2021; Montello & Xiao 2011), so SBSOD scores are considered balanced in this study. Finally, the landmark group was slightly more unfamiliar with the study area than the narrative group.



(a) Average SBSOD score by study condition *(b) ...and by gender identity*

Figure 6: Average Santa Barbara Sense of Direction Scale (SBSOD) score grouped by study group and gender identity. These violin plots show the distribution of the group (curves) in addition to the median (dot), IQ range (blank space), whiskers (line), and mean (crossbar).

5.2 Phase 2a: Verbal generation of route directions

Overall, participants were able to remember and describe the route well. In total, 11 routes were rated

as “good,” four as “fair,” and three as “poor.” Table 3 shows the resulting ratings of the route directions. The two groups had similar performance: in the landmark group, five of eight (62.5%) routes were rated as good, compared to six of ten (60%) in the narrative group. Only two routes were rated as poor in the narrative group, and one in the landmark group. This means that in both groups, most users recalled a route that would allow the follower to travel the route with little or no additional help, and that most or all of the route was discussed. The results are similar to Denis et al. (2014), who found 50% and 66% of routes rated as ‘good’ in a visually dull environment and visually rich environment, respectively.

Results of rating route descriptions

Condition	Rating	Number of routes rated	Percentage of total (%)
Landmark (n = 8)	Good	5	62.5
	Fair	2	25
	Poor	1	12.5
Narrative (n = 10)	Good	6	60
	Fair	2	20
	Poor	2	20

Table 3: Shows results of rating the user-generated route descriptions.

Asking participants to describe the route verbally was chosen because it was hypothesized that users would be able to provide more information about why they remembered the route in their answers than with sketch maps. However, this was not the case. For the most part, participants in both groups answered similarly: they gave concise, landmark-based turn-by-turn directions, mentioning only a landmark, an action ("turn right"), and locomotion ("go" or "walk"). and an action. Compare Participant 39 from the landmark group with Participant 98 from the narrative group:

> **39** ...exit the palace and turn left and then turn left at the furniture store. Then walk past the purple door. Turn right at the sign for the toilets. Enter the park and turn left at the table tennis table. Exit the park and walk straight ahead...

> **98** Then there was a toilet sign and there you turn right and then the next one left...it was a street with lots of trees. Then I think the next one was right. And then straight and then...there were some pink houses and just before you are at the pink house you turn right again. And then there’s a park and you turn left in the park and then you go... like a quarter circle and then you exit and on the left again.

The general absence of mentions of the narrative could have been due to the way the prompt was formulated. Participants were asked to describe the route to their friend so that the friend may follow it and look for their keys. Additional information, such as where Johann Strauss met his wife, may have been seen as irrelevant to the friend’s task. In fact, Participant 50 brought this up in the interview, “I need to give a generalized view of the path to follow because I guess he’s [friend on phone] not interested in...if that building, I don’t know, has any value. Just like, go quickly? Probably I need him to go fast, I need my keys” (Participant 50). An alternative could be to ask the participant to describe the route so that their friend can memorize it and to see which information the participant chooses to include.

5.2.1 Mentions of narrative in the semi-structured interviews

While the narrative was barely mentioned in the users’ route descriptions, it was brought up by all ten participants in the narrative condition in the interview that followed. Sometimes participants just mentioned characteristics or events described in the narrative:

> **Researcher** And you really remembered the toilets...what made it stick in your mind?

33 I think it's because it's the oldest one in Vienna. Yeah. I think that that was what made it stick in my mind.

Other times participants mentioned that the narrative helped them remember a landmark or a part of the route:

Researcher Were there any points...that really stuck with you?

70 I don't know, maybe the furniture shop? I don't know why. And the purple door, probably from the backstory, I would say...those really like struck in my memory, specifically the furniture store. Because it was also saying like: oh, how I wish to be sat down right now. And I feel like, okay, that's kind of interesting.

...

Researcher You also remembered the orange building pretty well. And multiple times you've brought it up. Why do you think you remember that one?

70 Probably because I feel like it had a lot of essence to the story. It's like... the people, the line... I think it also connects with the fact that he also came to this tree to join the other people. So I guess that's probably why. And it was mentioned also a lot on the audio like, of how he... kind of like... it also affected like his emotions while walking. So I guess that's why I also remember it.

86 [Speaking about why the border between 4th and 5th district was interesting] And it was also nice, the way you narrated it, because, like... you mentioned that there are people on both sides. Fourth, fifth. And so this also, I think, helps the person as you're walking to also kind of animate it in your mind.

27 Yeah, I remember the oldest toilet of the city. And I really would like to see it. Of course it might be interesting. And that was also interesting that they were protesting against it with the roses.

Researcher Do you remember where that happened in the environment, that protest?

27 Yeah, the buildings were on a crossing. And they were also kind of purple colored? And it's... I think it was aft- no, before the park.

The quote above from Participant 27 is particularly interesting because the participant performed poorly on the route description task, giving a very brief overview of general directions. This segment described in the quotation was forgotten by the participant in the route description task, however, here they describe the segment perfectly.

The route directions that participants in the two groups generated showed no difference in quality of the route. However, that all ten participants in the narrative group later discussed the narrative in their interviews is intriguing. It suggests that at least some parts of the narrative remained in their memory after navigating.

5.3 Phase 2b: First photo sequencing test

The KWt affirmed that the average number of correct photo pairs between the four sub-groups showed non-significant differences ($H = 3.073$, $p = 0.3806$, $df = 3$). This meant that the order in which the photo pairs were presented likely had no effect on correct answers. Therefore, the two landmark groups, LM16 and LM61, were combined and analyzed together, as were the two narrative groups, NAR16 and NAR61. Of the six photo pairs presented, the mean number of pairs eliciting correct responses was 5.5 ($SD = 0.756$) for the landmark condition and 4.8 ($SD = 1.23$) for the narrative condition. The difference is not significant ($H = 1.55$, $p = 0.2131$, $df = 1$).

Both groups showed high average confidence in their answers for the photo task. On a scale from one to five, with five being "extremely confident" and one being "not confident at all," the average answer was 4.25 ($SD = 0.463$) for the landmark group and 4.10 ($SD = 0.738$) for the narrative group.

For each photo pair, participants were asked why they remembered the pairs in the order they chose. Mostly, answers were similar across both groups. Common reasons for remembering a photo pair included the position of the landmark relative to the start or end of the route ("this was literally the first direction that I got, take the left at the furniture store" [Participant 113]), uncertainty ("actually I couldn't find like the reference to the toilet in the street...So that's how I remember it again" [Participant 86]), mistakes in navigation ("this is where I made the mistake with the trees" [Participant 104]), and slope of the street ("and that must have been after the park because it's higher up on the hill" [Participant 60]). One difference between the two groups was that the narrative group frequently mentioned the narrative as a reason for remembering photo sequences, discussed in detail below.

5.3.1 Mentions of narrative in Phase 2b

Nine of ten participants in the narrative condition brought up a part of the narrative for at least one photo answer when responding to the question. Sometimes a participant used the landmark's identity in the narrative simply as an identifier (instead of, for example, its visual or semantic salience, or the name of the landmark used in the instructions, as was common in the landmark group). Participant 104 said about the second photo pair:

> **104** We're entering the park and then there is the table that they're like playing and fighting, and then we exit and...after we exit the park we reach the veterinarian and then we go to the right.

At times, the narrative seemed to be used to distinguish two photos that looked similar, or to recognize the scenes, such as Participant 27 choosing the sequence of photo pair five:

> **27**...is it not the same? Ah! This is the street where the dog wants to pee and theseare the houses with the flowers. I think this was... this was first [points correctly to tree-lined street].

Sometimes participants seemed to use the narrative more as an anchor point to determine the order of other landmarks. Participant 70, speaking about their correct answer of the second photo pair is a good example:

> **70** ...And then he turned right, and he reached to the orange building. So that's... this is like after he left to join the people I think, after he left the park.
>
> **Researcher** Because he had learned about the people in the park?
>
> **70** Yeah. So it was like he turned... I remember turning left. And then he meets another person and the person tells him like to go take a look. So he also turns left and goes to join them. Yeah, I think.

"Them" in this case is the group of protesters along the border of the 4th and 5th districts. This part of the narrative has very strong causality; Strauss proceeds to the protest because he hears about it from people in the park. Participant 86 felt similarly:

> **Researcher** Why do you remember it that way?
>
> **86** The same. Because it's too powerful...this is the border at the end so much later in the story.
>
> **86** This is the very, like, strong part of the story, it helps you also. Because I think that like... like in Europe, I think every other street looks the same. I mean, you know, especially in the suburbs, I would say, because I think we are also a bit not in the center right now.

The results from Phase 2 are conflicting. On the one hand, there was little quantitative difference between the two groups in their route descriptions and performance on the landmark sequencing task. On the route descriptions, 60% (narrative) and 62.5% (landmark) of routes were rated as 'good,' though taken together with the 'fair' category, 87.5% (landmark) and 80% (narrative) of routes were able to get the listener heading towards their destination with little or no additional assistance, a good result, especially given that

many participants mentioned thatrecalling the route was difficult. The photo sequencing task also showed good performance, with non-significant differences between the groups. On the other hand, data from the interviews shows that the narrative group additionally recalled information from the narrative, sometimes seeming to rely on it to connect locations in sequence, so it is also impossible to conclude thatthe narrative did *not* lead to improved recall of the route shortly after navigating.

5.4 Phase 3: Route recognition and second photo sequencing test

5.4.1 Phase 3a: Route recognition

After a period of one week, each group completed the online survey, starting with the route recognition task. Of the 12 questions asked in this task, the narrative group performed slightly worse, with an average of 10.1 questions answered correctly. The landmark group averaged 11.4 questions correctly, a barely significant difference ($H = 3.918$, $p = 0.0478$ [$\alpha = 0.05$], $df = 1$).

5.4.2 Phase 3b: Second photo sequencing test

Like the first photo test, a KWt between the four resulting groups confirmed that the average number of correct photo pairs showed non-significant differences ($H = 1.94$, $p = 0.585$, $df = 3$). Therefore, the two landmark groups were combined, as were the two narrative groups. Of the six photo pairs presented, the mean number of pairs eliciting correct responses was 5.88 ($SD = 0.354$) for the landmark condition and 5.60 ($SD = 0.699$) for the narrative condition. The difference is not significant ($H = 0.844$, $p = 0.3583$, $df = 1$).

Both groups showed the same average confidence in their answers for the photo task, with an average of 4.00 (landmark $SD = 0.756$, narrative $SD = 0.816$). Again, the scale was from one to five, with five being “extremely confident” and one being “not confident at all.” This slight decrease in confidence compared to the levels reported in Phase 2b is expected given the one-week delay between navigation and Phase 3b.

5.4.3 Memory of photo answers

While there was no difference between the groups in quantitative terms, some differences arose when participants were asked how they remembered all of their photo answers, and if any information in the instructions helped them to remember their answers. Some excerpts from the landmark group are provided below.

> **15** I think [it] is the combination of listening to the instructions, certain peculiar descriptions, and walking along the streets.
>
> **39** If I was given simply street names and directions which way to turn I probably would not have remembered any of the photos at all. If I were to walk the same path again, I would find my way without instructions. Had I used Google Maps or any other standard navigation system that would not be the case.
>
> **60** I think the most helpful part of the instructions was that they were very detailed and location specific instead of just “turn right/left.” I remember some of the route we walked and the tree lined street because I forgot about that last week in the questions after walking.
>
> **95** Just like the machine learning algorithms, we’re tested several times...the memory of those “correct” answers will be kept for a longer and longer time. For the first time, the instructions definitely help me to remember the answers, but this time, the tests last time are also very important, like half-half.

In general, the comments about memory of the second photo task can be summarized into type of directions (landmark-based) and learning effects from the tasks completed previously. One user also mentioned that mistakes they made in navigation helped them to remember the sequences.

Like the landmark group, the narrative group also noted learning effects from the previous week and

landmarks having an influence on their memory. Additionally, corresponding to their responses following the first photo task in Phase 2b, the narrative group also brought up the narrative as a strategy for remembering the photo sequences.

> **22** The instructions made me remember the sequence itself and I relate them with some of the remarkable elements in the path walked.
>
> **50** The instructions definitely helped; Words such as 'he followed the WC sign' and 'he turned right at the veterinarian' have been deeply engraved in my mind!
>
> **30** I think the fact of having a story behind the instructions helped me a lot. By remembering some important facts of the story which I associate with images I saw, it is easier to remember the order of facts even if there are some things that I don't remember.
>
> **86** I was able to remember the points with reference to what was happening in the storyline [sic].
>
> **98** I remembered special things like the purple door, the toilet sign, the tree lane, etc. cause I thought they had either funny or nice background information [sic].
>
> **70** Personally, some of the information I got during the survey one week ago were kind of engraved in my brain. Since the elements were seen by walking, heard from the headphones and then discussed with pictures it really helped to remember some without even trying to.

Similar to the second phase, the third phase showed little difference between the two groups' answers when measured, with the exception of Phase 3a, which showed a slight advantage to the landmark group. Both groups were equally confident in their answers. However, like in the second phase, users in the narrative group in the third phase additionally brought up the narrative either as a feature of a landmark or as a way to determine the sequence of landmarks. Finally, users in both groups gave positive feedback about the style of the instructions and the incorporation of landmarks.

5.5 Summary of results

In the first phase of the study, users navigated a route of nine turns with few errors. In the second phase, participants in both the narrative and landmark groups remembered the route well, with over 80% of participants in each group discussing all or most of the route, using directions that would allow the follower to head in the correct direction with little or no additional help. There was little difference between the way in which the two groups described the route, with most descriptions following the pattern of landmark + turn + locomotion. In the interviews, however, all members of the narrative group mentioned the narrative. The quantitative results of the landmark sequencing task of the second phase showed no difference between the two groups, however the narrative group additionally brought parts of the narrative as additional attributes of some landmarks. Both groups were highly confident in their answers.

In Phase 3, the landmark group showed a slight advantage in a route recognition task. In the second landmark sequencing task the two groups performed similarly with high confidence. As memory aids, both groups mentioned landmark-based directions and learning effects, with the narrative group additionally mentioning the remarkable elements from the narrative as helping their recall.

6 Discussion

This study determined the base elements of narrative and designed narrative navigation instructions for a short route in the city of Vienna. The instructions were evaluated using an in-situ wayfinding study and mixed-method design, introducing interviews to attempt to better understand users' responses to both the route recall and photo sequencing tasks. The research was broken into two primary research questions

and three sub-questions, the outcomes of which are addressed below.

As a starting point, it was necessary to determine how to draft a narrative for navigation. In response to the first research question, the principal components of narrative were identified in Section 3.1.3. Some principal components could be already identified in state-of-the-art metric instructions, primarily that directions are already actions which take place in a setting, sequenced to provide meaning to a user, and communicated in some way. This allowed for the design of the narrative for this study to focus on introducing strong causal relationships between story events, which were tied to landmarks in the physical environment (see Section 4.1.1). This is not the only way to incorporate narrative into wayfinding instructions; nor is it necessarily the best, but it offers an initial approach to the subject. Narratology is a broad field, and there are likely other interpretations of the definition of narrative available from which designers can draw from to build narrative instructions. Other approaches such as layering short narratives onto each landmark individually may be entirely suitable for navigation instructions and have different effects on memory, suggesting a further research direction.

6.1 Positive feedback about both types of instructions

It can be argued that a narrative involving Johann Strauss may not be engaging enough to some participants to provoke a stronger memory of a route, however in this particular study, we found the response to the narrative instructions to be overwhelmingly positive and enthusiastic. In fact, despite not being explicitly asked, there were positive reviews about the type of directions across both groups. An excerpt from the landmark group:

> **39** I'm not that good at receiving directions...I usually take the wrong turn at least once if it's a new area. So this worked kind of better. I don't know why. But it was very clear. I always knew where to go. Like as soon as I saw the point. I knew where to go immediately It was pretty clear and easy and uncomplicated, so there's not much to think about.

In the narrative group, users mentioned that they enjoyed the route directions, though some noted that they needed some time to get used to the style:

> **70** Yeah, it was pretty easy to follow the direction to be honest. So I did not feel the need to check [the map] out. I feel like it was totally clear.

> **30** And it was like the story was explaining about this line of people voting in the city hall. I think it's super nice, that. Perhaps in the beginning, it takes time to get used to it. Like that you have to follow the instructions, but it's a story at the sametime, but once you are in, you kind of get it.

> **98** But I really really like it. I think it's interesting. And I didn't think it would work this good.
>
> **Researcher** So when you started out, you were like, hmm.
>
> **98** Yeah. But then going in.....I felt confident.

No user said that they did not like the directions, though it is important to remember that participants were not explicitly asked for their preference. Nevertheless, many participants gave positive and at times quite enthusiastic feedback about the instructions, independent of which group they were in. Results from the narrative group indicate that there is a learning period for some for this type of narrative directions. The learning period could be accounted for in future studies by the incorporation of a training phase. This positive feedback from both groups, as well as their successful navigation further encourage the design of landmark-based route directions, and indicate that the approach taken in this research to incorporate narrative into wayfinding instructions was successful.

6.2 Similar results seen in quantitative tasks

When testing the memorability of the instructions with quantitative methods, the overall results from Phase 2 and 3 show almost no difference in route memory between landmark and narrative instructions. This was measured by whether the route was recalled more accurately (RQ 2.1) in phases 2a and 3a, and whether the sequence of two given landmarks was better remembered (RQ 2.2) in phases 2b and 3b. In Phase 2a, both groups performed well, with almost all (83%) participants recalling routes that were rated as "good" or "fair", meaning that most parts of the route were discussed, and that the directions would generally lead a navigator to their goal. This is interesting given that the task was difficult for some participants, who noted that it would be far easier to re-walk the route. In the cued recall task of Phase 3a, both groups were able to complete directions with a high success rate, as well as select the next landmark with few errors. This was the only phase that showed a statistically significant difference between the two groups, with the landmark group slightly outperforming the narrative group.

The quantitative results addressing RQ 2.2 show no difference between the narrative and landmark control groups in terms of memory of landmark sequence. This was measured in phases 2b and 3b with paired photo sequencing tasks. Participants in both groups recalled almost all photo pairs accurately in Phase 2b, as well as one week later in Phase 3b. Additionally, user confidence for the photo sequencing tasks was similar in each group, both shortly after navigating and one week later. It can be concluded that the narrative instructions did not increase user confidence compared to landmark instructions. However, the overall confidence for the photo tasks of both groups was high, supporting findings from Rehrl et al. (2010), who found that landmark-based directions resulted in higher user confidence.

These quantitative results would suggest that there is no difference in memorability between the two types of directions. However, the relatively homogenous sample of this study may be a contributing factor. Due to the research timeframe, a convenience sampling method was used to recruit participants (Roth et al. 2016). This consisted of posting flyers in and around the campus and spreading the word through professional networks, which resulted in mostly student participants in the field of cartography. Further work on the topic would benefit from a more diverse participant group. Additionally, targeting specific groups such as children or the elderly could provide interesting insight into the memorability of these instructions.

Furthermore, it is important to remember that landmark-based instructions like those used in the landmark control group have been proven to be more memorable than the metric turn-by-turn instructions being used in state-of-the-art navigation products (Denis et al. 2014; Löwen et al. 2019; Ross et al. 2004; Wunderlich & Gramann 2021; Wunderlich et al. 2022). This is a further explanation for the lack of quantitative difference between the two groups, and may have contributed to a ceiling effect in the study. This may further be supported by the comments given by users in Phase 3b regarding learning effects, and should be carefully considered in future studies. On the other hand, the strong performance reiterates the strength of landmark-based instructions.

6.3 Further insight from interviews

Taken alone, these quantitative results indicate no improvement on memory of a route when using narrative vs landmark instructions, measured by accuracy of route recall and better memory of the sequence of landmarks. The qualitative results of the study, however, do show differences between the two test groups. In the interviews from Phase 2a, all participants in the narrative condition brought up the narrative while discussing the route. Sometimes users just referred to a narrative event or character as a descriptive or defining characteristic of a landmark, while other times users directly mentioned that it helped them to remember a part of the route. This finding was also present in the qualitative results from phases 2b and 3b. When asked why they remembered a certain photo sequence, participants in both groups cited reasons such as the position of the landmark relative to the start or end of the route, uncertainty and mistakes, use of global landmarks, and slope. The narrative group, however, also relied on parts of the narrative to facilitate their memory of the sequences, with 9 of 10 participants citing the narrative at least once as a reason for remembering a sequence. When asked how they remembered their photo answers in Phase 3b, participants in the landmark group primarily cited landmarks and learning effects as reasons for memory. The narrative group, on the other hand, primarily cited the narrative, with some

mentioning landmarks and learning effects as other reasons.

Taken together, the quantitative results of the study show that the incorporation of this narrative did not lead to improved memorability compared with landmark-based directions. On the other hand, the qualitative results from this study do not support this result, and suggest that narrative may have an effect on users' memories of the route. Participants did form some relationship to the narrative about Johann Strauss, which appeared in results from phases 2a, 2b, and 3b. This suggests that a narrative might act as an additional source of information that a navigator can rely on to remember landmark sequences along a route. Further research is necessary regarding exactly which components of a narrative are the most useful to the user and at which points in the route, however, that there was an effect is an important initial finding. Furthermore, the differences between quantitative and qualitative results suggest that a reconsideration of methodology may be necessary to address the phenomenon observed in the qualitative data.

6.4 Narrative navigation instructions work

Finally, while this study did not set out to measure navigation performance, there was no observed difference in how participants in the narrative condition navigated the route in comparison with the control group. Participants in both groups reached the final destination with very few errors overall. This indicates that implementing a narrative into wayfinding instructions is an entirely feasible alternative to simple landmark-based directions. Furthermore, the enthusiasm and positive feedback about the instructions across both groups further encourage the development of landmark-based wayfinding instructions for pedestrians.

These results suggest that incorporating a narrative into wayfinding directions can affect the memory of a route, but that different methods may be required for assessing the impact on memory. However, considering the qualitative evidence from this research, it is clear that narrative can be successfully implemented in wayfinding directions, and that this implementation does leave a mark in users' memories. The results further suggest that more research is needed to develop appropriate methods to analyzing route memorability and the effects of narrative, as the quantitative methods used in this research may not suffice.

6.5 Limitations

To assess what parts of the navigation instructions were remembered, a semi-structured interview and open-ended questions were added to existing methods so that the user might explain their choices. This mixed-method design is a novel method for assessing route memorability. The method was useful as it gave the researcher more information in cases of ambiguity in rating the route directions and gave the participant the opportunity to correct or add any additional information that came to mind immediately after describing the route, ultimately giving a more wholesome representation of their memory of the route. Discussion mostly centered on why a participant did or did not remember particular route segments or landmarks, but questions about the actual route also came up. Great care was taken to avoid re-telling the route to the participant by instead prompting the participant to fill in any blanks in their route memory on their own. However, discussing these themes may have led to some learning effects, which are critical to manage in a study focused on memory.

Additionally, the period of one week between the second and third phases was chosen based on research that sequential information remembered after one week is similar to that remembered after one month (Baddeley et al. 2015). However, it may be that a one-week period is too short, and a longer recall period of several weeks or months is more revealing, an interesting direction for further research.

While the participant numbers were small for this study which likely affected the results, they were similar to other related work (e.g. Anacta et al. 2018; Anacta et al. 2017; Huang et al. 2012a, 2012b). One unexpected benefit of this smaller sample size was that it was easier to rate the quality of the route for one researcher, as it allowed direct comparison between routes to ensure consistency. However it is common for route depictions (verbal or sketch) to be rated by two or three researchers (e.g. Anacta et al. 2017; Denis et al. 2014; Krukar et al. 2020). This research would benefit from two or three raters. Additionally, transcripts were blinded; only the participant number was available to the researcher, not

which condition the participant was in. Nevertheless, it was typically clear which group the participant was in based on what was said, which has the potential to affect results.

7 Conclusion

Narratives are powerful tools for memory, from oral histories that pass down knowledge of terrain and landscapes, to successful mnemonic devices (Baddeley 1999; Livo 2018). Narratives are good memory devices because they organize incoming information, and provide additional imagery that humans can incorporate into their already existing knowledge (Baddeley 1999; Crowley 2018; Reisberg 2010). Meanwhile, in the last decade, navigation systems designers have turned towards more human-centered approaches. Of particular interest has been how to develop digital mobile systems that support instead of hindering spatial knowledge acquisition, which includes the ability to remember a route. While narratives have been incorporated into maps in diverse ways, it has not yet been explored whether narratives can be implemented in wayfinding as a memory aid. The objective of this research was to identify whether the augmentation of verbal route instructions with a narrative can be used to increase the memorability of a route to pedestrians. This study incorporated a narrative about Johann Strauss into wayfinding instructions and evaluated the effect on route memorability, measured by accuracy of route recall, memory of landmark sequences, and user confidence.

As in prior research, this study implemented multiple methods to assess what information a user had retained about a route. Novel in this research was the implementation of a mixed-method design, introducing interviews to attempt to better understand users' responses to both the route recall and photo sequencing tasks. The mixed results indicate that while narrative may not lead to improved memorability of the route, it can change what type of information about the route is remembered. This is remarkable, given that adding just any type of additional information to a landmark does not necessarily make it more memorable (Gramann et al. 2017). Additionally, the insight gained during the interviews indicate that only using quantitative methods to assess the memory of a route may not be sufficient.

Further research is necessary regarding exactly which components of a narrative are most useful to the user, whether it is simply the additional information, causal relationships, or some other reason, and at which points in the route, however, that there was an effect is an important initial finding. As discussed, it may be of interest to study how different groups perform using narrative directions, such as people with a good sense of direction versus those with a poorer sense of direction, given that those with a better sense of direction tend to use survey knowledge, while those with a poorer sense of direction tend to rely more on route knowledge (Ishikawa 2019). Route characteristics, such as complexity, length, richness, or relevance to the user could also be investigated. Finally, it is important to remember that landmark-based instructions like those used in the landmark control group have been proven to be more memorable than the metric turn-by-turn instructions being used in state-of-the-art navigation products. Further research could investigate the layering of a narrative onto state-of-the-art metric instructions to reduce the impact of landmarks on memory, perhaps gaining a better sense on the overall impact of the narrative (Denis et al. 2014; Löwen et al. 2019; Ross et al. 2004; Wunderlich & Gramann 2021; Wunderlich et al. 2022). Given the cost of developing such instructions, further research is required into potential specific use cases in the outdoor environment, though the development of recent AI tools may make it easier to augment navigation instructions with narratives or other information at a lower cost.

More broadly, the research opens up pathways for further exploration of the topic and builds on existing research exploring creative alternatives to simple landmark-based navigation directions. Overall, it is clear that narrative can be incorporated into wayfinding directions, but the question still remains open as to how it may lead to improved memory of a route.

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Appendix

Appendix

Route directions designed for the study

Landmark	Narrative
1. Exiting the *palace,* turn left.	Johann Strauss needed to take his dog to the veterinarian. He left his white palace and turned left down the street.
2. Turn left at the *furniture restoration shop.*	By the time he got to the *furniture restoration shop* on the corner, his old body was tired, and he wished for a rest in one of their chairs. But he turned left and continued up the street.
3. Walk past the *purple door.*	He smiled as he passed the *purple door* where he had met his wife 30 years ago.
4. Turn right at the *sign for the toilet*.	At this age, he couldn't make it far without a toilet, so he took a right at the *sign for the toilet*, the oldest public toilet in Vienna.
5. Turn left onto the *tree-lined street.*	When they turned left onto the *tree-lined street*, his dog had the same idea, stopping at every single tree to mark her territory.
6. Turn right at the *pink houses*.	When they reached the *pink houses,* they turned right. Famously in 1855, a resident threw dozens of pink roses from the balcony in protest of the construction of the first public toilet. Oh, how Strauss missed politics.
7. Enter the *park* and turn left at the *table tennis table.*	When Strauss entered the *park*, there were two table tennis players fighting in the dust. Some people hate to lose, Strauss thought. He turned left at the *table tennis table.*
8. Exit the *park* left.	Wait!" One of the players ran up to Strauss, panting. "They are voting to separate our district into two! Exit the *park* left and go see for yourself!"
9. Turn right at the veterinarian towards the *orange building.*	Strauss hurried straight ahead, turning right at the veterinarian towards the orange city council building. The veterinarian could wait, this was important.
10. Walk past the *orange building.*	Passing the orange city council building, he could see lines of people voting. He grew outraged. "Separating our districts! And I didn't even know! It cannot be."
11. Take the *first right.*	He took the *first right*. (Pause) This was the proposed border between the two new districts. The street was filled with people, on one side shouting "5th! 5th! 5th!" and on the other side shouting "4th district! 4th! 4th!" But where could Strauss make a stand?
12. ---	Feeling young again, he climbed the *tall skinny tree* on the corner, and joined in the shouting, excited to be involved once more.

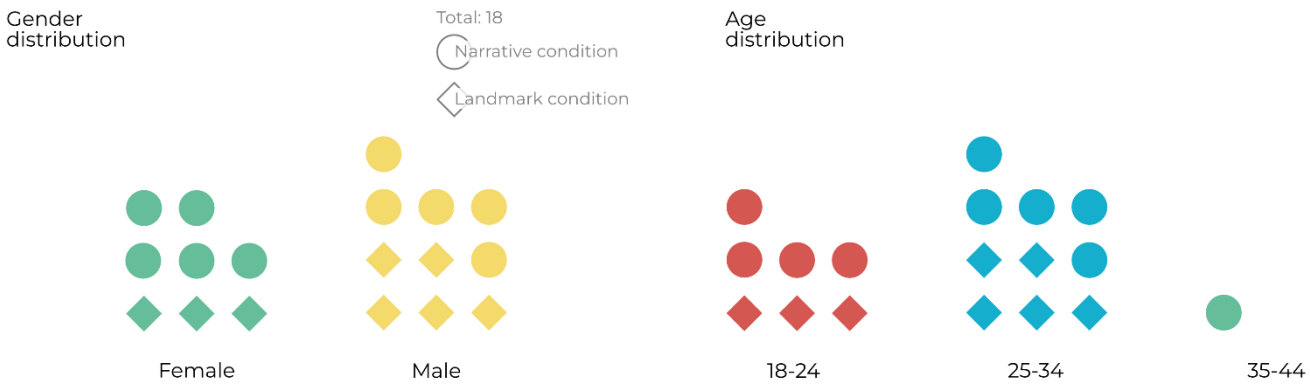
13. Turn left at the *tall skinny tree.*	`urn left at the tall skinny tree, which stands in the same spot as the tree Strauss climbed, marking the controversial division of the 4th and 5th districts of Vienna in the 19th century.
14. Your destination is the *brown door* on the left.	Your destination is the *brown door* on the left, where Strauss's dog sat comfortably waiting for her friend.

Table A.1: Shows both the landmark and narrative route instructions designed for the study. Landmarks are highlighted in italics. The location of each landmark can be seen in Figure 5.

Selection of photo pairs for sequencing tasks

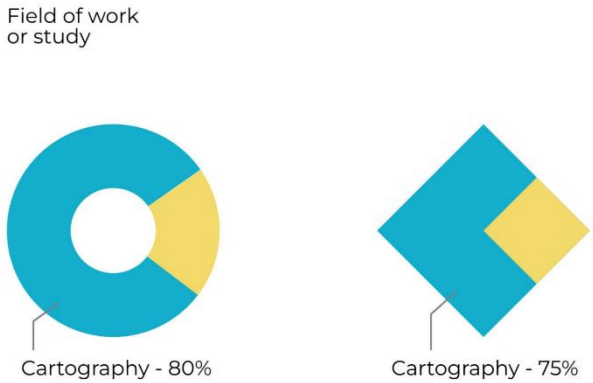
Related by...	Phase 2b	Phase 3b
Narrative causality	WC and furniture shop Table tennis table and veterinarian WC and pink houses	Park exit and 4th & 5th Tall skinny tree and pink houses *(f)* Tree-lined street and WC
Physical appearance	Purple door and 4th & 5th *(f)* Pink houses and tree-lined street Park exit and tall skinny tree *(f)*	Furniture shop and orange build. *(f)* Table tennis table and WC Veterinarian and tree-lined street

Table A.2: Distribution of the photo pairs into groups for the photo sequencing tasks. Selection was based on narrative causality or physical appearance, along with physical distance between two landmarks, with further landmarks marked with *(f)*.

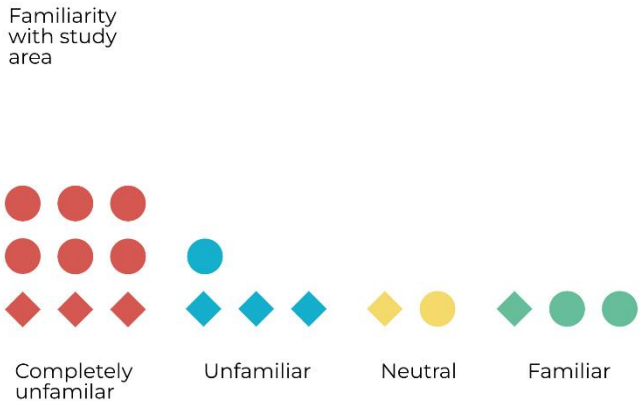


(a) Gender

(b) Age distribution



(c) Field of work or study



(d) Familiarity with study area

Figure A.1: Demographic information for the 18 participants of the user study.