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It's also about timing! When do Pedestrians Want to Receive Route Instructions

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Abstract: The preferences of a pedestrian on the timing of route instructions are studied based on observations obtained during an outdoor wayfinding study conducted in an urban environment (N=52): Participants walked two different routes following auditory navigation instructions which they could request whenever and how often they wanted. By means of an exploratory analysis using regression-based modeling techniques, a set of user and environmental variables that influence the observed participant behavior are obtained. Results suggest the relevance of both user and environment characteristics for the prediction of preferred route instruction timing; among these are, e.g., landcover-related variables and psychological personality traits such as e.g., neuroticism (emotional stability).

1 Introduction

One of the core goals in the research of a pedestrian navigation system design is to reduce a person's cognitive load during wayfinding (e.g., GIANNOPOLOUS et al. 2014). Consequently, optimizing how route instructions are phrased and presented on mobile devices has seen much attention by research (e.g., KLIPPEL et al. 2009). However, the question of *when* to present a route instruction to a navigated pedestrian has remained a desideratum – even though there is an obvious potential to facilitate the wayfinding process by presenting an instruction at the optimal point in time: Receiving it too close to the approached decision point might cause uncertainty or presenting it too early might be disturbing to the wayfinder. The virtual reality study by GIANNOPOLOUS et al. (2017) presents the first one addressing this research gap explicitly. Using time-to-event modeling, the authors predicted the distance to a decision point at which a first presentation of a route instruction would be most preferable to the navigated person. The present work builds on this study and expands it considerably by means of an outdoor wayfinding study: On the one hand, similar time-to-event modeling is, again, used to predict the optimal timing of route instruction presentation (*RQ 1*). On the other hand, the problem of repeated requests for navigation instructions is approached, and hence, factors that impact why a person would want to listen to a route instruction for a second time are identified (*RQ 2*). The research question of when to present a route instruction for a first time was studied within an international, interdisciplinary cooperation, together with Prof. Ioannis Giannopolous (Geoinformation, TU Wien) and Dr. Markus Kattenbeck (Geoinformation, TU Wien), and Transportation researcher Dr. Georgios Sarlas (ETH Zürich) who applied the time-to-event modeling to the data which I collected and preprocessed. Our work was published as a journal paper for which I have taken first-author responsibilities, GOLAB et al. (2021). For the submission of the diploma thesis, an analysis on parameters impacting a person's preference to want to listen to a route instruction more than once (*RQ 2*) was added, within which

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I applied the Generalized Estimating Equations (GEE) model. In the following sections of this paper, the cornerstones of my work such as the wayfinding study, applied modeling methodology and the core findings are presented.

2 Problem Statement

Tab. 1 illustrates the research questions addressed in this work by means of an example.

Tab. 1: Illustration of research questions (*RQ 1* and *RQ 2*).

The following scenario is considered: Alice walks from her home to the dentist and uses a mobile navigation system providing auditory route instructions. She starts walking and is approaching an intersection at which she does not know if she has to make a turn.	
RQ 1	When will she want to hear the navigation instruction?
RQ 2	Will she want to hear the navigation instruction for a second time before she makes a turn?
Alice might be distracted or feel uncertain by listening to a route instruction earlier or later than personally preferred. She might also want to hear a route instruction more than once in specific circumstances to, e.g., be reminded of it.	

These individual preferences are observed during an outdoor wayfinding study. By modeling the relationship between these observations and user and environment variables, the goal is to identify the influential parameters impacting the observed behavior. Following the paper by GIANNOPOLOUS et al. 2014 who suggest an impact by the user and environment on the complexity of decision situation, the following categories of features are considered in the analysis addressing *RQ 1* and *RQ 2*: **route**-related (e.g., route length), **environmental** (e.g., the density of points of interest), **behavioral** (timing of route instruction requests) and **personal** features (e.g., age).

3 Wayfinding Study

3.1 Materials

Prior to the outdoor experiments, participants answered questionnaires on demographic data (e.g., age, sex), the German language *FRS* questionnaire on spatial strategies (MÜNZER & HÖSCHEL 2011), and a questionnaire on personal characteristics based on the so-called Big Five Personality traits (RAMMSTEDT et al. 2012). A further essential part of this data collection was the outlining of familiar areas and routes using a self-programmed online GIS application. This data was used twofold: Firstly, this information allowed to introduce a binary variable describing whether the person is familiar or unfamiliar with the environment during the experiment, enabling the within-subject design of the experiment which is further explained in Section *3.2*. Secondly, the provided routes by the participants were processed to design routes for the outdoor experiments. For these, spoken navigation instructions were prepared using an algorithm described by ROUSSEL & ZIPF (2017). These were landmark-based, i.e. referencing salient objects in the environment, exclusively designed for turning points (following the concept of spatial chunking described in

KLIPPEL et al 2009) and formulated in German language, e.g., *Biegen Sie bei der Apotheke links ab.* (English translation: *Turn left at the pharmacy*.).

3.2 Outdoor Experiments

The experiment was designed as a within-subject experiment during which each participant walked a familiar route and one which was located in an unfamiliar environment, essentially resulting in two trials per participant. During each trial, locational data of participants was collected using a high-precision PPM 10-xx38 GNSS receiver, head movements were tracked using an Xsens MTi-300 IMU and gaze data was collected using a PupilLabs Invisible mobile eye-tracker. The participant's task during a trial was to walk to a specific destination by following auditory route instructions. In order to directly observe preferences of when people would want to hear a route instruction and whether people would want to hear instructions multiple times, participants were allowed to issue requests for route instructions whenever and how often they wanted by informing the experimenter using a custom-built clicking device (Fig. 1). The experiments took place during the months between June and October 2020. In total, 52 people participated which resulted in 104 conducted trials.

Fig. 1: **A:** A sample participant in full equipment. **B:** GNSS receiver (PPM 10-xx38). **C:** During the experiment, participants requested navigation instructions using a custom-built clicker-device (circled in red) which triggers a LED light located in the backpack informing the experimenter about the request.

4 Data Analysis

4.1 Preprocessing

The primary goal of the preprocessing procedures was to extract variables describing the observations and to retrieve associated features needed in the modelling part of this work. For this, the GPS data and logged times of requests were processed. Extracting all observations of first requests of route instructions, resulted in a number of 304 data points. These were further processed to obtain observational variables for the analysis of *RQ 1* and *RQ 2*. While the aim was to predict the optimal timing of a route instruction in addressing *RQ 1*, the spatial dimension of a request was chosen to be modeled. This decision was made in order to counterbalance potential biases resulting from walking speed fluctuations due to e.g. crows, red lights, etc. Therefore, the predicted output by the survival analysis was the distance between the position of a first instruction request and the last turning point, normalized by the overall distance between the approached intersection and the last turning point, yielding values in the range $[0,1]$. Further, the observations were labeled with a binary variable $\in \{0,1\}$, 1 indicating that a route instruction was requested more than once, which served as the dependent variable to analyze *RQ 2*. Associated features were extracted from the questionnaires which provided data on personal variables, and from information on walked routes from which route-specific features were extracted (e.g., type of approached intersection). Further, characteristics of the environment were calculated using spatial data drawn from OpenStreetMap and Urban Atlas databases (EUROPEAN COMMISSION 2016).

4.2 RQ 1: Rationale to use Survival Analysis

To address *RQ 1*, a survival model was applied. Such a model essentially predicts the probability of the occurrence of an event over time. WALDORF (2003) verified the conceptual equality of applying survival models to temporal and spatial processes which is exploited in this work as the distance (instead of actual time) at which a first presentation of a route instruction is preferred is predicted.

4.3 RQ 2: Rationale to use Generalized Estimating Equations (GEE)

The relation between the binary labels indicating whether participants requested a route instruction more than once and retrieved features was modeled using the Generalized Estimating Equations (GEE) model. This model was first described by LIANG & ZEGER (1986). It was chosen for this analysis because it allows within-subject correlation which is present in the dataset at hand, solves a marginal model describing population-average effects, and is adaptable to a logistic output.

5 Results and Discussion

Two models were obtained to answer the research questions at hand: Firstly, a survival model predicting the optimal distance since the last turning point at which a user of a navigation system would want to hear a route instruction for the upcoming turning point; secondly, a GEE model expressing the population mean of pedestrians' preference of wanting to hear an instruction more than once. Both models express the observed value as a function of user and environmental

characteristics. While initially including all retrieved features, each model was carefully reduced to the influential ones. This was done in a step-wise manner by increasing information criteria such as the AIC and the QIC. Features were finally classified as influential when their p-values were below 5%. During this model building process, attention was paid to avoiding multicollinearity and model overfitting by observing VIF and Cook's Distance values. The influence of a variable in the final models is interpreted based on the magnitude and sign of obtained covariates.
Overall, influential variables in both final models encompassed features from all initially considered categories which is in line with the research suggesting an impact of both user and environmental characteristics on the wayfinder's behavior (e.g., GIANNOPOLOUS et al. (2014) and the findings of GIANNOPOLOUS et al. (2017). Interestingly, results revealed a different effect by the variable age within the model by GIANNOPOLOUS et al. (2017) than within the survival model obtained in the present study: While the model by GIANNOPOLOUS et al. (2017) suggests that people of higher age would tend to request route instructions earlier, the opposite was found in the present study. Further research is needed to understand the reasons for this contradiction. Two potential explanations come to mind: This contradiction may stem from the different experiments' set-up (virtual vs. outdoor environment) which raises questions concerning the ecological validity of a study in virtual setting. Another reason may be the presence of a bias arising from differences in participant samples. However, there are also similarities among the findings by, e.g., the effect of route-related features such as the length of the currently walked route segment. Figure 2 displays the impact on the survival rate by the environmental and route-related variables in the obtained survival model. LC_1, LC_2 and LC_3 represent area shares of different landcover classes in the area the currently walked route segment lies in. $lgnSegm$ is a binary variable; equaled 1, it implies that the currently walked route segment is greater than $120m$ long. Considering an artificial observation ("base case"), the direct impact on the survival rate by an alternation of the values of selected variables is displayed (decrease/increase by one standard deviation or value change in a binary variable). For example, by the decrease of the variable LC_1 (representing areas with *Industrial, commercial, public, military and private units,* EUROPEAN COMMISSION 2020), the survival rate decreases at earlier distances which implies that when the variable's value increases, persons would be more prone to request a route instruction earlier. This quantification of an effect on the preference of route instruction timing holds the potential of being directly applied in the adaptation of a navigation system to a user's needs in different environments.
An interesting finding within the obtained GEE model was the effect of the personal characteristic *neuroticism* which was measured using the BFI-10 scale. The model indicates that people who have high scores on the *neuroticism* scale tend to request a route instruction at the beginning of the experiment more often than later on. As a person scoring high on this scale suffers from anxiety and stress (COSTA & MCCREA 2017), it is reasonable that this person also feels stressed during the experiment. The stress might decrease in time for anxious people as they might feel more comfortable over time. However, it remains unknown whether this observed effect can be reduced to the experiment situation or if people with a strong trait of neuroticism generally feel stressed when navigating. Having said this, spatial anxiety was reported to correlate positively with making more errors during wayfinding (HUND & MARINARIK 2016). Though, it is unknown how and if neuroticism is related to spatial anxiety. Nevertheless, it can be assumed that listening to a route instruction more often reduces uncertainty and therefore also the error rate during navigation.

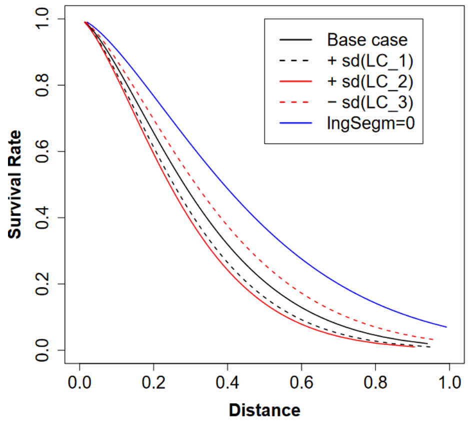

Fig. 2: Survival model: changing survival rate depending on effects given by the presence of different landcover classes (LC_1, LC_2, LC_3) and a distance between the last turning point and approached decision point which is below $120m$ ($lngSegm = 0$).

6 Conclusion and Future Work

A set of user and environmental variables influencing a pedestrian's preferences in respect to route instruction timing has been found, and the size and direction of their effect quantified. Given the observed differences to the findings by GIANNOPOLOUS et al. (2017) and the yet-to-be-conducted validation of the obtained results, further studies on this topic are needed. Besides, the contribution of this work has been evident as the conducted outdoor wayfinding study has been serving to answer different types of research questions, due to the careful experiment design, which incorporated various sensors and measurements of a multitude of behavioral variables: While the present work was dedicated to studying the timing of route instructions, ALINAGHI et al. (2021) analyzed the acquired eye-tracking data to predict a turning decision at intersections. Moreover, a further journal paper is currently being prepared which uses IMU and eye-tracking data collected during this study to predict a participant's familiarity.

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