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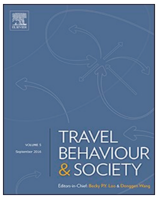

Determinants of urban wayfinding styles

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ABSTRACT

Everyday people find their way towards work, supermarkets, or unfamiliar places are explored for a social visit. Understanding how differences in urban wayfinding behaviour relate to daily travel patterns is important to describe route choice behaviour, identify potential navigation problems, design more legible cities, and provide comprehensible travel information. Therefore, the goal of this study is to jointly investigate the differences between urban wayfinding styles and the relations with socio-demographic, motility, urban environment, navigational preferences, and daily travel behaviour.

The findings of this study are based on a sample of the Dutch population of 1101 respondents. All respondents completed a three-day travel diary as part of the Mobility Panel Netherlands (MPN), and an additional cross-sectional survey designed to capture perceptions, attitudes, and wayfinding for active modes (PAW-AM). A Factor Analysis is conducted to identify urban wayfinding styles based on a Dutch version of the self-report questionnaire of environmental spatial skills originally developed in Santa Barbara (SBSOD). Generalized Linear Models (GLMs) are used to estimate to what extent various determinants affect two hypothesized urban wayfinding styles, in this study coined as Orientation Ability (OA) and Knowledge Gathering & Processing Ability (KA).

The main findings of the study are an associated effect of gender and age on both urban wayfinding styles, while the navigational preference to follow the bearing line and average daily distance travelled by car have disassociated effects. The remaining determinants are only significant in either OA or KA, providing evidence that mainly different processes describe each wayfinding style.

1. Introduction

Each trip requires people to make various decisions before and during travelling. These decisions regard which modes and routes are to be used, and which activities will be performed where and when. Due to individual differences in preferences (e.g. minimize turns and thus choosing a simpler yet longer route) the urban experience differs, and as a consequence, the mental representation of the environment is likely to be different. In turn, these differences will influence future travel decisions resulting in different choice behaviour. Wayfinding behaviour is commonly defined as *the strategies that people use to decide how to move from one place to another* (Montello, 1995). It relates to the set of preferences, selection, and application of navigational strategies, the attitude towards travelling, and the ability to reach the intended destination. Differences in travel behaviour are expected to determine the extent to which wayfinding styles and navigational preferences are important to individuals.

Understanding how urban wayfinding behaviour relates to daily travel patterns is important to describe differences in route choice behaviour, identify potential navigation problems, design more legible cities, and provide comprehensible travel information. However, to date, relations between urban wayfinding styles and the complexity of daily travel behaviour, urban environment, and navigational preferences are largely unknown. Recent advances in cognition and travel behaviour research increased the understanding of the impact of socio-demographic factors on wayfinding and navigation behaviour of people through fMRI, (virtual reality) experiments, and questionnaires (Andreano and Cahill 2009; Golledge et al., 1995; Prestopnik and Roskos-Ewoldsen, 2000). Commonly, these studies are conducted amongst small groups of undergraduates, using controlled experiments in small-scale environments primarily interested in the influence of gender and age (Maguire et al., 1999). Nonetheless, there are indications that active navigation (e.g. being the driver while driving or bicycling) relates to the ability to solve wayfinding tasks that require

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"route" and "map/survey" knowledge (Nori and Giusberti, 2006).

Wayfinding styles and navigational preferences in this study stem from a cross-sectional survey specially designed to capture perceptions, attitudes, and wayfinding for active modes (PAW-AM). A total of 1101 respondents not only completed this survey, but also a 3-day travel diary, personal, and household survey as part of the longitudinal Mobility Panel Netherlands (MPN) Survey in 2016 (Hoogendoorn-Lanser et al., 2015). Wayfinding styles are based on the standardized self-report questionnaire of environmental spatial skills (SBSOD) originally developed and tested at the University of California-Santa Barbara (Hegarty et al., 2002). In explaining urban wayfinding behaviour based on literature on experimental studies, the variables of interest can be divided into four groups: *socio-demographic and motility* (e.g. gender, age, mode availability, and financial compensation), *urban environment* (e.g. urban density and perceived accessibility levels), *navigational preferences* (e.g. minimize number of turns and active navigation ratio), and *daily travel behaviour and patterns* (e.g. mobility portfolio, mobility cluster pattern). The objective of this study is to investigate how these determinants jointly relate to urban wayfinding styles. To this end, based on the SBSOD a Factor Analysis has been conducted to identify how many, and which, urban wayfinding styles exist. Generalized Linear Models (GLMs) are used to estimate to what extent various determinants affect two hypothesized urban wayfinding styles, in this study coined as Orientation Ability and Knowledge Gathering & Processing Ability.

The structure of the remainder of the paper is as follows: the next section (Section 2) provides background on (urban) wayfinding behaviour. A description of the data and research approach is provided in Section 3. A Factor Analysis to derive the urban wayfinding styles from the self-reported preferences is provided in Section 4. The modelling results and relevance of the GLMs for the urban wayfinding styles are described in Section 5. We then synthesize the findings of this study in Section 6. This paper finishes in Section 7 with a conclusion.

2. Literature background

This section provides an overview of wayfinding behaviour and determinants that have been found to impact wayfinding based on experimental studies. The remainder of this section first elaborates on the definition of wayfinding behaviour, followed by a synthesis of the main findings in relation to four categories of variables that are found in literature: socio-demographic and motility, urban environment, navigational preferences, and (daily) travel behaviour.

2.1. Urban wayfinding behaviour

Although strongly related, a distinction can be made between wayfinding, orientation, and navigational strategies. Wayfinding behaviour is typically associated with the *exploration* of the (possible) route(s) between an origin and a destination, given the urban network (Passini, 1980; Golledge, 2004). In this study, wayfinding behaviour encompasses two styles based on the attitudes towards spatial (network) knowledge and the orientation attitude. In theory, the combination of these wayfinding styles influences the boundary of the considered choices in daily travel behaviour, e.g. when deciding where to go, which travel mode to use, or which route to take. In turn, travel choices result in a specific urban experience that may stimulate to different wayfinding abilities and navigational preferences. Hence, we postulate that there might be a bi-directional relation between these two notions. A navigational strategy is more *goal-oriented* and is aimed at arriving at a destination with reference to a specific objective such as minimize travel time or distance (Hund and Minarik, 2006; Baldwin 2009). Navigational strategies are considered as a preference that may be associated with different wayfinding styles. Spatial orientation is one of the wayfinding abilities, it is the *ability to identify and recall places from different physical positions and graphical representations* (Gärling et al., 1986). This study investigates *wayfinding styles* based on the standardized self-report questionnaire of environmental spatial skills (SBSOD) relating to attitudes towards spatial knowledge acquisition (exploration), orientation within, and mental representation of, the environment, anxiety, and usage of route information (Hegarty et al., 2002).

Most wayfinding studies have investigated to what extent two hypothesized wayfinding styles, route-based and map/survey based, can describe how individuals find their way (Foo et al., 2005; Hund and Minarik, 2006; Xia et al., 2008; Carlson et al. 2010). These studies depict *Route-based wayfinding* as more or less an egocentric orientation style (with memorized sequences of local views) along a route. Consequently, specific decisions and actions are associated with landmarks, intersections, and sights. Whereas, *map-based wayfinding* is used when orientation is considered to be allocentric and/or coordinated. In the latter style, the developed mental map includes spatial relations and distances between important urban elements. Especially in urban environments the ability to orient and memorize the current position, and to construct a mental representation are crucial, as moving through a city requires one to integrate the sequence of views that change with one's movement in the environment (Hegarty et al., 2006). The likeability that identified styles can be disassociated at different scales of space has been investigated using factor analyses (Hegarty et al., 2006). To date, the extent to which these wayfinding styles relate to daily travel behaviour (e.g. activity and route choice behaviour) in the urban environment remains unclear.

To investigate the extent in which daily travel behaviour (e.g. activities, mode use and travel distance) actually explains urban wayfinding behaviour this study builds on top of the majority of wayfinding studies by proposing a theoretical framework inspired by literature on wayfinding behaviour (Stea and Blaut, 1973; Siegel and White, 1975; Golledge and Gärling, 2001). An Exploratory Factor Analysis is used to reduce the dimension of wayfinding styles from the SBSOD into components of mutually exclusive wayfinding styles. Each factor component can be divided into three levels of a wayfinding style; lower than average, average, and higher than average.

2.2. Determinants of wayfinding behaviour

The aim of this section is to describe behavioural insights related to preferences, attitudes and urban wayfinding behaviour reported in literature. Wayfinding behaviour based on self-report questionnaires, such as the SBSOD, is widely and extensively investigated in various fields, ranging from neurosciences and psychology to anthropology. To compare our findings with existing studies, the most relevant studies have been selected based on three requirements: 1) Reference to the original SBSOD questionnaire, 2) New data collection efforts, and 3) The analysis contains at least one determinant related to the urban environment, navigational preferences, and (daily) travel behaviour. This section is limited to the identification of some general trends in research methodology. The remainder of the section describes the key determinants that have been investigated in relation to wayfinding and travel behaviour.

2.2.1. Trends in research methodologies to study wayfinding behaviour using the SBSOD

Research into wayfinding behaviour dates back to the beginning of the 20th century. However, most determinants have been systematically investigated from 1990 onward. The majority of the studies conducted in the past two decades are controlled experiments, where a small number of participants are asked to complete a specific order of predefined tasks in a delineated spatial environment. These studies required time-intensive data collection efforts per participant (e.g. fMRI, 1-on-1 shadowing of movements, VR studio). As a result, the median sample size is 32 participants, and merely 8 studies have a sample size of more than 100 participants. Consequently, there are not many studies that aimed to relate multiple aspects with wayfinding behaviour and often only the influences of gender and age have been investigated. Regardless of the number of participants, most studies apply (multivariate) analysis of variance ((M)ANOVA) with a limited number of determinants and/or Structural Equation Models (SEM).

Although most studies included a(n adapted) version of the SBSOD, the processing of the responses varied from verification of non-significant differences within clusters in the sample to an average score for all questions, or a Factor Analysis. Also, sense-of-orientation (as a wayfinding style) has been used both as explanatory as well as dependent variable. As a consequence, discrepancy exists in results for many determinants. For example, there is no unified consensus on the relation with gender, the most researched determinant. Interestingly, also within research groups, findings and conclusions vary, which leads to critical theoretical reflection studies (Shelton et al., 2013, Piccardi et al., 2011).

Several research gaps can be identified related to the urban environment, such as the extent to which the larger metropolitan urban environment, where daily travel behaviour takes place, affects urban wayfinding behaviour. Also, while urban density has been identified as an important characteristic for salience and legibility of an environment, its role as a determinant remains unknown (Brunyé et al. 2010; Hölscher et al., 2011; Emo, 2012; Chrastil and Warren, 2014; Li and Klippel, 2016).

Navigational preferences are analysed using verbalized reports of respondents while walking or driving along a predefined route (Kato and Takeuchi, 2003; Hölscher et al., 2011; Arnold et al. 2013; Meilinger et al., 2014; Weisberg and Newcombe, 2016). A strong focus on wayfinding efficiency in many studies leads to a rather subjective classification such as good and bad orienteers while refraining from these definitions allows a deeper understanding of the versatility exercised by individuals (Shelton et al., 2013). However, due to the lack of extensive studies, the low number of participants, and differences in operationalization of both wayfinding and navigational preferences, it remains insofar unclear how daily travel behaviour in urban environments influences which navigational strategies are preferred, and if differences exist in relation with wayfinding behaviour.

Furthermore, very few experimental studies are positioned within the travel behaviour research field. However, relations between wayfinding and travel behaviour have been investigated in numerous studies at the operational (route) level, leaving a research gap on the influences on tactical and strategic levels relating to mode, route and activity choices, but also on the average daily travel behaviour. Most of these studies are goal-directed while there is empirical evidence to suggest that specific tasks influence wayfinding and search behaviour (Emo, 2012). Some studies investigated the relation between wayfinding and daily travel behaviour, but either based on a homogeneous and often very specific sample (elderly or children (Turano et al., 2009; Phillips, 2013; Taillade et al., 2016), students (Kato and Takeuchi, 2003; Hegarty et al., 2006; Ishikawa and Kiyomoto, 2008), Yucatec Maya farmers (Cashdan et al., 2016), limited to one travel mode (pedestrian (Li, 2006; Arnold et al. 2013; Giannopoulos et al., 2014), taxi/car (Turano et al., 2009; Han and Becker, 2014)), or a qualitative assessment of verbalized responses (Phillips et al., 2013). Hence, it remains unclear how wayfinding styles translate to urban navigation and daily travel behaviour in practice, and how individual characteristics potentially mediate differences, also acknowledged by Shelton et al. (2013). Moreover, to increase realism and establish a more extensive framework there is a need for a more heterogeneous and diverse sample (e.g. not only walking behaviour, students, children, elderly, or women) and move beyond extremely unrealistic environments (e.g. simplified VR mazes) into common wayfinding situations.

2.2.2. Wayfinding determinants in relation to travel behaviour in literature

This section elaborates on the main and most striking determinants that have been investigated in relation to wayfinding and travel behaviour. To summarise, the experimental studies that included travel behaviour characteristics are conducted at operational route level, leaving a research gap on the influences of tactical and strategic levels relating to mode, route, and activity choices, but also on the average daily travel behaviour.

Most studies were performed in a North American, European (UK and Germany), or Japanese context, where the majority of the findings lean towards the hypothesis that men are better at orientation and navigational tasks, while women have enhanced knowledge gathering, memory and processing ability. Results indicate that different cognitive strategies are used; men rely more on Euclidean distance and direction, whereas women prefer to find their way based on salient landmarks (Schmitz, 1997; Kimura, 2000; Waller, 2000; Lawton and Kallai, 2002). The difference can become more apparent depending on the environment (Silverman et al., 2000; Malinowski and Gillespie, 2001; Saucier et al., 2002; Andreano and Cahill 2009). Research focusing on brain activity using fMRI studies investigated socio-demographic differences during tasked viewpoint resemblance based on photographs (Epstein et al., 2005), wayfinding in a museum (Janzen et al., 2008), and relations between memory engagement, navigational learning strategies, and percentage of finding destinations using short-cuts (Furman et al., 2014).

With aging societies, there is increasing research interest in wayfinding abilities and difficulties among the elderly. Turano et al. (2009) investigated mobility levels, described by the visit frequency to neighbouring areas, of elderly by car in Maryland (USA). Phillips (2013) and Phillips et al. (2013) explored the influences of landmarks and complexity of street layout, familiarity, various navigational preferences, and trip purpose on how the elderly experience urban environments. Also, differences at operational travel behaviour have been investigated, such as the frequency of stops and detours due to decreased orientation (Taillade et al., 2016).

In travel behaviour research it is common to also include household characteristics, such as the number of children, as this poses limitations to the flexibility and induces certain type of activities. This is sometimes also be regarded as motility, the potential and ability to move (Lucas, 2012). Slightly different from individual or household characteristics, motility relates more to availability of, and accessibility to transport modes, monetary compensation that may affect the affordability, and childhood experiences that may affect the development of initial wayfinding behaviour (experienced motility). A unique study on the Yucatec Maya farmer community in a rural and remote area showed that mobility, based on the number and frequency of visits to various sights in the region, has a direct relation with an interaction effect of gender and marital status, which would explain gender differences in self-reported wayfinding styles. During childhood there are no significant differences in mobility patterns between boys and girls, only once married Yucatec men start to travel to more distant areas, while Yucatec women stay more frequently at home (Cashdan et al., 2016). Slightly different are studies using the NASA Task Load Index (NASA TLX) to assess subjective cognitive workload due to difficulties with navigating using (innovative) travel information applications (e.g. Baldwin 2009; Rehrl et al., 2012). Provision of more information will only benefit those with suitable wayfinding abilities and aligned navigational preferences to successfully process the information.

Nearly two-thirds of the studies included at least one determinant describing travel behaviour. Travel behaviour has commonly been described at the operational or route level where participants either were requested to follow a predetermined route, or walk to a predetermined location within delineated environments (Hölscher et al., 2011; Ishikawa and Nakamura, 2012; Emo, 2012; Chrastil and Warren, 2014; Taillade et al., 2016; Li and Klippel, 2016). Findings from these studies consistently indicate that travel distance and time have a negative relation with the wayfinding score obtained in the SBSOD. Also, local and global salience of a location influences how easy it is to find a destination, which affects the travel distance and time. Participants with lower wayfinding scores also make more errors while finding their way and show higher workloads when required to use travel information services.

Several studies investigated the relation with wayfinding behaviour and more common daily travel characteristics, mainly by asking the frequency of visits to certain neighbourhoods or locations (Nori and Giusberti, 2006; Turano et al., 2009; Piccardi et al., 2011; Phillips, 2013; Cashdan et al., 2016). Travel behaviour at route level is usually investigated in the form of a description of the differences between chosen alternatives in terms of distance, turns, or most traversed intersections (Hölscher et al., 2011; Furman et al., 2014).

Based on past findings, it can be expected that respondents with a better sense of orientation choose routes with shorter travel distance and time, but not necessarily higher travel speed. This requires flexible navigational preferences as the structure and layout of each urban environment demands different abilities. To the authors' knowledge, the relation between wayfinding behaviour and real-life daily travel behaviour has not been quantified except for specific target groups.

3 Research approach & methodology

To investigate to what extent urban wayfinding behaviour can be described from a holistic perspective, by jointly including urban environment, navigational preferences, and daily travel behaviour, we have enriched the longitudinal Mobility Panel Netherlands (MPN) with a cross-sectional survey in 2016. This additional survey (PAW-AM) is designed to capture perceptions, attitudes, and wayfinding for active modes, and included a Dutch version of the standardized self-report questionnaire called the Santa Barbara Sense of Direction (SBSOD). Upon aggregation of both questionnaires (MPN 2016 and PAW-AM) to the individual level, various data processing techniques have been used to derive determinants of interest, such as a latent class cluster analysis (LCCA) to capture daily mobility patterns, instead of separate determinants describing daily travel behaviour characteristics (Ton et al., 2019).

To operationalize wayfinding styles, an Exploratory Factor Analysis based on the standardized self-report SBSOD is performed. Generalized Linear Models (GLM) are used to identify how differences in wayfinding styles can be explained by socio-demographic, (perceived) urban environment, navigational preferences, and daily travel behaviour. These research steps are visualized in Fig. 1 and further detailed in the remainder of this section.

3.1. Data on urban wayfinding

The data used in this study stem from Dutch citizens that have completed a three-day travel diary, and personal and household surveys as part of the Mobility Panel Netherlands (MPN) in 2016 (Hoogendoorn-Lanser et al., 2015). The travel diary was computer-based and designed to provide information on activity and trip level. The travel diary provides different insights than commonly measured at route level or regional level travel behaviour in relation to wayfinding behaviour.

Enriching the MPN with cross-sectional special issues is important to better describe the underlying behavioural dynamics. To enhance the explanatory power of the MPN regarding pedestrian and cyclist mobility choices, the PAW-AM survey was designed. This survey featured among other things social norms and mode choice habits. One section of the PAW-AM survey was related to urban wayfinding behaviour and navigational styles. The PAW-AM survey has been designed to reduce respondents' fatigue, as such; half of the respondents of the PAW-AM received questions related to wayfinding behaviour, while the other half received questions related to social norms. Thus, the presented analyses and models stem from 1101 respondents that completed a 3-day travel diary, personal and household survey, and the PAW-AM survey focused on wayfinding behaviour in order to investigate which determinants, and to what extent, relate to urban wayfinding styles.

Urban wayfinding variables in the MPN and PAW-AM. Urban wayfinding behaviour is investigated based on the SBSOD (Hegarty et al., 2002). The focus of this questionnaire is on the attitudes towards spatial knowledge acquisition (exploration), orientation within an environment, mental representation of the environment, anxiety, and usage of route information. All respondents are asked to indicate how much a statement reflects their behaviour, ability, or attitude at 5-point Likert-scale (1: strongly disagree and 5: strongly agree). All questions were translated to Dutch, and approximately half of the questions are stated positively, and half negatively. In total 23 statements have been used, two examples are: *"I easily get lost in a new city"* and *"I enjoy reading maps"*.

The explanatory variables in this study are visualized in Fig. 2 and further detailed in the remainder of this section. There are four independent variable categories: socio-demographic and motility, urban environment, navigational preferences, and daily travel behaviour. *Individual* and *household characteristics* such as gender, age, occupation, education, household size, and number of children are derived from the individual and household questionnaires of the MPN survey. Also, motility indicators of ownership of a car, bicycle and/or a transport subscription and eligibility to any form of compensation for a certain mode by the employer or special discount for low-income households are derived from the MPN survey. An additional subgroup related to *motility* has been included in the PAW-AM survey, namely, whether people during their childhood experienced travelling to school by foot, bike, public transport, or were driven by car. This metric is intended to provide an indication of the size of travel environment at the age when people are likely to start developing their wayfinding skills. In line with the cultural-behavioural-brain (CBB) loop model (Han and Ma, 2015), the underlying hypothesis is that these "first" experiences may influence today's attitude and perception towards travelling.

Variables related to the physical urban environment are derived from the MPN survey, where a high-level indication is available regarding the urban density in the region (rural, urban, or highly urbanized region). The PAW-AM survey focused on the perception of the *urban environment*, and included statements such as "*in my neighbourhood there are shops/restaurants/old buildings within walk or bicycle distance*", and "*the infrastructure in my neighbourhood is walk/bicycle/public transport/car friendly*". In the first section of the PAW-AM survey participants are asked to identify for which trip purpose they used the bicycle most often. In the section featuring navigation styles, respondents were asked to identify from a list of 26 urban elements which urban elements they would avoid on their way to this activity. The English translation of this question is: *"I am willing to **make a detour** when I **cycle** to [**personalized trip purpose**] if I can **avoid** …"*. The urban elements were very diverse, ranging from "crowded bicycle paths" to "streets with townhouses", and "areas where many traffic accidents happen". The chosen elements were classified with the label 'negative'. From the list of urban elements remaining after their first selection, respondents were asked to identify which urban elements would attract them, which were accordingly labelled 'positive'. All items that have not been indicated as repellent or attractive are classified as 'neutral'.

Navigational preferences relate to the decision-making strategies to choose or follow a specific route. The PAW-AM survey includes 5-point Likert scale questions regarding five navigational preferences minimizing (i) travel distance, (ii) travel time, (iii) number of turns, or (iv) following the direction (bearing) towards the destination, and (v) taking short-cuts. Active navigation ratio has been derived from the 3-day-travel diary and depicts how often a respondent has actually been in charge of wayfinding for a certain trip, for example as the driver of a car, and any bicycle or walking trip. In this study, the average active navigation ratio is 0,70 (70%) with a standard deviation of 0,42. The related hypothesis is that individuals with a higher active navigation ratio have more advanced wayfinding abilities, as one relies more often on his or her abilities.

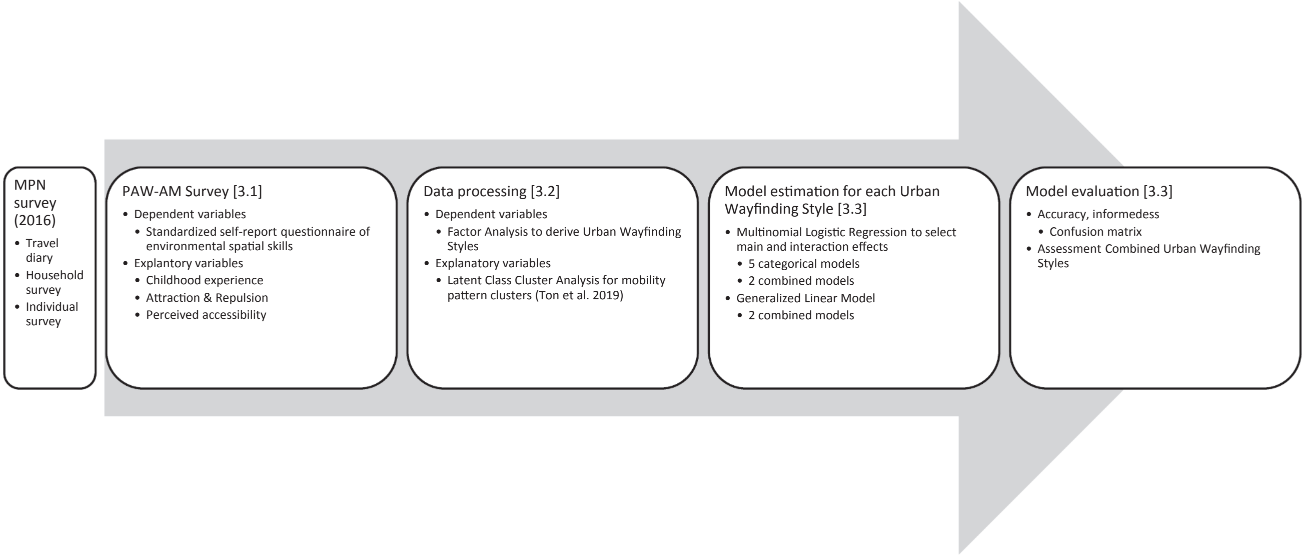

Fig. 1. Research Steps.

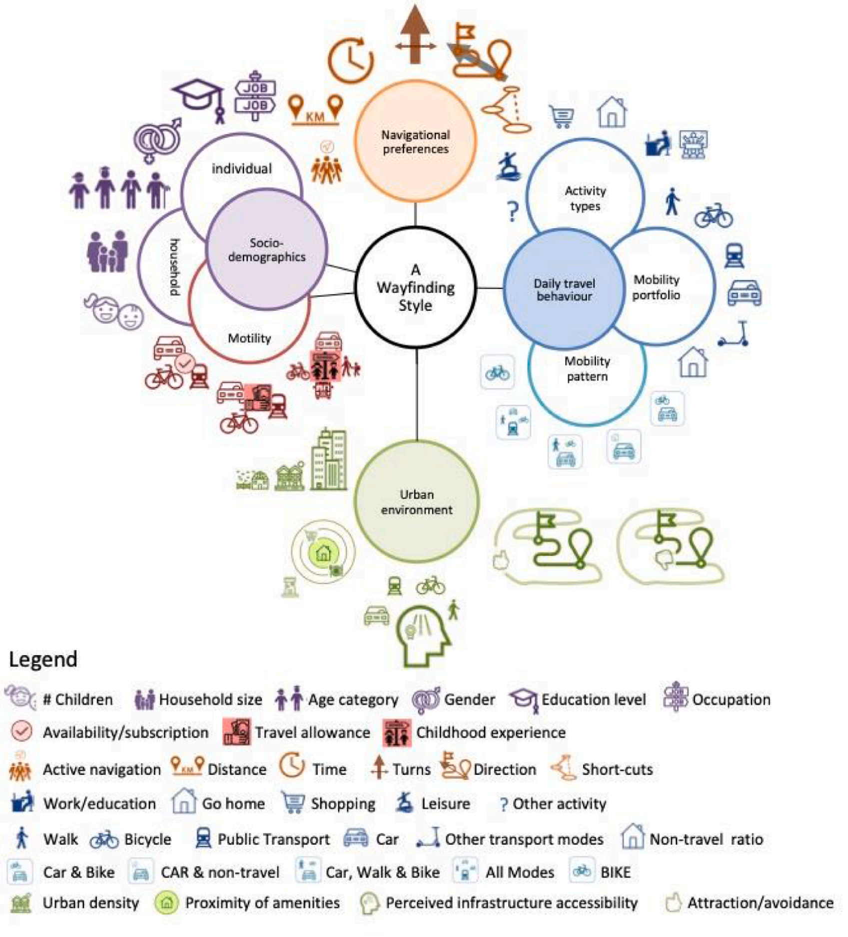

Fig. 2. Conceptual Framework of Relations with Urban Wayfinding Behaviour.

All *travel behaviour* characteristics are aggregated based on the average behaviour reported during weekdays that needed to be reported in the 3-day travel diary as part of the MPN in 2016. Note that respondent A with 3 trips on Monday, 1 trip on Tuesday, and 1 trip on Wednesday yields an average daily number of trips of 1.67, with a non-travel ratio of 0. Respondent B with 2 trips on Sunday (weekend), 0 trips on Monday, and 3 trips on Tuesday yield an average daily number of trips of 1.5, with a non-travel ratio of 0.5, because only two weekdays needed to be reported. The non-travel ratio is important because it shows the share of active days. Trip purpose (activity type) has been classified into 5 categories: (i) going to work/school, (ii) going back home, (iii) doing (grocery) shopping, (iv) performing a leisure activity (sports, restaurant), and (v) other activities. Commonly, shopping, sightseeing, social visits to family and friends require people to travel through, or to, unfamiliar environments (Phillips, 2013).

3.2. Derivation of urban wayfinding styles

Previous work described in the Literature Background (Section 2) established that the SBSOD has a high degree of test–retest reliability. SBSOD scores are able to predict performance on experimental tests that require subjects to update one's location and orientation in space. In order to reduce the dimensionality of 23 questions of the self-report questionnaire, an Exploratory Factor Analysis is used to derive urban wayfinding styles. Prior to the factor analysis, negatively stated questions were reversed to derive a positive relation with each component. To minimize multicollinearity effects and to identify the underlying dimensions of urban wayfinding styles, principal component extraction and varimax rotation have been applied. The resulting components of the factor analysis constitute a set of latent variables that describe environmental spatial skills and urban wayfinding behaviour. Categorization of the latent variables to three levels with cut-off values at $-0,5$ and 0,5 transforms the latent variables to three wayfinding styles per component: lower than average (-1), average (0), and higher than average (1). The results of the factor analysis and components are described in 4.1.

3.3. Model estimation of urban wayfinding styles

The goal of this study is to answer the research question "To what extent can differences in the urban wayfinding styles coined as 'Orientation Ability' and 'Knowledge Gathering & Processing Ability' be explained by a comprehensive model including the relations with socio-demographic and motility, urban environment, navigational preferences, and travel behaviour?" This can be investigated using different statistical models, including Generalized Linear Models (GLM) (Nelder and Wedderburn, 1972; Diggle et al., 1994; Cox et al., 2013) and multinomial logistic regression. One of the major pitfalls of multinomial logistic regression is the reduction in degrees of freedom when many parameters are included. Different from regression models, GLM assumes that there is no clustering of the data and thus responses of all respondents are mutually independent.

GLMs consist of three components: the systematic linear prediction, a multinomial random component, and a Logit link function (Nelder and Wedderburn, 1972; Diggle et al., 1994; Cox et al., 2013). The first component is similar to OLS regression as it describes the linear relation between a function of the expected dependent variable $Y = g^{-1}(\eta)$, and the explanatory variables in the model,

$$Y = g^{-1}\left(b_0 + \sum_{i \in j} b_i X_i\right) \tag{1}$$

where,

Y = Measured ability level of a wayfinding style (low, average, or high)

g = Logit link function, transforms the *predicted value of the dependent variable* (η) to a new form that has a linear relationship with Y.

b_0 = intercept

b_i = estimated weight coefficient for a given explanatory variable i

X_i = Explanatory variables (age category or average daily distance by car)

The link function allows for non-linear relations between explanatory variables and the predicted outcome. Applying the parallel regression assumption, the link function transforms the expected value of Y to a new form that has a linear combination of the explanatory variables, ordered from high to low with respect to the highest level. The model output includes b-coefficients to represent the average effect across the entire population of a change in X on the probability of the urban wayfinding style condition. For example, a 1-unit increase in an explanatory variable (i.e. age category) corresponds to a b_{age}-unit increase in the Logit of the expected value of "high Orientation Ability" versus lower conditions, holding all other variables in the model constant.

Before using Generalized Linear Models (GLM), a systematic approach of multiple multinomial logistic regression analyses has been used to provide a first selection of interaction effects and control for correlations between determinants in the holistic (combined) models. This systematic approach consists of four steps. To start, five categorical models are estimated for each of the variable categories (socio-demographic, motility, urban environment, navigational preferences, and travel behaviour). To derive a categorical model, first only main effects are included in a logistic regression using a forward stepwise method. The probability to include (resp. exclude) variables is 0,05 (resp. 0,10) with a maximum number of stepped effects of 40. Secondly, 2-way interaction effects are included, while insignificant main effects from step 1 are excluded. The outcome is a set of "primary determinants". Thirdly, all "primary determinants" are excluded in order to find "secondary determinants", under the premise that secondary determinants should have been significant as main effect in step 1. Fourthly, when all primary and secondary determinants of interest for all five variable categories are known, a last logistic regression is used to derive a combined model. Accordingly, for the combined model also interaction effects are included between categories, but only of variables that appeared significant at step 3 and 4. Given that relations between urban wayfinding ability and travel behaviour are of special interest, significant variables related to walking, bicycling, public transport, or car travel behaviour are always included in the combined model.

All determinants included in the two combined logistic regression models for Orientation Ability and Knowledge Gathering & Processing Ability are included in the estimation of two GLMs. To test the model fit, generally a Type I analysis is recommended when main effects are specified before first-order interaction effects. A model with an insignificant value implies that the related effect is not different from 0 if only the preceding effects are included. Therefore, next to a Type I test, also the Type III test is used to determine whether an effect is significantly different from 0 containing all modelled effects. Finally, model evaluation is performed using a confusion matrix to derive, amongst others, Accuracy and Informedness.

4. Theoretical framework & descriptive results

This section starts with the results from the Exploratory Factor Analysis and derivation of two urban wayfinding styles (4.1). Then, the preliminary results for daily travel behaviour based on travel diaries are described (4.2).

4.1. Factor analysis to derive wayfinding styles

After studying the Factor Analysis results for 2 to 5 components, it is concluded that the most applicable (consistent) number of components is two including 19 out of 23 questions. The results are depicted in Table 1. The two components are coined *Orientation Ability* (attitude and basic skills to be able to orient and navigate effectively in an urban environment) and *Knowledge Gathering & Processing Ability* (attitude and preferences to extend knowledge about the environment, e.g. explore cities and take new routes). With this clustering, 50% of the total variance is explained. The KMO value is 0.940 and the Bartlett test indicates significance ($p < 0.001$). Each wayfinding style relies largely on unique variables, while also three common variables exist: ability to give route directions, perception of distances, and attitude to read maps. These results advocate that Orientation Ability and Knowledge Gathering & Processing Ability are partially dissociated.

Table 1
Rotated component matrix.

	1: Orientation Ability	2: Knowledge Gathering & Processing Ability
1. Sense of orientation[a]	0,75	
2. Ability to find the way in an unfamiliar city[a]	0,74	
3. Ability to understand route directions[a]	0,73	
4. Memorize a route after following it once	0,68	
5. Memorize a route as a passenger in a car[a]	0,68	
6. Ability to give route directions	0,67	0,44
7. Active navigation for longer journeys[a]	0,65	
8. Attitude to give route directions[a]	0,61	
9. Perception of distances	0,59	0,47
10. Perception of mental map[a]	0,57	
11. Ability to recall places[a]	0,54	
12. Attitude to read maps	0,54	0,48
13. Coordinated perception of environment (NSEW)		0,61
14. Exploration attitude to find new routes		0,68
15. Regularly choose new routes		0,76

[a] scored in reverse order as the survey question was negatively phrased.

Based on the resulting components a theoretical framework is proposed inspired by literature on wayfinding (Fig. 3A). In this framework Orientation Ability is the latent variable that captures three basic types of spatial orientation: egocentric, allocentric (fixed-point), and map-based (coordinated) orientation and navigation (Stea and Blaut, 1973). Similarly, Knowledge Gathering & Processing Ability is the latent variable for three basic types of spatial knowledge that can be acquired: declarative knowledge of landmarks, procedural route (network), and relational survey (map) knowledge (Siegel and White, 1975; Golledge and Gärling, 2001). However, the classification based on literature is not mutually exclusive, i.e. one can simultaneously rely on egocentric and fixed-point orientation. The factor analysis is used to transform the latent variables into unique wayfinding styles as it reduces the dimension to 2 components (Fig. 3B). Each component can be divided into three levels of a wayfinding style; lower than average (−1), average (0), higher than average (1). Using Generalized Linear Models (GLMs) the wayfinding styles can be investigated through the relationships with discrete and continuous variables related to socio-demographic, motility, urban environment, navigational preferences, and daily travel behaviour (Fig. 3C). The number at the centre of each box depicts the number of respondents diagnosed with each of the styles.

4.2. Daily travel behaviour

Regarding daily travel behaviour in The Netherlands, almost 45% of the respondents did perform at least one bicycle trip during the three-day travel diary period, but every respondent in this study did make a bicycle trip in the past 6 months. From the 45% of respondents that used the bicycle during the travel diary period, 60% biked on average up to 6.0 km on a day. Furthermore, assuming an average cycling speed of 15 km/h, the results in Fig. 4 suggest that 40% of the respondents are on average 24 to 46 min active on their bicycle on a daily basis. Moreover, approximately 37% of the respondents do not include any trips by car in their daily travel behaviour during the three-day travel diary period. From the respondents where the car is part of their daily travel pattern 20% travel only for short distances (not more than 9.0 km a day) Fig. 4.

For this study, it is of interest to investigate to what extent *activity patterns* and *mobility portfolio* (frequency and distance of modal trips) relate to wayfinding styles. Furthermore, a *daily mobility pattern* is assumed to capture travel behaviour more realistically than individual mobility portfolio per travel mode, because consists of the combined intensity of all modes used. The MPN travel diaries are used to derive five mobility pattern typologies using a latent class cluster analysis. For more information on the technique used to derive the pattern typologies, the reader is referred to (Ton et al., 2019). For the estimation of the latent clusters, the average daily number of trips by car, public transport, bicycle, foot, other modes, and the share of non-travel days during the week have been used as input variables. The active covariates are urbanization level, occupation, and number of household members. The data concerning the complexity of daily mobility patterns includes stems from a larger set of 2425 respondents.

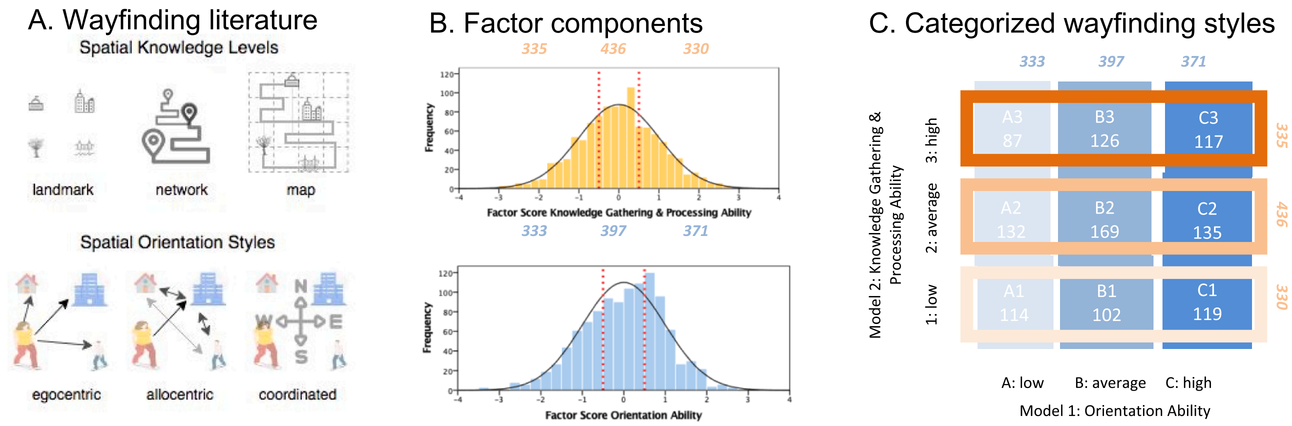

Fig. 3. Theoretical framework (A,B) for operationalization of urban wayfinding styles and results (C).

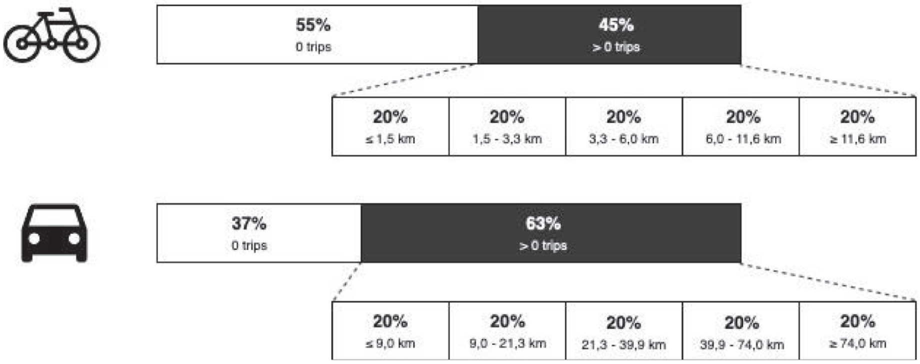

Fig. 4. Mobility portfolio: average daily trips & travelled distance reported during travel diary period.

5. Results

This section continues with the outcome of the Generalized Linear Models (GLM) for both urban wayfinding styles (5.1). After the explanation of model results, both models are evaluated based on confusion matrices (5.2).

5.1. Model estimation of urban wayfinding styles

Prior to the Generalized Linear Model (GLM) estimation, several multinomial logistic regression analyses have been performed to identify primary and secondary variables of interest for each variable category (socio-demographic, urban environment, navigational preferences, and daily travel behaviour). An overview of significant determinants based on the combined models with an urban wayfinding style can be found in Table 2. Three socio-demographic variables yield significant relations in one or both Generalized Linear Models (GLMs): gender, age, and education level. Regarding the urban environment, four determinants have been included related to attractiveness of urban elements, namely familiar streets, unfamiliar streets, greenopy, and rivers and lakes. Also, the perceived accessibility of the bicycle infrastructure in one's neighbourhood yielded significant differences in Orientation Ability. Note that merely 1–2% of the respondents avoid familiar streets, greenopy, or have a negative perception of the accessibility of the bicycle infrastructure. Therefore, it is likely that these variable levels will not yield significant results. Additionally, three determinants describing various facets of navigational preferences are found to be significant: preference to minimize turns, take short-cuts, and follow the bearing line (direction towards the destination). The latter four determinants were originally measured at a 5-point Likert scale. Active navigation ratio (0,0–1,0), average daily distance travelled by bike and car, and the average number of trips by car are included as continuous variables. Trip purpose and daily mobility patterns did not yield any significant relations with either wayfinding styles.

Table 2
Overview of determinants.

Discrete Variable Information	Levels		Freq.	Perc.
gender	male		488	44%
	female		613	56%
education level	university degree		403	37%
	vocational education		420	38%
	basic education		278	25%
age	greater than65 years		183	17%
	30–65 years		504	46%
	19–29 years		336	31%
	12–18 years		78	7%
perceived bicycle accessibility	good		959	87%
	normal		126	11%
	bad		16	2%
familiar streets	attracted		261	24%
	neutral		831	76%
	repelled		9	1%
unfamiliar streets	attracted		77	7%
	neutral		917	83%
	repelled		107	10%
greenopy	attracted		441	40%
	neutral		647	59%
	repelled		13	1%
rivers & lakes	attracted		16	2%
	neutral		1068	84%
	repelled		50	5%
navigational preference minimize turns	(strongly) positive		275	25%
	neutral		424	39%
	(strongly) negative		402	37%
navigational preference to take short-cuts	(strongly) positive		279	25%
	neutral		492	45%
	(strongly) negative		330	30%
navigational preference follow bearing line	(strongly) positive		660	60%
	neutral		360	33%
	(strongly) negative		81	7%
Continuous Variable Information	**Min.**	**Max.**	**Mean**	**Std. Dev.**
active navigation ratio	0	1	0,70	0,42
average daily distance by bike [km]	0	50,70	3,14	6,07
average number daily car trips	0	11	1,52	1,60
average daily distance by car [km]	0	454	30	49

5.1.1. Urban wayfinding style 1: orientation ability

The first GLM model is used to estimate the latent ability for spatial orientation. The variables with the highest factor loadings are: sense of orientation, ability to find the way in an unfamiliar city, and ability to understand route directions. A total of 11 parameters are included (Table 3), the main effects of the GLM are gender (female or male), age (teenagers, young adults, middle-aged adults, or (young) seniors), perceived accessibility of bicycle infrastructure in the neighbourhood (bad, neutral, or good), preference to make detours via familiar streets and rivers or lakes (detour due to attraction or repulsion, or a neutral attitude), and the navigational preference to minimize turns and follow the bearing line towards the destination (disagree, neutral, or agree). Also four interaction effects yield significant results: gender and self-reported average daily distance travelled by bicycle (continuous measurement scale 0,0–50,7 km), self-reported average daily distance travelled by bicycle and preference to minimize turns, self-reported average daily distance travelled by car (continuous measurement scale 0,0–454,0 km) and preference to minimize turns, and self-reported average daily number of trips travelled by car (discrete measurement scale 0–11) and active navigation ratio (continuous measurement scale 0,0–1,0).

Socio-demographic. In line with literature, gender has a strong effect. Compared to men, women have more often a self-reported average score, but not necessarily a lower score than average for

Table 3
Model results.

		Orientation Ability		Knowledge Gathering & Processing Ability	
Number of parameters (df)		11 (22)		6 (23)	
AIC | BIC		2.153 | 2.273		2.081 | 2.206	
Parameters		B	Std. Error	B	Std. Error
Threshold: low score		−1,39***	0,29	−3,20***	0,41
Threshold: medium score		0,42	0,30	−1,27***	0,39
Determinants	Level/Scale				
gender *[ref: male]*	female	−1,36***	0,14	−0,68***	0,12
age *[ref: older than 65]*	12–18 years	−0,82**	0,28	−1,18***	0,28
	19–29 years	0,23	0,19	−1,08***	0,19
	30–65 years	0,39	0,17	−0,80***	0,18
perceived bicycle accessibility *[ref: good]*	bad	−0,39	0,37		
	normal	−0,49**	0,18		
familiar streets *[ref: attracted]*	avoid	−0,75	0,55		
	neutral	0,41**	0,15		
rivers & lakes *[ref: attracted]*	avoid	0,22	0,33		
	neutral	−0,48*	0,18		
preference to minimize turns *[ref: agree]*	disagree	1,02***	0,22		
	neutral	0,46*	0,20		
preference to follow bearing line *[ref: agree]*	disagree	−0,38	0,25	0,18	0,30
	neutral	−0,39**	0,13	0,29**	0,13
average daily distance by car	kilometre			0,01***	0,00
gender * bicycle distance	female	−0,02	0,02		
	male	−0,08***	0,02		
bicycle distance * minimize turns *[ref: preference to minimize turns]*	disagree	0,04	0,03		
	neutral	0,06*	0,02		
car distance * minimize turns	disagree	−0,00	0,00		
	neutral	−0,04*	0,00		
	agree	0,04	0,00		
trips by car * active navigation ratio		0,14**	0,05		
basic education * unfamiliar streets	avoid			−1,96***	0,46
	neutral			−1,01***	0,35
	attract			1,32**	0,78
vocational education * unfamiliar streets	avoid			−1,57***	0,46
	neutral			−1,01***	0,34
	attract			0,02	0,47
university degree * unfamiliar streets	avoid			−0,10	0,58
	neutral			−0,68*	0,34
	attract			ˆ	
no preference for short cuts * greenopy	avoid			−0,49	1,71
	neutral			−1,29***	0,25
	attract			−0,50*	0,26
neutral to short cuts * greenopy	avoid			−0,76	0,53
	neutral			−0,44*	0,21
	attract			−0,10	0,24
preference for short cuts * greenopy	avoid			0,25	0,80
	neutral			−0,32	0,24
	attract			ˆ	

N = 1101. ***, **, * Significant at 99%, 98%, 95% confidence level, ˆ reference, [blank] not included in model.

Orientation Ability (beta-coefficient of −1.36), while the threshold for a low score for Orientation Ability is −1.39 (see Table 3). The odds-ratio implies that compared to men, women have on average 26% chance of having a high self-reported sense of orientation, holding all other variables in the model constant. However, there is also a negative significant interaction effect (-0,08) for men and the average daily distance travelled by bicycle. Therefore, gender differences in bicycling behaviour have been investigated in more detail. A Mann-Whitney *U* test indicated no significant difference (U = 147.752,5, p = 0,70) between average daily distances travelled by bicycle for women and men. Therefore, it can be concluded that only for men each additional travelled kilometre by bike corresponds to a 0,08-unit decrease in the Logit of the expected value of "high Orientation Ability", holding all other variables in the model constant. Theoretically, this implies that on average for men who cycle on average 17 km a day, their self-reported Orientation Ability has equal chances for a low, average, or high score, compared to women, holding all other variables in the model constant.

Urban environment. Respondents who are not inclined to make detours to travel along familiar streets have an odds-ratio of 1,5. Hence, they are more likely to self-report a high Orientation Ability compared to respondents that would make detours because they value to travel through familiar streets. The negative effect for respondents who indicated to avoid familiar streets is not significantly different from attraction, which can be explained by the small group size. Overall, these findings suggest that people with lower levels of Orientation Ability compensate for the complexity of the urban wayfinding task by preferring a longer route along familiar streets. Furthermore, it can be hypothesized that high Orientation Ability is more likely to correspond to higher variability in the streets of chosen routes. In literature there are already some indications that also navigational preferences (Hölscher et al., 2011) and salient characteristics of the environment (Li and Klippel, 2016) result in different route patterns. A similar reasoning applies to natural boundaries (rivers and lakes) and perceived accessibility of the bicycle infrastructure in the neighbourhood. Indifference to natural boundaries corresponds to a lower probability to have high self-reported Orientation Ability, and a positive perception towards bicycle accessibility corresponds to a higher probability to have high self-reported Orientation Ability. The latter result implies that higher (perceived) connectivity of the bicycle infrastructure requires more Orientation Ability than average. This is in line with the evolutionary model of Giannopoulos et al. (2014) including the complexity of wayfinding decisions in relation to the complexity of the urban environment, spatial ability, and preferences.

Navigational preferences. Regarding navigational preferences, both bearing line and minimize turns are included as determinants. These preferences are correlated, but including both determinants does not change the direction of the relation with Orientation Ability. The preference in favour of following the bearing line (the perceived direction towards the destination) is associated with a higher probability to self-report a high Orientation Ability, while no preference (or a neutral attitude) to minimize turns is correlated with a higher probability to have high self-reported Orientation Ability. This implies that using these two navigational strategies simultaneously is not beneficial for high self-reported Orientation Ability. Especially respondents that are aware that minimizing turns is not one of their navigational preferences have an increased likelihood to self-report a high Orientation Ability, as their odds-ratio is 2,77.

Interaction effects. Furthermore, there are three significant interaction effects with navigational preferences: average daily distance travelled by car and by bicycle with preference to minimize turns, and the average daily number of trips made by car and active navigation ratio. Compared to respondents with a preference to minimize turns, every additional cycled kilometre of respondents with a neutral attitude to minimize turns corresponds to an increase of 0,06 in the Logit of the expected value of “high self-reported Orientation Ability”, holding all other variables in the model constant. For the average bicycle distance of 3,14 km, the combined beta-coefficient is 0,19. In other words, every additional kilometre cycled a day amplifies the positive effect of a neutral preference to minimize turns.

Contrarily, car distance has a negative coefficient for a neutral preference to minimize turns. The average distance by car reported in the MPN travel diary is 29,5 km, which results in a combined beta-coefficient of $-0{,}72$. Thus, it can be concluded that for car travellers, being aware that minimizing turns is not a preference increases the chance to have high self-reported Orientation Ability, while indifference will decrease the chance. Last, there is a negative relation for respondents with low Orientation Ability between the daily number of trips made by car and the active navigation ratio. In other words, for people with lower levels of Orientation Ability the number of trips made by car is higher when on average the respondent is less often in control of the navigation (e.g. as the passenger in a car, or when the daily mobility pattern also includes public transport trips), while for people with high orientation there is positive relation.

5.1.2. Urban wayfinding style 2: knowledge gathering & processing ability

The second GLM model is used to estimate the latent ability for spatial knowledge. The variables with the highest factor loadings are: regularly choose new routes, exploration attitude to find new routes, and coordinated perception of the environment (NSEW). A total of 6 parameters are included in the GLM (Table 3). The main effects are gender (female or male), age (teenagers, young adults, middle-aged adults, or (young) seniors), navigation preference to follow the bearing line towards the destination (disagree, neutral, or agree), and reported average daily distance travelled by car (0,0–454,0 km). Also, two interaction effects yield significant results; education level and preference to make detours due to unfamiliar streets (detour due to attraction, neutral, or detour due to repulsion). The second interaction is a navigational preference to take short cuts (disagree, neutral, or neutral) and preference to make detours due to the greenopy of the street (detour due to attraction, neutral, or detour due to repulsion).

Socio-demographic. The strongest negative effect on Knowledge Gathering & Processing Ability is found for teenagers (-1,18), with a threshold for an average level of Knowledge Gathering & Processing Ability of $-1{,}27$. The odds-ratio implies that, compared to (young) seniors, teenagers have 31% chance of having a high self-reported Knowledge Gathering & Processing Ability, holding all other variables in the model constant. This means that, although significant, age category is not sufficient to distinguish between the 3 levels of Knowledge Gathering & Processing Ability. The main difference in socio-demographic compared to the Orientation Ability model is that the effect of age (odds-ratio of 0,31) is stronger than the effect of gender (odds-ratio of 0,51).

Navigational preferences. Regarding navigational preferences, the preference for following the bearing line (or direction towards the destination) corresponds to a lower probability to have high self-reported Knowledge Gathering & Processing Ability, while a neutral attitude to minimize turns corresponds to a higher probability to have high self-reported Knowledge Gathering & Processing Ability. Note that this determinant has the opposite effect on Orientation Ability. Hence, people reporting a lower Knowledge Gathering & Processing Ability and a higher Orientation Ability are more likely to correspond to a navigational preference to follow the bearing line. This shows that some determinants have an ambiguous effect on both wayfinding styles; also car distance, included as interaction effect for Orientation Ability, has a positive relation with Knowledge Gathering & Processing Ability, and a negative relation with Orientation Ability. Each additional travelled kilometre by car corresponds to a 0,01-unit increase in the Logit of the expected value of “high Knowledge Gathering & Processing Ability” versus lower conditions, holding all other variables in the model constant.

Interaction effects. Furthermore, there are two interaction effects with the attraction to urban elements while using the bicycle for a personalized trip purpose. Exploration of unfamiliar routes has an interaction effect with the highest completed education level. Significant differences with people with high education and attraction to unfamiliar routes are negative for people with basic or vocational education and repulsion or neutral attitude towards unfamiliar streets. For people with a university degree, there is only a smaller significant negative difference for neutral attitude towards unfamiliar streets. Being attracted to unfamiliar streets is not significantly different between people with a university degree and vocational education, but there is a higher chance for people with a low vocational education (5% of the respondents) to have a significantly higher self-reported Knowledge Gathering & Processing Ability. One reason could be related to differences in mental, verbal and memory abilities also found in (Shelton et al., 2013). Another possibility is that children younger than 21 have no chance of having a completed vocational education or university degree and therefore are compensated if they state to be attracted by unfamiliar streets. A third reason could be to latent different travel patterns between different levels of education. However, the current data and model do not provide strong evidence for these explanations.

The second interaction effect is the navigational preference to take short-cuts and the greenopy (street with trees). What can be observed is that with a preference to take short-cuts, effect of the attitude towards greenopy is not significantly different on their self-report Knowledge Gathering & Processing Ability. Thus, taking short-cuts in very urban (many buildings, little green) areas and areas where trees have a prominent role requires similar Knowledge Gathering & Processing Abilities. However, as merely 1% of the respondents indicated to avoid streets with trees, the results do indicate that avoiding greenopy requires a little more Knowledge Gathering & Processing Ability. For respondents who do not prefer to take short-cuts, cycling a longer distance due to attractive greenery corresponds with lower Knowledge Gathering & Processing Ability. This could be interpreted as a detour through green streets is easier to memorize for people that do not wish to make short-cuts along the route. Secondly, with neutral or no preference to take short-cuts and a neutral attitude towards the greenopy, the chance to also have a lower level of Knowledge Gathering & Processing Ability is higher. 40% of the respondents indicate to be attracted to make a detour along green passages to the activity they most frequently visit by bicycle. Similar are natural boundaries caused by rivers and lakes beneficial and they do not require more Orientation

Table 4
Contingency tables of wayfinding styles.

A. Orientation Ability					B. Knowledge Gathering & Processing Ability					C. Score			
Predicted	Actual			Total	Predicted	Actual			Total	Weights			
	−1	0	1			−1	0	1					
−1	**168**	112	41	320	−1	**137**	110	24	237	5	1	0	**6**
0	124	**149**	127	396	0	168	**243**	174	641	1	4	1	**6**
1	41	136	**203**	385	1	30	83	**132**	223	0	1	5	**6**
Total	333	397	371	***1101***	Total	335	436	330	***1101***	**6**	**6**	**6**	

Abilities. Also, in this study the perceived accessibility of the bicycle infrastructure showed a significant relation with Orientation Ability, which is in line with existing literature where street connectivity is a significant determinant. These results could be important insights for the design of active and healthy cities; each additional minute travelled by foot or bike can beneficial for somebody's health. However, more research is needed to investigate how urban design affects the number of bicycle trips, bicycling time and distance.

5.2. Model evaluation

This section evaluates the two estimated GLM models. Contingency tables (Table 4A, B) are used to calculate the prevalence (overall accuracy). It is defined as the number of all correct predictions divided by the total number of respondents from the contingency tables, with an evaluation of 1 (0) as the best (worst) possible. On average both Orientation Ability and Knowledge Gathering & Processing Ability yield a prevalence of 0,47. These results are acceptable as they are a 42% improvement compared to a random accuracy of 0,33. However, these evaluations can be too optimistic when the accuracy of the prediction is unequally distributed. An estimate that is only one degree off (predicted "average ability" instead of "low" or "high") is better than an estimate predicting a "high ability", while it should have been a "low ability" (second degree). Therefore the models are also evaluated with a weighted scoring shown in Table 4C. This particular combination of weights yields a maximum score of 5108 points for 1101 respondents, with an evaluation of 1. The "penalty" is higher when the prediction is 2 conditions of (0 points) compared to 1 (1 point), while there is no differentiation between conditions (each row and column has equal points; 6). The model describing Orientation Ability yields a score of 0.57, while Knowledge Gathering & Processing Ability performs slightly less with a score of 0.56.

Each contingency table can be used to derive three confusion matrices for a more detailed evaluation (Table 5). For each of the three ability conditions (lower than average (−1), average (0), higher than average (1)) a confusion matrix is computed that reports the number of false positives, false negatives, true positives, and true negatives. The sensitivity is calculated as the number of correct positive predictions divided by the total number of actual positives. Colloquially, given a specific ability condition (i.e. low, average, or high) how often is the prediction correct. From Table 5 it can be observed that given a condition both wayfinding models yield predictions that are for 38% to 56% of the cases correct. "Average Orientation Ability" and "high Knowledge Gathering & Processing Ability" have the lowest performance, while "average Knowledge Gathering & Processing Ability" and "high Orientation Ability" have the highest. Regarding specificity, the table indicates that only "average Knowledge Gathering & Processing Ability" scores low. In other words, the models are quite suitable to identify a respondent that has not low Orientation Ability as someone who has either neutral or high Orientation Ability.

Moreover, the model precision is calculated as the number of correct positive predictions divided by the total number of positive predictions. This metric is useful if the model is generalized. It provides an indication of how many of the predicted ability conditions are actually correct. For these models, all low and high abilities can be estimated with more than 50% precision. However, the models have a tendency to assign individuals that are "low" or "high" to the "average" ability level category.

The ratio between TPR and TNR also provides insight into any bias to specific ability conditions and how conservative the model is. The TPR and TNR values for orientation abilities are very similar, but there is a bias for average Knowledge Gathering & Processing Ability, while low and high knowledge gathering & processing abilities are too conservative. Finally, Informedness describes the extent of any form of guessing of an informed decision. A value of 0 (both "average" conditions) depicts the highest possible probability that the model outcome is more a guess than an informed decision. From the results in Table 4A, B it can be concluded that the quality of the model results is not equally

Table 5
Evaluation measures based on derived confusion matrices.

		Orientation Ability *Condition i*			Knowledge Gathering & Processing Ability *Condition i*		
Description	Formula	−1	0	1	−1	0	1
Prevalence	$TP_i/(TP_i + FN_i + FP_i + TN_i)$	0,30	0,36	0,34	0,30	0,40	0,30
Sensitivity (TPR)	$TP_i/(TP_i + FN_i)$	0,50	0,38	0,55	0,41	0,56	0,40
Specificity (TNR)	$TN_i/(TN_i + FP_i)$	0,80	0,64	0,76	0,83	0,49	0,85
Precision (PREC)	$TP_i/(TP_i + FP_i)$	0,52	0,37	0,53	0,51	0,42	0,54
Informedness	$TPR_i + TNR_i - 1$	0,31	0,02	0,30	0,23	0,04	0,25
Description	Formula	Weighted average			Weighted average		
Overall accuracy	$(TP_1 + TP_2 + TP_3)/(P + N)$	0,47			0,47		
Weighted score	$((TP_1 + TP_3) * 5) + (TP_2 * 4) + FN^1 + FP^1/((AA_1 + AA_3) * 5) + (AA_2 * 4)$	0,57			0,56		
Overall informedness	$TPR_{w.mean} + TNR_{w.mean} - 1$	0,21			0,20		

P: all Positive, N: all Negative, TP: True Positive, FN: False Negative, FP: False Positive, TN: True Negative, FN^1: first degree False Negative, FP^1: first degree False Positive, AA: Actual Ability.

distributed. It can be concluded that “low” and “high” wayfinding abilities are better modelled compared to the respective “average” wayfinding ability.

6. Synthesis on wayfinding styles

This study aimed to investigate differences in urban wayfinding behaviour and relations with individual navigational preferences in the larger (metropolitan) urban environment where daily travel behaviour takes place in The Netherlands (See Fig. 5). This section elaborates how the findings of holistic GLMs on Orientation Ability and Knowledge Gathering & Processing Ability contribute to (i) the understanding of urban travel and mobility behaviour, (ii) provision of comprehensible travel information, (iii) design of legible cities, (iv) identify potential navigation problems, and (v) limitations of this study.

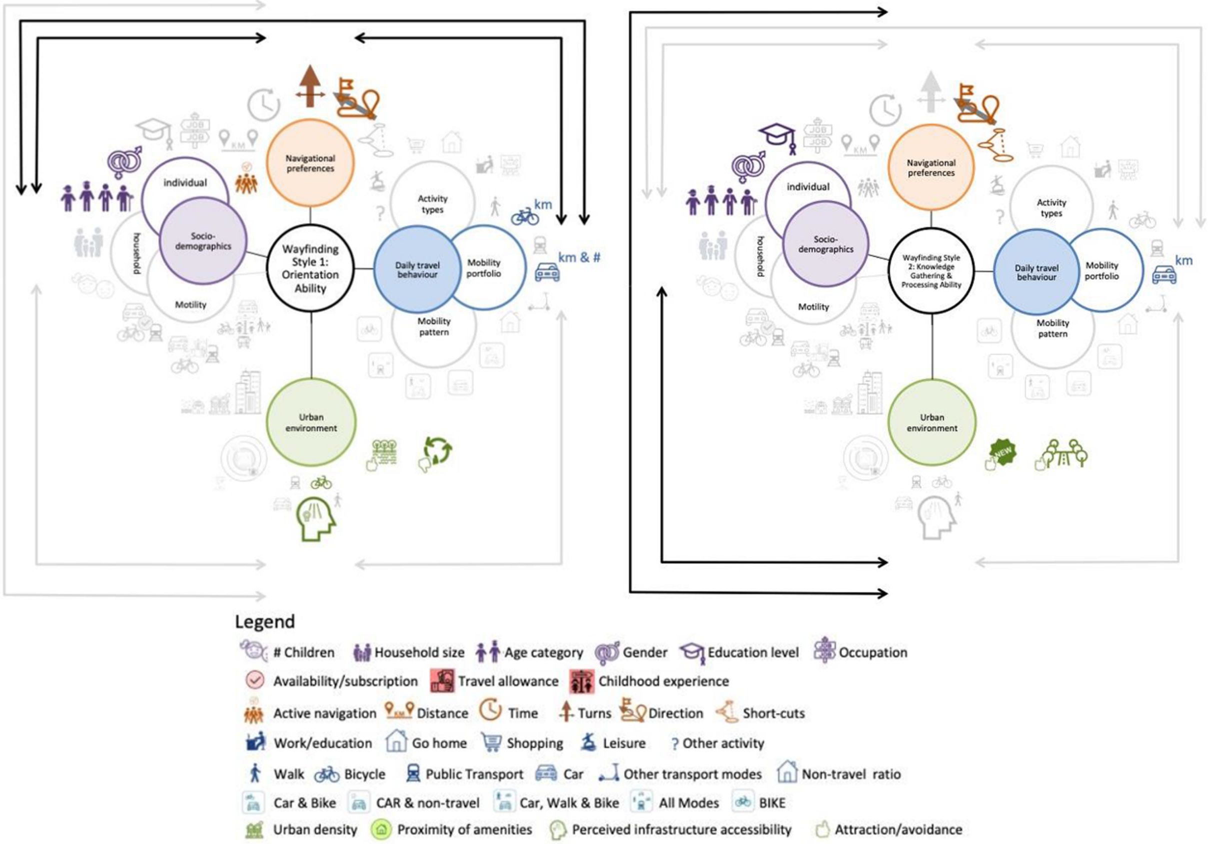

Fig. 5. Significant Determinants of Two Urban Wayfinding Styles in The Netherlands. Dark arrows indicate significant interaction effects. Urban elements to avoid or attract are rivers and lakes, (un)familiar streets, and greenopy.

6.1. Relation between travel behaviour and urban wayfinding styles

From the literature background it was hypothesized that the total average travel distance (by car and foot) have a negative relation with the wayfinding score. The results in this study also show a negative relation for distance travelled by car, and for the first time, also distance bicycled by men with Orientation Ability. However, this study also shows that the total average distance travelled by car and the interaction effect between average number of car trips and active navigation ratio have positive relations with Knowledge Gathering & Processing Ability. Although the majority of the research found in literature investigates pedestrian wayfinding, the distance travelled by foot and public transport are not significant in this study. Furthermore, a latent cluster analysis has been performed using the average number of trips per travel mode (Ton et al., 2019). Noteworthy, although significance in a categorical model only including travel behaviour, in both GLMs the identified mobility patterns clusters did not yield any significant relation in combination with other determinants.

6.2. Travel information and route choice

Based on findings in literature, it can be expected that respondents with a better sense of orientation choose routes with shorter travel distance and time, but not necessarily higher travel speed. This requires flexible navigational preferences as the structure and layout of each urban environment demands different abilities. However, both GLMs did not include navigational preferences to minimize travel distance or time. Regarding the provision of comprehensible travel information, this indicates that wayfinding styles are more related to number of turns, bearing line and short-cuts than travel distance or travel time. In the future, a similar study including travel data at route level could be used to investigate differences in route choice behaviour and variability.

6.3. Legible urban wayfinding

Fig. 4 demonstrates that approximately 30% of the respondents use the bicycle for urban short trips up to 10 km, while only 15% use the car. This travel behaviour is typical for the Netherlands, where many people consider the bicycle as the main transport mode, especially within cities. Also, the bicycle is an important transport mode to achieve the climate goals stated in the Paris Agreement. Notwithstanding, little is known about what makes it easy to navigate a city by bicycle and how the urban environment affects bicycle behaviour. To this end, this study identifies several factors concerning the design of legible cities for cycling behaviour.

Based on the models it seems that a combination of high Orientation

Ability and Knowledge Gathering & Processing Ability will correspond to higher variability in the streets of chosen routes. With higher (perceived) connectivity of the bicycle infrastructure more Orientation Ability is required than average. This implies that people with lower levels of Orientation Ability will compensate for the complexity of the urban wayfinding task by preferring a longer route along familiar streets. Thus, even if high connectivity exists, but all people have low orientation abilities, still not much route variation will occur and it will become more difficult to mitigate congestion and distribute large cyclists flows more evenly. Insights related to navigational preferences and urban environment on Knowledge Gathering & Processing Ability can be interpreted as for people that do not wish to make short-cuts, for example due to absent time pressure, it is easier to memorize a detour through a green passage. Last, although urban density has been identified as important characteristic for salience and legibility of an environment, its role as a determinant remains unknown, as neither model indicated significance.

6.4. Interactions between urban wayfinding styles

Both wayfinding styles can be used complementary as different processes influence them. However, two determinants (navigational preference to follow the bearing line and average daily distance travelled by car) have an ambiguous effect on both wayfinding styles. This could indicate a trade-off, because gathering and processing more spatial knowledge will ultimately require more orientation ability in order to process the knowledge into useable wayfinding styles. The navigational preference to follow the bearing line is not beneficial when there is a low amount of spatial knowledge, as this does not encourage the acquisition of more spatial knowledge. If a satisfactory amount of spatial knowledge has been acquired using the bearing line as a navigational preference is useful to reduce the workload.

6.5. Limitations of urban wayfinding styles

One of the limitations of this study is the assumption that urban wayfinding styles are static personality traits. To investigate if this assumption is valid, either a study should target visitors unfamiliar with a city, or this questionnaire should become part of the longitudinal data collection efforts of the MPN. In the latter case Generalized Estimating Equations (GEEs) can be used to deal with correlated observations, such as clustered data of subjects or classes (Hardin and Hilbe, 2012; Ballinger, 2004). A second recommendation for future work is the development a route choice model including the taste heterogeneity based on wayfinding styles to describe variability is chosen street segments.

The second limitation relates to the subjective nature of factor analysis and self-reporting behaviour of respondents (Fabrigar et al., 1999; Willis et al., 2009). There are indications of socio-cultural differences in reporting behaviour. For example, there might be some variation in how people assess their ability. So far it is unknown to what extent does this depends on the perceived ability of a partner, parents, and/or friends. Additionally, mistakes can be made while completing the three-day travel diaries. Therefore it is recommended to compare the accuracy of travel diaries with activity data and complementary travel data using GPS or mobile phones.

Furthermore, it should be stressed that socio-demographic differences in wayfinding styles in this study should be interpreted in terms of variations in development of beliefs and behaviour rather than overall ability or intelligence. Significant gender differences in favour of men are found for both Orientation Ability and Knowledge Gathering and Processing Ability. This is to some extent different from findings in most studies, where the majority of the findings lean towards the hypothesis that men are better at orientation and navigational tasks, while women have enhanced knowledge gathering, memory and processing ability. The difference can be partly ascribed to different questionnaires and experimental set-ups to measure knowledge gathering and processing abilities, as well as measured at different levels of spatial scale (e.g. toy model, indoor, route level, small VR environment, real city, realm of daily travel patterns).

In addition, there are always limitations to the length of a survey. The PAW-AM data collection is designed to gather many insights regarding pedestrian and cyclist mobility behaviour, from attitude towards mode choice, social norms, to wayfinding behaviour. Consequently, to reduce respondents' fatigue a number of questions related to avoidance and attraction of urban element was limited to bicycle trips. As this study is the first of its kind to investigate these types of bicycle landmarks, it is recommended to extend this approach to other travel modes to capture the complete picture of urban legibility.

Finally, with extensive models this study shows that only a limited number of determinants have a combined effect on each wayfinding style. Although more determinants, such as the mobility cluster patterns, show significant relations if included in solitude, it is believed that these simple model results are too optimistic. Moreover, many variables have been included in the surveys and have been tested for in the GLMs, many variables still need to be investigated. Both reasons probably contribute to the relative low Accuracy and Informedness of both models.

7. Conclusions

This is one of the first studies to investigate differences between urban wayfinding styles in relation to travel behaviour and navigation preferences in The Netherlands. Dutch travel behaviour is rather particular with relative short travel distances, a substantial amount of intercity commute, a long history of high bicycle shares, many rivers and canals, and nearly no inclination. Therefore, moderate differences with existing studies are expected and a Confirmatory Factor Analysis can be used for the generalization of the content of wayfinding styles in other contexts and estimate to what extent similar determinants have an influence.

The main contribution of this paper is the theoretical insight of how urban wayfinding behaviour relates to daily travel patterns. Moreover, possibilities and relevance for route choice behaviour, identify potential navigation problems, design more legible cities, and provision of comprehensible travel information are discussed.

Two holistic Generalized Linear Models (GLMs) describe urban wayfinding styles based on two dependent factor components "Orientation Ability" and "Knowledge Gathering & Processing Ability". The results are acceptable as they are a 42% improvement compared to a random accuracy of 0,33. However, the quality of the model results is not equally distributed; "low" and "high" wayfinding abilities are better modelled compared to the respective "average" wayfinding ability. The following determinants are significant: gender, age, education level, perceived bicycle accessibility of the neighbourhood, attraction to familiar and unfamiliar streets, and greenopy of the streets, navigational preferences to minimize turns, follow the bearing line, and take short-cuts, ratio of active navigation, average daily distance travelled by car and bicycle, and average daily number of trips made by car. Gender and age have similar effect signs on both OA and KA, while the navigational preference to follow the bearing line and average daily distance travelled by car have disassociated effects. The remaining determinants are only significant in either OA or KA, providing evidence that predominantly different processes describe each wayfinding style.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.tbs.2019.07.002.

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