Assessing Perceived Route Difficulty in Environments with Different Complexity

Arvid Horned[1]
Department of Computing Science, Umeå University, Sweden

Zoe Falomir
Department of Computing Science, Umeå University, Sweden

Kai-Florian Richter
Department of Computing Science, Umeå University, Sweden

Abstract

Today, anyone feeling lost in a city or unsure about how to navigate can use navigation services to look up routes to where they want to go. Current research investigating these services has primarily focused on how to find an appropriate route and how to best support navigation along it, and not how routes and the maps they are presented on are perceived. What makes one route look more difficult to navigate than another? And how does experience with using navigation services and maps in daily life influence how difficult a route is perceived to be? We explored these questions in a survey study where participants rated the perceived difficulty of pedestrian routes in ten different cities. The results show that routes in more complex urban environments were perceived as more complex than routes in easier environments. At least partly, perceived difficulty seems to follow earlier conceptualizations of route complexity, but open questions remain regarding the interplay of environmental structure, route properties, and the map representation.

2012 ACM Subject Classification Human-centered computing → Empirical studies in visualization; Human-centered computing → Human computer interaction (HCI); Applied computing → Psychology; Applied computing → Cartography

Keywords and phrases navigation complexity, perceived difficulty, route display, spatial cognition

Digital Object Identifier 10.4230/LIPIcs.COSIT.2024.29

Category Short Paper

Supplementary Material *Image (Stimuli)*: `https://osf.io/x7cmp/`

Funding *Zoe Falomir*: acknowledges the funding by the Wallenberg AI, Autonomous Systems and Software Program (WASP) awarded by the Knut and Alice Wallenberg Foundation, Sweden.

Acknowledgements To the participants in this study and the reviewers, for their useful feedback.

1 Introduction

Mobile maps and navigational aids are often used in support of trip-planning and in decisions about how and when to travel before we begin to travel. Yet, most research on wayfinding difficulty and route complexity has taken the perspective that the navigator is already en-route from point A to point B in an environment, or at least at the origin A, not how the environment or route may appear "from a distance." How difficult routes appear to be before navigation can influence decisions about if and how we choose to navigate, and the expectations and feelings we have about the upcoming actual navigation. However, the perceived difficulty of the route may differ significantly from how difficult it will actually be to

[1] Corresponding author.

navigate. The route is perceived as a line on a map representing the generated path, and how difficult it is perceived to be will depend on what is inferred about the environment depicted on the map, and about the steps of the route [7]. Furthermore, accurately estimating the difficulty of a route would involve two categories of spatial skills [17], *extrinsic-static* skills involved in reading and inferring spatial properties from a static depiction of an environment like a map, and *extrinsic-dynamic* skills when taking the perspective of navigating the route through the inferred environment. In this exploratory study, we investigate how difficult routes are perceived to be in a non-situated and prospective context, and how the urban environment the route takes place in influences how complex the route is perceived to be. We did this with a survey where 16 participants rated the complexity of 10 routes in urban environments categorized as either *complex* or *easy* and also explored how individuals might differ in how they assess route difficulty.

2 Perceived route difficulty

When displaying a route to a user, the system frames the route on a map that depicts the surrounding environment, including streets and how they are configured, landmarks that may or may not be visible while navigating, and parts of the environment that you may end up in if you make a navigation error. In other words, the route is perceived within the context of the map display and the environment that the map represents. Thus, route difficulty may be inferred from, or at least be strongly influenced by, the depicted environment as a whole. Perceived route difficulty in this sense is the impression made by the mapped urban environment on the map reader.

Several different factors contribute to environmental complexity, often also called legibility. These factors include architectural differentiation, the degree of visual access, the complexity of the layout, and competing reference systems [3, 18, 19]. In urban environments, environmental complexity is largely determined by the road network i.e., the width and length of different road segments, and their orientation and branching factor [11, 12]. Noticeable regions, (i.e., being able to visually tell apart different parts of the environment) offer structuring of an environment and, therefore, may reduce complexity, for example, by enabling hierarchization of the space [9, 20]. Furthermore, the structure of street networks influence what we remember, with properties such as higher street-continuity, street-width and streets following patterns being remembered more often [10]. The routes themselves may also differ in their complexity, in how complex different decision points are [4], and how complex it is for the particular person and situation that will navigate it [16]. Some people are better at reading maps, navigating an environment, and spatial reasoning more generally [6, 7, 21]. Perceived difficulty may be further modulated by experience in using maps or navigation services, and by one's confidence in being able to successfully perform the task [8], among others.

Finally, the chosen map style may well influence perceived difficulty. Depicting routes at a small scale may smooth them, making them appear less difficult because smaller direction changes are less visible. At the same time, fewer individual map elements may appear, in particular fewer individual buildings and small streets. The map may look less busy, which may reduce perceived difficulty. But also if the map scale is the same, different map styles may impact perceived difficulty differently. The use of colors and color schemes, the number and placement of labels and icons, the inclusion of region boundaries, and whether or not the map display emphasizes environmental structure as well as how the route is highlighted on the map may all contribute to the legibility of the map [1] or to perceived visual clutter [13].

3 An exploratory study of perceived route difficulty

3.1 Map stimuli

The aim of this study is to explore whether participants rate perceived difficulty of different routes differently, and which factors may contribute to such differences. One such factor we assumed concerns the complexity of the environment the route is in. Thus, as a first step, we identified environments we consider to be easy or complex using the following criteria, based on the findings of Mohsenin and Sevtsuk [10]. Easy environments are characterized by:

E1 The streets on the map have a "high" average street continuity.

E2 The streets on the map have a "high" average street width.

E3 The streets on the map follow easily recognized patterns.

Accordingly, complex environments exhibit the opposite criteria:

D1 The streets on the map have a "low" average street continuity

D2 The streets on the map have a "low" average street width.

D3 The streets on the map do not follow any easily recognized pattern.

For the easy urban environments, we used New York, Washington and New Delhi, which were given as examples of cities with well-defined street patterns by Mohsenin and Sevtsuk [10]. We identified Toronto and Paris to meet above criteria as two additional easy urban environments. For the complex environments, we searched for cities described online as being unstructured, complex or having difficult streets, finding European cities known to have an older, often partly medieval, street layout: Thessaloniki, Prague, Cologne, Florence and Seville.

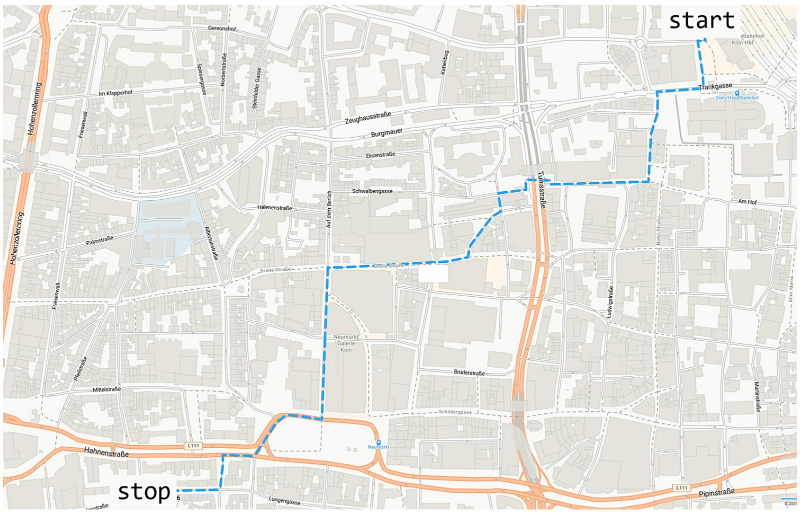

Figure 1 Example of map stimuli used in the survey meeting the criteria of a complex environment. Displaying a route in Cologne as it was presented by Microsoft Bing's online mapping service.

For the study itself, we created a scenario where someone arrives at a train station in an unfamiliar city and looks up a pedestrian route to their hotel. The length of the route is set to be approximately 2km, such that for every route, the map can be displayed at the same scale. The following three criteria were applied to find routes that fit the scenario:

A1 The length of the route is approximately 2km long.

A2 The origin of the route is a train station.

A3 The destination of the route is close to a hotel.

We applied these criteria in order to produce route stimuli for our study, which were set to be pedestrian routes in the previously identified urban environments optimized for shortest time by default. We used Microsoft's Bing Maps browser. A route was included if the map upon visual inspection met all the criteria stated above. The "road map" style was used in the display to emphasize the geometric properties of the streets in the environment, and the zoom level and scale of the map was set to 16.7. Finally, a screenshot of the route as seen in the web-browser was taken and then cropped to only show the part of the map containing the route as seen in the example shown in Figure 1[2]. Participant responses were collected using an online survey platform provided by Pavlovia[3], and to ensure that the images of the routes were displayed at the same size to all participants, it was important to do the survey on a screen with a 16:9 aspect ratio, and a minimum resolution of 1920 × 1080 pixels. This was provided to all participants who did the survey in person, and was required of all participants who did it remotely.

3.2 Procedure

In total, $N = 16$ participants took part in our study: 8 participants did the survey remotely, and 8 participants did it in person. We recruited participants through social media and informed them that they could complete the survey together with the experimenter or do it remotely at their own computer. The survey took about an hour to complete, and the participants did not receive any compensation. Overall, participants had a mean age of 33, with two participants above the age of 50. Most of the participants were university students. Nine of the participants identified themselves as male, 4 as female, and 3 as non-binary.

The participants were informed about how long it may take to complete the survey, and received instructions and an overview of the content of the survey. Then, they were asked to confirm that they consent to participate and allow their responses to be analyzed and reported. The survey proceeded with a demographic questionnaire concerning gender, age, frequency of using navigation services on their phone, frequency of following routes suggested by these services, and if they have any hobbies that involve map reading. Further, participants were asked to fill out the 8-item short form version of the PROMIS (Patient Reported Outcomes Measurement Information System) anxiety questionnaire [14], answering how often they have experienced symptoms of anxiety in the past seven days. Participants were asked to assess their spatial anxiety using the questionnaire developed by Lions *et al.* [8], responding how anxious they would feel if they had to complete different spatial tasks of different categories. In the final questionnaire, they assessed their sense of direction using the Santa Barbara Sense of Direction questionnaire [6].

In the main part of the survey, participants were shown each route for 20 seconds to control the amount of time they had to assess the routes, and limit the time to a duration that might better reflect how quickly we assess routes normally. The routes were presented in the same predetermined randomized order to all participants, and after each route they were asked to rate the route along three scales: How simple or complex did the route look? (*1:"Very simple" – 7:"Very complex"*); How easy or demanding did the route look? (*1:"Very easy" – 7:"Very demanding"*); How forgiving or punishing did the route look? (*1:"Very forgiving" – 7:"Very punishing"*). These three scales were derived from the description of the mental demand measurement in the NASA Task Load Index (NASA-TLX) [5], with the

[2] All map stimuli and more on the statistical analysis can be found here: `https://osf.io/x7cmp/`
[3] `https://pavlovia.org`

difference being that in NASA-TLX these questions are asked and rated together between 1 and 100. How these scales were used was left open for participants' interpretation, and they were only given an example of how they could evaluate how punishing a route looks.

In the last part of the survey, we asked the participants to complete a map planning test, where their ability to scan a map and find the shortest path between pairs of points was evaluated [2]. The test begins with a practice round where the participant has unlimited time and access to the correct answers, after which they are given 2 minutes per page to identify as many paths as possible.

4 Results

In the demographic questionnaires, a majority of the participants reported that they used navigation services more than once a month, and use these services to follow routes about once a month. Participants rated their sense of direction as slightly above average and their anxiety as normal in comparison to a global reference population. Furthermore, they had very low scores on the spatial anxiety questionnaire across all subcategories overall.

In the interest of space, we only report statistics of the rating along the *simple-complex* scale below (the other scales are correlated with this scale). We begin by comparing routes in the two kinds of environments, finding that the participants rated the routes in the *complex* environments as more complex ($M = 3.58, SD = 1.57$) than the routes in the *easy* environments ($M = 1.52, SD = 0.87$). A Mann-Whitney U test shows a significant difference between the two groups ($U = 795, p < 0.001$). We investigated how the routes within the *easy* and *complex* environments varied from each other using a Kruskal-Wallis test, finding that the route in Thessaloniki was rated as significantly more complex in comparison to the route in Florence; $z = 2.793, p = 0.026$. No within-group differences regarding complexity were found in the *easy* environments.

To further assess differences between the routes, the number of turns and intersections of each route was counted and compared between the two groups. The routes in the *complex* environments had on average more than twice the number of turns than routes in the *easy* environments ($easy : M = 5; complex : M = 12.6$). Moreover, the routes in the *complex* environment had on average more intersections than the routes in the easy environments ($easy : M = 19.2; complex : M = 23.4$). Further, we investigated how individual differences between the participants were related to their rating. A Mann-Whitney's U-test indicates no significant differences between participants above and below the median age of 30. We also found no significant differences when comparing the ratings given by participants online and in person, or between participants with different gender identities. Interestingly, participants that used navigation services more than once a month to follow routes ($N = 9$) gave significantly higher ratings ($U = 2029, p < 0.01, MD = 1$). Participants who used navigation services more often generally perceived routes to be more complex than the other participants, independent of the environment.

Qualitative results

Participants were asked to comment on what looked difficult about each route. These answers were subject to a thematic analysis where themes were identified inductively by first analyzing and coding each answer individually, and then combining these codes into five themes: *path*, *places*, *effort*, *structure*, *navigation support*, *social*. Comments on the difficulty of the *path* occurred 45 times, with comments referring to the number of turns and intersections or that crossing a large street made it look difficult. Moreover, a long and straight segment made it look easy, and contrary, a winding street segment made it look difficult. Comments referring to *places* occurred 30 times, where participants pointed out that a lack of landmarks along a route made it look difficult, especially if there were no landmarks in proximity to turns or the destination. Landmarks were also reported as making the route look easier, i.e., that it looked easier because there were "many" landmarks, and that rivers and churches were good or clear landmarks. Participants wrote about forms of *effort* (20 occurrences) they suspected that the route will require. For example, participants wrote that some routes look boring or repetitive. Participants wrote about the larger *structure* (17 occurrences) of the streets and the environment surrounding a route, writing that a "lack of structure" or a "messy" structure in the city made the route look more difficult, and vice versa that a clear structure visible on the map or good city planning made it look easier. As an example, some participants commented on the "messiness" of the second half of the route where it enters a different neighborhood. Participants made comments on the *navigation support* (15 occurrences), indicating that they did not understand why the system suggested this particular route. As an example, participants wrote that the route in Thessaloniki looked "illogical." Some answers referred to *social* aspects of the route (8 occurrences), stating that some of the streets a route follows look unfriendly to pedestrians, or that they might have a lot of traffic. Some comments were also made about the street names, that they were missing at a turn, or that the participants did not speak the language they were written in.

5 Discussion

In this study, we explored how route difficulty is perceived differently depending on the complexity of the surrounding environment. We tested the hypothesis that routes in urban environments with more unstructured and complex properties are perceived as more difficult than routes in urban environments with more structured properties. Overall, this is indeed what we find: participants rated the routes in those environments we classified as "complex" as more complex than those routes in the "easy" environments. Thus, it seems that our initial conceptualization of perceived (environmental) complexity is shared by the participants. But on closer inspection, the high variance among routes within the groups indicates that there are differences in perceived difficulty that are not explained by the criteria. For example, the number of turns or the angle of the turns along a route might explain why the route in Thessaloniki was rated as significantly more complex than the route in Florence.

The qualitative data gives some insight into how the routes were evaluated differently. Participants wrote about properties of the environment more often in reaction to routes in more complex urban environments, i.e., about the *path* of the route and *places* along the route as well as the *structure* of the surrounding environment. In contrast, participants wrote more often about the *effort* and *social* aspects associated with the routes in the less complex environments. A possible explanation for this difference is that it is easier to describe the difficulty of the environment when the environment has more abundant or visible complex properties. Moreover, focus seems to shift to additional, possibly more secondary, factors, such as the language of the map labels or the consequences of missing a turn, when the environment is less complex, i.e., less attention is drawn to the environmental structure. Further, participants who use navigation services to follow routes more frequently rated all routes as significantly more complex than other participants. This result indicates that *how* people use navigation services is associated to how difficult they perceive routes to be. From our data is difficult to tell why this difference emerges, but there are two plausible explanations: 1) people who perceive routes as more complex, or more generally consider wayfinding to be a difficult task, are more likely to rely on navigation services to follow routes; 2) people who use navigation services more often have a lower confidence in own wayfinding abilities and therefore perceive these routes as more complex.

There are some limitations to our study. While using an online survey-platform made it easier to reach participants outside the university, and allowed participants to do the test at their own pace and place, it also carried some problems with it. The order of the map stimuli may have influenced the results because the images could not be shown in a random order to each participant. A different presentation order may have produced somewhat different ratings, though we believe that statistical differences would still emerge. Also, participants were not given any instructions on how to interpret the rating scales. A more common understanding of these scales may have an impact on the results.

By exploring how route difficulty is perceived and how it may be investigated empirically, this study provides valuable insights for future research on perceived route difficulty. The quantitative data indicates that perceived route difficulty seems to follow what has been conceptualized as route complexity in earlier research. Furthermore, the qualitative data supports the interpretation of participants engaging with the task of evaluating route difficulty as an *extrinsic-dynamic* task (see Section 1), imagining what it would be like to navigate the route. A direction for future research is to compare what people imagine makes a route difficult to navigate with what is actually experienced as difficult while navigating the route. Approximating this, the perceived difficulty of routes may also be compared to the calculated difficulty of routes generated by cognitively motivated models (e.g., [15]). The quantitative data of this study says very little about perceived difficulty as an *extrinsic-static* task because all the routes were displayed using the same map style. How different map styles influence the inference of qualitative aspects, such as perceived difficulty, remains largely unexplored. On the other hand, computational methods to infer structural aspects of maps and environments, such as neighborhoods and landmarks, may be helpful in creating more adaptive visualizations. As participants wrote about the route in Seville, it became difficult when it entered a more complex neighborhood, and perhaps this part of the route should also be visualized differently. And could the route in Thessaloniki be visualized in such a way that it does not look "illogical" anymore? This may help a navigator make sense of how the route has been generated and why it is suggested.

Finally, both what is inferred about the route and how navigating the route is imagined may be compared to each other in future research. This study found that routes in more difficult environments were also perceived as more difficult. But how would participants perceive the difficulty of two identical routes in two different environments? And how would they perceive the difficulty of the same route displayed in two different map styles? How we perceptually judge routes raises questions about how the environment, the decision points along the route, and their representation are connected to one another.

References

1 James R. Antes, Kang-tsung Chang, and Chad Mullis. The visual effect of map design: An eye-movement analysis. *The American Cartographer*, 12(2):143–155, 1985. doi:doi:10.1559/152304085783915036.

2 Ruth B Ekstrom. *Kit of Factor-Referenced Cognitive Tests*. Educational testing service, 1976.

3 Tommy Gärling, Anders Böök, and Erik Linberg. Spatial orientation and wayfinding in the designed environment – a conceptual analysis and some suggestions for postoccupancy evaluation. *Journal of Architectural and Planning Research*, 3:55–64, 1986.

4 Ioannis Giannopoulos, Peter Kiefer, Martin Raubal, Kai-Florian Richter, and Tyler Thrash. Wayfinding decision situations: A conceptual model and evaluation. In Matt Duckham, Edzer Pebesma, Kathleen Stewart, and Andrew U. Frank, editors, *Geographic Information Science*, pages 221–234, Cham, 2014. Springer International Publishing. doi:10.1007/978-3-319-11593-1_15.

5 Sandra G. Hart and Lowell E. Staveland. Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research. In *Advances in Psychology*, volume 52, pages 139–183. Elsevier, 1988. doi:10.1016/S0166-4115(08)62386-9.

6 Mary Hegarty, Anthony E Richardson, Daniel R Montello, Kristin Lovelace, and Ilavanil Subbiah. Development of a self-report measure of environmental spatial ability. *Intelligence*, 30(5):425–447, 2002. doi:10.1016/S0160-2896(02)00116-2.

7 Amy K. Lobben. Navigational map reading: Predicting performance and identifying relative influence of map-related abilities. *Annals of the Association of American Geographers*, 97(1):64–85, 2004.

8 Ian M. Lyons, Gerardo Ramirez, Erin A. Maloney, Danielle N. Rendina, Susan C. Levine, and Sian L. Beilock. Spatial anxiety: A novel questionnaire with subscales for measuring three aspects of spatial anxiety. *Journal of Numerical Cognition*, 4(3):526–553, 2018. doi:10.5964/jnc.v4i3.154.

9 E.J. Manley, S.W. Orr, and T. Cheng. A heuristic model of bounded route choice in urban areas. *Transportation Research Part C: Emerging Technologies*, 56:195–209, 2015. doi:10.1016/j.trc.2015.03.020.

10 Mahsan Mohsenin and Andres Sevtsuk. The impact of street properties on cognitive maps. *Journal of Architecture and Urbanism*, 37(4):301–309, 2013. doi:10.3846/20297955.2013.866864.

11 Daniel R. Montello. Spatial orientation and the angularity of urban routes — a field study. *Environment and Behavior*, 23(1):47–69, 1991.

12 Michael J. O'Neill. Evaluation of a conceptual model of architectural legibility. *Environment and Behaviour*, 23(3):259–284, 1991.

13 Ruth Rosenholtz, Yuanzhen Li, and Lisa Nakano. Measuring visual clutter. *Journal of Vision*, 7(2):1–22, August 2007.

14 Benjamin D. Schalet, Karon F. Cook, Seung W. Choi, and David Cella. Establishing a Common Metric for Self-Reported Anxiety: Linking the MASQ, PANAS, and GAD-7 to PROMIS Anxiety. *Journal of anxiety disorders*, 28(1):88–96, 2014. doi:10.1016/j.janxdis.2013.11.006.

15 Fateme Teimouri and Kai-Florian Richter. You are not alone : Path search models, traffic, and social costs. In *11th International Conference on Geographic Information Science (GIScience 2021) – Part I.*, volume 177 of *Leibniz International Proceedings in Informatics (LIPIcs)*, pages 14:1–14:16. Schloss Dagstuhl – Leibniz-Zentrum für Informatik, 2020. doi:10.4230/LIPIcs.GIScience.2021.I.14.

16 Sabine Timpf and Corinna Heye. Complexity of routes in multi-modal wayfinding. Technical report, ETH Zurich, 2002. doi:10.3929/ETHZ-A-004370509.

17 David H. Uttal, Nathaniel G. Meadow, Elizabeth Tipton, Linda L. Hand, Alison R. Alden, Christopher Warren, and Nora S. Newcombe. The malleability of spatial skills: A meta-analysis of training studies. *Psychological Bulletin*, 139(2):352–402, 2013. doi:10.1037/a0028446.

18 Jerry Weisman. Evaluating architectural legibility: Way-finding in the built environment. *Environment and Behaviour*, 13(2):189–204, March 1981.

19 Steffen Werner and Paul Long. Cognition meets Le Corbusier – cognitive principles of architectural design. In Christian Freksa, Wilfried Brauer, Christopher Habel, and Karl F. Wender, editors, *Spatial Cognition III*, volume 2685 of *Lecture Notes in Artificial Intelligence*, pages 112–126, Berlin, 2003. Springer.

20 Jan Malte Wiener and Hanspeter A. Mallot. 'Fine to coarse' route planning and navigation in regionalized environments. *Spatial Cognition and Computation*, 3(4):331–358, 2003.

21 Thomas Wolbers and Mary Hegarty. What determines our navigational abilities? *Trends in Cognitive Sciences*, 14(3):138–146, 2010. doi:10.1016/j.tics.2010.01.001.