Master's Thesis - Geo 511

WHERE ARE THE UPS AND DOWNS?

Evaluating Elevation Representations for Bicycle Paths in City Maps

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Abstract

Navigation and wayfinding are everyday activities. When the environment is unknown, people often look on a map to decide which way to go. Previous research claims that, for cyclists and walkers, terrain information plays an essential role in route planning. In order to know where the ups and downs are, people need information about the elevation change of the routes. However, research further has revealed that map users often have problems identifying terrain information on 2D maps. In contrast, these maps are found to be most effective for navigational tasks. This is where map design is crucial in finding an optimal solution. Previously discussed design methods focused on aerial elevation representation such as contour lines but barely touched on the value of linear terrain information along a path. Since research confirms that elevation representation beside the network is irrelevant, the latter method could be fairly helpful, especially in rather cluttered city maps. For the purpose of this study, an empirical experiment was conducted to test three types of linear elevation representation in typical navigational tasks. The representation types tested were arrow symbols, elevation profiles and colour coded lines. Firstly, the results revealed that the representation type does have an influence on path choice whereas distance and elevation were named as the relevant criteria for the respective choice. Furthermore, the arrow symbolization stands out as the most efficient and effective representation type in height detection tasks. However, when defining steepness, the colour representation is most effective and efficient. Yet the elevation profile representation type, which is the best known and most preferred, seems to be the least efficient and effective method in all tasks. This study brings insight into the value of three existing elevation representations that are suitable for supporting the detection of 'ups and downs' in route planning tasks. Based on the results, conclusions for further map design issues can be drawn.

Keywords

elevation representation, navigation, city map, bicycle, arrow, colour, elevation profile, path, choice, height, slope, efficiency, effectiveness

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1 Introduction

Reading and using maps for the purpose of navigation and route planning is probably something everybody comes across in their lives (Lobben, 2004). Nowadays, people have a wide range of options of supporting tools to get from one place to another. Besides the well-known folded paper maps, there are online route planners and mobile applications. All these options have one thing in common: an underlying map.

A map is a geographic communication tool (Lobben, 2004) and according to MacEachren & Ganter (1990), a map has the function to communicate, identify and understand patterns. Bertin (1967) distinguished two different types of map: maps to be seen and maps to be read. According to Bertin (1967), the difference is the cognitive load (or efficiency). Maps to be seen are considered low cost, and maps to be read have a high cost realization of extracting information. Freksa (1999) formulates that especially in route planning, people try to minimize cognitive and physical effort and the conceptual message should be comprehensible in graphic displays. In other words, humans can be seen as minimizers in terms of endeavour, but maximizers in terms of pleasure (Edwards, 1954). In order to put this theory to maps and navigation, a wayfinding tool needs to provide as much information about a route as possible (Hochmair, 2004) to see without much difficulty where to expect endeavour or pleasure. But what do we mean by 'endeavour' and 'pleasure'? For cyclists, the route should be simple, attractive, fast and safe (Hochmair, 2004), whereas hikers might prefer trails including nature or sightseeing attractions, which are seen as pleasure. On the other hand, elevation change, length, time or handicap accessible trails are considered to be endeavours (Chiou et al., 2010). These varying considerations depending on different needs, different contents are required from a map.

All navigation related needs, however, seem to have one thing in common: the *environment* shapes people's route choices (Lobben, 2004). For cyclists and walkers, terrain information plays an essential role in route planning. More precisely, reasons of effort are required, but also of time assessment, view etc. (Chiou et al., 2010).

In general, static 2D maps are found to be the most effective medium for navigation (Semmo et al., 2012). However, Sutula (2007)'s findings claim that people have problems when identifying terrain structures with these maps and the transformation of 2D representation into 3D perspective is often a source of error as well as being time consuming. Brunyé et al. (2010) additionally found that travel times on static 2D maps are difficult to judge owing to lack of information about topography, weather, traffic etc. For this reason, it is even more important that the thematic information (in this case terrain) is based on cartographic design guidelines that are usable and understood without much cognitive effort (Fabrikant & Skupin, 2005). This is especially true because humans are only capable of remembering a limited amount of information (Miller, 1956). Since the variety of these elevation representations is tremendous, all the more so is map design fundamental.

Previous research (e.g. Wilkening & Fabrikant (2011a), Irvankoski (2012)) mainly focused on maps with contour lines or hill shading to communicate elevation information. These approaches represent terrain information over the whole map. However, many route planners have also implemented linear types of elevation representation, especially in city maps. The reason for this is that the map content next to the streets is just as important as the terrain itself. However, terrain besides the road is not significant for navigation (Sutula, 2007). Among other things, terrain structures determine which direction we take and they give us information to see what lies ahead of us. A city map with contour lines would be too overloaded, or as Tufte & Graves-Morris (1983) call it 'chartjunk'. The cognitive effort required to extract task-relevant information out of extraneous information would be enormous. For this reason, various approaches have been used and suggested for representing elevation change on paths (such as roads, streets) in city maps. However, in the related literature, user evaluations are hardly reported to measure the associated cognitive load, and to understand whether a particular design approach may be better in terms of user efficiency. This research gap defines the outline of this thesis.

In this project, three elevation representation types are chosen based on existing applications and literature and these form the basis of a small-scale urban environmental test study. The case study addresses bicycle maps and the goal is to see if there are differences in efficiency and effectiveness between the three representation types. To measure the efficiency and effectiveness of the three representations, participants solve three tasks involving navigation by bicycle. Furthermore, participants state their preferences among the tested representations before and after they solve the tasks. As a result of measuring performance (i.e. efficiency and effectiveness) as well as preference, we can compare whether people's preferences align with their performance. If there are no performance differences with the tested representations, we can take the preference data as a sign of user satisfaction and possibly make cartographic recommendations based on this measurement. These recommendations should then apply to similar scenarios when elevation change matters. The representation type for paths should contain elevation information without sacrificing other map content but also to minimize cognitive load.

The composition of this thesis is similar to that of a research paper. Firstly, Chapter 2 formulates the four research questions. Chapter 3 then gives an overview of the state of research and Chapter 4 describes the details of an experimental user study to approach the research questions. The results of the study are then specified in Chapter 5 and put into context in Chapter 6. The main outcomes are summarised in Chapter 7. This chapter also provides an outlook for further research. The material used for the experimental study can be looked up in the Appendix.

2 Research Questions

The field of elevation information represented in maps is diverse and analysed in a variety of ways. As different approaches are already investigated, others often seen in mobile applications have already been investigated but have not been tested. Therefore, the following core question is divided in four detailed research questions that lead the experimental framework of this thesis.

How do varying elevation representations on paths in city maps affect efficiency and effectiveness of user choice and response statements?

Research Question 1:
Does the elevation representation *affect* path choice? If so, why?

Research Question 2:
Is there a significant difference in *effectiveness* between the elevation representation types when answering questions about terrain characteristics?

Research Question 3:
Is there a significant difference in *efficiency* between the elevation representation types when

- making a path choice?
- identifying terrain characteristics?

Research Question 4:
Do people *prefer* different representation types for different tasks?

3 Literature Review

This chapter presents an overview of the current research in this field. First, research about map design is discussed followed by a deeper insight into path choice literature. Individual differences are also briefly mentioned.

3.1 Map Design

A map is a communication tool presenting spatial information. Initially it is a graphic representation, usually used for spatial identification (Lobben, 2004) as well as for highlighting thematic information (Brewer, 1994). Since simplification is one of the crucial processes in map-making, it is important to consider and communicate only relevant information (Jobst & Döllner, 2008). This is because people have limits in perceiving a reasonably displayed amount of data (Shepherd, 2008). Furthermore, time to learn and understand the representation method is sometimes not available in this case of cyclists for example and therefore, the map should be efficiently readable (Huffmann, 2009). For this reason, Hegarty et al. (2009) suggest that the display designs should be task specific and task dependent recommendations should be defined and considered.

For navigation, e.g. reading driving directions, 2D maps are found to be an efficient and effective medium. As such, the abstract 2D map view provided by Google Maps[1] is suitable for the communication of the relevant information while navigating (Semmo et al., 2012). This argument is also supported by Looije et al. (2007) who observed that 2D paper maps are more usable than 3D maps. Similar results were found by Tavanti & Lind (2001) as they could not confirm that a 3D display supports the cognitive spatial abilities in a superior way to 2D maps. In terms of route planning, Boer et al. (2013) asserted that people would choose 2D abstract maps for navigation. However, a 'flat map' does come with its difficulties. For some people, the representation of three dimensional data seems to be a rather complex task (Sutula,

[1] Google Maps: www.google.ch/maps

2007) due to the problem of understanding the additional topographical data (Shepherd, 2008). At this point, cartography becomes indispensable. MacEachren & Ganter (1990, 65) specified the goal of cartography as "to effectively communicate a particular message" and further defines cartographic visualization as "facilitating the identification of patterns, relationships, and anomalies in data". However, "symbol identification is a task facing every map reader, and the ability to understand symbolization relies on the ability to differentiate between symbols and understand that they represent real three-dimensional environmental objects."(Lobben, 2004, 276). 50 years ago, Imhof (1965) invented techniques for displaying the third dimension (terrain) on 2D maps. He proposed several approaches to show equidistances, profile constructions or altitudinal belts. But in order to visualize elevation information, the question is what exactly should be presented in terms of terrain. Fabrikant et al. (2009) suggest using elevation above sea level to show topography. However, Sutula (2007) and (Huffmann, 2009) consider change of elevation (= slope) as the important information for the map user. Wilkening & Fabrikant (2011a) approached this debate when they performed a slope detection task and showed that people performed more effectively and efficiently with the slope map than with contour lines or shaded relief maps (see Fig. 3.1 for the different map stimuli).

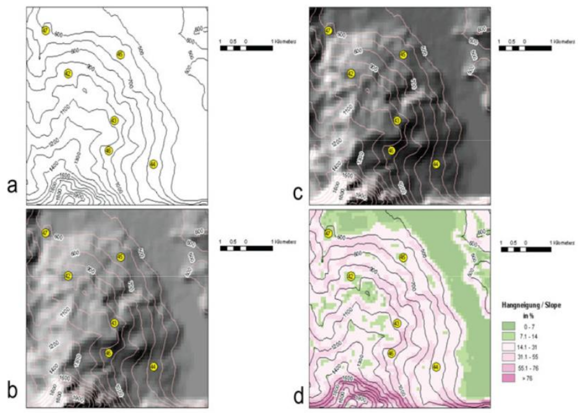


Figure 3.1: Reduced examples of emplyed map stimuli: only contour line map (a), light hill shaded relief map (b), dark hill shaded relief map (c), and slope map (d) (Wilkening & Fabrikant, 2011a)

Similar stimuli were used in Irvankoski (2012)'s thesis. People were asked to judge which of two points was higher in elevation and she found that visualization of elevation information actually affects task performance and in contrary to Wilkening &

Fabrikant (2011a)'s results, people performed most accurately and most efficiently with contour lines. However, Dennehy et al. (1994) found that realistic looking maps reduce cognitive effort.

In all the previously depicted map examples, the thematic information of terrain covers the entire map. In these cases, every map location could be referred to as topological information. However, the question arises as to whether all this information is really necessary. Sutula (2007) argued that especially in case of maps showing a route network, terrain information in addition to the actual routes is of limited interest. But is it then necessary for navigational purposes to depict elevation information at all? The navigation criteria are different for pedestrians, cyclists or car drivers. According to Hochmair (2004), the four most important criteria for cyclists (for example) are that paths should be fast, attractive, simple and safe. All these criteria can to some extent be related to terrain. Therefore, Semmo et al. (2012) concluded that the simple highlighting of routes to guide map users might not be enough and should be supplemented with relevant criteria information. People need as much trail information as possible in order to ascertain the optimal route (Hochmair & Rinner, 2005). By way of an example, Huffmann (2009) proposed a network map where terrain information is depicted along the route itself. Figure 3.2 shows that slope is represented by varying line thickness. Here, the visual variable of size represents quantity (Bertin, 1967).

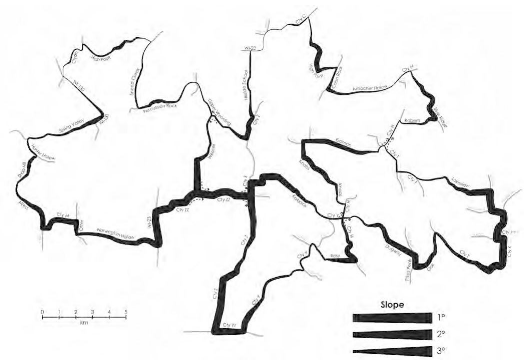


Figure 3.2: A sample map: Encode the elevation along the route using line width (Huffmann, 2009)

Size and width of a path representing quantity is also illustrated in the map created by Minard in 1869 (Fig. 3.3). He represented the loss of soldiers along the route during Napoleon's March on Moscow on a map and in addition illustrated a connected temperature profile (Kraak, 2003).

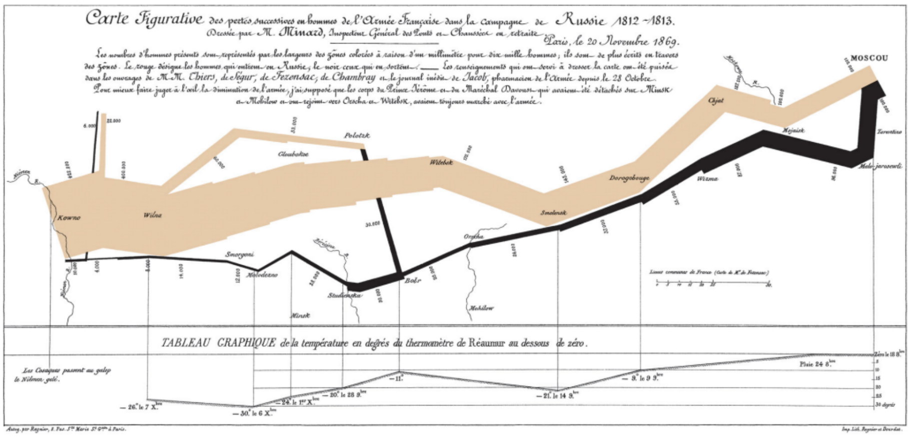


Figure 3.3: Napoleon's March on Moscow Map by Charles Minard, 1869: Loss of soldiers (size and width of graph) and connected temperature profile (bottom of display) (http://mapdesign.icaci.org/2014/08; 23/01/15)

Returning to terrain information, Huffmann's example highlights the problem that altitude in metres above sea level is not the same as slope, which is independent of altitude. Does the map user really need to know meters above sea level when navigating in a city or is it sufficient to know the ups and downs? Unchallenged, linear information along a route is an intuitive way of presenting elevation information and leaves room for other ways of depicting navigation-relevant map content. However, Huffmann's example is just one of its kind and there are other possible ways to depict linear based topological information in a network map. Three available and widely-used applications are now introduced and analysed in turn.

Elevation Profile

Elevation profiles can be understood as a representation of a vertical cut through a small section of the earth (Imhof, 1965). The result is a line graph whose goal is to simplify the encodings of elevation information along the 'cut' (MacEachren, 1995). The human visual system needs to be able to process the geometric information from the graph without much effort and encode the desired and expected information (Pinker, 1990). Online route planners, such as Google Maps or Schweizmobil[2], use elevation profiles to represent change in elevation along routes. Figure 3.4 illustrates an example of Google

[2] SchweizMobil: www.schweizmobil.ch

Maps, where the profile is placed in the legend. Additionally, the map even provides suggested alternatives. Sutula (2007) reports that people have a good understanding of

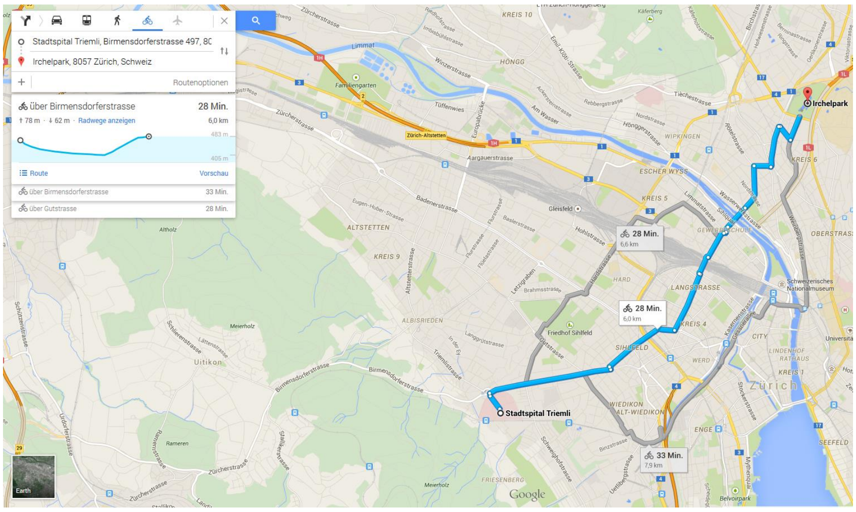


Figure 3.4: An example of Google Maps route planner: route highlighting on the map (blue line) with corresponding elevation profile (top-left corner) and alternative routes (grey) (Google Maps; 23/01/15)

the trail with elevation profiles, but an association between the map and the profile is essential. The map reader has to match the profile to the trail which is only possible with some form of reference points, markers, text labels or lines of constant elevation (Sutula, 2007). In Minard's map (Fig. 3.3), this matching is represented by joint lines between path and profile. Similarly, a segmentation of the path is also the result in order to have lines of constant elevation change, as proposed by Imhof (1965). Another advantage of trail profile and elevation data is that slope information can be extracted (Chiou et al., 2010). Elevation on its own is not useful, however slope is what people are interested in (Huffmann, 2009) and profiles fulfil this condition.

Colour

Mobile route planning applications for the purpose of sports activities often use the visual variable of colour. One example is the application Runtastic Road Bike [3] that displays colour-coded slopes on paths. Brewer (1994) and Griffin & Robinson (2010) mention that the visual variable colour works for illustrating special thematic maps in order to communicate embedded data. The colour scheme by Brewer (1994) is also applied for

[3] Runtastic: www.runtastic.com/de/apps/roadbike

network visualization. Furthermore, Fabrikant & Skupin (2005) point out that colour value of line symbols in a network could also represent how strongly these features are linked and in the case of this study how much difference in altitude lies between them. An advantage of colour values compared to the visual variable of size as shown in Huffmann (2009)'s example (Fig. 3.2) is that the line thickness does not vary and stays constant. This argument is important in dense city maps, where a large amount of important information is printed close to streets which might then be obscured. One disadvantage could be that the highest elevation might not be as eye-catching with colour as with the line thickness method (Huffmann, 2009). Additionally, slope can be visualized with colour values, but one has to be careful because slope might be the same at different elevations (Huffmann, 2009). Colour-coded slope representation is also a topic in the work of Su et al. (2010). The authors found that steep route segments can quickly be identified when using colour. Figure 3.5 shows one of their examples where colour is coded to show different categories of steepness. A similar approach is demonstrated by

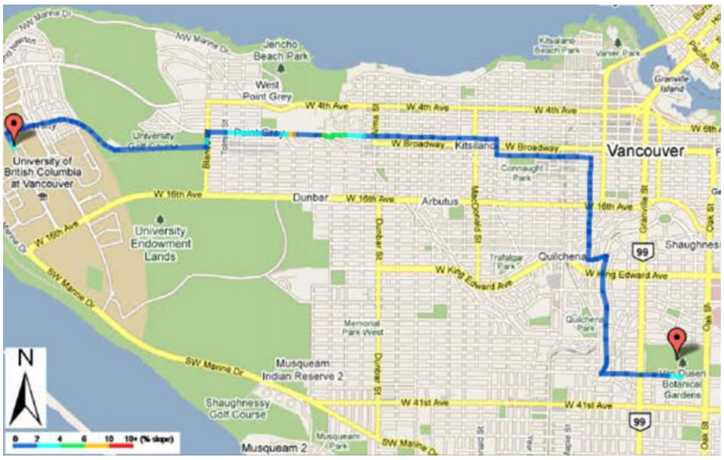


Figure 3.5: Cycling trip planner case study in Vancouver, Canada: Route using colour classification for slope [%] (Su et al., 2010)

Ólafsdóttir & Runnström (2013). They use colour to show different states of conditions along paths. Figure 3.6 shows such a map, where all trails are colour coded, representing different condition classes. Although this example does not represent elevation, it is a colour-coded way to add thematic information on the linear feature of a map. One could argue that these colours on routes cover important street information such as street names. San Francisco's Bike and Walking Guide (Fig. 3.7) addresses this problem by positioning street names beside the road. However, this was no solution for Pittsburgh as an employee (email communication with Boerer, BikePGH, 07/01/15) argues that the street names beside roads make the map look cluttered as not only street classifications are represented in colour, but blue contour lines additionally show absolute elevation.

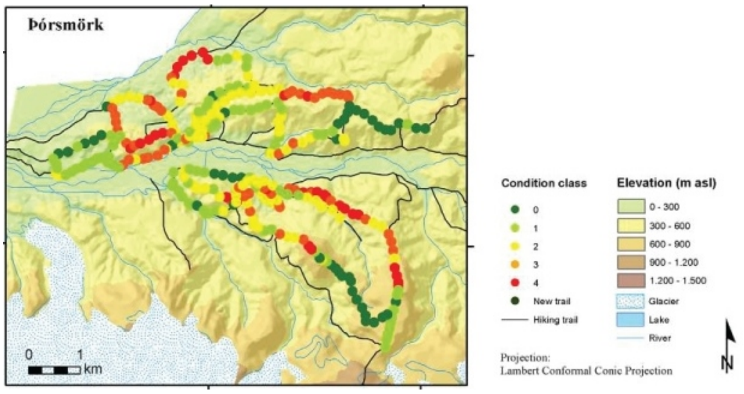


Figure 3.6: The spatial pattern of the assessed hiking trail condition: condition classes and elevation presented with colours (Ólafsdóttir & Runnström, 2013)

Figure 3.7: Map excerpt from San Francisco Bike & Walking Guide: arrows indicate travel in one direction; contour lines; colour coded street grades (San Francisco Municipal Transportation Agency: www.sfmta.com/maps/san-francisco-bike-map-walking-guide; 22/01/15)

A slightly different representation is shown in Figure 3.8. Here, the basis is a 3D terrain model which also has varying colour lightness based on slope categories of the trail (Chiou et al., 2010). All these different types of colour-coded linear entity types represent either elevation or elevation change and are subject of recent research as described above.

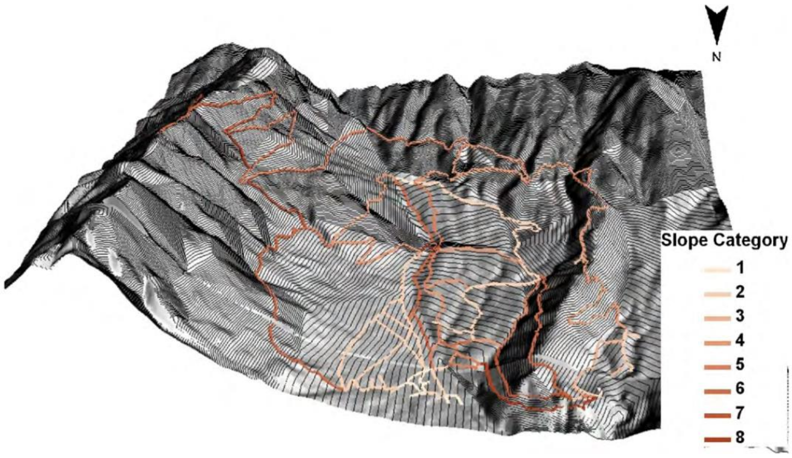


Figure 3.8: A three-dimensional representation of a trail system with its slope categories (Chiou et al., 2010)

Arrow

All previously mentioned elevation representation types exist and are discussed in published research findings. However, on many folded paper maps for activities such as cycling, arrow symbols are used to represent terrain characteristics. Tversky (2001, 87) defines arrows as a "special kind of line, with one end marked, inducing an asymmetry". Arrows have a tail and head in order to draw one's attention to the head end of the symbol (Kurata & Egenhofer, 2008). In other words, something is going on or is changing dynamically.
The symbol is popular because of its diversity as it can indicate direction, movements, order, transition and association (Kurata & Egenhofer, 2008). Since it can be utilised in different ways, each arrow symbolization has a different meaning in each case and therefore has to be interpreted anew each time by the user (Horn, 1998). For example, Chittaro & Burigat (2004) demonstrate that arrows are effective navigational aids and according to Baudisch & Rosenholtz (2003) and Looije et al. (2007) they also indicate direction. In other words, arrows represent two visual variables, namely shape and direction (Bertin, 1967). As direction indicates a spatial phenomena (Slocum et al., 2009), these arrows can also be used to show distance. However, if distance information is required, a second annotation has to be added to the arrows. These annotations are presented by Burigat et al. (2006). They suggest varying the visual variables of length, size, colour, shape and label in order to present, for example, distance information. When taking labels for instance, Bigler et al. (2014) found that

an arrow with a label is an effective way of indicating indoor level changes. Furthermore, arrows can also be applied for terrain in order to show uphill and downhill information (Huffmann, 2009). He suggests that changing the size or saturation of arrows is a good way to represent slope. Figure 3.9 shows two such examples. These studies show that not only 2D navigation, but also distance or change in altitude can be reported with adapted arrows.

Figure 3.9: A possible symbolization method for showing slope: patterns of arrows pointing downhill and varying size and lightness to show the degree of the slope (Huffmann, 2009)

The idea of using arrows to represent a combination of distance and elevation change (= slope) is a theoretical approach, but it can also be applied in a practical way. One example is the Pittsburgh BIKE MAP as shown in Figure 3.10. One single white arrow indicates a steep hill whereas two white arrows stand for a very steep hill. The directions of the arrows always point uphill.

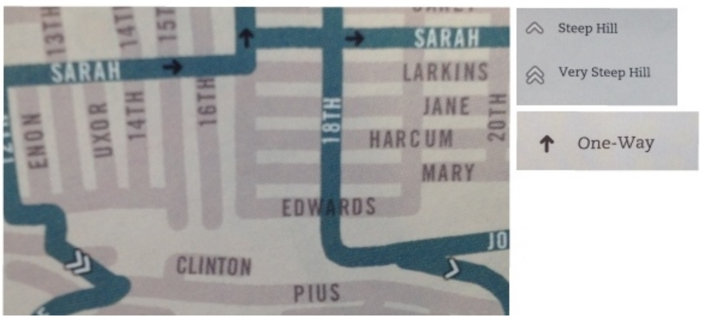


Figure 3.10: Pittsburgh BIKE MAP: map excerpt with steepness of hills (white arrows) and one way steets (black arrows) (Pittsburgh BIKE MAP , BIKE PGH: www.bikepgh.org)

The same approach was applied in a walking guide (see Fig. 3.11) where individual maps were also supported with elevation profiles (Stedman et al., 2014). However, the map user has to pay attention with these arrow symbolizations. For instance, the BIKE

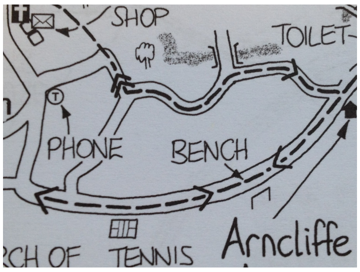


Figure 3.11: Excerpt of Map 86: arrows point uphill, two arrows for steeper segments (Stedman et al., 2014, 238)

MAP of Pittsburgh has two arrow types in one map. Besides the white arrows indicating slope, a second type of arrow (black) indicates one-way routes to show direction of travel. This supports the findings of Horn (1998) that the interpretation of arrows is different with each different symbolization of them and consequently the legend plays a crucial role and must clearly define the symbols (Slocum et al., 2009). The approach of two arrow types on a map is also implemented in the Bike Map Zurich as illustrated by a map excerpt in Figure 3.12. In this example, the previously-described approximation of steep and very steep path segments becomes more precise. Two arrows indicate a 10 meter height difference. In other words, the closer two arrows are, the steeper the segment between them. This is the same thought that lies behind the proposed contour line map by Imhof (1965).

Figure 3.12: Excerpt of Bike Map Zurich: height difference of 10m (black arrows) and one-way street (red arrows) (Excerpt of Bike Map Zurich, City of Zurich, Department of Civil Engineering: www.stadt-zuerich.ch)

These examples show just a part of the diverse implementations of elevation profiles, colour and arrow symbols in maps. Elevation information is an ongoing topic in map design research and already exists in practical applications. However, these different types of graphical display influence how people use them and these effects on map users will be discussed in detail in the following two sub-chapters.

3.2 Path Choice

Edwards (1954) reported that people's behaviour is based on utility and found that humans make their choices so as to seek pleasure and to avoid endeavour. The definition also accepts that a person has expectations about the outcome and wants to maximize it, but in turn also thinks about the worst-case scenario and tries to minimize this. Huffman & Williams (1985) point out that route information is crucial for selecting the optimal path because the theory of seeking pleasure can be adapted to the criteria of selecting a path (Hochmair, 2004). Montello (2009) observes that people constantly try to reduce effort. One example is that various lengths of paths lead to different route choices because not all people like to walk, bike or drive longer than actually necessary (Montello, 2009). However, distance was not found to be the only relevant criteria for route choice. Hochmair (2004) investigated route choice behaviour in an urban environment and focused on cyclists. He was interested in the criteria cyclists use to select a path and then defined the multi-criteria theory. This theory indicates that people base their route choice on many different criteria simultaneously. Suggested selection criteria are, for example, separate bicycle lanes, slopes, one-way streets, distance etc. (Hochmair, 2008a). Chiou et al. (2010) agree and further find slope to be a significant criterion in path choice because slope in addition to distance information tells the map user about the energy cost and the respective challenges ahead. From theory to practice, according to references from the Bike Maps of Zurich and Pittsburgh, elevation information is essential, being in great demand for path choice. However, these stated criteria might also be dependent on motivation, gain seeking and availability of time (e.g. Huffman & Williams (1985) and Chiou et al. (2010)). Additionally, task type, gender and spatial ability are found to be potential factors affecting path choice (Wilkening & Fabrikant, 2011b). Further work by Bailenson et al. (2000) reports that even the route geometry leads to different choices as people more often choose straight, less-angular routes which is supported by Hochmair & Frank (2002). Duckham & Kulik (2003) agree that the simplicity of a path is as important as its distance. Another important factor, especially when it comes to choices based on elevation information, is that humans misinterpret routes that point in a northerly direction. As research shows, people tend to associate these route directions with increasing altitude (Brunyé et al. (2010) and Brunyé et al. (2012)).

To conclude, the presentation of these criteria are reported as potential influences on path choice. Display types, geometry of paths, individual criteria and individual differences (explained in the section below) are found to influence path choice and should therefore be kept in mind when designing a navigational aid for a certain user group.

3.3 Individual Differences, Familiarity, Preference

MacEachren et al. (1992) reveal the importance of graphic displays in information-processing as they address the most influential human abilities, namely those linked to vision. The eye-brain system is therefore important in recognising, identifying and processing the symbolization of the map (Slocum et al., 2009). In particular, the cognitive load should not be too high in order to ensure an effective and efficient map-reading process (Huang et al., 2009). However, map effectiveness and efficiency is explained not only by the map and its representations but also by people's map-reading capability (Lobben, 2004). These skills vary between humans. Slocum et al. (2001) presented five individual differences: expertise, culture, gender, age and sensory disabilities. Furthermore, Wilkening & Fabrikant (2011b) reported that spatial abilities affect human-spatial inference and decision making with maps and people show different map-reading processes on the basis of their levels of ability (Lobben, 2004).

Therefore, French et al. (1963) suggest different tests to enlighten different cognitive factors. For example, Montello et al. (1999) used the psychometric test 'The Hidden Pattern' (by French et al. (1963)) which includes static spatial abilities within a two-dimensional environment. This test combines visualization and orientation dimension as well as 2D spaces, but in Montello et al. (1999)'s study, the test did not reveal any differences due to gender. However, with the 'Mental Rotation Test' (by French et al. (1963)), Wilkening & Fabrikant (2011b) revealed gender differences. Here, the test showed that men outperformed women. When analysing specific geography-related tasks on the basis of gender, Montello et al. (1999) could not find any difference between men and women when for example estimating distances. However, distance estimation could be important, for example, when detecting slope.

Another factor is expertise or prior knowledge of a visualization that can result in more efficient map-reading (Slocum et al., 2009). Interestingly, even experts do not perform effectively with the preferred display (Hegarty et al., 2009). When asking people about their display preference, they chose the one that they think is the most effective and looks most realistic (Hegarty et al., 2009). Levy et al. (1996) found that user preference changes not only according to display but also with changing scenarios. Furthermore, Wilkening & Fabrikant (2011b) found that different classification methods of spatial abilities lead to different preferences. To summarise, Hegarty et al. (2009) pointed out that preference assertions are found to be a bad indicator when choosing a display because effectiveness did not mirror it. For this reason, preference should be tested against effectiveness without taking display preference into account (Hegarty et al., 2009).

With all these findings, the three (previously referred to) elevation representation types will be investigated in an bicycle-related empirical user study. Spatial tasks such as path choice, estimating heights and finding steep segments along a path will be analysed based on effectiveness, efficiency and preference in order to answer the four research questions.

4 Methods

4.1 Participants

In order to answer the research questions a user study was performed at the Institute of Geography at the University of Zurich. Participants were personally asked to take part in the experiment on a voluntary basis. A total number of 43 students and postgraduates from the University of Zurich and the Swiss Federal Institute of Technology (ETH) Zurich participated. This sample is considered to be large (Field, 2009).

4.2 Materials

The experiment took part in the eye movement lab (henceforth referred to a 'lab') at the Institute of Geography at the University of Zurich. The lab has no windows, thus ensuring the same light exposure for all participants. The lab features a fix-installed computer and an eye tracker apparatus (see 4.2.1 Eye Tracker Apparatus). Additionally, a lenovo[1] T440s laptop was used for pre and post questionnaires.

4.2.1 Eye Tracker Apparatus

The lab is equipped with a Tobii TX300 [2] eye tracker. The eye tracker features a data rate of 300 Hz, an accuracy of 0.4 degrees and works with its own software, 'Tobii Studio'. The Estecom display is 23"(diagonal) and has a maximal resolution of 1920x1080. Figure 4.1 shows the display including the eye tracker below the screen. The software 'Tobii Sutdio' allows the user to design, visualize and analyse the data. An advantage of this software is that it records each page of the questionnaire individually based on the respective URL. Thereby the export of data, such as the response time to a question, simplifies the data analysis. After completing the test, the whole recording can be replayed and eye movement data can be visualized and analysed (e.g. with areas of interest (AOI)). All these features were used to provide explanations for resulting test patterns.

[1]lenovo: www.lenovo.com
[2]Tobii: www.tobii.com

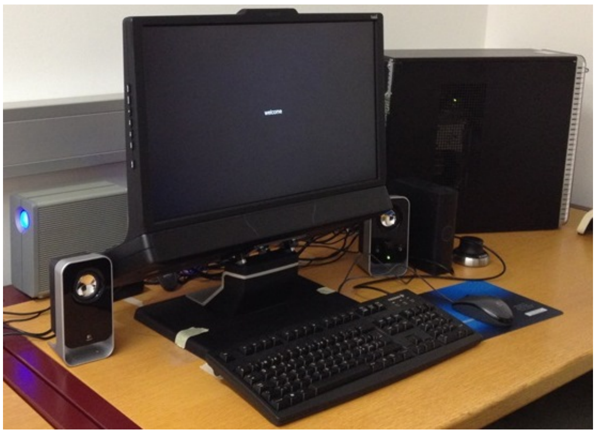


Figure 4.1: Eye movement lab equipment: Estecom Display incl.Tobii TX300 eye tracker

4.2.2 Online Questionnaires

As already mentioned, online questionnaires were used throughout the study. Therefore, the online tool SurveyMonkey[3] was chosen because this platform allows for graphics as well as different types of answers. A randomization function allows the order of questions to be changed for each participant. The random order of stimuli was important for the main experiment, however not for the other questionnaires. The whole study consisted of four parts (pre-questionnaire, spatial ability test, main experiment and post-questionnaire) and in turn four online questionnaires (see Appendix) were prepared. These are explained in detail in the following sub-sections.

4.2.3 Demographics and Experience

The pre-questionnaire contained eight questions about personal information such as gender, age, visual impairment, level of experience (5-point Likert Scale: none to professional/daily exposure), regularity of sports (5-point Likert Scale: never to everyday) as well as a general preference question about the types of elevation representation.

4.2.4 Spatial Ability: Hidden Pattern Test

In order to determine the spatial ability of all participants, the Hidden Pattern Test by French et al. (1963) was used. The test consists of a model pattern (Fig. 4.2)

[3]SurveyMonkey: www.surveymonkey.com

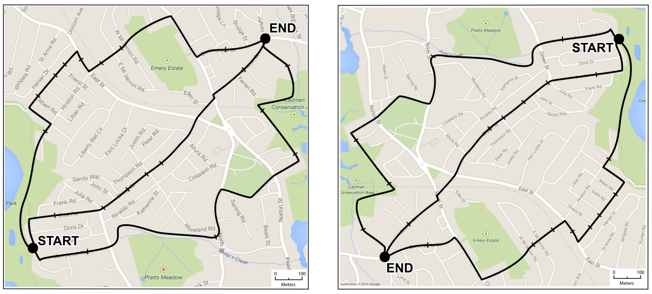
that is embedded within different environments (Fig. 4.3). The test is based on the theory of 'Flexibility of Closure', which is based on the assumption that people have to keep in mind a pattern and not only remember it but also recognize it within different environments under time pressure (French et al., 1963). A short introduction, ten pilot environments and two parts with 200 environments each make up the test. Participants were given three minutes for each part (in total 6 minutes) to mark as many correct environments as possible but without sacrificing accuracy. Once the time for the first part was over, participants had to stop and continue with the second part; again a three minute time limit was set. It is important to state that the test was originally a paper and pencil test but for this study the whole test has been digitized and integrated into an online questionnaire (see Appendix). The reason for this digitization is the faster evaluation of the answers at the end. However, this slightly changed the way participants responded to the test. Instead of marking the identified pattern with an 'x' and the non-correct ones with an 'o', as in the original version, the new version only required an affirmative response.

Figure 4.2: Hidden Pattern Test: model pattern (French et al., 1963)

Figure 4.3: Hidden Pattern Test: model pattern within different environments (environments two and five contain the model pattern) (French et al., 1963)

4.2.5 Main Experiment

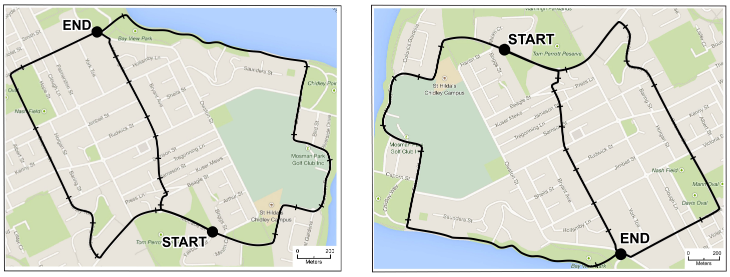
After the pre-questionnaire and the spatial ability test, participants were asked to change to the eye movement screen and were given detailed instructions about the system. The questionnaire was embedded with the software Tobii Studio as further outlined in chapter 4.3.1 Experimental Procedure. The questionnaire comprised written instructions about the tasks, slope theory (as done in Wilkening & Fabrikant (2013)'s work), trial runs and how to understand the term 'segment' in order to give all participants the same pre-conditions. Task materials were static background maps derived from Google Maps. Boston (USA) and Perth (AUS) were chosen as the two locations and represented the base maps. These map excerpts were all designed with three paths leading from a start point to an end point. The instructions were always to proceed from start to finish. Su et al. (2010) have suggested using the same start and end point and the same map but each with only one route suggestion. However, in our experiment, the three marked route suggestions were all integrated in one map (also done by Hochmair (2004)). The two maps were also rotated (Griffin & Robinson, 2010) and randomized (Martin, 2008) in order to discourage learning effects. The left path is always the one from the participants' view on the screen and not when being in the field with the map at the starting point. This misunderstanding of left and right was prevented with a clarification in the written introduction. There were no vertical north-south paths chosen because of established correlations between perspective navigation and the association to uphill (Brunyé et al., 2012). The two base maps Boston and Perth and the route options are shown in Figures 4.4 and 4.5, one north-up (a) and one rotated by 180 degrees (b). The



(a) north-up (b) rotated

Figure 4.4: Base Map (from Google Maps): Boston (USA) with three path options

main questionnaire consisted of 18 pages, each with a scenario, a question, a selection of answers and a map excerpt (with varying types of elevation representations, see Chapter 4.3.2 Independent Variable). Two types of questions appeared and participants had to make choices and rate criteria according to their relevance (Task 1: Path Choice) and find correct answers (Task 2: Height of Marker and Task 3: Steepest Slope Segment). The order of background maps, questions and representation types was applied in order to discourage learning effects (Martin, 2008). These 18 questions can be divided into three tasks each and are described in the following.



(a) north-up (b) rotated

Figure 4.5: Base Map (from Google Maps): Perth (AUS) with three path options

Task 1: Path Choice

Based on the scenario 'to be there as soon as possible' and a map excerpt, participants were asked to decide which path they would choose from start to end by bicycle. Possible choices were 'left', 'middle' and 'right'. Furthermore, participants had to state how relevant a given choice of criteria was to their choice. Figure 4.6 lists these criteria and if people rate the criteria as relevant, they have the following meanings:

	not applicable	1 (least relevant)	2	3	4	5 (most relevant)
Multiple, but small hills	○	○	○	○	○	○
Scenic path	○	○	○	○	○	○
Path is easy to remember	○	○	○	○	○	○
Only one hill	○	○	○	○	○	○
Steep slopes	○	○	○	○	○	○
Shortest path (distance)	○	○	○	○	○	○
Most even path	○	○	○	○	○	○
First hills, then downhill	○	○	○	○	○	○

Figure 4.6: Criteria rating for Task 1: Path Choice (excerpt from the online questionnaire)

- Multiple, but small hills : people do not mind if it is hilly, as long as the hills are small
- Scenic path: there are parks, water areas such as lakes or rivers etc. along the

path

- Path is easy to remember: the geometry of the path does not include many turns and is largely straight
- Only one hill: people prefer one hill instead of repeated undulation
- Steep slopes: leading either to the choice of even paths or a preference for steepness (see 6.5 Limitations)
- Shortest path: the distance of the path is the shortest possible as people do not want to cycle far
- Most even path: flat terrain
- First hills, then downhill: arrive relaxed and without sweating, or prefer physical effort at the beginning of the journey

These criteria have been cited some of the most influential criteria on path choice by several research groups (e.g. Su et al. (2010), Hochmair & Rinner (2005), Hochmair (2007)).

Task 2: Height of Marker

This task is based on the fact that people plan and mark stopover points along the route when navigating (Hochmair, 2004), as also applied in the work of Wilkening & Fabrikant (2013). Therefore, the marker task asked participants to select the highest view point in order to take a picture. A similar task was conducted by Irvankoski (2012) but with contour line maps. In our study, yellow markers represented these view points on the map and each path featured one marker only. Figure 4.7 gives an example of the markers added with a letter to identify the marker with the answer selections (marker letters: G,P and M). This task required a correct answer, so an 'I don't know' answer was provided to reduce instances of random answers because of guessing.

Figure 4.7: Example of a yellow marker representing the view point "M"

Task 3: Steepest Slope Segment

The third task requested participants to choose the path with the steepest slope segment. Possible answers were again path 'left', 'middle' and 'right'. This task could either be answered right or wrong, while an 'I don't know' option was also provided. In order to ensure that each participant knew what a segment is and that the focus was on elevation, participants were given the chance to practise it according to Figure 4.8. Start and end of segments are defined as small lines at a right-angle to the path.

Figure 4.8: Example of segment separation (2 complete and two incomplete segments)

4.2.6 Preference and Familiarity

The post-questionnaire included a preference question for each task. For each task a representation type can be marked as a preferred type to solve this specific task. The questionnaire provided the possibility to write reasons/comments for the chosen preference. A general question of preference for elevation information was again asked to reveal potential changes in preference with the performance of the experiment. As preference does not automatically mean useful, a usefulness rating (5-point Likert Scale) was also included to see if they think the representation was helpful in solving the task. Additionally, participants were asked whether they were familiar (yes/no answer) with the elevation representation before they took part in the experiment.

4.3 Experimental Design

4.3.1 Experimental Procedure

All potential participants received a Doodle[4] link and as soon as they indicated a suitable date, each participant received confirmation by email including date, time and room information for the study, as well as contact details for the test supervisor in case of any short-term changes. Each participant was individually invited to be at the eye movement recording lab at the confirmed date and time as the set-up was the same for

[4]Doodle: www.doodle.com

each participant. The study was conducted between September 24th and October 9th in 2014.

After the participant's arrival, they were briefly and verbally introduced to the study procedure (see Fig. 4.9) and asked to fill out a consent form (see Appendix). The test proceedings followed a pre-determined protocol (see Appendix) to ensure that each participant was given the same information. Therefore, only short verbal instructions were presented and most of the instructions were included in the corresponding questionnaires. After their agreement, each participant was given a code number to ensure anonymous analysis. Then participants filled out the pre-questionnaire about demographics followed by the Hidden Pattern Test (as described in 4.2.4) on the laptop. After the first two questionnaires, participants were then asked to move to the eye movement computer and given some general instructions about the eye movement technology followed by an apparatus calibration. The main experiment began with written instructions. After this briefing, 18 randomly ordered questions had to be answered within 30 minutes. Participants were given a time-check halfway through the exercise and again five minutes before time was up. Additionally, a number at the top left corner of the screen indicated the progression of questions to ensure that all questions could be answered within the given time limit. After finishing the main experiment, participants were asked to fill out the post-questionnaire including questions of preference and familiarity. Once participants had completed the last part, they were given a bar of chocolate as a thank you gift and the test supervisor verbally thanked the participants for taking part. Participants needed 45 minutes on average to complete the whole study.

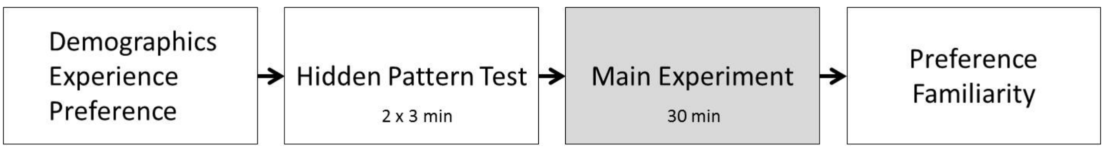


Figure 4.9: Experimental procedure incl. corresponding time limits (grey area: eye movement recording)

4.3.2 Independent Variable

The experimental design is a within-subject design, so each participant was exposed to all levels Martin (2008). The design is based on the independent variable, namely the representation of elevation information (henceforth referred to a 'representation type'). This information was provided with three different representations (arrow, colour and elevation profile) as further explained. Every task combination was completed by each candidate. Figure 4.10 summarizes the experimental design. The whole design is applied for two locations (Boston (USA); Perth (AUS)) in order to discourage learning effects. All in all, each participant performed the same tasks with every representation for both maps.

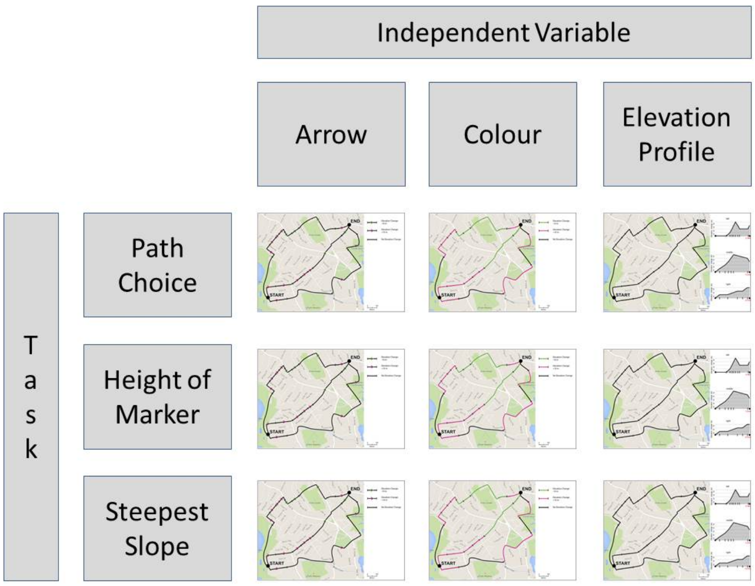


Figure 4.10: Experimental design: tasks and independent variables for Boston (the same for the second location Perth)

The design of the experiment was prepared with the help of the book Doing Psychology Experiments' written by David W. Martin (2008). It was important that all three representations revealed the same information, therefore, elevation change rather than meters above sea-level or slope was used. Additionally the routes were segmented in order to allow a classification of either an uphill (+10 m), a downhill (-10 m) or no elevation change (Sutula, 2007). Each of the classes was represented with a unique symbol (Slocum et al., 2009) for the intrinsic information (arrow and colour). The elevation profiles were placed in the legend and consequently the segment separation as well as the start and end points had to be included here to match map and profile. Start and end point on the maps were labelled and placed according to Slocum et al. (2009).

Elevation Profile

The elevation changes for this kind of representation are depicted in an elevation profile, which is on the right hand side of the map in the legend. The elevation information is therefore extrinsically designed and an example of the Boston base map is shown in Figure 4.11. The profiles were labelled with the paths left, middle and right from the participants' point of view.

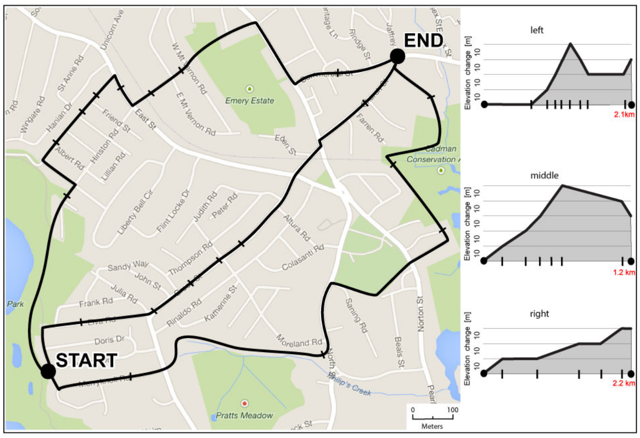


Figure 4.11: Example of the elevation profile representation type (Boston)

Arrow

The paths have arrows in the middle of each segment to indicate a ten-metre difference in elevation. They indicate either downhill or uphill and are marked with green or purple respectively. A segment without an arrow indicates no elevation change. The arrows point in the direction of travel, more precisely from Start to End. The independent variable is intrinsically designed, with an explanation of the meaning in the legend (see Fig. 4.12).

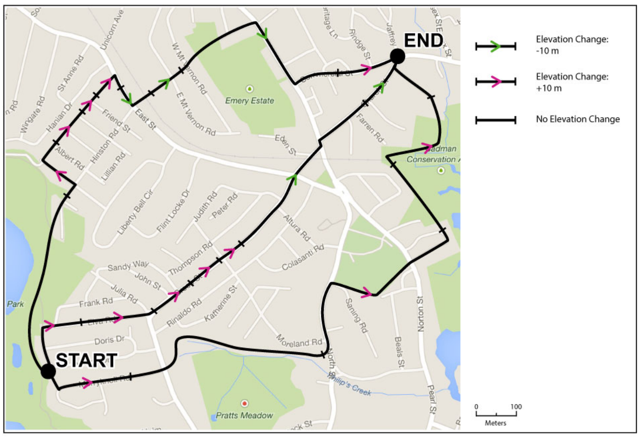


Figure 4.12: Example of the arrow representation type (Boston)

Colour

In this representation, the path segments on the map are either coloured green, purple or black, representing ten meters downhill, ten meters uphill or no elevation change. Here, the information of the independent variable is also intrinsically designed with a legend to explain the different colours. The elevation change in the form of colour coded segments is displayed in Figure 4.13.

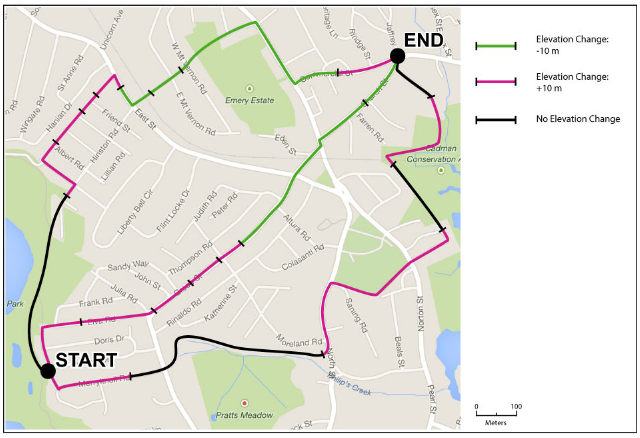


Figure 4.13: Example of the colour representation type (Boston)

4.3.3 Dependent Variable

Path Choice

Participants were able to state which path they would choose from start to end when riding a bicycle. So this result is a bar chart based on representation type and chosen paths (left, middle, right). Here, the two locations were differentiated as the two maps are slightly different from each other and could affect choice as well as the relevance of criteria.

Accuracy/Effectiveness

The marker and slope task required correct answers and the percentage score was calculated by using the total number of possible correct answers. The 'I don't know' answers were considered to be wrong (according to Çöltekin et al. (2010)) and since each participant answered every question, no adjustments in this percentage score were necessary.

Response Time/Efficiency

Efficiency is defined as reaction time (Lobben et al., 2009) but in this study efficiency is the time a participant needed to respond to a question. Response time was calculated by Tobii Studio from the moment the URL was accessed until the participant left it, where one URL equates to one question. This was only possible due to the fact that each question was written on a separate page in the online (main) questionnaire. Response time was measured in milliseconds and converted into seconds. In order to complete all 18 questions, a time limit of 30 minutes was stipulated, allowing an average of 100 seconds per question. The time limit was decided after pilot studies revealed 30 minutes to be a manageable amount of time.

4.4 Statistics

All results are statistically significant at a p-value of 0.05. All analyses were performed with PASW[5] Statistics 18. Repeated-measures analysis of variance (ANOVA) were performed as it analyses the data based on the fact that all participants used all independent variables in all conditions (Field, 2009). When interactions were found, they were confirmed with pairwise comparisons. Descriptive statistics are declared

[5]SPSS software by IBM: www-01.ibm.com/software/ch/de/analytics/spss/

with a Mean (M) and standard error (SE). Each result from the ANOVA is written with a F-ratio (F), degrees of freedom (df), p-values (p) and the partial measure of strength of relationship (η_p^2). Plot and diagrams (e.g. error bar charts) were generated in Microsoft[6] Excel. The proportion of correct responses was measured on a scale of 0 to 1 and percent is between 0 and 100. Response time is reported in seconds and the eye gaze data (visit duration) in milliseconds.

[6]Microsoft Excel: http://products.office.com/de-CH/

5 Results

This chapter describes the results derived from the user study, segmented in different parts. First off, some descriptive statistics about the participants are presented, followed by three sections including results of tasks, response time and correct response analyses. The results about the preference concerning the representation types are summing up the data analyses. As far as it has been analysed, the findings of the eye gaze data are directly included in each section.

5.1 Participants

A total of 43 people participated in the study. Gender representation is more or less equal with 23 women and 20 men. Participants were aged between 18 and 45 years old, but the majority (93%) is between the ages of 18 and 31. They are all students or post-graduates from the University of Zurich or ETH Zurich.

Level of Experience

All participants stated their level of experience in eight of the study related fields in order to gain an overview of knowledge prior to the study. Figure 5.1 illustrates those thematic fields and their corresponding results. The sample of participants generally has professional experience in spatial data, mobile maps as well as geographic information systems and cartography. However, the level of experience in the fields of elevation profiles, bike and hiking maps in paper form as well as graphic design is low to medium across the sample of participants.

Spatial Ability

All participants took the Hidden Pattern Test in order to determine the spatial ability and possibly different performance depending on spatial ability. Based on the resulting test score each participant was categorized in a spatial ability group. Similar to Wilkening & Fabrikant (2011b), the median was chosen to divide the sample into a low

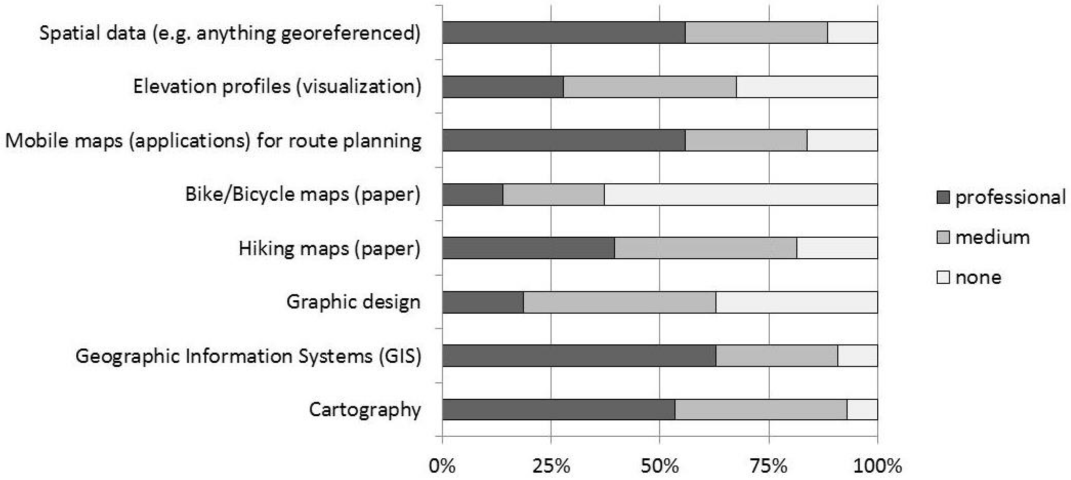


Figure 5.1: Level of experience for eight study related fields. Participants with professional (dark grey), medium (bright grey) and none (white) experience in the respective field [in %]

(n = 21, $M_{score} = 58.35$, $SE_{score} = 0.893$) and a high (n = 22, $M_{score} = 74.69$, $SE_{score} = 0.194$) spatial ability group. A Mann-Whitney U test revealed no significant difference when comparing spatial ability scores for men and for women (U = 163.5, Z = -1.62, $p > 0.05$). The scores for men and women are displayed in Figure 5.2. The next division is to see if gender is equally distributed in the two groups, but results show that there are more women (n = 14) in the low spatial ability group than men (n = 7), but more men (n = 13) and less women (n = 9) in the high spatial ability group.

Familiarity

Figure 5.3 shows that all participants apart from one have seen an elevation profile before. In contrast, only one quarter of all participants had seen the arrow and colour representation of elevation information before they took part in the study. So most of the participants had seen elevation profiles before but had not much experience using it (according to Fig. 5.1).

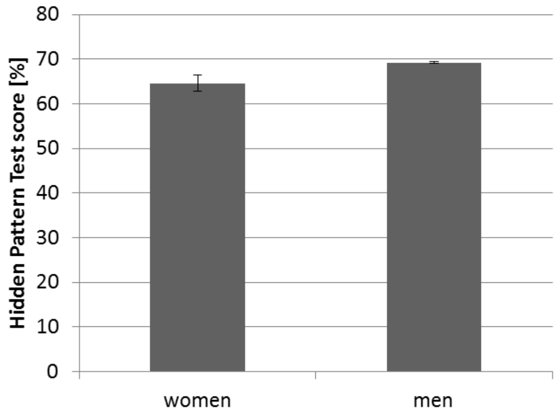


Figure 5.2: Hidden Pattern Test score: women vs. men. Mean and error bars: ±2SE

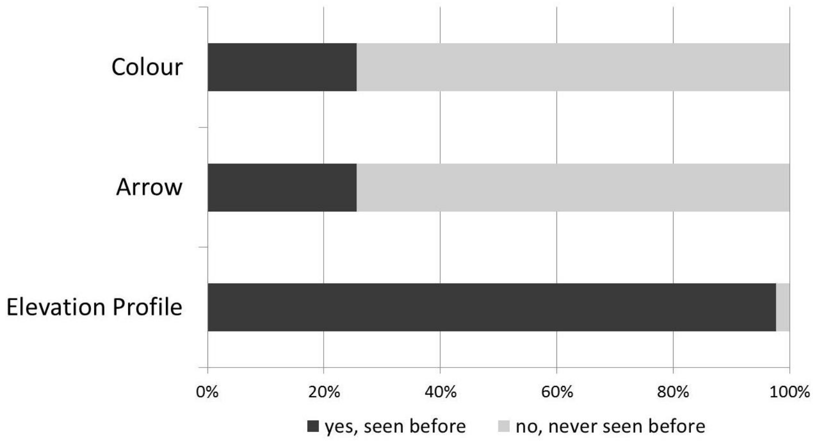


Figure 5.3: Percentage [%] of participants that have seen (dark grey) and not seen (bright grey) the representation type before the experiment

5.2 Path Choice and Criteria

Each participant had six opportunities (two times per representation type) to select one path from a choice of three. This task did not require a correct answer. The two locations are therefore individually analysed as small details may be important for path choice and its criteria.

Figure 5.4 illustrates the counts of chosen paths based on the representation with the background map of *Boston*. So, if participants receive the arrow representation type, they either choose the right or the middle path. The same two were chosen with the elevation profile representation type but here, the middle path is the most chosen path. The result is not surprising if the heat maps (see Fig. 5.5) are taken into consideration. Here, people clearly focus on the profiles and not the map itself. The elevation profile heat map (right) reveals that in the map, only the most direct (also the shortest) path was looked at, but participants did not consider the left and right path at the map. As for the colour representation, most people decided to take the middle path, however also looked at the other two paths as illustrated in Figure 5.5 (left). If people choose the left path it was most often done with the colour representation. We see that the representation affects path choice as different representation types reveal different choices of path.

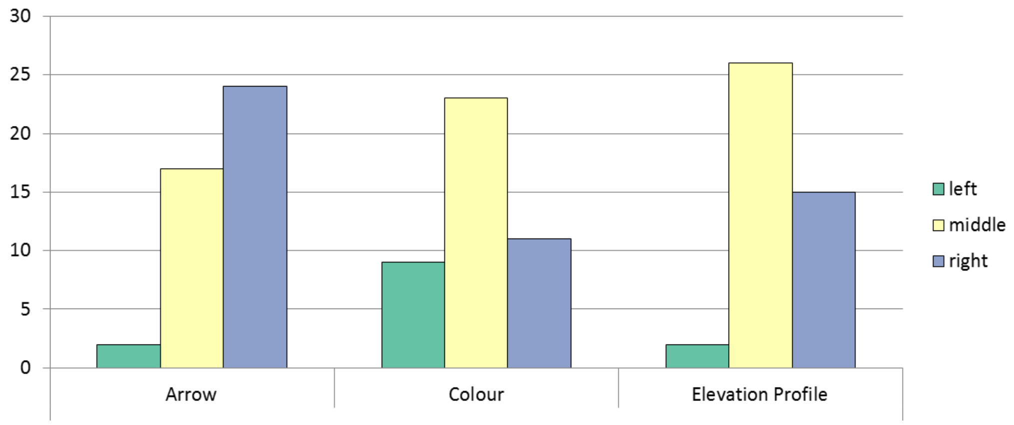


Figure 5.4: Path Choice (Boston): Counts of chosen path for each representation type

Figure 5.5: Heat Map: Gaze opacity for colour (left) and elevation profile (right) representation (Boston)

The number of chosen paths are not interestingly, however, without looking at the criteria. For this reason, people were asked to state how much an option of criteria (e.g. scenery, hills, distance) contributed to their choice. Figure 4.6 (in chapter 4.2.5) lists all these eight criteria. The most contributory criteria are summarized in Table 5.1. As one can see, when the middle path was chosen, the most relevant criterion is the shortest path for all representations. For the right-hand path the reason was also the same for all representations, however the criteria is the most even path. Different reasons contributed to the chosen left path based on representation. People choose this path because hills come first and the end of the path is going downhill, but only with the arrow and colour representation type. If the left path was chosen with the elevation profile representation, the most relevant criteria was the scenic path.

	Arrow	Colour	Elevation Profile
left	first hills, then downwards	first hills, then downwards	scenic path
middle	shortest path	shortest path	shortest path
right	most even path	most even path	most even path

Table 5.1: Criteria for the path choice task (Boston). The table lists for each representation type and chosen path the overall highest rated (= most relevant) criterion.

Figure 5.6 reveals the path choices for the second location *Perth*. The choices made with the arrow and the elevation profile representation types are the same. Most people choose the left path, followed by the middle and least of all the right-hand path. In contrast, participants mostly opted for the middle path with the colour representation. To see what criteria led to the path choice, Table 5.2 summarizes the answers. When a path was chosen, then the most relevant criteria stayed the same for all representations. This means that if participants chose the middle path, the criteria is always that it is the shortest path. The same is the case for the other two paths, but with different criteria though. The left path is chosen for its multiple but small hills along the path and the right path is chosen due to its plain characteristics.

Concerning the scenario, people do not consider a scenic path as relevant, in fact, the criteria of scenery is considered to be as low to not relevant for 91% of all answers. Overall, the path choice is affected by the type of elevation representation and different criteria (e.g. shortest or most even path) contributed to the respective choice as

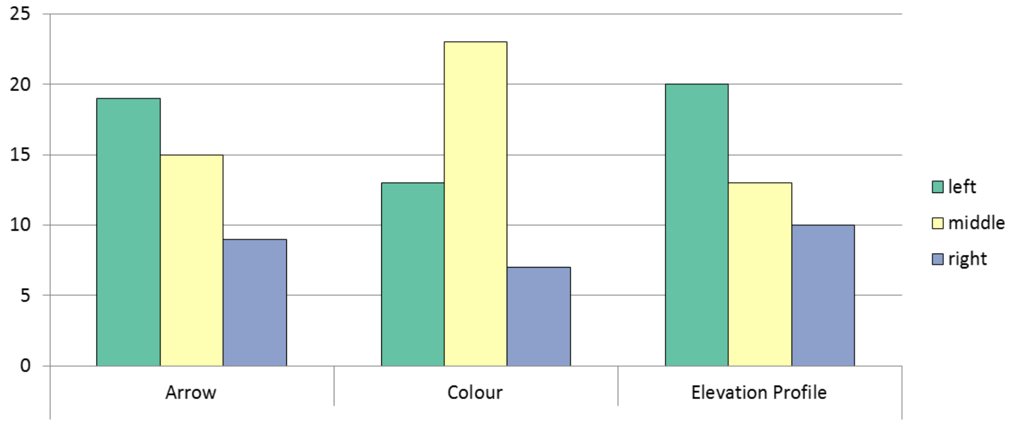


Figure 5.6: Path Choice (Perth): Counts of chosen path for each representation type

	Arrow	Colour	Elevation Profile
left	multiple, but small hills	multiple, but small hills	multiple, but small hills
middle	shortest path	shortest path	shortest path
right	most even path	most even path	most even path

Table 5.2: Criteria for the path choice task (Perth). The table lists for each representation type and chosen path the overall highest rated (= most relevant) criterion.

elevation (e.g. hills) and distance are the most relevant. Scenery and geometry (criteria: path is easy to remember) are not relevant for the path choices with this specific scenario.

5.3 Accuracy (Effectiveness)

The accuracy analysis refers to the percentage of correct answers for the slope and marker task, as described in 4.3.3. A repeated-measures ANOVA reveals that the three representation types vary significantly in percentage of correct responses when looking at both tasks together [$F(2,84) = 15.768$, $p < 0.05$; $n_p^2 = 0.273$]. The overall percentage of correct responses is significantly affected by the type of elevation representation. A pairwise comparison shows that there is a significant accuracy difference between the elevation profile and the arrow representation ($p < 0.05$), the colour and the elevation profile representation ($p < 0.05$), but no significant difference can be found between the arrow and the colour representation ($p > 0.05$). Mean values of percentage of correct answers performed by the participants with the elevation profile (M = 0.709, SE = 0.023) are slightly lower than the means achieved with the arrow (M = 0.872, SE = 0.023), and the colour (M = 0.843, SE = 0.029) representations (Fig. 5.7). Furthermore, a significant effect of spatial ability can be reported [F(1,39) = 4.431 ,p < 0.05, $n_p^2 = 0.102$]. Participants showed different percentages of correct responses if they were in the high spatial ability group (M = 0.849, SE = 0.024) than the ones in the low spatial ability group (M = 0.774, SE = 0.026). No significant effects due to gender were found [F(1,39) = 0.076, p > 0.05]. In order to see whether people also show

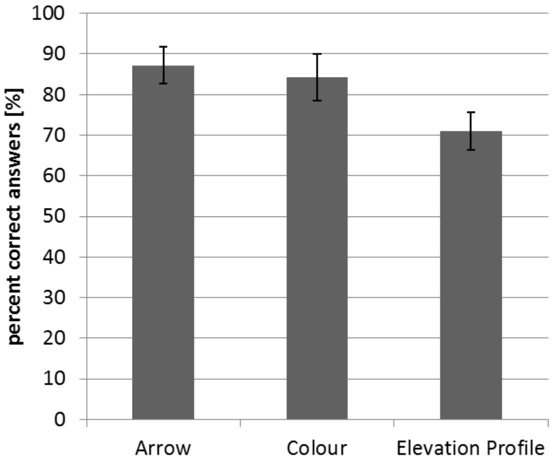


Figure 5.7: Percent correct answers: Overall (Marker & Slope Task together). Mean and error bars: ±2SE

differences in percentage of correct answers based on question, the two tasks were individually analysed.

The percentages of correct answers from the *slope task* are not significantly affected by the representations [F(2,78) = 1.948, p > 0.05] (see Fig. 5.8). This means that the slope task percentages are the same no matter which representation participants received. Furthermore, no significant effect due to spatial ability [F(1,39) = 1.006, p > 0.05], and no effects due to gender [F(1,39) = 0.282, p > 0.05] can be reported for the slope task.

In contrast to the slope task, participants performance in the *marker task* was significantly affected by the type of representation [F(2,78) = 17.300, p < 0.05, $n_p^2 = 0.307$]. Pairwise comparison reveal that people performed significant differently with all representation types (p < 0.05). Participants achieved higher percentages of

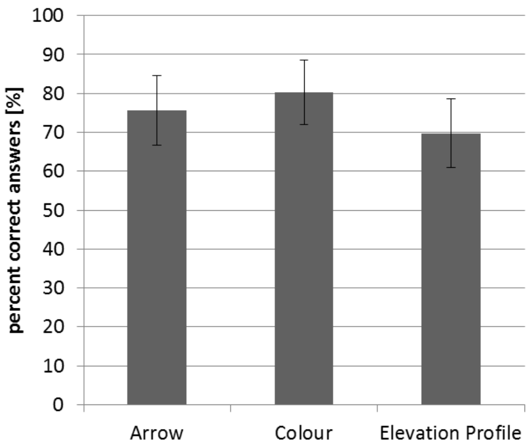


Figure 5.8: Percent correct answers: Slope Task. Mean and error bars: ±2SE

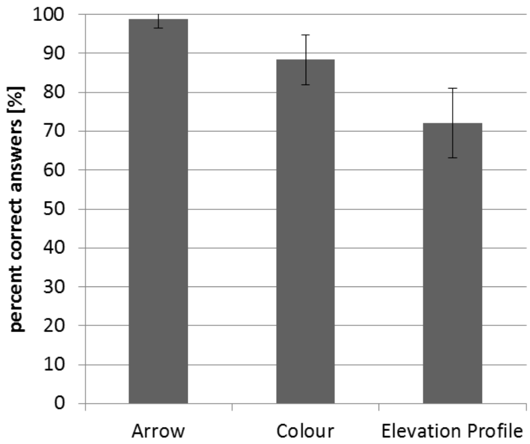


Figure 5.9: Percent correct answers: Marker Task. Mean and error bars: ±2SE

correct responses with the arrow representation (M = 0.988, SE = 0.012) than with the colour (M = 0.884, SE = 0.033) or the elevation profile (M = 0.721, SE = 0.045) representation as shown in Figure 5.9. No significant interaction effects between percentages of correct responses and spatial ability was found [F(2,78) = 1.712, $p > 0.05$]. However, a significant interaction between percentage and gender [F(2,39) = 4.685, $p < 0.05$, $n_p^2 = 0.107$] can be revealed. The percentage of correct answers is significantly higher for men than for women with the arrow ($M_{Men} = 1.00$, $SE_{Men} = 0.018$, $M_{Women} = 0.982$, $SE_{Women} = 0.016$) and the colour ($M_{Men} = 0.964$, $SE_{Men} = 0.047$, $M_{Women} = 0.810$, $SE_{Women} = 0.043$) representation but lower when using the elevation profile representation ($M_{Men} = 0.651$, $SE_{Men} = 0.067$, $M_{Women} = 0.784$, $SE_{Women} = 0.061$).

5.4 Response Time (Efficiency)

The accuracy analysis reveals differences in correct responses between the representation types. The question now is if participants' response times differ between representation types as well. A repeated-measures ANOVA reveals that response time is significantly affected by the type of representation [F(2,84) = 5.829, $p < 0.05$, $n_p^2 = 0.130$]. Pairwise comparisons show that participants answer significantly ($p < 0.05$) faster with the arrow (M = 48.162, SE = 2.314) and colour (M = 49.54, SE = 2.699) representation than with the elevation profile representation (M = 55.241, SE = 3.028). No significant difference in the time participants used to respond can be found between the arrow and the colour representation ($p > 0.05$). These results are shown in Figure 5.10. Furthermore, no significant interaction between response time and spatial ability [$F(2,38) = 2.757$, $p > 0.05$] as well as between response time and gender [$F(2,38) = 0.370$, $p > 0.05$] can be found. Again, response time is analysed separately for each task.

A repeated-measures ANOVA reveals no significant difference in response time between the three representations in the *path choice task* [$F(2,84) = 0.606$, $p > 0.05$]. However, participants used slightly more time to answer with the colour representation (M = 80.627, SE = 4.817) than with the arrow (M = 74.197, SE = 5.185) and the elevation profile (M = 77.268, SE = 5.530) representation but without significance (Fig. 5.11).

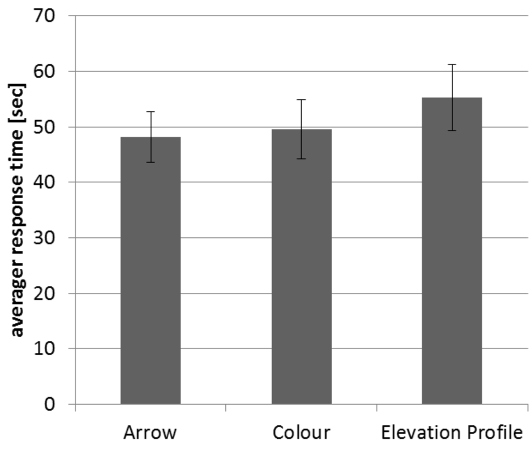


Figure 5.10: Response Time: Overall. Mean and error bars: ±2SE

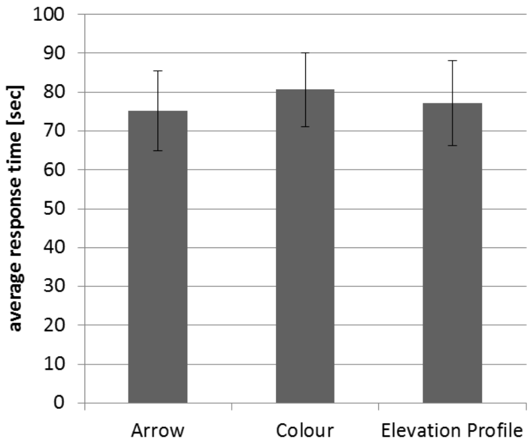


Figure 5.11: Response Time: Path Choice Task. Mean and error bars: ±2SE

The response time for the slope and marker tasks required correct answers and therefore if participants answered correctly, the respective response time is included in the following analysis. Response times for wrong answers were not included (as discussed by Çöltekin et al. (2010)).

A repeated-measures ANOVA reveals no significant difference in response time between representation types for the *slope task* [$F(2,10) = 1.061$, $p > 0.05$] (Fig. 5.12).

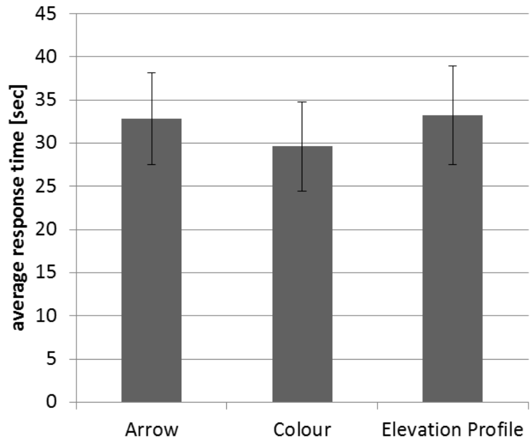


Figure 5.12: Response Time: Slope Task. Mean and error bars: ±2SE

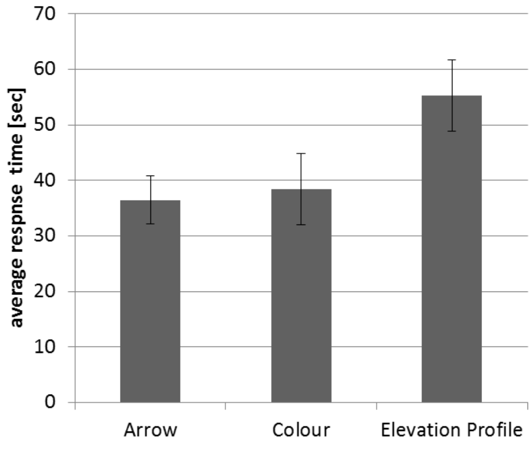
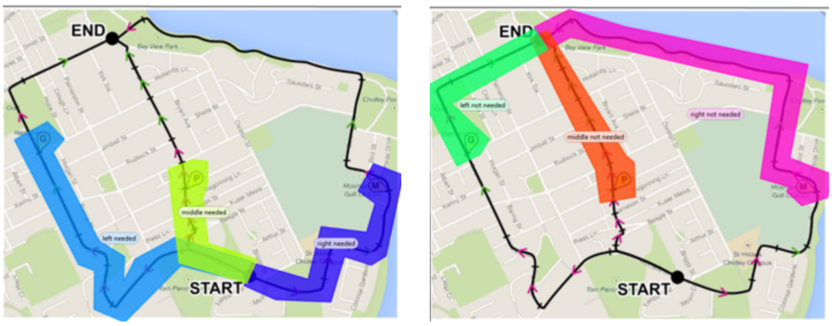


Figure 5.13: Response Time: Marker Task. Mean and error bars: ±2SE

For the *marker task*, a repeated-measures ANOVA shows significant effect of response time based on the representation type [$F(2,28) = 12.674$, $p < 0.05$, $n_p^2 = 0.475$]. Pairwise comparisons show that response time between the arrow and the elevation profile ($p < 0.05$) and between the colour and the elevation profile ($p < 0.05$) representation significantly differ. Response time is much higher for the elevation profile ($M = 59.374$, $SE = 5.715$) than for the arrow ($M = 35.157$, $SE = 4.236$) and colour ($M = 33.175$, $SE = 3.222$) representation. No significant difference can be found between the arrow and colour representation types ($p > 0.05$). Figure 5.13 shows the error bar charts of the time participants used to respond correctly to the marker task questions for the three representation types. Also, no significant effects due to spatial ability [$F(2,22) = 0.613$, $p > 0.05$] or due to gender [$F(2,22) = 1.038$, $p > 0.05$] were found. Furthermore, no significant interaction effect can be reported between response time and percentages of correct responses [$F(2,78) = 1.054$, $p > 0.05$].

Owing to the differences in response time identified in the *marker task*, AOI's were defined in a top-down approach as shown in Figure 5.14. Figure 5.14(a) defines the areas that are relevant to gaze at in order to answering the question correctly. Figure 5.14(b) shows the areas of the paths that are not relevant to answer the question. The percentage of relevant eye gaze visit duration is calculated as the time spent at the relevant AOI's divided by the total time spent on both (relevant and not relevant) AOI's. A repeated-measures ANOVA reveals differences in percentage of relevant visit duration between the three representation types [$F(2,38) = 13.613$, $p < 0.05$,

$n_p^2 = 0.264$]. Pairwise comparisons show that participants spent more time on the relevant part in comparison to the overall time spent at the arrow representation ($M = 0.75$, $SE = 0.011$) was significantly ($p < 0.05$) longer than at the colour ($M = 0.675$, $SE = 0.022$) and the elevation profile ($M = 0.635$, $SE = 0.021$) representation (Fig. 5.15). No significant difference of the percentage relevant visit duration can be found between the colour and the elevation profile representation ($p > 0.05$). Also no effects due to gender [$F(2,35) = 2.749$, $p > 0.05$] or due to spatial ability [$F(2,35) = 0.447$, $p > 0.05$] were found.



(a) relevant (b) not relevant

Figure 5.14: Marker task: (a) relevant: AOI's from start to marker, (b) not relevant: AOI's from end to marker

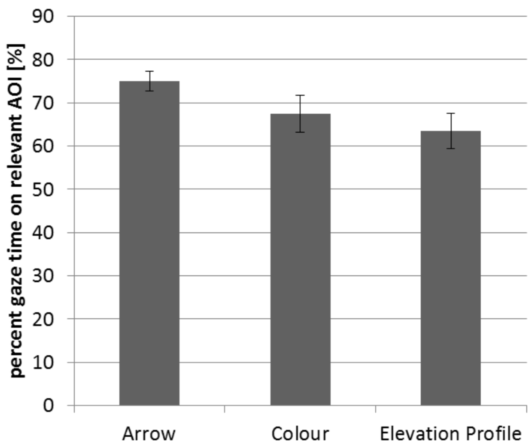


Figure 5.15: Percent of eye gaze visit duration on relevant AOI (relevant / (relevant + not relevant)): Marker Task. Mean and error bars: ±2SE

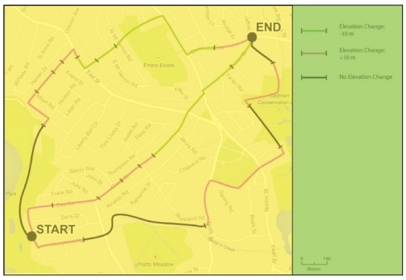


Figure 5.16: AOI: map (yellow) and legend (green)

Furthermore, two additional AOI's were defined, one covering the whole map area and the other the legend part (Fig. 5.16). This should help ascertain why these differences between representation types were found. For this reason, visit duration of the map and the legend were analysed. A repeated-measures ANOVA revealed that participants' visit duration on map and legend were significantly different [F(1,38) = 244.916, $p < 0.05$, $n_p^2 = 0.866$] as clearly less time is spent on the legend (M = 8.775, SE = 0.692) than on the map (M = 18.727, SE = 1.034). Additionally, visit duration of map and legend are found to be affected by the representation type [F(2,76) = 36.717, $p < 0.05$, $n_p^2 = 0.491$]. Here, visit duration of map and legend for the arrow, colour and elevation profile representation differ significantly. It is interesting to note the interaction between the two AOI's considering the three representations which produces a significant result [F(2,76) = 132.609, $p < 0.05$, $n_p^2 = 0.777$]. The interaction effects of map and legend visit duration compared to the arrow and the colour representation is significant [F(1,38) = 4.288, $p > 0.05$, $n_p^2 = 0.101$]. The interaction effect of map and legend compared to the colour and the elevation profile is also significant [F(1,38) = 196,702, $p < 0.05$, $n_p^2 = 0.838$]. The mean visit durations of the arrow ($M_{legend} = 1.16$, $M_{map} = 17.032$) and the colour ($M_{legend} = 2.430$, $M_{map} = 20.880$) representations both show a similar pattern, as the map itself is longer focused on than the legend. For the elevation profile the visit duration of the legend (M = 22.734, SE = 1.933) is higher than of the map (M = 18.267, SE = 1.570). The elevation profile representation is special, as the elevation profiles and the map have to be considered in order to answer the marker tasks correctly. In contrast, participants with the arrow and colour representation need to consult the legend only for a short amount of time and mainly focus on the map to respond correctly. In spite of this, the result shows a significant difference between the arrow and colour representation type although both have the information intrinsically displayed.

These results reveal differences in response time and visit duration on relevant AOI's between the representation types. In particular, visit duration for the AOI's map and legend also highlighted differences in intrinsically displayed elevation information.

5.5 Preference and Usefulness

Participants were also asked to state which of the three representation types they would prefer for each task. Figure 5.17 summarizes the answers. The *path choice* and *slope task* reveal a similar distribution pattern of preferred representation type. Most people prefer elevation profiles in order to receive information about terrain. For these two tasks, arrow symbols are clearly least popular.

However, participants prefer the arrow representation for the *marker task*. The marker task requires a calculation of the heights of three view points from the starting point. Participants therefore need to add up elevation changes of plus/minus 10 meters and as Figure 5.17 reveals, people preferred calculating heights least of all with the colour representation.

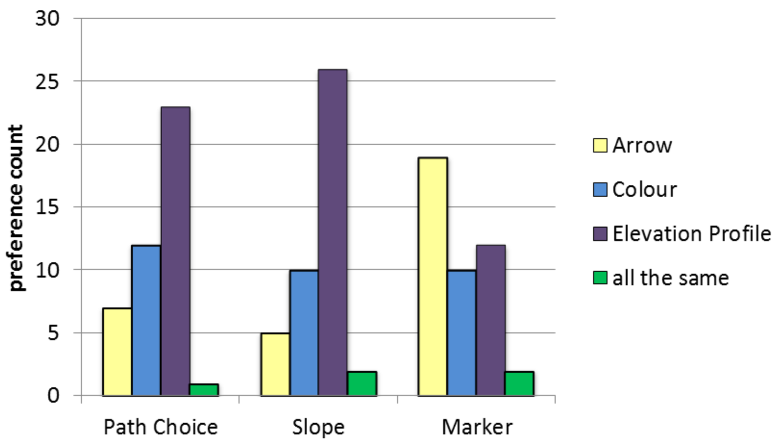


Figure 5.17: Counts of representation preference based on Task

When analysing the *preference changes* from before to after the experimental study, 26 out of 43 participants (approx. 60 %) did not change their preference at all. From these non-changers, 80 % preferred the elevation profile representation and stayed with this type. However, nearly 40% of all participants changed their preference of representation type between the beginning and the end of the experiment. When participants changed their preference, it was 40 % each to colour and elevation profile and only 20 % to the arrow representation.

Furthermore, participants answered helpfulness questions in order to see potential differences between preference and utility. Answers revealed that for the *slope task*, elevation profile representations were rated as most useful. This representation type was also found to be the most preferred type for this task, however, participants were least effective with the elevation profile when defining steepness. The colour representation type is rated as least useful for slope detection by the participants, although, participants' answers produced the most effective and efficient results for this task. The *marker task* shows different usefulness results. The arrow and colour representations were rated as most useful in answering the question about the heights of markers. Participants stated that the arrow representation type was their preference for the marker task and this also produced the most efficient and effective results. For the *path choice task*, participants found the arrow symbols to be least helpful and also rated them as least preferred type of elevation representation. Participants rated the elevation profile representation type as most useful in choosing a path.

Last but not least, the participants' comments will be used in part to interpret the results in Chapter 6 and are not listed in this chapter. However, Figure 5.18 shows these comments in varying size according to the frequency they were mentioned and illustrates the importance of segments.

Figure 5.18: Participants' comments: size according to their count (created with Wordle: www.wordle.net)

5.6 Summary of Results

The data analysis reveals that participants changed their choice of path with changing elevation representation type. The scenario, which instructed people to be in a hurry, is specific and participants stated that a short and flat path was the most relevant criterion. This means that distance as well as elevation information were the two dominating criteria.

The slope and marker tasks required correct answers. Results revealed that the type of representation significantly affects the percentage correct responses. Participants produced the most effective results with the arrow representation for the marker task, with the colour representation for the slope task, and overall the least effective with the elevation profile representation type.

Furthermore, analysis of response time revealed differences between representation types. Participants needed longer to answer with the elevation profile than with the other two representation types. When breaking these response times down into tasks, participants were most efficient with the arrow representation in the marker task. The slope task was most efficiently solved by participants with the colour representation. No such result can be found in the path choice task.

No significant effects due to spatial ability or gender can be reported, except that men performed more effectively than women in the marker task.

Further eye gaze analyses revealed that people focused significantly less on the irrelevant part of the path when using the arrow representation than with the colour and elevation profile representation types when defining heights of markers. People did not waste time on the irrelevant part of the paths with the arrow representation and were therefore more efficient.

In summary, participants displayed differences in effectiveness and efficiency between the three representation types. When the overall results are split into tasks, these differences can be traced back to the marker task. Here, people performed most effectively and most efficiently with the arrow representation. Participants stated different representation preferences for different tasks. As for the path choice and slope task, the elevation profile comes out as the clear favourite, yet, arrows are popular when defining the height of a marker. Although participants rated elevation profiles as the most useful and most preferred type of elevation representation, participants were not at their most efficient and effective with this type.

6 Discussion

In the following chapter, the results are reviewed and set into the context of current research. The findings are then analysed separately according to the research questions and the chapter concludes by examining the limitations of the study.

6.1 Research Question 1: Path Choice

The task involved selecting a path based on the scenario of getting from a start to an end point as quickly as possible. This is a real life setting. The situation, of being in a hurry was chosen to see whether participants rated the criterion 'distance' or 'elevation' to be as more relevant. These two criteria seem interesting when being in a hurry due to the fact that amongst others slope and distance are found to be as the most influential criteria for path choice (Hochmair, 2004) and that people make a route choice between 'long and steep' or 'short and very steep' (email communication with E.Boerer, BikePGH, 07/01/15).

Results show that the representation type influences path choice. Regardless of background map, different paths were chosen depending on elevation representation type. The colour representation showed a different distribution than the arrow and elevation profile type. When participants got the colour representation, they chose the shortest path no matter how steep and how many metres they would have to overcome. As for the arrow representation type, results reveal it is not distance but elevation which is most important. Participants rated flatness and lowest peaks as most relevant to their decision. Different results can be reported for the elevation profile representation as here both shortest path and lowest peak criteria stand out. Because the findings of the pattern with colour was not repeated with arrows and elevation profiles; it might be argued that participants did not see the big hill as clear with the other two types and mainly focused on the criterion of distance. However, these overall findings confirm the multi-criterion theory for path choice by Hochmair (2008b). The results support his findings as none of the participants rated one criterion as most relevant and all the others as not applicable. In other words, people never stated that one criterion alone was relevant when choosing a path.

In their early work, Huffman & Williams (1985) suggest that motivation and pleasure seeking could influence path selection. The argument of motivation and pleasure seeking could also explain the high ratings for even paths. People constantly try to reduce effort (e.g. Edwards (1954), Montello (2009)) and because the case study was stipulated the use of a bicycle, the fact that participants avoided hills should not come as a surprise. This explains why the shortest path was not always chosen as this path featured the highest hill. Therefore, slope plays a role when choosing the longer but less steep path, also observed by Boer et al. (2013). It is important to state that the criterion 'to avoid hills' specifically holds for the physical effort associated with riding a bicycle and would probably not arise when driving a car. Pleasure seeking (e.g. a nice view) is another argument, but with the scenario of being under time pressure, the criterion 'scenic path' received the lowest relevance ratings in the study. On the other hand, Huffman & Williams (1985) demonstrate that the selection of a path is based on time availability. More recent research shows that people select a path based on time availability (Chiou et al., 2010). Since the scenario tells participants to hurry from one place to another, time availability is a factor and if the scenario were different, people would probably decide differently. In short, the scenario, or as presented in Wilkening & Fabrikant (2011b) and Boer et al. (2013) the type of task, influences choice of path.

Bailenson et al. (2000) observe that the geometry of the route (e.g. straightness, least-angular routes) changes peoples choice of route. This observation is supported by Hochmair & Frank (2002). One could expect that when in a hurry, the time to look at a map during the drive is limited, so the memorization of the route would be important. Interestingly, however, in our study, the criterion 'path is easy to remember' was rated as slightly relevant in only 30% of all answers covering all representation types and nearly 50% rated the geometry as least to not relevant at all. A possible interpretation of the low rating of simplicity could be that people were focusing on elevation and interpreting the elevation representations. Nearly all participants are geographers and are more or less familiar with map reading so consider themselves able to find a more complex path without any problems. This further leads to our interpretation that people believe elevation change is more time consuming than looking at the map again to check the direction of travel. This agrees with the findings of Hochmair (2004) who observes that simple routes are not so relevant when deciding between road options. In our study, the left and right-hand paths feature a slightly more complex geometry than the middle, most direct path, but have clear landmarks (park, lake, river) to help people remember driving directions from start to finish. The scenario in the lab did not specifically ask participants to remember the path, however the testing of the geometry of these paths in a path choice task would be interesting and people would probably choose the most direct and straight path, as suggested by Bailenson et al. (2000).

Additionally, other (not map relevant) factors such as gender or spatial ability could influence choice (Wilkening & Fabrikant, 2011b) but we did not observe these in our experiment, except that more men than women are in the high spatial ability group. One possible interpretation is that 41 out of 43 participants were geographers and the overall spatial ability scores were correspondingly high. Nearly all have expertise in geography and related fields, therefore this result does not cause surprise within the given sample. This result might be different when testing students from fields of study other than geography to see if gender and spatial ability differences occur.

In summary, the results reveal that when people have to choose a path and have to maximize time-gain, different paths are chosen depending on the representation used. Representation type resulted in different path choices although background map, path options, elevation and distance did not change. This result is interesting because even if they are shown exactly the same conditions, they are influenced by the design. However, when asked why they chose a particular path for all the representation types, participants indicated (with slight variations) that they were predominantly driven by the criteria of distance and elevation change, and not by scenery or geometry. This suggests the participants are not necessarily aware that they are changing their decisions on the basis of how the elevation information is represented.

6.2 Research Question 2: Effectiveness

The study shows that path choice is indeed affected by representation type. Moreover, effectiveness is also influenced by the kind of elevation representation. Overall findings are traced back to the marker task (determine highest view point). Participants answered most effectively with the arrows and least effectively with the elevation profile. People with the colour representation performed more accurately than those with the elevation profile but slightly worse than those with the arrow representation.

In terms of finding the highest view point, previous research (Irvankoski, 2012) found similar results as the type of visualizing elevation change affected response accuracy. It is not surprising that when getting the elevation profile representation, people achieved lowest percentage of correct answers as this representation type needs extra cognitive effort to match the map and the integrated legend display (Sutula, 2007). Results revealed percentages of correct responses between 84 to 89 for the colour representation type. Even higher scores were achieved with the arrow representation, which could potentially be explained with symbolization. The marker task involved adding up the differences of $\pm 10\,\mathrm{m}$ elevation differences from the start to the markers. Arrows are point symbols that can be counted easily in contrast to the colour coded lines. Counting lines probably causes more problems than counting single objects. However, that is just one possible interpretation. The other would be that arrows are found to be useful to indicate ascents and descents and participants could relate to these annotations (Huffmann, 2009). For this reason, the results are not surprising. 87 to 98 percent correct answers were forthcoming in the overall respective marker task with the arrow representation type.

The *marker task* indirectly included a short-term memory task as each marker's height had to be remembered and compared with the other two. The 'Hidden Pattern Test' (by French et al. (1963)) measures how well we remember a model pattern (Fig. 4.2) and if we find it within other environments as shown in Fig. 4.3. This is a possible explanation for the resulting correlation between participants' spatial ability scores and the percentage of correct answers. Participants in the high spatial ability group performed more effectively than those in the low spatial ability group when analysing the marker task. Or in other words, people who achieved a higher score on the Hidden Pattern Test were also more accurate in the marker task. This result may indicate higher short-term memory ability for those participants. Furthermore, results suggest gender differences based on the accuracy scores for the marker task. Although Montello et al. (1999) did not find gender differences, they pointed out that there are geography-related tasks that show gender differences. One such task is the identification of height when representing elevation change for paths as found in our analysis.

No significant effect on accuracy between the three representation types could be found in the *steepest slope task*. In our study, it was not slope that was represented, but elevation change. In order to find the steepest slope segment, the length (distance) of the segments had to be compared. In other words, the combination of distance estimation of a segment and its respective elevation change led to the correct answer of the slope task. Participants should not have had any problem in calculating slope because an introduction of the slope concept was given at the beginning of the main test. Our analysis revealed no difference in effectiveness between the three representation types. However, participants achieved slightly higher percentages of correct answers with the colour representation type. Huffmann (2009) found that colour is not useful for tasks such as the marker task (find altitude of a point) but suitable when defining elevation change. As colour coded lines clearly highlight the segments' length differences and because Brewer et al. (2003) found that a diverging colour scheme with different colour hues is useful to visualize values within opposite data range (in this case 10 m uphill and 10 m downhill), the colour representation type achieved highest scores in the slope task. Furthermore, Su et al. (2010) have demonstrated that colour is an effective medium for identifying steep slope segments. However, lower scores were recorded for the other two representations. Hence, all representation types show more or less equal results with the slope task. Reasons for this could be that representations with elevation profile are reported as an effective medium for slope detection (Chiou et al., 2010). Slope could easily be determined with the profiles but it was crucial to check the distance as each elevation profile was slightly different in distance. For this reason, a salient kilometre declaration was added beneath each profile. The consideration of both, the map with its segments and the profile, was fundamental in order to find the correct answer. Montello et al. (1999) found that men and women performed similarly in the task where they had to estimate distances and also in this study, males and females did not differ in finding the steepest slope segment. So in the slope task, participants' (men and women) performance was equally effective for all three representations, however further testing is needed to confirm the slightly more effective results with the colour representation.

Furthermore, time pressure could have had an effect on response accuracy, however this does not necessarily need to be viewed as negative. Wilkening & Fabrikant (2013) point out that a slight time pressure leads to greater accuracy than when there is no time pressure at all. We cannot confirm these findings because all participants were under time pressure, but a differentiation between time pressure and no time pressure would be interesting to include in a further experiment. Participants demonstrated different levels of experience with folded hiking maps, mobile maps for route planning etc. and may therefore have different map-reading capabilities (Lobben, 2004), which could additionally explain the differences observed in map effectiveness for the marker task. However, the study background of participants could be an indication for the similar results between representation types for the slope task.

Our study suggests differences in effectiveness based on task and based on elevation representation, which should be considered when designing a map. In particular, when accurate information is called-for, arrow symbols should be applied on streets in order to represent elevation change. All in all, the goal of cartography is "to effectively communicate a particular message" (MacEachren & Ganter, 1990, 65) and "to identify and document locations of real world objects as accurately as possible" (Boer et al., 2013, 2). In our task and context, the arrow representation fulfils these requirements best of all.

6.3 Research Question 3: Efficiency

The results from the efficiency analysis are discussed in the following sub-chapter. The evaluation of the overall result shows that there are significant differences in response times based on representation type. Participants' response time with the arrow and the elevation profile as well as with the colour and the elevation profile representation types are found to differ significantly. However, no difference in response time was observed between the arrow and the colour representation. Again, these differences were only found when looking at the marker task, while the other tasks did not yield to differences in efficiency. The efficiency analysis (of the slope and the marker tasks) only included response times for correct answers.

Firstly, for the *path choice task*, no difference in response time between the three representation types was observed. So participants did not respond faster when, for example, having the arrow representation. In other words, when choosing a path, no response time differences between elevation representation types were found. Path choice is a process that needs time and map users have to evaluate the relevant criteria carefully. According to Edwards (1954) and Montello (2009), the decision needs to be made, for example, on the basis of whether or not physical effort is involved. If people plan and navigate a route, the process of optimising efficiency is ongoing (Gärling & Gärling, 1988), however our study could not confirm differences in efficiency between representation type.

No difference in efficiency was found when identifying the *steepest slope segment*. Participants responded within the same amount of time no matter which type of representation they had. However, colour representation did show slightly more efficient results. This result can be interpreted by the fact that colour was suggested as an appropriate variable to identify steep slope sections along a route efficiently (Su et al., 2010). In order to detect steep slope segments efficiently, participants did not show differences between representation type, however further testing is needed to confirm the slightly more efficient results with the colour representation.

The arrow and the colour representations have the relevant information displayed 'intrinsically'. Elevation profiles have the relevant part displayed 'extrinsically' (in the legend) and map users need to reconcile the map with the elevation profiles (Sutula, 2007). The matching and constant switching between map and legend needs time and could be one reason why answers with elevation profiles are clearly least efficient for all tasks. When looking at the AOI's (map and legend), there is the fact that participants clearly spent more time on the map when working with the arrow and the colour representation but more time was spent on the legend when having the elevation profile. This result is not surprising if we think how the intrinsically and extrinsically displayed information may affect the efficiency of the participants. The analysis of the overall response time revealed that participants showed significant differences between the representation types, however as seen above, no efficiency differences for the path choice and slope tasks were found. However, this difference in efficiency can be traced back to the *marker task*. When looking at the arrow and the colour representation, the difference between them was not significant, but still, participants with the arrow representation type were a bit quicker than with the other two types when solving the marker tasks. One interpretation is that the arrows not only have different colours to indicate opposite elevation changes, but also show direction. The tail and head already give the reader a hint of where the potential navigator begins and ends their journey (Kurata & Egenhofer, 2008) and can therefore save time. In order to check this hypothesis, we studied the eye movement data. AOI's were defined and analysed on the basis of visit duration. The arrows significantly lead the reader to the relevant path segments as the irrelevant segments of the paths were longer fixated on as was the case with the other two representation types. The other two representation types show that the irrelevant segments of the paths were studied for longer despite not being required in order to answer the question. The arrows assisted the map user with the faster recognition of the start and end point.

Slocum et al. (2009) suggest that prior knowledge of a representation task could result in more efficient map reading. All participants except one had seen the elevation profile before, so the difference in response time, in this case, is not supported by the theory of prior knowledge. An analysis of interaction effects between effectiveness and efficiency to examine whether there may be a speed-accuracy trade-off did not yield any significant results.

The efficiency analysis again revealed significant differences between the representation types for the marker task. Participants are most efficient with the arrow representation as it also shows direction and least efficient with the elevation profile representation because the switching between profile and map is time consuming. To sum up, when tasks involve path choice or detection of steepness, all three representation types are equally efficient, but when efficient map reading for exact information retrieval (e.g. height of a marker) is needed, profiles are not suitable representation types, while arrows are.

6.4 Research Question 4: Preference

Results revealed differences in preference of representation type for the different tasks. Elevation profiles are preferred for the path choice and steepest slope tasks. However, the arrow representation type is preferred when defining the height of the marker on a map. If the preference question is asked without specifying a task, the most chosen representation type is the elevation profile.

There is no surprise about this pattern because elevation profiles give the map reader already a sort of third dimensional structure to the terrain and as Chiou et al. (2010) stated, slope is a criterion for path choice. It therefore appears to follow that people probably get a faster impression of steepness when considering an elevation profile and therefore also chose it as preferred communication tool for both path choice and steepness. Huffmann (2009) reports that map users expect to see the topography directly. Additionally, Sutula (2007) mentions that elevation profiles give people a good understanding of the characteristics of the trail but a matching between the map and the legend is still needed to understand elevation information.

Therefore, when taking response time and accuracy into consideration, it is not the most efficient representation type or the most effective. The findings on preference confirm the statements of Hegarty et al. (2009) that people are neither performing effectively nor efficiently with the preferred representation type. Arrow and colour representations are less preferred. This might be due to the fact that people have difficulties when identifying the third dimension on a static 2D map (Sutula, 2007) and the terrain characteristics cannot be seen at first sight. Huffmann (2009), for example, reported that arrows are too abstract and cognitive and learning investment is too high in order to see the terrain. Participants need more cognitive effort to see hills and valleys, in other words these are maps which have to be read and not just to seen (theory by Bertin (1967)). This prevents map users expressing a general preference of the arrow or the colour representation. In contrast, the arrow representation type was most preferred in the marker task. This again can be argued with the simple counting of single point objects and the suggestion of Huffmann (2009) to indicate ascents and descents with arrows. A memorization and comparison of heights was required and no connection between elevation change and distance (as in the slope task) had to be performed.

We can confirm the findings of Levy et al. (1996) that user preference changes not only according to display but also with changing scenarios. However, it has to be said, that in our study, the task specific preference questions were asked after the experiment. Consequently, the results of preferred representation type might look different if people were asked before they actually performed the specific tasks.

6.5 Limitations

All in all, the analyses revealed that people choose different paths with different elevation representation types. Additionally, participants' effectiveness, efficiency and preference results show differences with changing representation type. However, there are some study limitations that could lead to different results and should be taken into consideration.

- First of all, 43 participants took part in the experimental study, which is considered to be large (Field, 2009), however a higher number of participants would verify the results and possibly improve effectiveness and efficiency of the colour representation for the slope task. Furthermore, 41 participants are from a geography-related background. Other fields of study would allow a between-subject design for the experiment as not only geographers use maps although they may be more frequently exposed to them. Additionally, the study was designed as a map that people would plan a journey with, however the test environment (lab) did not support a relaxing planning environment. Path choice, in particular, may change when people are actually in the field and therefore, it would be interesting to run the experimental study outside the laboratory environment.

- Secondly, the whole study had a time limit of 30 minutes and participants were required to finish all 18 questions within the given time limit, which all managed to do. Wilkening & Fabrikant (2011a) report that time pressure leads to differences in decision making. In our study, we can not measure if time pressure had a positive or negative impact because all participants were under the same controlled conditions. It would, however, be desirable to run a further study to understand better whether different degrees of time pressure would affect people's path choices or have an impact on the accuracy or response time results with different types of elevation representation of paths.

- Another limitation imposed so as to conform with general design recommendations was that the path choice scenario is very specific (cycling from A to B as quickly as possible) and therefore the fact that the choice is dominated by the criteria of elevation and distance comes as no surprise. We can therefore support the findings by Wilkening & Fabrikant (2011a) that task type influences path choice. However, a different scenario (e.g. taking a scenic route to visit a friend on your day off) would lead to different choices being made since time would no longer be a motivating factor (e.g. Huffman & Williams (1985), Chiou et al. (2010)).

- From participants comments in the introduction of the main experiment, steepness could have been defined as uphill or downhill. So the steepest street segment could also have been downhill and this was not clear for some participants. Also several participants mentioned that when rating the criteria 'most even path' as most relevant, the criteria 'steep slopes' could be stated as relevant too and not only when choosing the most direct but hilliest path. For this reason, a modification of the choices' criteria could have led to a better understanding of these contributory criteria and should be considered in further research.

- Another constraint is that the base maps are in a urban environment and on small scale. A more down-town or larger scale map would probably feature greater detail and could have an influence on path choice, effectiveness and efficiency. The reason for this is that the number of points of interest and information density might be higher and distract from elevation information. Only the (to the user) relevant information should be provided (Kosslyn, 1989) and extraneous information could lead to poorer map reading (Tufte & Graves-Morris, 1983). In other words, the representations might be scale dependent and perhaps elevation profiles would perform more effectively and more efficiently on a large scale, more rural and less dense area (e.g. a mountainous region). Furthermore, all elevation changes for the two locations chosen were invented and do not actually exist. In order to verify these methods, testing a representation of exact terrain representation may be helpful and possibly could give more insights in testing these methods.

- Additionally, this study provided three recommended paths, however many already existing and researched (e.g. Huffmann (2009)) elevation representations apply the relevant information over the whole street network. To enable comparability between the three representation types, they were modified and do not exactly portray what actually exists or what has been suggested by researchers. In our study all representation types would need some modification. As mentioned, in practice all of the three proposed representation types exist in a slightly different way, so for example most maps using arrows have the classification of steep or very steep and arrows always point uphill. The main problem with our proposed arrow representation would be the direction and road intersections (Cui et al., 2008). Linear features that are colour coded are often represented with sequential colour schemes and show slope categories not elevation change. Elevation profiles often show metres above sea-level, however the modification for this experiment was to show elevation change of plus/minus 10 metres. For mobile/online route planners, elevation profiles are useful representation types because profiles only work for route suggestions and no application for the whole map network would be possible. In fact, all three proposed representations only work when route suggestions are made. They can not be applied for the whole network as for example the methods of San Francisco, Pittsburgh or Zurich employ in their bike maps. A slightly modified version of the arrow and colour representation could easily be applied to a whole network on a static map, however not with the elevation profiles.

- The comparability adjustments raise the question of precision. How precise do map users need details about the 'ups and downs'? Is it important in a urban environment to know exactly how much elevation change is ahead? We suggest that some of the existing types of representation miss one fact, namely how far the steepness lasts. If maps only show the difference of steep/steeper or hill/big hill, the information may not be enough for a cyclist. In our study, we therefore suggest a combination of elevation change and distance using the method of dividing the path into segments. This segmentation is related to the concept of contour lines by Imhof (1965) because a difference between two indications represents elevation change and their proximity represents steepness. Our proposal should be considered for further research and map design in urban environment.

The map user (e.g. cyclist) should have an effective and efficient supporting tool in order to see the duration of the inclines along a path. The proposed elevation representation types provide an initial assessment of elevation information for paths when navigating by bicycle. We believe, however, the user response to these slightly modified representations are indicative of user performance and their implications for map design should be considered. To conclude, elevation profiles give a good impression of the terrain characteristics but when going more into detail (e.g. determining heights or slope) they are not sufficient for effective and efficient task solving. Map design should include arrow symbolization when efficient and effective altitude information is required and probably use colour coded lines for tasks involving slope detection. However, preference is no suitable indicator of effective and efficient representation types. Cartographers, planners and especially cycling map providers need to be aware that path choice, map reading and understanding is dependent on the elevation representation type, but further research in the field of bicycle map and its representation of relevant information for paths is needed (see Chapter 7 for Future Research).

7 Conclusion and Future Research

So where are the ups and downs? To simplify navigation, the objective of this thesis is to evaluate three elevation representations for bicycle paths in city maps. The empirical user study reveals that participants show differences in geography-related tasks such as path choice, comparing heights and detecting steepness with the three elevation representation types. Each representation has its advantages and disadvantages for specific tasks. In order to follow Hegarty et al. (2009)'s suggestion, task specific elevation representation recommendations of a map's fulfilment and implications for future work are provided:

Path Choice

Our analysis reveals that the design of elevation representation affects path choice. The specific scenario of being in a hurry and riding a bicycle causes people to maximize time-gain and to minimize physical effort (Edwards (1954) and Montello (2009)). Participants with the colour representation type mainly chose the shortest path without getting discouraged by elevation. When taking the other two representation results into account, one could argue that people did not see elevation change as well as with the arrows and elevation profiles. The colour coded paths make the already colourful city maps even more cluttered and information extraction more difficult. An interpretation could be that people are not able to see the endeavour (of elevation change) ahead of them with the colour representation, but try to minimize it with the arrow and elevation profile representation type (Chiou et al., 2010). Additionally, participants rated distance and elevation as the most relevant criteria, and therefore our task of path choice supports the multi-criterion theory for cyclists proposed by Hochmair (2008a). Among other criteria, elevation information is relevant, especially in bike maps and should therefore be implemented in graphic displays.

Demand for Effectiveness

A particular message should be effectively communicated with map space according to MacEachren & Ganter (1990). Our results indicate that not all suggested representation types fulfil these cartographic requirements equally. In order to find the highest marker, the arrow representation appears to generate nearly 100 percent correct answers, whereas the colour and in particular the elevation profile representation could not match this. More problems occurred with these two maps when identifying heights and therefore should not be used as cartographic design guidelines when precision is demanded. When finding the steepest slope segment, people did not perform more effectively with any one of the representation types, although slightly more accurately with the colour representation. This task involved distance estimation as the shortest path segment showing elevation change simultaneously is the steepest (similar to contour lines). Our findings support the study of Montello et al. (1999) that colour is suitable for distance estimation. Possibly, other colours could be tested and analysed if effectiveness were to increase.
Furthermore, research argues that preference is a bad indicator for choosing a display as effectiveness was not proportional (Hegarty et al., 2009). Elevation profiles are preferred because the process of extracting geometric information from elevation profiles is possible without much effort (Pinker, 1990) and people see the trail characteristics from the outset (Sutula, 2007). However, our findings confirm the results of Hegarty et al. (2009) that the most preferred and most familiar representation type (elevation profile) is also least effective. There are performance differences with the tested representations, so we can not take preference data as a sign of user satisfaction and make cartographic recommendations based on these statements. It would be interesting to link the profiles to the paths in a similar way as in Minard's map (Fig. 3.3) to enable the user to make direct associations and improve effectiveness and efficiency with elevation profiles potentially.

Demand for Efficiency

Static 2D maps are found to be not only effective but also efficient for navigation (Semmo et al., 2012). Therefore, our study set out to establish whether one elevation representation is more efficient when either making path choice or identifying terrain characteristics. According to our analyses, the reading of exact heights is most efficient with the arrow representation. We interpret that this is due to the arrow's indication of direction (in our case arrows pointed from start to finish). Eye gaze data confirm these findings as people do not spend time on the wrong parts of the map to find the heights of the markers. In contrast, the elevation profile representation requires constant synchronization between the map and the legend from the map reader (Sutula, 2007). This association needs time and therefore resulted in the least efficient responses with the elevation profile representation type. When a task demands efficiency, the representation type of choice should be the proposed arrow display.

Route Suggestions or Whole Network?

The main question of a map designer for navigational tasks should be if the map is for the purpose of route suggestions or if the whole network should be represented with elevation information. Our proposed representation types could be applied for route suggestion, however a slightly modified version of the arrow and colour representation could easily be applied to a whole network on a static map, however not with the elevation profiles. It should be kept in mind that terrain besides the road is found to be not significant for navigation (Sutula, 2007).

To conclude, our empirical user study is an initial rough assessment of three elevation representation types for bicycle paths when map space is limited. These types are slightly modified from existing applications (e.g. Mini Map Zurich, Bike Map Pittsburgh) for comparability reasons. We can say that they all portray suitable tools for revealing elevation information when map space is restricted. However, the combination of the visual variables of colour, shape and direction makes the difference from the arrow representation to the other two types. The list of stated advantages of arrow symbols is long (e.g. Chittaro & Burigat (2004), Baudisch & Rosenholtz (2003), Looije et al. (2007), Kurata & Egenhofer (2008)) and focuses mainly on giving directions and indicates that something is happening between one point and another. The study therefore confirms the findings of Huffmann (2009), namely that arrows are suitable representations for uphill and downhill information, especially for tasks demanding precision and efficiency, but not necessarily for path choice preference. As the study combines practical approaches with research, these representations and generally applied map designs of city maps still show limitations and the previously described task-dependent recommendations have to take these limitations into account. However, more testing is needed to state explicit implications for cartographers.

Future Research

Future work should include different scenarios for the path choice task because of identified task-dependent decisions (Wilkening & Fabrikant, 2011b). The whole path choice task needs to be tested in field to ensure the practical validity of the representation types, however this is connected with an expenditure of time and an issue of familiarity of the environment. Furthermore, time pressure may have stressed some participants, and for this reason, the experiment could be performed with stress-level assessments and adjustments of these levels for different scenarios. Confidence questions after each answer could allow further inspection of gender, spatial ability and representation type differences. Human factors are partly included in our study, however they should be further investigated with specifically construed tasks. As this study only touches on eye gaze data analysis, this could be further investigated in order to gain an insight into the strategies map users employ to solve geographical tasks with different representation types (Çöltekin et al., 2010). Finally, the existing methodology could be implemented in similar navigation-themed tasks and compared to the results of this thesis. The contrast could then be used to advise map designers/planners in particular to adapt or at least review their representation type of elevation in order to provide map users (e.g. cyclists) with a navigational tool to determine the environmental terrain ('Where are the ups and downs?') effectively and efficiently.

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Appendix

Consent Form

The University of Zurich - **Participant Information Statement and Consent Form**
Evaluating three elevation visualizations for paths in city maps: A Case Study with Eye Movement Analysis
September/October, 2014
Participant No:

Purpose of study

You are invited to participate in a study regarding how we use city maps. We hope to learn more about the understanding of elevation information visualized on paths in 2D city maps and how it is understood.

Description of study and risks

If you decide to participate, we will ask you to begin by filling out a short background questionnaire including demographic information. This will be followed by a session at the computer where you will be asked to answer questions about path decision and about your understanding of the shown visualisation. During this process we will record your interactions with the computer using a webcam, audio recorder and eye tracking. The eye tracking device is non-contact, uses near infrared light and should not cause any discomfort. After the experiment we will ask you to fill out a second questionnaire.

The whole procedure should take approximately 60 minutes and there are no particular risks or benefits to you from participating in this experiment.

Confidentiality and disclosure of information

Any information that can be identified with you in connection with this study will remain confidential and will be disclosed only with your permission. If you give us permission by signing this document, we plan to publish the results of this research in scientific publications. In any publication, information will be provided in such a way that you cannot be identified.

Compensation

We do not provide any compensation for your participation in this experiment, nor are there any costs for you for your participation.

Feedback to participants

If you would like to be kept informed about the results of this research, please leave your name and contact details with the experiment leader. A copy of publications resulting from this research will be sent to you when available.

Your consent

Your decision whether or not to participate will not prejudice your future relations with University of Zurich. If you decide to participate, you are free to withdraw your consent and to discontinue participation at any time without prejudice.

If you have any questions, please feel free to ask us. If you have any additional questions later, Annina Brügger (079 515 49 02, annina.bruegger@bluewin.ch) or Dr. Arzu Cöltekin (044 635 54 40, arzu@geo.uzh.ch) will be happy to answer them. You will be given a copy of this form to keep.

The University of Zurich - **Participant Information Statement and Consent Form**
Evaluating three elevation visualizations for paths in city maps: A Case Study with Eye Movement Analysis
September/October, 2014
Participant No:

You are making a decision whether or not to participate. Your signature indicates that, having read the information provided above, you have decided to participate.

....

Signature of Research Participant

....

Signature of Experimenter

....

Please PRINT name

....

Please PRINT name

....

Date and Place

The University of Zurich - **Participant Information Statement and Consent Form (continued)**
Evaluating three elevation visualizations for paths in city maps: A Case Study with Eye Movement Analysis
September/October, 2014
Participant No:

REVOCATION OF CONSENT

Evaluating three elevation visualizations for paths in city maps: A Case Study with Eye Movement Analysis

I hereby wish to WITHDRAW my consent to participate in the research proposal described above and understand that such withdrawal WILL NOT jeopardize any treatment or my relationship with the University of Zurich.

....

Signature

....

Date

....

Please PRINT name

This section of Revocation of Consent should be forwarded to Dr. Arzu Cöltekin, Geographic Information Visualization and Analysis, Dept. of Geography, University of Zurich, CH-8057, Zurich.

Pre-Questionnaire

Personal Information

***1. Participant No: (to be filled by the experimenter)**

***2. Gender:**

- female
- male

***3. Age:**

- under 18
- 18-24
- 25-31
- 32-38
- 39-45
- 45-51
- 51 or older

***4. Have you ever been told by a professional that you have a visual impairment?**

- No.
- Yes, color blindness.
- Yes.
- Yes (please specify below - e.g. color vision deficiency, prescription glasses, etc.)

*5. Please rate your level of experience (knowledge or training) in following categories.

	1 None	2	3	4	5 Professional/daily exposure
Cartography	○	○	○	○	○
Geographic Information Systems (GIS)	○	○	○	○	○
Graphic design	○	○	○	○	○
Hiking maps (paper)	○	○	○	○	○
Bike/Bicycle maps (paper)	○	○	○	○	○
Mobile maps (applications) for route planning	○	○	○	○	○
Elevation profiles (visualization)	○	○	○	○	○
Spatial data (e.g. anything georeferenced)	○	○	○	○	○

*6. How regularly do you use a bicycle?

- ○ Everyday (with exceptions)
- ○ Very regularly (several times a week)
- ○ Regularly (once a week)
- ○ Not regularly (sometimes)
- ○ Not at all (never)

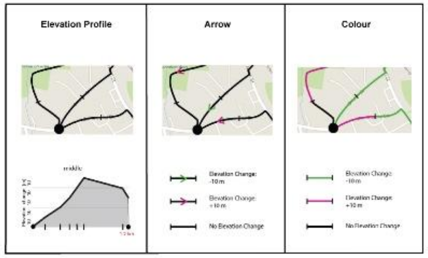
*7. How regularly do you perform a sports activity?

- ○ Everyday (with exceptions)
- ○ Very regularly (several times a week)
- ○ Regularly (once a week)
- ○ Not regularly (sometimes)
- ○ Not at all (never)

*8. Imagine you are asked to choose between different path visualizations on a map (see examples below). Which one would you choose?

- ○ Elevation Profile
- ○ Arrow
- ○ Colour
- ○ All the same.

Please state your reasons for chosing this visualization (please specify)



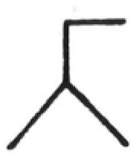
Thank you! We will now move to the next section.

Hidden Pattern Test

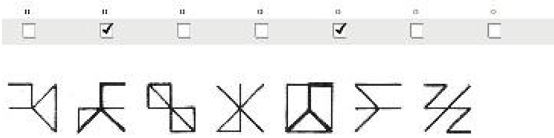
1.

Participant No: (to be filled by the experimenter)

How quickly can you recognize a figure that is hidden among other lines?
This test contains many rows of patterns. In each pattern you are to look for the model shown below:

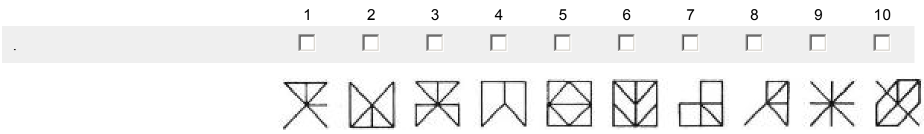


The model must always be in this position, not on its side or upside down.
In the next row, when the model appears, it is shown by heavy lines:



Your task will be to select the patterns in which the model appears.

***Now try this row:**



You should have selected patterns 1, 3, 4, 8 and 10 because they contain the model.

Your score on this test will be the number marked correctly minus the number marked incorrectly. Work as quickly as you can without sacrificing accuracy.

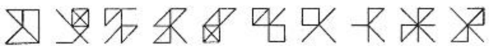
You will have 3 minutes for each of the two parts of this test. When you have finished Part I, STOP. Please do not go on to Part II until you are asked to do so.

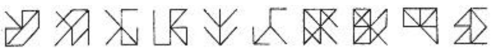
PLEASE DO NOT SKIP TO THE NEXT PAGE UNTIL ASKED TO DO SO.

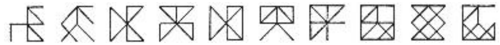
2. PART I

PART I (3 minutes)

Model:







83

DO NOT GO ON TO THE NEXT PAGE UNTIL ASKED TO DO SO.
STOP.

3. PART II

PART II (3 minutes)

Model:

84

DO NOT GO BACK TO PART I.
STOP!

Main Questionnaire

1.

Participant No: (to be filled by the experimenter)

The experiment consists of 18 questions. There is a time limit of 30 min and the presenter will announce half-time and 1 min before the end.

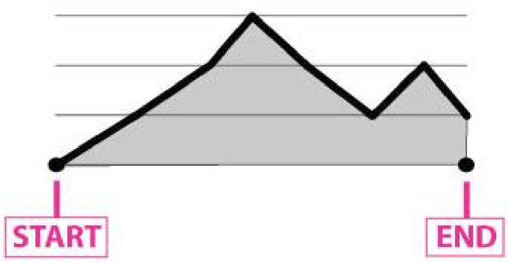
All questions have to be answered.

Please answer as quickly but as accuratley as possible!

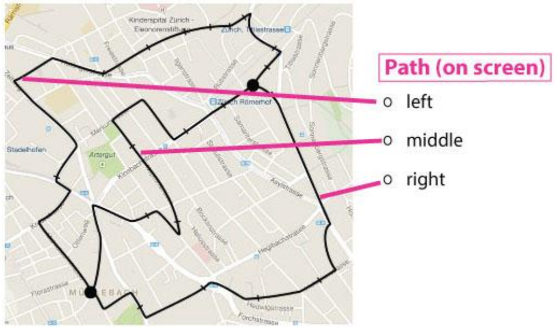
If you click next, you can not go back.

Please now have a look at some illustrations below which should be considered during the experiment.

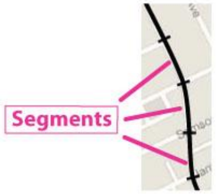
The elevation profile has to be read as follows: the circle on the left is always the START point and the circle on the right is always the END point.



The paths are named with LEFT, MIDDLE and RIGHT.
As an example: the path "left" is always the one situated left on your screen.



The image below illustrates path segments. Segments vary in length.



How many complete segments do you see at the image below?

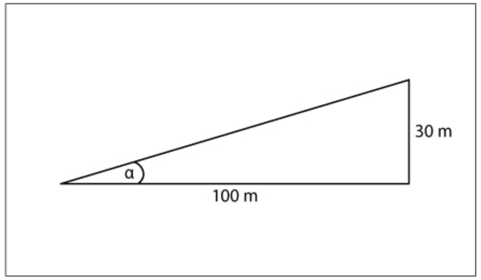
- ○ 1
- ○ 2
- ○ 3
- ○ 4

2.

The correct answer is 2.

Below you find an image illustrating the theory of slope.
The example shows a slope of 30%, which is 30 meters of vertical distance (elevation difference) on 100 meters horizontal distance.

-the higher this number, the steeper the path



You will be asked to decide on paths and to state how much the given statements contributed to your choice.
Please now have a look at the statements that will be given:

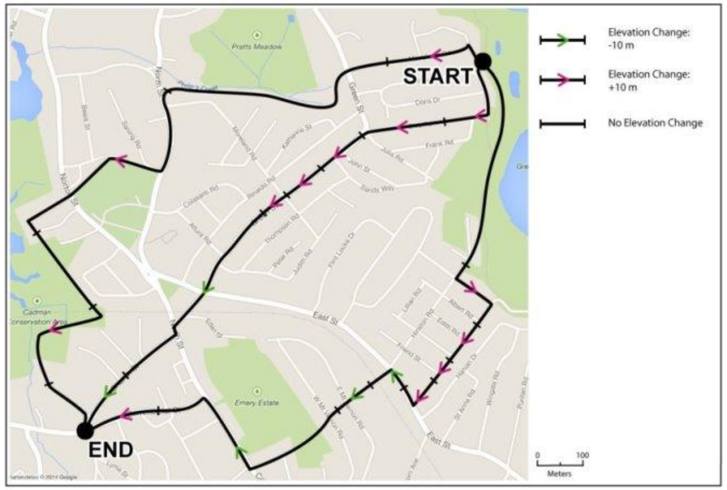
	not applicable	1 (least relevant)	2	3	4	5 (most relevant)
Multiple, but small hills						
Scenic path						
Path is easy to remember						
Only one hill						
Steep slopes						
Shortest path (distance)						
Most even path						
First hills, then downhill						

3.

Have a look at the map below.
Imagine you go from START to END by bicycle and you have to be there as soon as possible. You can choose from three different paths.
After you decided on a path, please state how much the given statements contributed to your choice.

Which path would you choose?

- left
- middle
- right



Please state how much the following statements contributed to your choice.

	not applicable	1 (least relevant)	2	3	4	5 (most relevant)
Only one hill						
Path is easy to remember						
Shortest path (distance)						
Multiple, but small hills						
Steep slopes						
Scenic path						
Park/lake side						
Most even path						
First hills, then downhill						

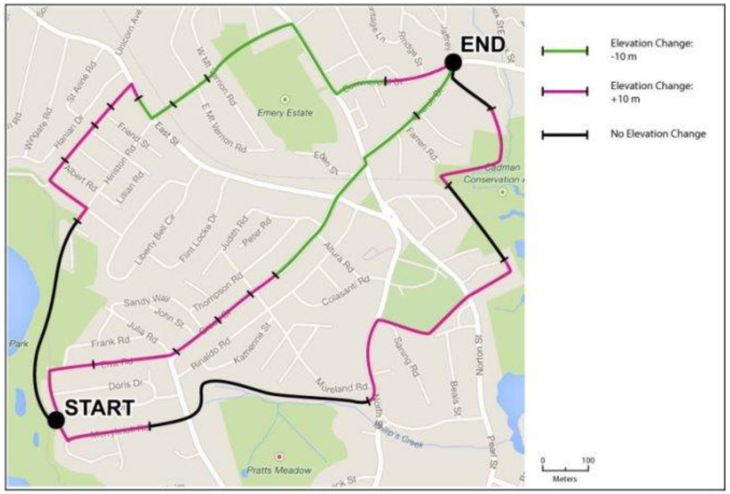
Comment

4.

Have a look at the map below.
Imagine you go from START to END by bicycle and you have to be there as soon as possible. You can choose from three different paths.
After you decided on a path, please state how much the given statements contributed to your choice.

Which path would you choose?

- left
- middle
- right



Please state how much the following statements contributed to your choice.

	not applicable	1 (least relevant)	2	3	4	5 (most relevant)
Most even path						
Path is easy to remember						
Scenic path						
Multiple, but small hills						
Shortest path (distance)						
Only one hill						
Park/lake side						
Steep slopes						
First hills, then downhill						

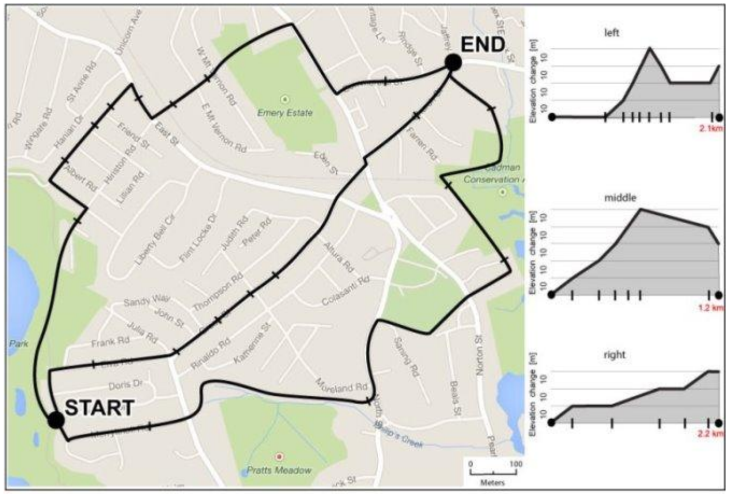
Comment

5.

Have a look at the map below.
Imagine you go from START to END by bicycle and you have to be there as soon as possible. You can choose from three different paths.
After you decided on a path, please state how much the given statements contributed to your choice.

Which path would you choose?

- left
- middle
- right



Please state how much the following statements contributed to your choice.

	not applicable	1 (least relevant)	2	3	4	5 (most relevant)
Scenic path	○	○	○	○	○	○
Steep slopes	○	○	○	○	○	○
Park/lake side	○	○	○	○	○	○
Shortest path (distance)	○	○	○	○	○	○
Path is easy to remember	○	○	○	○	○	○
Only one hill	○	○	○	○	○	○
Most even path	○	○	○	○	○	○
Multiple, but small hills	○	○	○	○	○	○
First hills, then downhill	○	○	○	○	○	○

Comment

6.

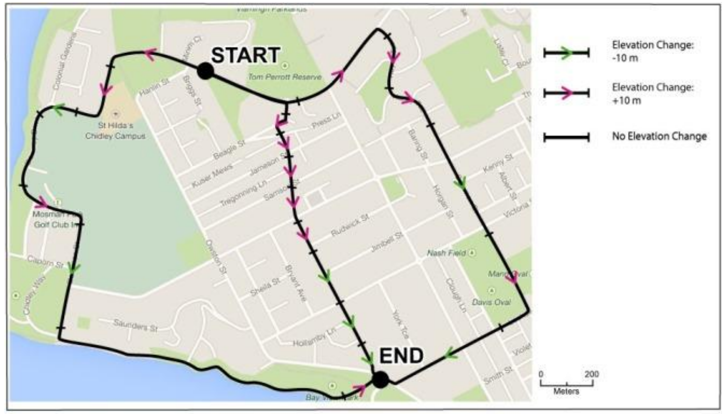
Have a look at the map below.
Imagine you go from START to END by bicycle and you have to be there as soon as possible. You can choose from three different paths.
After you decided on a path, please state how much the given statements contributed to your choice.

Which path would you choose?

○ left

○ middle

○ right



Please state how much the following statements contributed to your choice.

	not applicable	1 (least relevant)	2	3	4	5 (most relevant)
Only one hill						
Steep slopes						
Park/lake side						
Most even path						
Path is easy to remember						
Shortest path (distance)						
Multiple, but small hills						
Scenic path						
First hills, then downhill						

Comment

7.

Have a look at the map below.
Imagine you go from START to END by bicycle and you have to be there as soon as possible. You can choose from three different paths.
After you decided on a path, please state how much the given statements contributed to your choice.

Which path would you choose?

- left
- middle
- right

Please state how much the following statements contributed to your choice.

	not applicable	1 (least relevant)	2	3	4	5 (most relevant)
Only one hill	○	○	○	○	○	○
Park/lake side	○	○	○	○	○	○
Multiple, but small hills	○	○	○	○	○	○
Steep slopes	○	○	○	○	○	○
Scenic path	○	○	○	○	○	○
Shortest path (distance)	○	○	○	○	○	○
Most even path	○	○	○	○	○	○
Path is easy to remember	○	○	○	○	○	○
First hills, then downhill	○	○	○	○	○	○

Comment

8.

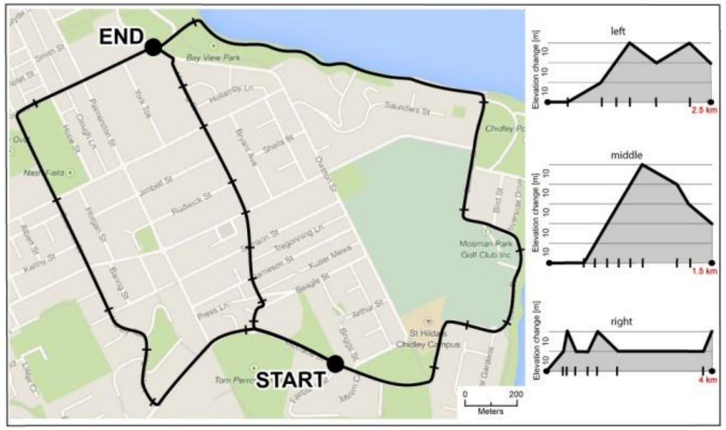
Have a look at the map below.
Imagine you go from START to END by bicycle and you have to be there as soon as possible. You can choose from three different paths.
After you decided on a path, please state how much the given statements contributed to your choice.

Which path would you choose?

○ left

○ middle

○ right



Please state how much the following statements contributed to your choice.

	not applicable	1 (least relevant)	2	3	4	5 (most relevant)
Shortest path (distance)	○	○	○	○	○	○
Path is easy to remember	○	○	○	○	○	○
Most even path	○	○	○	○	○	○
Only one hill	○	○	○	○	○	○
Multiple, but small hills	○	○	○	○	○	○
Scenic path	○	○	○	○	○	○
Steep slopes	○	○	○	○	○	○
Park/lake side	○	○	○	○	○	○
First hills, then downhill	○	○	○	○	○	○

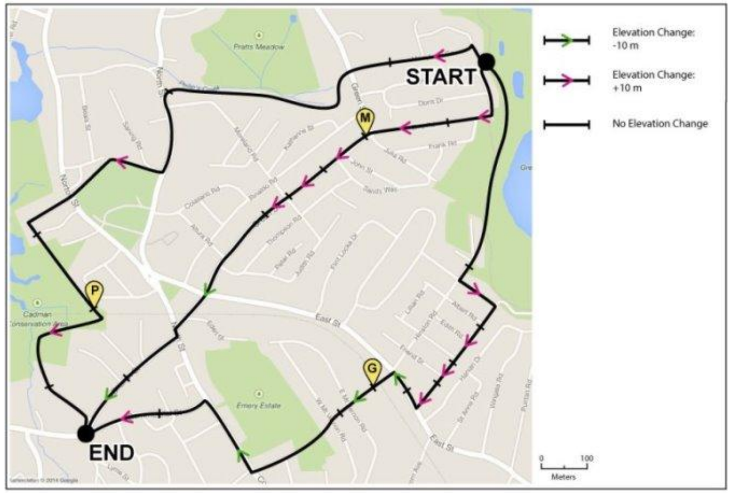
Comment

9.

Have a look at the map below.
You want to take a picture from the highest view point. Yellow markers represent these view points on the map.

Please select the highest marker (in terms of elevation).

- ○ M
- ○ P
- ○ G
- ○ I don't know.

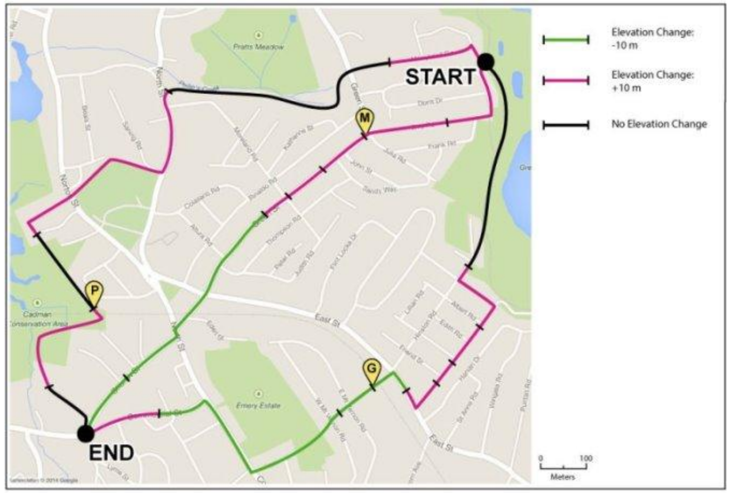


10.

Have a look at the map below.
You want to take a picture from the highest view point. Yellow markers represent these view points on the map.

Please select the highest marker (in terms of elevation).

- ○ M
- ○ G
- ○ P
- ○ I don't know.

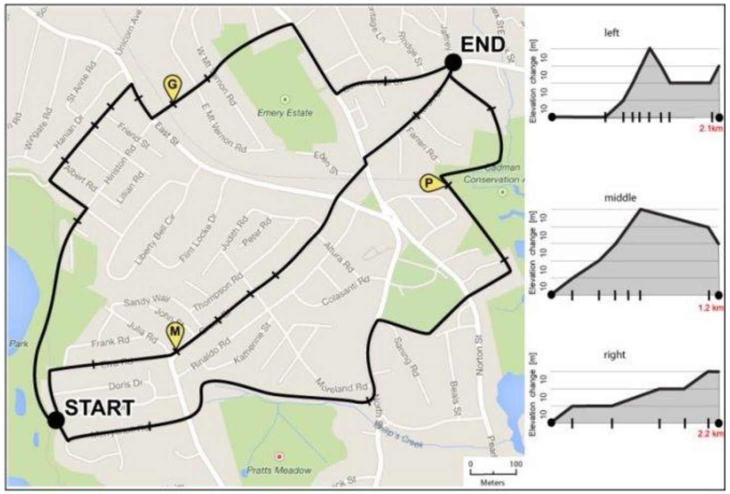


11.

Have a look at the map below.
You want to take a picture from the highest view point. Yellow markers represent these view points on the map.

Please select the highest marker (in terms of elevation).

- ○ M
- ○ P
- ○ G
- ○ I don't know.



12.

Have a look at the map below.
You want to take a picture from the highest view point. Yellow markers represent these view points on the map.

Please select the highest marker (in terms of elevation).

- ○ P
- ○ G
- ○ M
- ○ I don't know.

13.

Have a look at the map below.
You want to take a picture from the highest view point. Yellow markers represent these view points on the map.

Please select the highest marker (in terms of elevation).

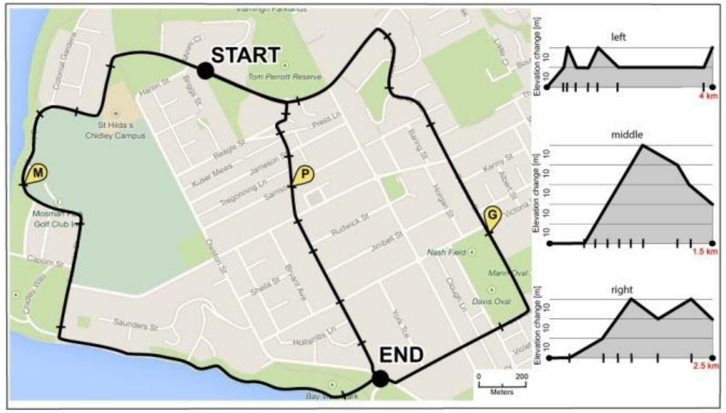
- ○ M
- ○ P
- ○ G
- ○ I don't know.

14.

Have a look at the map below.
You want to take a picture from the highest view point. Yellow markers represent these view points on the map.

Please select the highest marker (in terms of elevation).

- ○ G
- ○ P
- ○ M
- ○ I don't know.

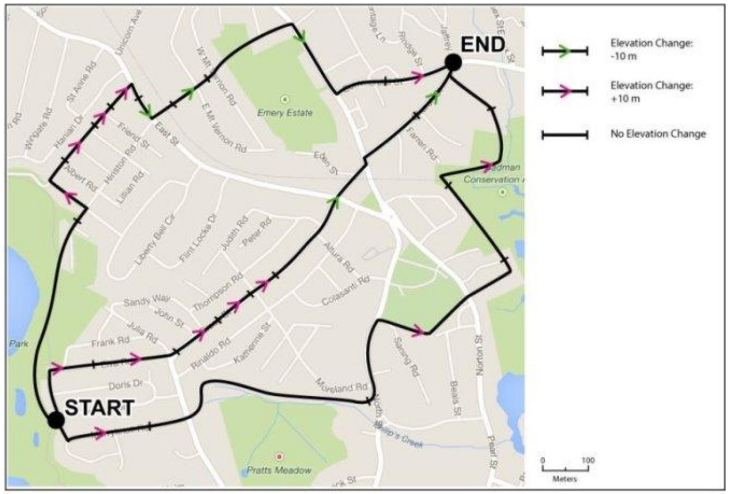


15.

Have a look at the map below.

Select the path with the steepest slope segment.

- ○ left
- ○ middle
- ○ right
- ○ I don't know.

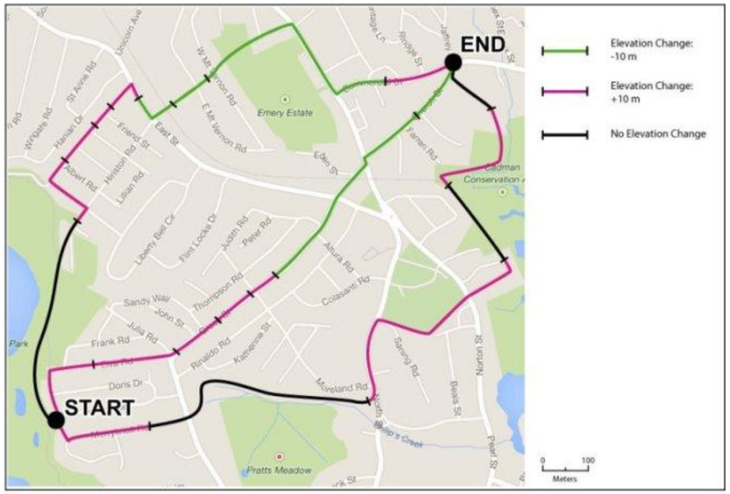


16.

Have a look at the map below.

Select the path with the steepest slope segment.

- ○ left
- ○ middle
- ○ right
- ○ I don't know.

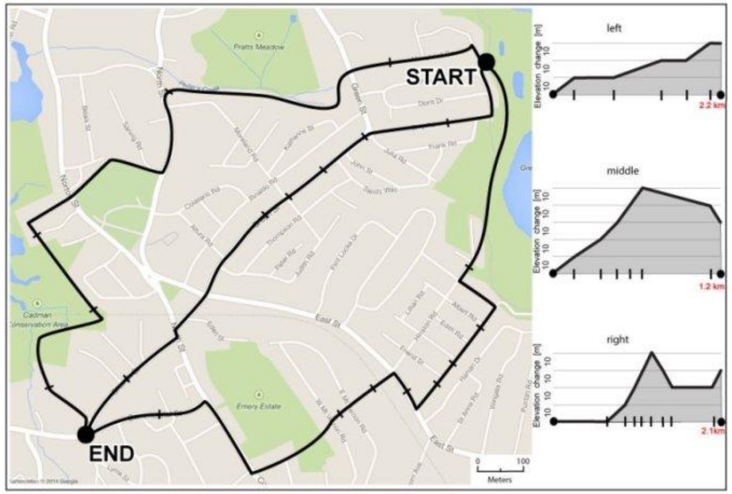


17.

Have a look at the map below.

Select the path with the steepest slope segment.

- ○ left
- ○ middle
- ○ right
- ○ I don't know.



18.

Have a look at the map below.

Select the path with the steepest slope segment.

- ○ left
- ○ middle
- ○ right
- ○ I don't know.

19.

Have a look at the map below.

Select the path with the steepest slope segment.

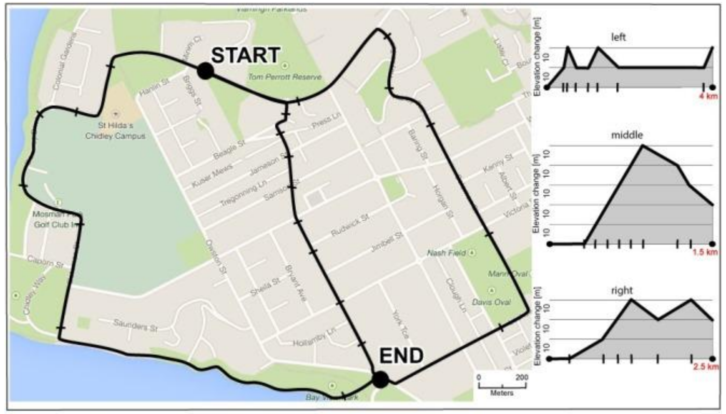
- ○ left
- ○ middle
- ○ right
- ○ I don't know.

20.

Have a look at the map below.

Select the path with the steepest slope segment.

- ◯ left
- ◯ middle
- ◯ right
- ◯ I don't know.



You finished the main experiment.
Thank you very much.
Please change to the laptop to answer some final questions.

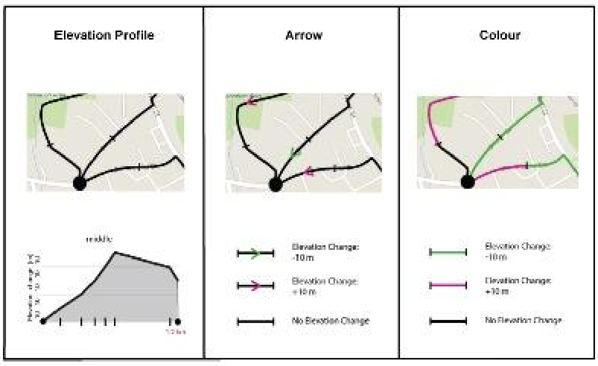
Post-Questionnaire

Preference Path Task

***1. Participant No: (to be filled by the experimenter)**

***2. You were asked choose paths based on the statement "to be there as soon as possible". Which visualization type would you prefer based on this scenario?**

- Elevation Profile
- Arrow
- Colour
- All the same

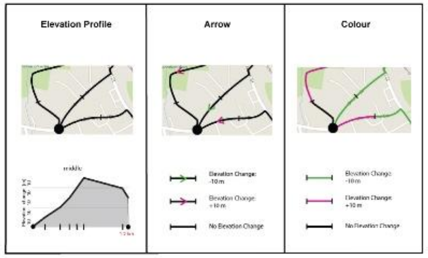


3. And why?

Preference Path Task 2

***4. You had to choose paths based on the statement "to be there as soon as possible". The visualization type was HELPFUL to make a decision.**

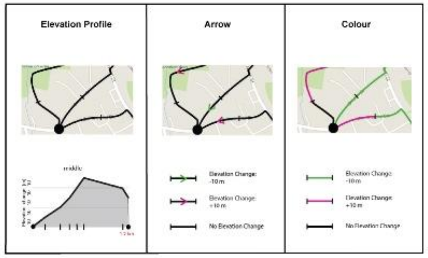
	strongly agree	agree	neutral	disagree	strongly disagree
Elevation Profile	○	○	○	○	○
Arrow	○	○	○	○	○
Colour	○	○	○	○	○



Preference Slope Task

***5. You had to select the path with the "steepest slope segment". Which visualization type would you prefer based on this task?**

- ○ Elevation Profile
- ○ Arrow
- ○ Colour
- ○ All the same

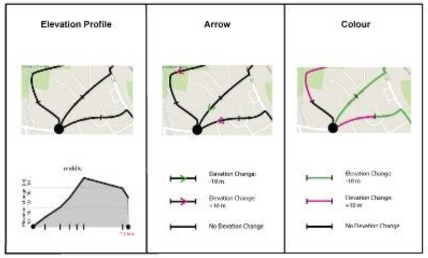


6. And why?

Preference Slope Task 2

***7. You had to select the path with the "steepest slope segment". How helpful were the visualization types?**

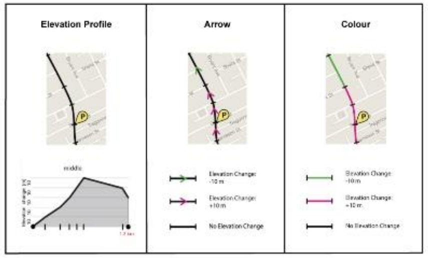
	very helpful	helpful	neutral	not so helpful	not helpful at all
Elevation Profile	○	○	○	○	○
Arrow	○	○	○	○	○
Colour	○	○	○	○	○



Preference Marker Task

***8. You had to select the "highest marker". Which visualization type would you prefer based on this task?**

- ○ Elevation profile
- ○ Arrow
- ○ Colour
- ○ All the same

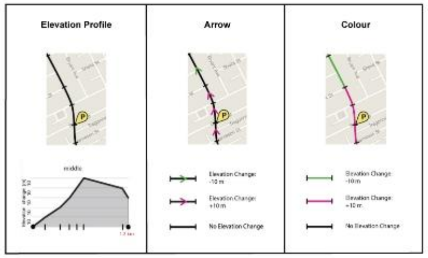


9. And why?

Preference Marker Task 2

***10. You had to select the "highest marker". How helpful were the visualization types?**

	very helpful	helpful	neutral	not so helpful	not helpful at all
Elevation Profile	○	○	○	○	○
Arrow	○	○	○	○	○
Colour	○	○	○	○	○



General Preference and Familiarity

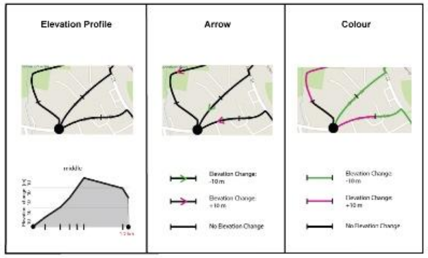
***11. You need a map with elevation information on paths. Which visualization type would you prefer?**

○ Elevation profile

○ Arrow

○ Colour

○ All the same

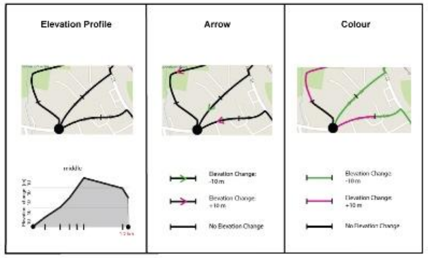


12. And why?

General Preference and Familiarity 2

***13. Have you ever seen one of the shown path visualization methods before the experiment?**

	Yes	No
Elevation profile	◯	◯
Arrow	◯	◯
Colour	◯	◯



End

14. Note any comment you want to share.

I hope you have enjoyed the experiment and I thank you very much for your participation.
This is the end of the experiment. Please finish the survey by pressing DONE.

Study Protocol

Study Protocol
Evaluating three elevation visualizations for paths in city maps.: A Case Study with Eye Movement Analysis
September/October, 2014

Preparation:

- Give participant a number.
- Switch cell phone off
- Laptop: check battery
- Prepare stopwatch

Web Browser

- Open Pre-Questionnaire
- Open Hidden Pattern Test
- Open Tobii Studio and 'Main Questionnaire'
- Open Post Questionnaire

When the participant arrives:

1) Welcome them, use a few minutes to see if they need to talk a little bit ask how they are, if they found the lab easily. → Sign: ***'Experiment in progress – Do not disturb'***

2) Explain always with same sentences what this is about
(We are trying to get insight into how people act with different depiction methods based on elevation information. If you are willing to participate, you will be given a series of tasks on a computer screen. While you are working on these tasks, you will be recorded by a camera, a microphone and an eye tracker. The eye tracker works with infrared light. This will neither be uncomfortable, nor do we know about harm caused by this).

3) Assign their participant number.

4) Have them sign the consent form.

5) Fill the 'Pre-Questionnaire' (Laptop)

6) Fill the Hidden Pattern Test (Laptop):

7) Tobii Studio
   - Connect to eye tracker
   - Start recording
   - Enter participant nr
   - Calibrate and start recording in Tobii Studio →Fill the 'Main Questionnaire'

8) Fill the 'Post-Questionnaire'(Laptop)

After Experiment

1. Thank the participant.
2. Hand over a bar of chocolate.

Personal Declaration

I hereby declare that the submitted thesis is the result of my own, independent work. All external sources are explicitly acknowledged in the thesis.

Annina Brügger

Zurich, January 30th 2015