The cognitive observer-based landmark-preference model

– What is the ideal landmark position at an intersection? –

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Abstract

Which object at an intersection is the ideal landmark for humans? Why one object and not other? These are the central questions in the exploration of human wayfinding processes, and they are thus part of spatial cognition research. The research literature so far provides quite a few concepts and approaches for how these landmarks should be classified and how the single factors – the saliences – influence the landmark preferences during wayfinding. This Dissertation follows this approach and presents a systematic variation of the saliences. I investigated the influence of the position, the color, and the shape of the landmark and further examined whether landmark preference depends on the observer's point of view and viewing direction. The features of an object, the relationship between the present objects, the relationship between the object and the environment, and the relationship between observer and object will be considered. A series of experiments in which participants were asked concerning their landmark preference for providing route directions revealed the following: First, the color of the potential landmark must contrast with the object colors in the environment in order to be preferred – this is the visual salience. Second, the ideal landmark position is before the intersection in the direction of the turn – this is the structural salience (allocentric perspective). When both saliences compete with each other, participants consider both aspects to different amounts. Third, the results reveal that the structural and the structural-visual effects in an egocentric perspective are influenced by the viewpoint-based salience. All relevant saliences are integrated into a landmark-preference model. The comparison of a mathematical abstraction from this model reveals a good fit with empirical results. These findings are discussed with respect to the current literature and other models and their relevance for everyday wayfinding.

Zusammenfassung

Welches Objekt an einer Kreuzung ist die ideale Landmarke für einen Menschen? Warum dieses Objekt und nicht ein anderes? Dies sind die zentralen Fragen bei der Erforschung der Prozesse beim menschlichen Wegfinden und ist damit dem Gebiet der Raumkognition zuzuordnen. Die Forschungsliteratur hat bisher einige Konzepte und Ansätze präsentiert, wie diese Landmarken zu klassifizieren sind und wie diese einzelnen Faktoren – die Salienzen – die Präferenzentscheidung von Landmarken beim Wegfinden beeinflussen. Die vorliegende Arbeit folgt diesem Ansatz und präsentiert eine systematische Variation der bedeutsamen Faktoren. Untersucht wird, welchen Einfluss die Position einer Landmarke, deren Farbe und Form sowie der Blickpunkt des Beobachters auf die Wahl der idealen Landmarke hat. Dabei werden sowohl die Eigenschaften des Objektes, als auch die Beziehungen der Objekte untereinander, die Beziehung des Objektes zur Umgebung und die Beziehung zwischen dem Beobachter und dem Objekt berücksichtigt. Eine Serie von Experimenten in welchen gefragt wurde, welche Landmarken man präferieren würde, um eine Wegbeschreibung zu geben, erbrachten Folgendes: Erstens muss sich die Landmarke farblich deutlich von der Umgebung abheben um präferiert zu werden – dies ist die visuelle Salienz. Zweitens ist die ideale Landmarkenposition vor der Kreuzung und in Abbiegerichtung – dies ist die strukturelle Salienz (allozentrische Perspektive). Wenn diese beiden Salienzen miteinander konkurrieren, berücksichtigen die Probanden beide Aspekte bei ihrer Landmarkenpräferenz. Drittens konnte gezeigt werden, dass die strukturellen und strukturell-visuellen Effekte in einer egozentrischen Perspektive durch die blickpunktabhängige Salienz beeinflusst werden. Alle relevanten Salienzen werden zu einem Landmarkenpräferenzmodell zusammengefasst. Ein Vergleich der mathematischen Ableitung aus diesem Modell zeigt eine sehr gute Passung mit den empirischen Befunden. Diese Befunde werden unter Berücksichtigung der relevanten Literatur sowie anderer Modelle diskutiert und die Relevanz für den alltäglichen Gebrauch wird aufgezeigt.

"What is the ideal landmark position?"

Unknown

Preface

In the year 1884 the teacher and mathematician E.A. Abbott published his well-known book *Flatland. A Romance of Many Dimensions* in which he described the life and experiences of *Albert Square*, who lived in a two-dimensional world. One day a sphere visited *Albert Square* in his two-dimensional world and explained and showed to him his own different world of three dimensions.

My research started with this book and in the group of Prof. Dr. Markus Knauff working on the following research project: *A Neuro-Cognitive Theory about Landmark Salience* (DFG HA 5954/1-1; to Kai Hamburger and Markus Knauff).

The idea how different these two dimensions are and which implications a presentation of a two-dimensional environment (Chapter 6, 8 and 9) and a three-dimensional environment (Chapter 10 and 11) have on the human's spatial cognition fascinated me from the very beginning. This idea combined with the research environment SQUARELAND developed by Hamburger and Knauff (2011) forms the basis of my Thesis. SQUARELAND has been designed to examine spatial cognition concepts and wayfinding processes in a well-defined and controllable virtual reality setting. The various possibilities of this research environment are described in Röser, Hamburger, and Knauff (2011) in which the focus is primarily on how landmarks are used in wayfinding. In 1960 Lynch wrote his book *The Image of the City* in which he defined the term landmark as a subject of research. In the following decades many theories and research about the general use of landmarks, their importance for route directions, and the definition of different landmark categories and classification systems have been added. It was until 1999 that Sorrows and Hirtle defined the term salience for the different aspects of landmarks, and many assumptions and research approaches about their importance and usability were subsequently published and discussed. All of this resulted in the often referred to landmark salience model of Klippel and Winter in 2005. However, this model was an assumption, and the definition and interaction of the included saliences were insufficiently studied. This mathematical model was the starting point for the red thread of my Thesis and ends in the evaluation of my own mathematical landmark-preference model after several intersections and salience research landmarks along the way.

Before you now start your journey on my research path, I want to thank some people who supported me during the last years and helped me to finish my Thesis. First, I would like to thank my supervisor and advisor Prof. Dr. Markus Knauff for the possibility to write my Thesis in his working group and for his help and guidance during all that time. Second, I thank Dr. Kai Hamburger for his continuous support, his patience and his contribution to our active scientific exchange. My many thanks also go to the colleagues in the research group of *Experimental Psychology and Cognitive Science* for the exciting time and the many research ideas and collaborations, especially to Jelica Nejasmic, with whom I shared the journey to PhD, and to my student assistants, especially Sarah J. Abbott, for their support and help with data collection.

Part 1
Introduction and Theoretical Background
--- page 1 ---

Part 2
Experiments
--- page 16 ---

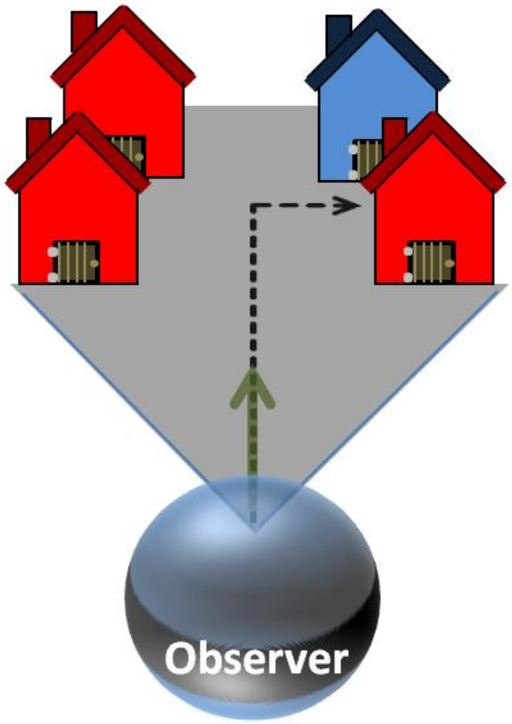
Part 3

The Mathematical Model of Landmark Preference

--- page 101 ---

Part 1

Introduction and Theoretical Background



1. Motivation and introduction

Imagine a pedestrian asks you for directions to get to the train station. You know that she has to turn left at the upcoming intersection that is depicted in Figure 1.1.

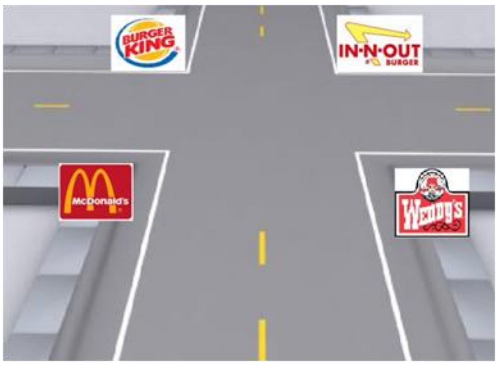


Figure 1.1. Example of a typical intersection[1] from a birds-eye perspective with four famous fast-food restaurants positioned at the four corners of the intersection.

The rich configuration of the intersection enables you to verbalize the route directions in several ways. Let us take a look at some convincing possibilities:

Turn left at the intersection.

Turn left directly after McDonald's.

Turn left before you pass the In-N-Out Burger.

Turn left directly before Burger King.

Turn left where Wendy's is on the right.

But which possibility is most convincing? Alternative 1 is the simplest description and is actually sufficient to tell the pedestrian in which direction to turn at the intersection. However, imagine that the pedestrian has to pass several further crossroads. In this case, it can be well-

[1] Fast-food restaurants are very good objects for memorizing route directions (i.e., good landmarks). They are easy to describe and clearly communicable. They have corporate colors and designs (high visual salience), almost everybody knows them and so they are prototypical (high semantic salience), they are mostly located at intersections or prominent places (good structural salience), and they are normally visible from a lot of places or could be seen very well from the observer's point of view (a good viewpoint-based salience).

argued that objects referenced along the route are quite informative and helpful. Which one would you prefer if you had to give directions to someone who is unfamiliar with this intersection? If you prefer one of the last four descriptions, you prefer one that includes a landmark, an object in the environment that acts as an anchor and orientation point. But beside the general preference of landmarks, what makes single object more useful than other ones? Why are some landmarks salient, meaning they stand out from the environment or have a unique characteristic? Also, how could they be classified? Do you prefer “Turn right at the McDonalds”, because McDonalds is your favorite fast-food restaurant? In this case you prefer a semantic salient landmark. Or, do you prefer “Turn right at the red fast-food restaurant”, because the red restaurant stands out in contrast to the other restaurants colors? In this case you prefer a visual salient landmark. Or, do you prefer “Turn right at the Wendy´s”, because Wendy´s is located before the intersection and on the right side? In this case you prefer the structural salient object. Or do you prefer “Turn right at the In-N-Out Burger”, because the In-N-Out Burger is directly in front of you and you see him best? In this case you prefer the viewpoint-based salient object.

Besides the semantic salience, I examine the influence of visual, structural, and viewpoint-based salience on landmark-preference of humans in this Thesis in detail and analyze how they interact. Additionally, I define the characteristics of the single saliences and model the participants’ preferences to understand the mechanism of landmark preference.

2. Theoretical background

In general, several empirical studies deriving from spatial cognition research indicate that people often enrich their route directions using buildings, objects, and all types of natural and human-made entities visible in the environment (Couclelis, Golledge, & Tobler, 1987; Denis, Pazzaglia, Cornoldi, & Bertolo, 1999; Lee, Klippel, & Tappe, 2003; Lee, Tappe, & Klippel, 2002; Lynch, 1960). Objects can be far away yet salient and serve as global orientation points (Lovelace, Hegarty, & Montello, 1999; Steck & Mallot, 2000), for instance: “Just go towards the Eiffel Tower, and you cannot miss your hotel.” However, most of the objects people consider using in wayfinding tasks and for route directions are located more or less directly along the route (local reference points; e.g., Daniel & Denis, 2004), for example: “You will cross a bridge, there will be a post office on the right, a monument on the left, a shopping center directly in front of you,” and so forth. Further, it can be said that people tend to use objects located at decision points (intersections with a change of direction; Janzen & van Tourennout, 2004). The fast-food restaurants in the example above belong to the class of local reference points and are objects at a decision point.

Spatial cognition researchers refer to these objects as *landmarks* (Lynch, 1960; Presson & Montello, 1988; Siegel & White, 1975). One important research question is how humans recognize and select potential landmarks from their surroundings and how these landmarks are cognitively processed and represented in spatial memory. In general, landmarks are defined as persistent, perceptual salient, and easily recognizable objects that stand out from the environment and thus help wayfinders determine their location or describe a route to someone else (Denis et al., 1999; Lynch, 1960; Sorrows & Hirtle, 1999; Stankiewicz & Kalia, 2007). In principle, people can select almost anything as a landmark: natural, artificial, or man-made objects; special topographies; or any type of signage (Tom & Denis, 2004; Tom &

Tversky, 2012). Several researchers have shown that the availability of landmarks leads to an increased wayfinding performance (Daniel & Denis, 1998; Denis et al., 1999; Golledge, 1999). Furthermore, it is easier to remember routes if the wayfinder has memorized the landmarks along the route (Steck & Mallot, 2000).

Landmark representations have been localized in the human brain. In general, spatial navigation in humans (and non-human primates) relies on complex neural networks that include parts of the medial temporal lobes, parietal cortex, the hippocampus, and parahippocampal areas, which are all crucial for the formation of spatial memory (Burgess, Jeffrey, & O'Keefe, 1998). Recent research indicates that at least four kinds of neurons in these areas are involved in spatial navigation: place cells encode specific locations, grid cells fire while traversing a space, head direction cells are active when facing a particular direction, and border cells encode the borders of a spatial region or area (Hassabis et al., 2009). Janzen and van Turennout (2004) distinguished between landmarks at decision points and non-decision points and found that the brain automatically (i.e., without conscious awareness) differentiates between the two. In behavioral studies, Michon and Denis (2001) showed that landmarks at decision points are considered more often and can be remembered more easily (Lee et al., 2002; Peters, Wu, & Winter, 2010). Further studies have shown that neurons in the parahippocampal place area (near the lingual gyrus) fire when people view navigation-relevant environmental stimuli such as buildings, streets, or landscapes, but remain inactive when people see everyday objects such as tools or appliances that are irrelevant for wayfinding (Epstein, 2005; Epstein & Kanwisher, 1998).

3. The importance of saliences in human spatial cognition research

This Thesis focuses on important questions for spatial cognition research in general and landmark research in particular. For this, let us return to the initial example. How could the different landmarks at this intersection be classified? Or more generally, how could landmarks be classified, or what are the relevant aspects of landmarks? Sorrows and Hirtle (1999), Raubal and Winter (2002), Klippel and Winter (2005) as well as Caduff and Timpf (2008) distinguish between different types of "landmark salience" – saliences in the meaning of standing-out from the environment either as inherent property (e.g., special color, prototypical look) or in contrast to the surrounding. Three of these saliences are landmark- and environment-based: the visual aspects of the landmark (visual salience), the location of the object (structural salience), and the visibility of the object defined by the position of the object in relation to the observer. Caduff and Timpf (2008) explain these saliences with a trilateral relationship between observer, object, and environment and highlight the contrast to the surrounding. Raubal and Winter (2002) formalize the salience concept from Sorrows and Hirtle (1999) mathematically and assume that the visual, semantic, and structural salience, each with a specific weighting factor, add up and result in the joint salience of the landmark. Klippel and Winter (2005) added visibility (Winter, 2003) as another important factor. They mention that the total salience of an object is the joint salience moderated by the visibility of the object. With this mathematical model they define how the saliences of an object could interact and influence the participants' preference. In the following sections I derive and define the relevant landmark saliences.

3.1 Visual salience

An important fact that guides landmark selection is the visual aspect of a potential landmark. In the initial example (Figure 1.1) the fast-food restaurants had different colors.

Imagine that three of them were yellow and one was red (ignoring their true colors). Which one would you prefer to give route directions?

Visual salience is generally defined as the property of an object or stimuli that stands out from the environment (e.g., Fine & Minnery, 2009; Itti, 2003; Itti & Koch, 2000; Koch & Ullman, 1985; Scholl, 2001; Treisman & Gelade, 1980; Ullman, 2000). Itti (2007) defined it in more detail and mentioned that "The core of visual salience is a bottom-up, stimulus-driven signal that announces ´this location is sufficiently different from its surroundings to be worthy of your attention´" (Definitions, para. 3). However, this could be strongly influenced by top-down processes (Desimone & Duncan, 1995; Itti & Koch, 2001), which will be demonstrated in later experiments. In wayfinding research Sorrows and Hirtle (1999) defined visual salience as the inherent visual object characteristics and stated that "[…] these may include the features of contrast with surroundings […]" (p. 45). Caduff and Timpf (2008) provided a different definition and understood visual salience as a bottom-up salience with the components location-based and object-based attention as well as the scene context.

One interesting aspect is that in the research literature the effect of visual salience is mostly examined in an arrangement of many objects where one object is different from the others (see e.g., Itti, 2007) and is mainly focused on the question of what happens when only one object is different (in comparison to all other available objects); this research literature does not consider the effect of visual salience when several different stimuli are used (competing for attention).

3.2 Structural salience

Another important factor that guides the landmark selection process is the location of an object in the environment. In the initial example (Figure 1.1), the four fast-food restaurants are located at different locations of the intersection, and they are all visually salient. Also, there are no relevant differences in meaning (ignoring that some of you may have individual preferences and that one branch is more popular than the others). Hence, the only difference between the four restaurants is the location at the intersection. These location-related aspects of landmarks are referred to as structural salience.

Structural salience is generally defined as the location of an object in the environment. A better term might be “spatial salience” because this salience defines the spatial location of the landmark (in relation to the observer). But, due to the widely accepted term “structural salience” I will continue using this. Many researchers have emphasized the importance of this kind of salience for spatial cognition, but they define it differently. Richter and Klippel (2005) differentiate between global reference points, environmental structures, and paths, routes, and landmarks. Steck and Mallot (2000) followed a similar approach and differentiate between global and local landmarks. Klippel and Winter (2005) specify it even further and differentiate between on- and off-route landmarks. In addition, they divided the on-route landmarks into segment landmarks (placed between nodes) and node landmarks (at intersections). As Lovelace et al. (1999) showed, node landmarks are the more relevant ones in a wayfinding context. The node landmarks could additionally be divided into landmarks at decision-points and non-decision-points. A decision-point is defined as a route section where a change of direction is possible (Janzen & van Tourennout, 2004; Klippel & Winter, 2005). Objects at these decision points are the most relevant landmarks in the wayfinding process (Janzen & van Turennout, 2004; Lee et al., 2002; Michon & Denis, 2001; Peters et al., 2010).

The most basic definition of structural salience is the position of an object at an intersection, and, as described before, this becomes most relevant if a change of direction is necessary at this intersection. This results in four landmark positions at a four-way intersection:

1. Behind the intersection, opposite to the direction of turn (A);
2. Behind the intersection, in the direction of turn (B);

3. Before the intersection, opposite to the direction of turn (C); and
4. Before the intersection, in the direction of turn (D). This is demonstrated in Figure 5.1 in Chapter 5.

3.3 Viewpoint-based salience

A third important factor is closely connected with the structural salience. One problem with the traditional concept of structural salience is that researchers have not yet grasped the idea that the structural landmark salience may have two different aspects. One aspect refers to a landmark's general location in its physical surroundings (Lovelace et al., 1999; Sorrows & Hirtle, 1999; Steck & Mallot, 2000). This is the usual understanding of structural salience in spatial cognition research. The second aspect that I will explore, however, is the viewpoint-dependent location of a landmark from the observer's perspective. While the first aspect of structural salience refers to an allocentric view on the environment (i.e., the general location of an object that is sometimes related to the direction of change), our daily-life perspective is normal egocentric. In this egocentric perspective, the view-position and view-direction of an observer determines what she see from the environment. In general, many researchers differentiate between a representation of space in an egocentric (self-to-object) and allocentric (object-to-object) perspective (Klatzky, 1998; see also Bryant, 1997; Coluccia, Mammarella, De Beni, Ittyerah, & Cornoldi, 2007; Nadel & Hardt, 2004). They also mention that there are differences with respect to aspects of representation and processing. For example, the salience definitions of Sorrows and Hirtle (1999) do not consider the observer; they consider an allocentric perspective on the landmarks and evaluate their object-to-object relation only. In the evaluation of the self-to-object relation, however, the fact of what the observer sees from the environment must be considered besides the relation between the objects itself. This aspect is mentioned in the research literature as visibility. However, a wide range of different definitions can be found. Nothegger, Winter, and Raubal (2004) and Raubal and Winter

(2002) described a landmark-based visibility approach and focus more on the object-to-object relations and on the general position of an object in the environment. They define the visibility as the number of positions or size of area from which a landmark could be seen. This does not consider the observer's point of view. Elias and Brenner (2004) pursued an automatic, decision-based approach and performed a 360-degree visibility analysis to determine which objects are visible from a specific point of view; this is a person-to-objects relation but does not consider the possible view-direction of an observer. Furthermore, they defined the size of the visible object or part of the object in the viewing field and used this as the visibility. This approach or technique is a more automatic process and is used in automatic landmark identification in navigation systems. Richter (2007) defined visibility in the following way: "Checking for visibility is kept simple in the system. It is performed on the graph representation using scan-line methods. It just ensures that in the 2D projection an object is in line of sight from the route and in a distance shorter than some threshold." (p. 378). However, this also does not consider the viewing direction of the observer. Winter (2003) therefore defined the "advanced visibility", which includes the orientation of the landmark in dependence to the viewing direction of the observer and the changing visibility while the observer walks along a defined path. He considers the viewing direction of the observer as well as the "route segment that enters the considered decision point" (p. 352). This last concept defines what an observer could see from his point of view and what is therefore usable as a landmark. However, it is unclear if the observer decides which landmark she will use while she walks along the path or if the decision takes place at one point (e.g., if she sees the relevant intersection the first time). I prefer this last approach. Based on this fixed point of view it is possible to define what the observer sees from the environment. In vision research this concept is known as occlusion culling. The question is which objects or which parts of objects are within the "visible shadow" of other objects (Wonka, Wimmer, &

Schmalstieg, 2000). This means that it is of interest how much of a landmark must be visible for it to be "identified" by the observer with a high probability. In contrast to most of the other definitions of "visibility", it is a cognitive aspect. It implies, besides the perceptual aspect (i.e., view field and view direction), the evaluation of the object: is it visible enough to identify the object and to use it as a landmark? Moreover, although only a part of the landmark or landmark facade is visible, the entire landmark must be considered for the preference decision. This concept could be labeled as the visible part.

However, some aspects are not considered in this definition of the visible part (as well as in the other definitions of visibility): first, the distance between the observer and the potential landmarks (Caduff & Timpf, 2008; Waller, Loomis, Golledge & Beall, 2000) and second, the view direction of the observer and thus the orientation (Winter, 2003) of the landmarks facade to the view direction of the observer. These two aspects together with the visible part make up my definition of the viewpoint-based salience.

3.4 Excurse: semantic salience

An additional aspect is the so-called semantic (Raubal & Winter, 2002) or cognitive salience (Sorrows & Hirtle, 1999). They are related to the meaning, recognizability, prototypicality, or idiosyncratic relevance of the potential landmark (Caduff & Timpf, 2008; Quesnot & Roche, 2014; Raubal & Winter, 2002; Rosch, 1978; Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976). For instance, famous buildings such as the Brandenburg Gate, the Empire State Building, or the Eiffel Tower are better landmarks than other rather unknown buildings in the environment (Hamburger & Röser, 2014). However, the famousness, the object's meaning, and other semantic classifications vary from person to person. Also, the idiosyncratic relevance and the personal and historical background are parts of this salience. In summary, this salience is defined by individual experience and knowledge and is not definable as a generally valid salience. This Dissertation does not consider the semantic salience and inter-individual preferences; it focuses on the observer's evaluation of the visual and structural landmark saliences and on the influence of the viewpoint-based salience. However, I come back to this salience in more detail in Chapter 14 and present some first experiments.

4. The landmark-preference model

My landmark-preference model is based on findings and assumptions found in research literature and extends it substantially. In contrast to other models (e.g., Sorrows & Hirtle, 1999), the observer is in focus with this model. It describes which landmark at an intersection a wayfinder prefers for giving route directions and considers how the observer evaluates the visual and structural characteristics of the landmarks as well as how the point of view and the view direction influence the decision. The model is depicted in Figure 4.1 to give you an overview of my assumptions.

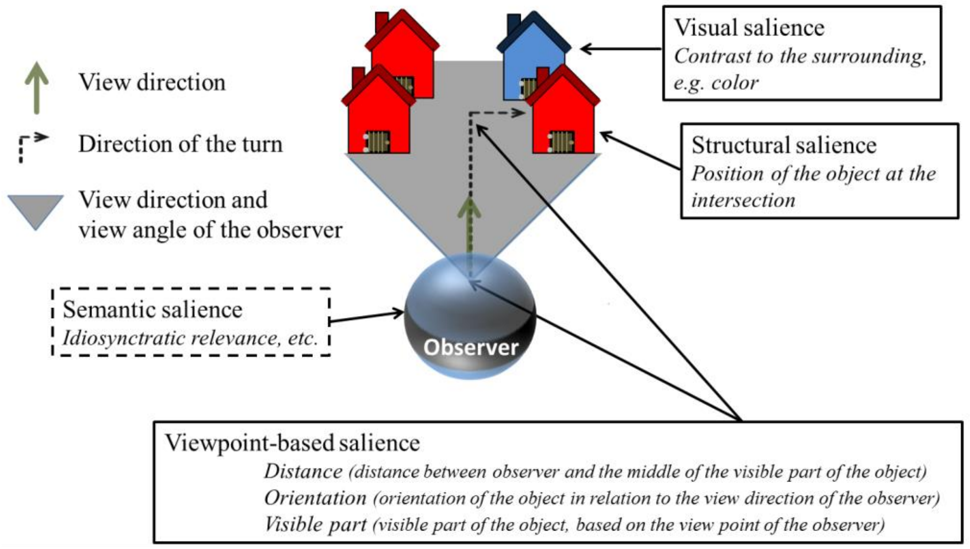


Figure 4.1. The landmark-preference model.

The model considers the saliences of the landmarks (Sorrows & Hirtle, 1999) but includes the observer as the pivotal point (e.g., Caduff & Timpf, 2008), and it includes aspects of the cognitive system, especially the spatial working memory as well as the point of view and viewing direction of the observer. Therefore, my model includes the object characteristics, the location characteristics, their cognitive evaluation, and the spatial relation between the observer and the potential landmark. For clarification, let us imagine you are the observer represented by the blue ball in the figure, and you have to say which landmark you prefer for giving a route direction. The assumptions of the landmark-preference model are that you perceive the potential landmarks and her specific visual characteristics and weights against each other to find the visual salient one. If this is a bottom-up or top-down mechanism is out of focus here. Parallel to this, you perceive the positions of the potential landmarks in relation to your position and in relation to the route direction, e.g., you see that one potential landmark is behind the intersection and in the direction of a turn. However, what you see from the environment is restricted by your position in relation to the potential landmarks. From your actual position, the object in and opposite the direction of turn can be equidistant or at different distances. Some potential objects are hidden by some others, etc. All of this determines your landmark preference at this special intersection, and these three saliences are general, which means that they determine your preference in the same way as my own and any other persons preference (apart from perceptual or cognitive limitations). The semantic salience is defined as the meaning and as the idiosyncratic (personal) relevance of objects, and it therefore differs strongly between the object observers. Due to my search for general saliences of landmarks, the semantic one is an exceptional salience and is not considered in my model.

To clarify any open questions, the following list present my working definitions of salience:

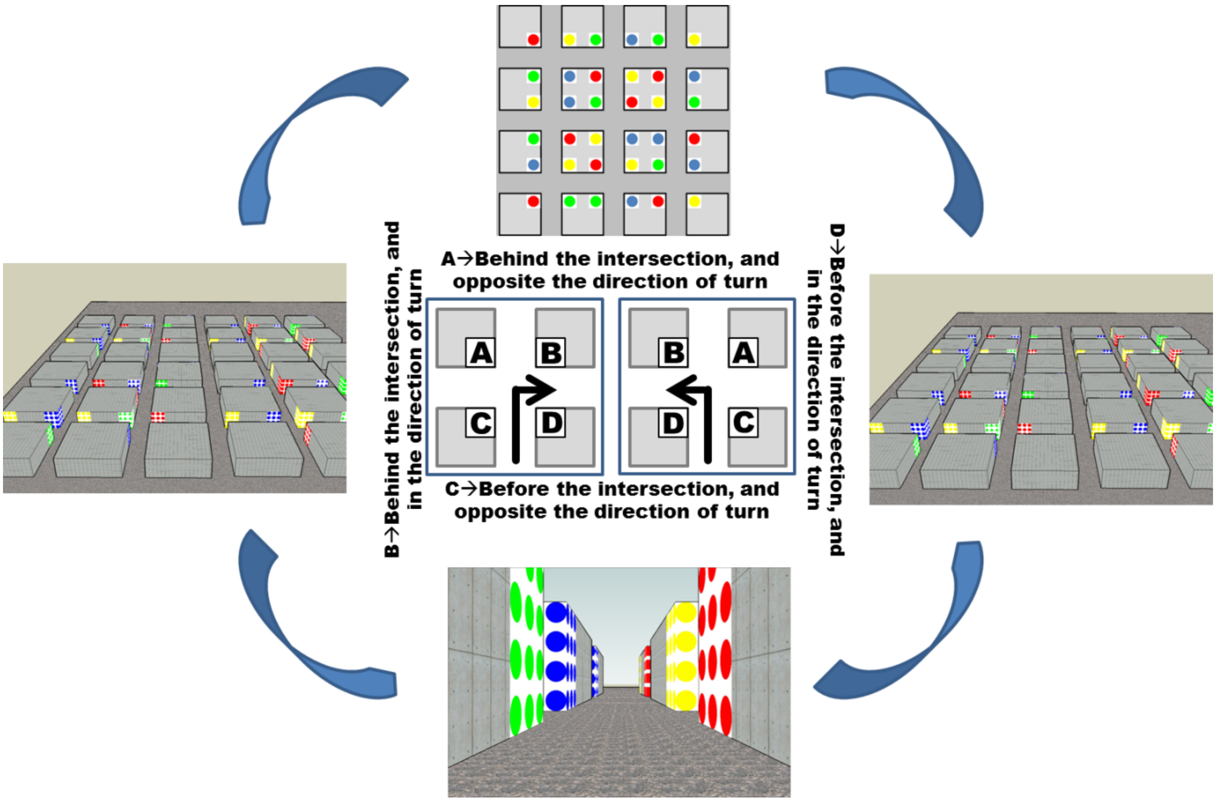
- The visual salience is defined as the contrast of an object to its surroundings. Meaning that on one side, an object is preferred when standing out from the environment, for example, as it has a different color than other objects. Imagine that there are three green houses and one red one; the red one is the one that stands out visually. On the other side, if all objects have different colors, none of them stands out, and consequently none of them will be preferred more often than the other ones. Additionally, instead of using the physical property of the visual characteristics of the landmark contrasts, I will employ the perceived properties. This indicates that visual salience characteristics are defined by the participants' evaluation.

- Structural salience is defined as the location of an object at an intersection. This assumes that when an object is located at a structurally ideal position, it is the preferred landmark. How does the preference distribution look over the four landmark positions at a four-way intersection?
- The viewpoint-based salience is defined as the relation between the object and the view point and direction of the observer. The distance between the observer and the object, the orientation of the object in relation to the observer, and the visible part of the object are parts of this kind of salience. For example, if you stand at the bottom of the Empire State building, you would have problems to identify it. This salience is defined by physical or geometric characteristics. The distance is metric, the orientation is given in degrees, and the visible part is given as a percentage of the whole landmark. There are then two questions: are all parameters of the viewpoint-based salience (equal) relevant, and how do they interact with the structural and the visual salience?

The main research questions of this Thesis are the following: which landmark does the participants prefer to give route directions? What role does the visual salience play? Which landmark position and general view position of the observer is optimal? Do these saliences interact, and if so, then how? And could all relevant factors be quantified and formalized?

Part 2

Experiments



5. Experimental settings I

The experiments' spatial material in this Thesis is entirely based on the same environment: SQUARELAND (Hamburger & Knauff, 2011; Hinterecker, Röser, Strickrodt, & Hamburger, 2014). This virtual environment was inspired by E. A. Abbotts "Flatland" (1884, 1992) and uses a more common type of intersection than for instance "Hexatown" (Gillner & Mallot, 1998). SQUARELAND is built like a modern planed city (planned community or new town; e.g., New York, Brasilia or parts of Mannheim). These cities consist of straight street grids with orthogonal intersections (appearance like a chessboard). SQUARELAND is designed as an X by X block raster (buildings or landmarks). The crossing streets make up the intersections, which all look identical – with the same width and symmetry – and represent a prototypical four-way intersection. This symmetry of the intersection and the environment is important, because consequently the "structure" of the environment itself cannot serve as a landmark (Elias & Brenner, 2005).

This environment was either presented:

- in an allocentric birds-eye perspective, vertically from above or
- in an egocentric perspective, the so called *I-Perspective*, and
- either with an arrow guiding the direction of turn or
- with the words left or right indicating the direction of turn, or
- blank, no spatial (wayfinding) information is given.

In the allocentric perspective the map or intersection and the streets are oriented north to south and east to west – the intersections or maps are never presented diagonally. In the egocentric perspective, the eye-height is set to 1.70m and the viewing direction is straight ahead (unless described otherwise) and horizontal – neither upward nor downward.

Screenshots of the intersections or maps of the whole environment are used mostly. Figure 5.1 illustrates examples of the map and the intersections in the allocentric and egocentric perspective.

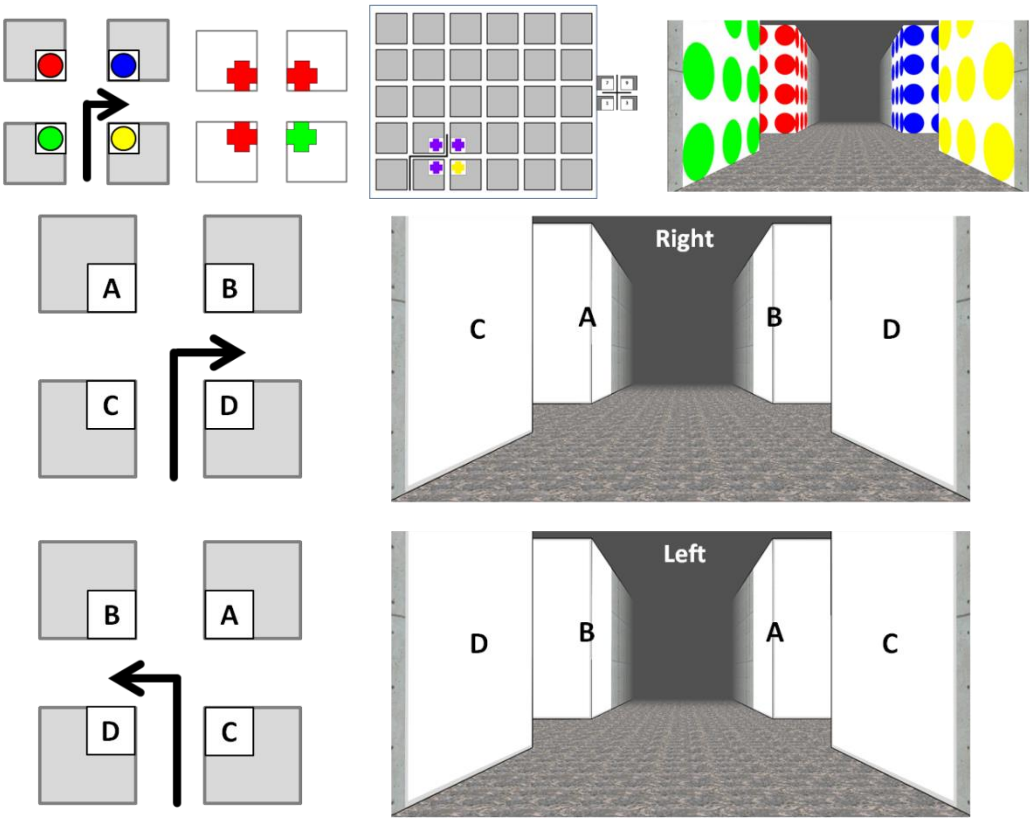


Figure 5.1 Examples of intersections and landmark positions either in the allocentric or egocentric perspective and with examples of different types of landmarks. The letters define the change of direction based on landmark positions (e.g. "D" is before the intersection and in the direction of turn).

Figure 5.1 also shows how the landmark positions are defined. I differentiate between four positions (A, B, C, D) depending on the direction of turn. In all of the following experiments the landmark-position preference results are presented as follows:

- Behind the intersection, opposite the direction of turn (A)
- Behind the intersection, in the direction of turn (B)
- Before the intersection, opposite the direction of turn (C)

- Before the intersection, in the direction of turn (D).

In most of the following experiments the participants had to choose their preferred object by pressing a key on a standard keyboard. Therefore, the numbers 1, 3, 7, and 9 where used. If you put the layout of my intersection on the number-pad of a standard key-board, these four numbers are located at the four corners of the intersection (see Figure 5.2). The number 7 represents the position above and left, the 9 above and right, the 1 below and left and the 3 below and right.

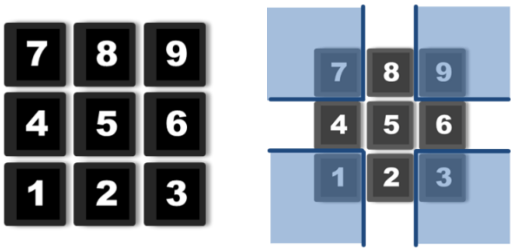


Figure 5.2 Illustration of the number-pad on a standard keyboard (left) and in combination with my intersection (right).

For the statistical analysis I calculated One-way and Repeated-Measurement ANOVAs, t-tests, Goodness-of-fit tests (chi-square tests), linear regressions and correlations. For a significant test of Sphericity (ANOVA) the Greenhouse-Geisser corrected degrees of freedom and p-values are reported. For a significant Levene´s test (t-Tests) the corrected degrees of freedom and p-values are reported. The Bonferroni-correction was used for adjusting the alpha-level in multiple t-tests. The significant test after the correction will be marked separately.

6. The effect of visual salience

The first salience in my landmark-preference model is the visual salience, which I defined as the contrast of an object to its surroundings. Meaning that on the one side an object is preferred when standing out from the environment; imagine there are three green houses and one red one, the red one is the one that stands out visually. On the other side, if all objects have different colors, none of them stands out; which means that none of them will be preferred more often than the other ones. However, instead of using the physical property of the visual characteristics of the landmark contrasts, I will employ the perceived properties, meaning that visual salience characteristics are defined by participants' evaluation.

In this chapter I will try to find answers for to following three questions: 1. Which kind of visual material is best suited to examine the visual salience? Therefore, different types of stimuli were used which are defined as visually salient by Wolfe and Horowitz (2004): colors (D´Zmura, 1991), shapes (Pomerantz & Cragin, in press; Treisman & Gormican, 1988) and different orientations of one shape (Cheal & Lyon, 1992; Wolfe, Friedman-Hill, Stewart, & O´Connell, 1992). 2. What is the effect of visual salience if only four objects are presented in a symmetric arrangement? 3. What happens when all objects are different?

6.1 Visual salience. The importance of the contrast to the surrounding (Experiment 1)

This experiment examines several aspects of visual salience and the visual material was presented in an arrangement that looks like an intersection (see Figure 5.1 and 6.1), but without a wayfinding context (parts of this are published in Röser, Krumnack, & Hamburger, 2013). This means that the visual objects are located at the four corners on a four-way intersection, but neither an arrow indicating a direction is available nor did the participants know that this configuration resembled an intersection. Participants were just required to say which object pops out (stands out) most in contrast to the other objects in this setting. If one object shows high contrast compared to the other objects, with respect to color, shape or orientation, this one is labeled as the outlier. For a better understanding the remaining three objects – besides the outlier – at an intersection are labeled as the identical ones (because these three have the same color, same shape or same orientation). Based on the remarks above I state the following hypothesis for this section: Participants are capable to identify the visually most salient object.

6.1.1 Participants, material and procedure

A total of 20 students from the University of Gießen (16 females) with a *mean age* of 24 years (*range*= 20–41) participated. All participants provided informed written consent. All had normal or corrected-to-normal visual acuity and normal color vision. They received course credit or money for participation.

Material

The material is a setting containing four visual objects placed in a square having the same distance between each other (see Figure 6.1). This setting resembles a schematic intersection, but participants were not explicitly made aware of the resemblance and were not given any navigational context. In this experiment there are three different conditions, four identical objects (filler objects), four different objects (distractors) and three identical objects and one outlier object (experimental objects). All of them were presented with the three different kinds of stimuli: colors, shapes and orientations (shapes in different orientations).

The distractor condition consisted of twelve intersections with different colors and twelve intersections with different shapes. For the different orientations twelve items with different shapes in different orientations were used (see Figure 6.1).

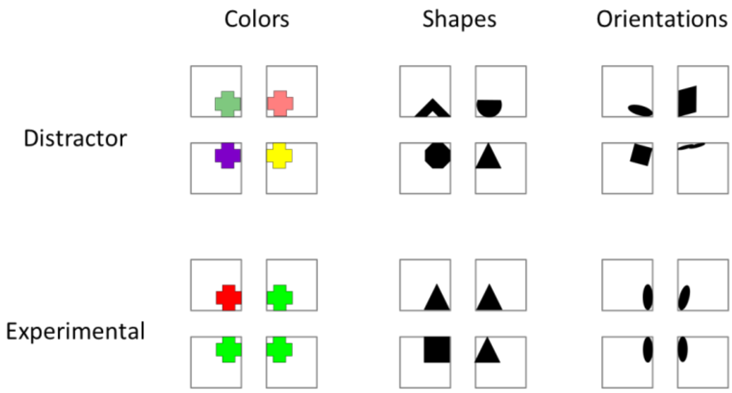


Figure 6.1: Material of Experiment 1. Examples of the three different types of stimuli and of the distractor and experimental condition.

To vary the visual salience of potential landmarks the same stimuli as in the distractor conditions – but now containing one outlier – served as items. The colors were presented using the same shape, a simple cross (Figure 6.1). In 24 items three identical colors and one outlier color (green and red; blue and yellow; red and yellow) were shown. Each color combination was presented eight times and the position of the outlier was counter-balanced across the four positions. For the shapes 24 objects with three identical shapes (e.g., a square; always in black, see Figure 6.1) and one outlier shape (e.g., a triangle), again balanced across the four positions were created. For the different orientations of shapes four identical forms were used (see Figure 6.1). Here the difference was with respect to orientation: Either three shapes are orientated vertically and the outlier is rotated 15° to the right or the three identically oriented objects are rotated 15° to the right and the outlier is orientated vertically. Again, the outliers are shown once at each of the four positions.

This resulted in 144 different object configurations, 72 experimental items, 36 distractors and 36 filler items. All images were presented on a custom computer screen (22´´). Superlab 4.0 (Cedrus Corporation 1991–2006) was used for running the study and for data recording.

Procedure

Participants received instructions on the computer screen. It was explained that four objects will be shown at a time and in a fixed arrangement. Participants were instructed to indicate the outlier, which in their opinion stands out the most. To select any object they should press the according response key on the keyboard. Those are the numbers 1, 3, 7, and 9 on the number block and were assigned to the corresponding position in the arrangement (see Figure 5.2). All images were presented in succession in a randomized order.

6.1.2 Results

Over all conditions and participants no button (on the keyboard) nor position preference could be detected ($\chi^2(3)=1.638$, $p=.651$). Two participants' data had to be excluded for the following analyses because they scored two standard deviations below the mean value of outlier preference and it is not clear whether they understood the instruction. In the following the results of the distractor (four different objects) and experimental (outlier) condition are analyzed in detail.

The participants' preferences are illustrated in Table 6.1. The relative frequency of the four positions indicates how often the participants chose an object which is placed at this position. In the condition with four different objects (colors, shapes and shapes in different orientations) the objects are chosen equally often indicating a similar preference.

On average the outliers are chosen in 92% of the cases. The values for the three kinds of stimuli are listed in Table 6.1 and all of them differ significantly from chance level. However, since the outliers were located equally often at each position of the four-way arrangement, each position should be chosen equally often. This is what happened across all stimuli ($\chi^2(3)=1.241$, $p=.743$) as well as for each kind of stimulus (see Table 6.1). But, the preference for the outlier differs significantly between the three object conditions ($F(1.150)=25.713$, $p<.001$). The preferences of the outlier in the condition color and shape does not differ significantly ($t(17)=1.102$, $p=.286$) but in both conditions the outliers were preferred more often than in the condition orientation (color vs. orientation: *t*(17)=5.172, *p*<.001; shape vs. orientation *t*(17)=5.226, *p*<.001).

Table 6.1. Distribution of the visual object preference

	Selected positions in the arrangement [in %]					
	Different objects (distractors)			Outlier objects		
	Colors	Shapes	Orientations	Colors	Shapes	Orientations
Above left	24.07	23.61	20.83	25.23	25.00	22.69
Above right	23.61	26.85	27.78	24.77	25.46	25.00
Below left	23.15	25.93	25.46	24.77	24.77	25.46
Below right	29.17	23.61	25.93	25.23	24.77	26.85
	χ^2(3)=.943, *p*=.815[1]	χ^2(3)=.326, *p*=.955[1]	χ^2(3)=1.046, *p*=.790[1]	χ^2(3)=.009, *p*=1.000[1]	χ^2(3)=.013, *p*=1.000[1]	χ^2(3)=.360, *p*=.948[1]
				General preference of the outlier[%]		
Preference of the outlier				99.31	97.92	78.47
				t(19)=197.298, *p*<.001[2]	*t*(19)=61.847, *p*<.001[2]	*t*(19)=13.599, *p*<.001[2]

[1]testing against uniform distribution
[2]testing against chance level (25%)

The mean decision time for choosing an object was 3924ms (*SD*=1924). The relevant values are listed in Table 6.2. For the main effect stimulus (colors, shapes and orientations) the decision times differ significantly (*F*(2)=6.528, *p*=.004). The post-hoc tests showed that the mean decision time for the colors and shapes does not differ (*t*(17)=-.858, *p*=.403). However, the mean decision time for color was significantly faster than for orientations (*t*(17)=-2.825, *p*=.012) and the mean decision time for shape was faster than the mean decision time for orientation (*t*(17)=-2.754, *p*=.014). Furthermore, participants responded significantly faster in the condition with the outliers in contrast to the condition with four different objects (*F*(1)=13.437, *p*=.002). However, the condition stimuli (color, shape and orientation) and the condition outlier (one vs. four different) do not interact ($F(2)=.339$, $p=.715$).

Table 6.2. Mean decision times for the condition combinations [ms]

	Colors	Shapes	Orientations	Mean
Different objects	3409	3772	4719	*3967*
Outlier objects	1619	1815	3308	*2247*
Mean	*2514*	*2794*	*4013*	*3107*

6.2 Discussion and the essence of visual salience

The initial hypothesis was that the participants are capable to identify an object which stands out from an arrangement of four objects. The results show that this is the case. However, there are differences between the three types of material used. Participants were better and faster when the material was colored circles compared to when different shapes and orientations were used. In addition, the results show that when all objects are different none of them will be preferred. This can be seen for all types of material. In summary, the assumption – an object that stands-out from the environment – can be retained for this kind of experiment and setting.

The essential question of this chapter was how well the participants could identify a visually salient object. The findings show that the participants identify and chose a visually salient object very fast. This finding is not entirely new, Treisman and Gelade (1980; Niebur, 2007) for example showed that an object with a physical contrast to the surrounding is perceived as to "stand-out". Itti (2007) summarized the findings about the visual salience in his encyclopedia article and mentioned that "Visual salience is sometimes carelessly described as a physical property of a visual stimulus. It is important to remember that salience is the consequence of an interaction of a stimulus with other stimuli, as well as with a visual system (biological or artificial)" (Definitions, para. 4). Besides the interaction with the visual system (e.g., color-blindness) the current results revealed a high contrast to the surrounding which in turn leads to a perceptual stand-out.

Besides this question I had three major questions for my thesis. The first was which kind of stimuli is best suited to examine visual salience. Here the results show that a different color leads to the best and fastest "outlier" identification and a different orientation to the least and slowest "outlier" identification. Why colors lead to a better and faster decision is beyond the scope of this thesis (e.g., Cheal & Lyon, 1992; Treisman & Gealde, 1980). With this experiment I wanted to show that the contrast of an object to the environment is important. Additionally I want to examine which features – colors, shapes or shapes in different orientations – reach the highest values for the visual salience and are therefore best suited for the examination of the visual salience.

The second question was about the effect of visual salience when four objects are presented in a symmetric arrangement and not – as otherwise usual – many objects in an unsystematic arrangement (e.g., Dowd & Mitroff, 2013; Itti, 2007). The results revealed that the concept of visual salience also holds for objects presented in a symmetric arrangement. Additionally, with this experiment I could show that the position of the "outlier" – the visually salient object – does not influence the participants' decision. The outlier was presented equally often at each of the four positions. And, as the results showed, each position is preferred equally often. This demonstrates that none of the four positions will be generally preferred (which will be relevant for the further experiments).

The third finding of the experiment – considering when all four objects are different, none of them will be preferred – is equally important. Let me describe this using an example:

If there is one red circle and the remaining three circles are green, the physical contrast of the red circle to all other stimuli is very high. But the same physical contrast occurs if the remaining three objects are green, blue and yellow. In both cases, the red object differs physically from the surrounding objects. However, in the first case the red one differs from all other objects, whereas one green circle differs only from one object (red) and does not differ from the other two green circles; the red circle is perceived as stand out. If all objects are different, each object differs from all other objects. In this case, none of them is perceived as standing out. So, in addition to the assumption made by Itti (2007) that the interaction of one stimulus with the other stimuli in the environment is important, these finding shows that for defining the visual salience of an object the interaction between all objects must be considered. Only then the visual salience of a stimulus can be clearly defined.

The essence of visual salience can be defined by three aspects:

1. If one object stands out significantly, it will always almost preferred (for a variation of the contrast to the surrounding see Chapter 9).
2. The position of the outlier does not influence the effect.
3. If all (four) objects are (sufficiently) different, none of them stands out. There, the visual salience is equal for all objects and as a result the visual salience does not influence the participants' decision.

The results and assumptions are summarized and described as a function of the four positions in the layout in Table 6.3. The second column shows the summarized preferences for the positions of the outlier when presented equally often at each position. Columns three to six show the preference if the outlier is located at one specific position. The last column shows the preferences when presenting four different objects at the four positions.

Table 6.3. Distribution of the visual object preference

	Position preference [in %]					**Position preference if all objects are different [%]**
	Over all	Position of the outlier				
Preferred position		Above, left	Above, right	Below, left	Below, right	
Above, left	**~25.00**	**~100**	0	0	0	**~25.00**
Above, right	**~25.00**	0	**~100**	0	0	**~25.00**
Below, left	**~25.00**	0	0	**~100**	0	**~25.00**
Below, right	**~25.00**	0	0	0	**~100**	**~25.00**

7. Experimental settings II

In the previous chapter of the thesis the effect of visual salience at an intersection but without a wayfinding context was examined. The finding is in line with the assumption that if all objects are different (all of them had different colors), each object will be preferred equally often. This means, the visual salience does not influence the participants' decision. Therefore, in all of the following experiments, where the influence of the visual salience is not examined – Experiment 2, 3, 7, 8, and 9 – objects with different colors were used. Additionally, no color preferences could be found in any of the following experiments. In Table 7.1 the preferences for the colors used over all other experimental conditions and positions are shown. As an exception, in Experiment 2 the landmark consists of different shapes in different colors, here also the shapes are preferred equally often ($\chi 2(3)=.221$, $p=.974$). In the results sections of the following parts I will concentrate on the main results.

Table 7.1. Visual salience of the experiments

	Red	**Green**	**Blue**	**Yellow**	**Statistic***
Exp. 2	25.72	25.96	23.08	25.24	$\chi^2(3)=.207$, $p=.976$
Exp. 3	26.51	27.85	21.48	24.16	$\chi^2(3)=.941$, $p=.815$
Exp. 7	28.26	28.26	21.74	21.74	$\chi^2(3)=1.701$, $p=.637$
Exp. 8	25.63	26.88	22.19	25.31	$\chi^2(3)=.477$, $p=.924$
Exp. 9	24.56	25.89	25.90	23.65	$\chi^2(3)=.145$, $p=.986$

*testing against uniform distribution

These findings impressively support my visual salience assumption: If different colors serve as landmarks, they do not influence the participants' decision. Or, more generally speaking: the contrast of the object to the environment alone is not important. The visual salience must be considered as being embedded in the surrounding as described in Chapter 3.1 and Chapter 6.

8. The effect of structural salience

The second salience in my landmark-preference model is the structural salience, which I defined as the location of an object at an intersection. In practical terms, when an object is located at a structurally ideal position, it is the preferred landmark. However, this raises the question, how the preference distribution looks like over the four landmark positions at a four-way intersection.

In this chapter I will try to find answers for the following two questions: 1. Which landmark position is the structurally preferred one at an intersection? 2. Is the position preference stable and reproducible?

8.1 Structural salience in maps (Experiment 2)

With this experiment I examine which landmark location at a four-way intersection presented on a map is the preferred one for giving route directions (see Röser, Krumnack, Hamburger, & Knauff, 2012). Therefore equal salient visual objects were presented and the participants should indicate which one they would prefer to give route directions. Due to the absence of other information only objects' position define the participants' landmark preference. Based on the landmark salience model by Raubal and Winter (2002) and in particular the model assumption by Klippel and Winter (2005; to which I will return later) I expected that participants have clear preferences (1) for landmarks which are located at the same side of the street in which the turn has to be made, (2) for landmarks that appear before the turn has to be made. Additionally I assume that (3) they prefer rather a position before the intersection and a position in the direction of turn than the other remaining positions (interaction between the previous factors).

8.1.1 Participants, material and procedure

A total of 49 individuals started the online-experiment. They were recruited via a circular e-mail at the University of Gießen. Twenty-six of them finished it completely (18 females; *mean age*=24.48, *range*=18–52). All participants provided informed consent and participation was voluntary.

Material

The experimental setup consists of a map within the environment SQUARELAND. A path runs though the map with 16 intersections in total. This represented a route length people can imagine and remember in a virtual setting (e.g., Hamburger, Röser, Bukow, & Knauff, 2011). Each map represents an environment containing 28 intersections (7 × 4 orthogonal streets). The current decision point with the four landmarks at the corners of the intersections was presented on each of the maps; also the path from the starting position to the current intersection was shown. At each decision point, four landmarks were shown and the participants had to select one of four route directions (instructions) referring to one of the four landmarks, respectively. They all had the same wording, except for the specific landmark. In the fast-food example they could, for instance, describe a left turn by saying “Left at the McDonald’s”, “Left at the In-N-Out Burger”, “Left at the Burger King”, or “Left at the Wendy’s”. As you can see each of these instructions refers to exactly one landmark (Figure 8.1; see procedure for more details). However, the experiment uses colored geometrical shapes instead of Fast-Food-Restaurants, e.g., right at the yellow square (to control for semantic effects). Examples for the 16 colored shapes (square, hexagon, circle, triangle; red, green, blue, yellow) are shown in Figure 8.1 and were counterbalanced across the positions at the intersections. The results of Experiment 1 showed that in this case the visual salience does not influence the participants' decision. Based on this, the visual salience is negligible here and color and shapes serve as valuable landmark objects.

All maps were presented sequentially and the data was recorded using the online platform LimeSurvey 1.85 (LimeSurvey Project Team, & Schmitz, 2012).

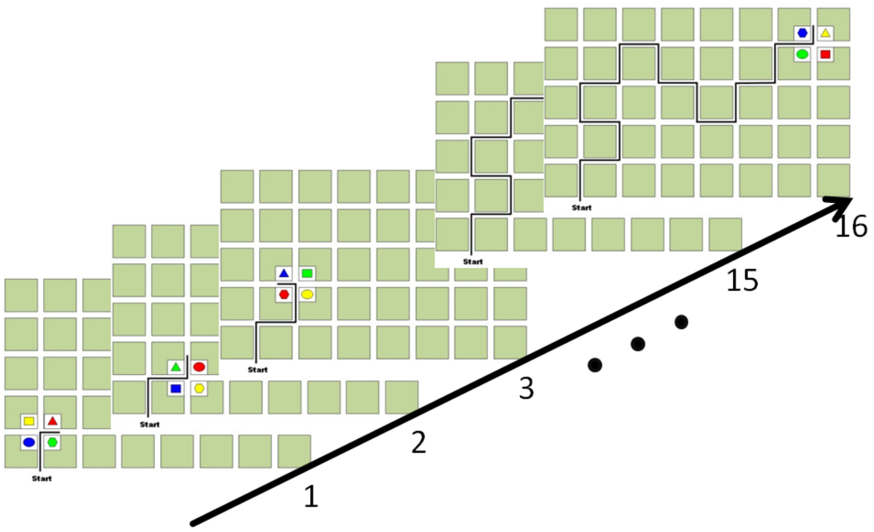


Figure 8.1. Material and schematic procedure of Experiment 2. Maps of the environment include the path from the start to the current intersection. The four landmarks are only depicted at the current intersection.

Procedure

At the beginning of the experiment participants were informed that the experiment was concerned with route directions in human wayfinding. They saw a survey map of the environment (as long as they want), including the path and all landmarks. The next slide presented a cover story: "imagine you have to give verbal directions to someone who is unfamiliar with this route, but needs to find his or her way to the goal location." Afterwards, the main experiment started. On the first slide the participants saw the map showing the path from the starting point to the first intersection, including the directional change. At this intersection the four landmarks were presented at the four corners. The second slide showed the path from the starting point to the second intersection, including the directional change and the four landmarks at this intersection, and so on (see Figure 8.1). At each intersection, the participants had to answer the following question: “Which of the following instructions appears to be the best to you?” Note that each instruction used one of the four landmarks, respectively (e.g., “Am grünen Hexagon rechts”; “At the green hexagon make a right turn”). The four possible instructions were presented below the map. The participants then had to choose one of the instructions by clicking on the corresponding sentence. This procedure was repeated for all intersections.

8.1.2 Results and discussion

In the main part of the analysis, I analyze whether instructions with landmarks on a certain corner of the intersection were selected more often than instructions with landmarks at other corners. Participants’ preferences are illustrated in Table 8.1

Table 8.1. Results of Experiment 2

Selected route instruction [in %]	
Behind the intersection, opposite to the direction of turn	05.53
Behind the intersection, in the direction of turn	18.51
Before the intersection, opposite to the direction of turn	03.61
Before the intersection, in the direction of turn	72.36

The relative frequencies at the four corners of the intersection indicate how often the instruction/landmark was selected depending on the direction of travel (across the entire group of tasks and participants; see also Figure 8.1). As can be seen in Table 8.1, in 72% of the tasks, the participants selected instructions with landmarks located before the intersection and in the direction of turn. With 19%, the second most frequent choice was the instruction with the landmark positioned in the direction of turn, but behind the intersection. The two instructions with landmark positions opposite to the direction of turn were rarely selected (9%

combined). Based on the position preference assumptions from above I ran a contrast analysis with the four positions divided into the positions in and opposite to the direction of turn, before and behind the intersection. The results showed a significant difference between the instructions depending on the landmark position ($F(1.433, 35.825)=41.019$, $p<.001$). A detailed inspection of the contrasts revealed the following: (1) instructions with landmark positions in the direction of turn were preferred significantly more often compared to instructions with landmark positions opposite to the direction of turn ($F(1, 25)=132.036$, $p<.001$); (2) the instructions with landmark positions before the intersection were preferred significantly in comparison to instructions with landmark positions behind the intersection ($F(1, 25)=19.837$, $p<.001$); and (3) they interact with each other ($F(1; 25)=26.380$, $p<.001$). Instructions with landmarks located before the intersection and in the direction of turn are preferred significantly more often than the other instructions.

Discussion

In more than 70% of cases, the participants preferred the instructions with landmarks at the position before the intersection in the direction of turn. Instructions with landmarks at the position behind the intersection, in the direction of turn were preferred in about 1/5 of the intersections. Instructions with landmarks at the positions opposite to the direction of turn were hardly ever chosen.

The results show a significant interaction between the landmark positions in and opposite to the direction of turn and before and behind the intersection. This in combination with the descriptive data shows that the position before the intersection in the direction of turn is the most preferred landmark position. This is discussed in more detail in Chapter 8.6.

8.2 Structural salience at an intersection (Experiment 3)

In the previous experiment a map showing the whole environment was presented to examine the structural salience of landmark positions at a four-way intersection. In such a setting the positions of the landmarks at the intersection (in relation to the direction of turn) were sometimes rotated; e.g. if the path comes from above (see intersection 11 in Figure 8.1). In this case the participants have to rotate the map – or at least the intersection – mentally if they want to look in the direction of movement. Additionally with the path coming from above in the allocentric perspective, the positions before the intersections are located above the positions behind the intersection – what represents an unusual view on an environment. However, the findings of previous experiments (Röser, Hamburger, Krumnack, & Knauff, 2012) showed that the preferences do not differ between a rotated map and a “north-centered” one (as presented in Experiment 2). With the following experiment I again examine the influence of the structural salience but now by presenting screenshots of intersections in isolation. The question is, does this difference in the presentation form – map vs. intersection – lead to different landmark position preferences?

8.2.1 Participants, material and procedure

A total of 19 students from the University of Gießen (18 females) participated in the experiment. The *mean age* was 22.42 years, with a *range* of 18–29 years. All participants provided informed written consent and they received course credits or money for participation.

Material

The material consisted of 12 screenshots from intersections in an allocentric perspective representing a path through a maze. In each of the intersections an arrow indicated the direction of turn and four landmarks were located at the four corners – all with the same distance to the middle of the intersection and to each other, also having the same size (see Figure 8.2). The landmarks were circles in four different colors (red, green, blue, and yellow; see Figure 8.2), which were counter-balanced across all positions (resulting in eight different versions). The experiment was presented on a standard computer screen (19´´) and Superlab 4.5 was used for presentation and data recording.

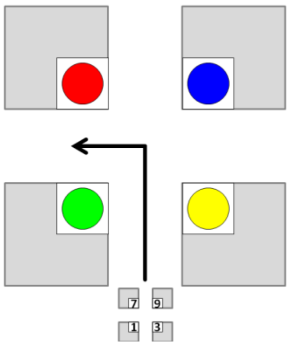


Figure 8.2. Material of Experiment 3. Exemplary intersection with the four colors as landmarks and the response options below the screenshot.

Procedure

The first instruction was to memorize a path through a maze. Afterwards the participants saw the whole SQUARELAND maze in an allocentric perspective with the path through it and all landmarks (overview). The following instruction informed the participants that the next task is to decide which landmark they would prefer to give route directions at each intersection; the answering mode was explained in the following instruction. They had to give their answer by pressing the buttons 1, 3, 7 or 9 on the number-pad of a standard keyboard. Each of these numbers was assigned to one position at the intersection (see Figure 5.1 and 5.2) and below each intersection a schematic intersection with the corresponding numbers was presented. In the experimental phase each intersection was presented separately in the sequence as seen in the overview slide. However, each intersection was oriented in the same direction as shown in Figure 8.2; the path always moves from below to the middle of the intersection and an arrow points either to the left or right according to the change of direction. After a response, a fixation cross appeared and the next intersection was presented after two seconds.

8.2.2 Results and discussion

Here I analyzed which landmark position at the intersection is preferred more often than the other landmark positions. The participants' preferences are illustrated in Table 8.2. The relative frequency of the four positions indicates how often landmarks at these positions were preferred depending on the direction of travel (over the entire group of task and participants). As can be seen in Table 8.2, in 71% of the intersections, the participants preferred landmarks at the position before the intersection and in the direction of turn. With 24.50%, the second most frequent preference are landmarks located at the position in the direction of turn, but behind the intersection. Landmarks located at the positions opposite to the direction of turn, were rarely chosen (5%). The mean decision time was 3302ms (*SEM*=381).

Table 8.2. Results of Experiment 3

Preferred landmark positions [in %]	
Behind the intersection, opposite the direction of turn (A)	01.34
Behind the intersection, in the direction of turn (B)	24.50
Before the intersection, opposite the direction of turn (C)	03.36
Before the intersection, in the direction of turn (D)	70.81

A comparison of the landmark position preference here with the instruction preference examined in the previous experiment (Table 8.1) revealed that the distribution across the four positions at the intersection does not differ significantly between these two experiments ($\chi^2(3)=5.164$ $p=.160$).

Discussion

Again, landmarks located at the position before the intersection in the direction of turn are the most preferred. Meaning: the position before the intersection in the direction of turn resembles the ideal landmark position.

The results of this experiment showed that the presentation form – map vs. intersections solely – does not influence the participants' preference. This means that mental rotation of the intersection (as in Experiment 2) does not influence the preference of the ideal landmark position. Also the different forms of decision making – giving instructions vs. free choice – do not influence the participants' preference. This indicates the position effect´s strength and the significance of the landmark position before the intersection and in the direction of turn.

8.3 Further experiments

I ran two further experiments with variations of the landmark material and the kind of landmark selection to support the above findings.

In the experiment "no arrow" (*N*=24; 18 females; 23 students; *mean age*=23.50 years; *range*= 18–39) the arrow used in Experiment 3, indicating the direction, was replaced by the verbal cues "left" or "right". The material and the procedure were otherwise identical. The landmark-position preferences are illustrated in Table 8.3.

In the experiment "landmark placement" (*N*=45; 29 females; 41 had at minimum a higher education entrance qualification; *mean age*=27.14 years; *range*= 19–53) the task was to learn a written route direction (e.g., turn left at the church). Afterwards they saw blank intersections and should decide at which position of the intersection they would locate the landmark ideally to give a route direction. The chosen are presented in Table 8.3 (for more details see Röser, Hamburger, et al., 2012). In the first experiment the visual salience does not influence the participants´ decision as previously described. In the second one no visual stimuli were used.

Table 8.3. Position preferences for the different experiments

	Position preference [in %]				
	Behind the intersection, opposite the direction of turn	Behind the intersection, in the direction of turn	Before the intersection, opposite the direction of turn	Before the intersection, in the direction of turn	Testing against Exp. 2
Exp. 2	05.53	18.51	03.61	72.36	
Exp. 3	01.34	24.50	03.36	70.81	$\chi^2(3)=5.164$ $p=.160$
Exp. "No arrow"	04.36	26.19	04.37	65.08	$\chi^2(3)=4.326$ $p=.228$
Exp. "Landmark placement"	06.75	19.00	06.00	68.25	$\chi^2(3)=2.098$ $p=.552$

These experiments undermine the findings supporting an ideal landmark position. Independent from the landmark material and the type of landmark selection the position before the intersection in the direction of turn resembles the ideal one. Especially the results received from the experiment "no arrow" are interesting. In the main experiments above the route directions were indicated by using an arrow. This arrow encloses the positions before the intersection and in the direction of turn (see Figure 8.1 and 8.2). One point of criticism could be that this arrow directs the attention of the observer to this position. However, in the experiment "no arrow" this problem does not exist and the findings do not statistically differ from the findings of Experiment 2.

8.4 Structural salience in route directions (Experiment 4)

At least one open question remains. Until now the participants had to choose which object they would prefer to use when giving a route direction. However, they never had to provide one themselves. In the following experiment I will examine whether there is a difference between the preference of the object positions and the real use of these landmarks and landmark positions in route directions. Looking at the above findings, I hypothesize, that the position before the intersection in the direction of turn will again appear to be the most preferred one.

8.4.1 Participants, material and procedure

A total of 127 individuals (79 females) participated in this online-experiment with a *mean age* of 23.96 years (*range*= 18–46). They were recruited via a circular e-mail at the University of Gießen and 67% (85) indicated to have a high-school diploma or similar, while 15 participants already had a Bachelor's degree and eight a Master's degree. For the analysis a total of 26 could be included, since the others either had another instruction (describing the return path, see Chapter 14.2) or dropped out during the experiment and did not complete it. The remaining sample consisted of 16 females and 10 males with a *mean age* of 23.85 (*range*= 19–32). All participants provided informed consent and participation was voluntary.

Material

The material consists of 12 screenshots of four-way intersections (SQUARELAND) in an allocentric perspective. In each of the intersections an arrow indicates the direction of turn (left or right) and four landmarks are placed at the four corners of the intersection. German nouns with the first letter ranging from A to L, consisting of six letters and two syllables each serve as landmarks. This results in a total of 12 intersections and therefore 48 different words. Every word at one intersection contains the same initial letter, each intersection has a different initial letter. Each landmark word has to occur at every position at an intersection and is combined with each turning direction (left, right). An exemplary intersection in the allocentric condition is visualized in Figure 8.3.

The experiment was run online using LimeSurvey 2.05+.

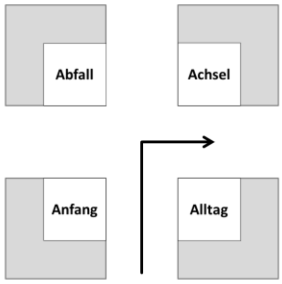


Figure 8.3. Material of Experiment 4. Exemplary intersection in the allocentric perspective; the four words starting with the letter A in German language (Abfall = trash; Achsel = armpit; Anfang = beginning; Alltag = everyday life) are shown.

Procedure

The participants were asked to memorize the path, which was presented via screenshots, providing an intersection with four different landmark words. At each intersection the task was to memorize at least one landmark and the associated turning direction. But, they should not only remember the path (recognition) but also be capable to subsequently provide route directions of the learned path to another person also unfamiliar with this environment. Afterwards, the learning phase started, in which the route of 12 screenshots had to be learned, one intersection after another in a randomized order. After the learning phase, hence for the testing phase, participants received the related instructions to provide route directions of the learned path. 24 input fields were presented on one screen, two for each intersection: One for the relevant and preferred landmark and one for the corresponding route direction.

8.4.2 Results and discussion

The descriptive results show that participants provided a total of 159 correct landmarks. All landmark words were described equally often ($\chi 2(47)=29.075$, $p=.981$). In the following part of the analysis, I analyze at which position of the intersection the described landmarks/words are placed: the participants' preferences are illustrated in Table 8.4.

Table 8.4. Results of Experiment 4

Describe landmark positions [in %]	
Behind the intersection, opposite to the direction of turn	05.22
Behind the intersection, in the direction of turn	07.46
Before the intersection, opposite to the direction of turn	03.73
Before the intersection, in the direction of turn	83.58

The relative frequency of the four positions at the intersection indicate how often landmarks located at this position were provided. As can be seen in the table, when the participants used words for their route directions, these words were located at the position before the intersection in the direction of turn in 83.58% of cases. This differs ($\chi 2(3)=8.355$, $p=.039$) from the position preferences described in Experiment 2.

Discussion

The findings here differ significantly from the position preferences found in Experiment 2. However, consistent with the above findings, the position before the intersection in the direction of turn is the most used one. The largest difference is visible for the position behind the intersection in the direction of turn. Here landmarks placed at this position are used for route directions in only 7 % of cases. Still it resembles the second most described landmark position, the same as in the previous experiments. Hence, the ordinal relation between the landmark position preferences and the landmark position description is identical: before the intersection in the direction of turn > behind the intersection in the direction of turn > behind the intersection opposite to the direction of turn > before the intersection opposite to the direction of turn.

Due to these findings, I ran a replication of this experiment as a classroom experiment (*N*=23; 16 females; 23 students; *mean age*=22.43 years; *range*= 19–35). The participants saw intersections with letters as landmarks and had to create route directions after seeing screenshots of all intersections. The majority of used landmarks again was located at the position before the intersection in the direction of turn (83%) and the results do not differ from the findings of Experiment 4 ($\chi 2(3)=4.834$, $p=.184$).

This explicit analysis of the landmark location at an intersection in route directions is new. Some studies examined route directions and analyzed the influence of structural aspects (Janzen, 2006; Michon & Denis, 2001). However, there the structural salience is mostly defined as the location of the object at a decision point and its exact location at the intersection is not considered.

8.5 The essence of structural salience

At the beginning of this chapter I stated that there should be an ideal landmark position. My findings suggest the position before the intersection in the direction of turn to be the ideal position. Furthermore, the findings of the different experiments revealed that it is a stable preference and reproducible. Taking all experiments together, the following landmark preference distribution results (Table 8.5):

Table 8.5. Landmark position preferences over all experiments

Preferred landmark positions [in %]	
Behind the intersection, opposite to the direction of turn	04.64
Behind the intersection, in the direction of turn	19.13
Before the intersection, opposite to the direction of turn	04.21
Before the intersection, in the direction of turn	72.02

This part' main finding is that people have strong preferences when selecting objects at an intersection as landmarks for route directions. In about three quarters of all tasks, the participants preferred or used landmarks before the intersection in the direction of turn. Objects opposite to the direction of turn were almost never used as landmarks. This finding is novel and makes a new contribution to landmark-based wayfinding research. On the one hand, Michon and Denis (2001) and Janzen and van Turennout (2004) showed that landmarks are very important at an intersection with a direction change, i.e. at so-called decision points. On the other hand, however, previous research did not empirically determine the actual landmark position at an intersection (which includes perception, attention, memory, decision making, etc.).

The finding that the position before the intersection in the direction of turn is the most preferred one is partly in line with the theoretical model of Klippel and Winter (2005). Moreover, I believe that the results are in line with our daily life experiences. It is easy to memorize and remember a landmark that is in the direction of turn, because the landmark functions as a beacon (Waller & Lippa, 2007). This might result in less cognitive load, because the mere recognition of a landmark leads to the knowledge of the correct turning direction (cued recall). This is in general agreement with the concept of cognitive economy in human wayfinding and route directions (Hölscher, Tenbrink, & Wiener, 2011). Moreover, the position before the intersection in the direction of turn might serve as an "anchor". Imagine a rope attached to such a landmark. If you follow the rope, you will be guided directly in the correct direction (i.e. going around the corner). This is the unique feature of landmarks located before the intersection in the direction of turn. And, this position is invariant, meaning that it is still at the position before the intersection in the direction of turn seen from the viewing direction of the learned path as well as seen from the view direction of the return path (return path, see Hamburger, Dienelt, Strickrodt, & Röser, 2013 or Chapter 14.2; see also “look back strategy” by Montello, 2005 and 2009). Another explanation could be that such landmarks are visible earlier, e.g. when walking along a path (see advance visibility by Winter, 2003). However, this is only relevant from an egocentric perspective (see Chapter 10 and 11) and normally should not be considered in an allocentric perspective. A final explanation could be that the position before the intersection fits in with the logical structure of classic route directions, where the landmark comes first, followed by the direction information (e.g., “at the red house, make a turn to the right”) (e.g., Denis, 1997). All of these approaches may explain why landmarks located before the intersection in the direction of turn are selected more often for route directions.

9. The interaction of visual and structural salience

In Chapter 6 of my Thesis I showed that an object, which stands out from the environment, will be chosen in almost 100% of the cases, independent from the position. In Chapter 8 I showed that potential landmarks located at the position before the intersection in the direction of turn are preferred in about 70% of cases. Overall objects located in the direction of turn are preferred in about 90%. But what happens, if a visual salient object is located at the ideal landmark position (before the intersection and in the direction of turn) or at a different position? How do the participants decide and which object is the preferred one?

Until now, the interaction of visual and structural salience at an intersection has yet rarely been examined, but was theoretically described by Raubal and Winter (2002), Winter (2003), and Klippel and Winter (2005). They mentioned that the salience of an object is influenced by both saliences and emphasized the importance of structural salience. Evidence for these assumptions was presented by Peters et al. (2010), which showed in an analysis of landmarks in route directions and viewing durations during a learning phase, that the structural salience of landmarks has a higher weight than the visual salience. However, they did not systematically vary and examine the interaction between the visual and structural salience as I will do in the following.

In the previously conducted experiments only one kind of salience was available, meaning participants had to decide, which object was the salient one. They only had to judge the visual salience (the contrast to the environment) or the structural salience (the ideal position at the intersection). In the following experiments I combine these two saliences and the participants have to choose between them or have to weight their importance. In the simplest case, the visual and structural saliences are congruent – the visually salient object is located at the ideal landmark position. In that case, they are mutually reinforcing. However, the two saliences compete with each other when the visually salient object is not placed at the ideal landmark position. In this incongruent case, the participants need to choose between these options, which is particularly interesting.

Additionally, it is interesting to examine the effect of the interaction of visual and structural salience, once the effect of visual salience varies. What will happen, if the contrast of the visual salient object to the surrounding objects is only minimal? Does the effect of structural salience increase or is there a threshold for the influence of visual and structural salience?

These are the major issues concerning the following experiments.

9.1 Visual and structural salience in a map (Experiment 5)

In this experiment I examine how visual saliences affect participants' performance in a wayfinding context. Here, in contrast to Experiment 1 the intersections are presented in a map with a path (and not only using blank intersections). Based on the findings obtaining in Chapter 6 I now used the objects with the highest visual salience: colors. In addition, an arrow now provided the direction of change at each intersection. The participants' task was to decide which object at the intersection they would prefer for route directions. Therefore, beside the outlier, the position effect was included as described in Chapter 8 (see also Table 8.5).

I assume that here the visual as well as the structural salience influence the participant's decision. Meaning, that the position preference should differ from those found in Chapter 6 and 8.

9.1.1 Participants, material and procedure

A total of 20 students from the University of Gießen (14 females) with a *mean age* of 22.5 years (*range*= 18–31) participated. All participants provided informed written consent.

They had normal or corrected-to-normal visual acuity and normal color vision. They received course credit or money for participation.

Material

In this Experiment I combined the material used in Experiment 1 and 2. As in Experiment 2 a map from the environment SQUARELAND was used. Each map shows an environment with 20 intersections (5×6 orthogonal streets; for an example see Figure 9.2 below). The route through the maze consisted of 16 intersections with equal numbers of left and right turns. Colored circles were used as landmarks and as in Experiment 1 three identical objects and one outlier were used to produce one visually salient object. In order to ensure that different colors represent the landmarks at each intersection, a total of 32 color combinations with sufficiently different hues were needed. To create these different colors I used the color circle and chose each color 11.25° away from the next color (see paletton.com and colorhexa.com). To create the outliers, I chose the complementary color – maximum contrast – for each color. This combination produces the material for one intersection, three identical colored circles and one circle in the complementary color. In Figure 9.1 all used colors with the corresponding complementary color are shown. Color combinations were distributed randomly over the path.

The positions of the outlier objects were systematically varied based on the direction of turn; the outliers were placed equally often at each position (see Figure 5.1) for a turn to the left and to the right. One set of intersections consists of 16 intersections with the outlier colors either from red to green (right side of the color circle) or green to red (left side of the color circle), resulting in two different mazes. The sequence of colors in the two mazes was randomized. Additionally, the direction of turn was mirrored for each intersection for both versions, resulting in four sets of intersections. Each participant was randomly assigned to one of the conditions. The experiment was conducted using a custom computer screen (22´´). Superlab 4.0 (Cedrus Corporation 1991–2006) was used for running the experiment and for data recording.

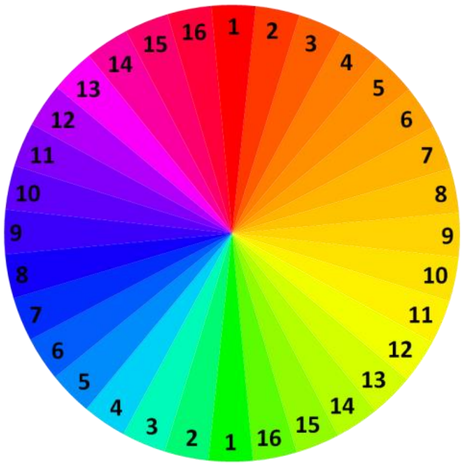


Figure 9.1. Each color (1–16) represents the color of one object in the environment. Complementary colors (same number) represent the colors at one intersection (one is the outlier, the other is the one of the surrounding objects [identical ones], and vice versa).

Procedure

The instruction explained that the participants will see a path through a maze. At each intersection four different objects were presented and participants were asked to imagine giving route directions based on the given information. The participants were instructed to decide/indicate at each intersection which object they are going to use for the route directions. To select one object they had to press the corresponding key on the keyboard (numbers 1, 3, 7 or 9 on the number block, see Figure 5.2). The response keys were presented on the right side of each slide in form of a schematic intersection (Figure 9.2). Before the experiment started, the instruction was repeated and supplemented with a pictorial explanation. On the first experimental slide the participants saw the map showing the path from the starting point to the first intersection, including the directional change. At this intersection the four objects were presented at the four corners. The second slide showed the path form the starting point to the second intersection, including the directional change and the four objects at this intersection, and so on (see Figure 9.2).

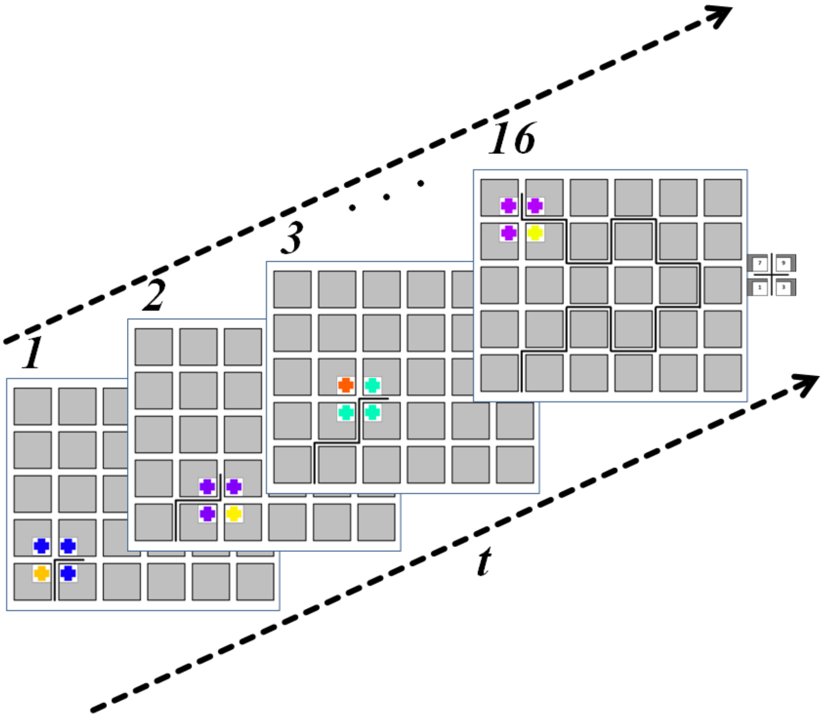


Figure 9.2. Material and schematic procedure of Experiment 5. Map of the environment including the path from the start to the particular intersection. At the intersection four landmarks are depicted. On the right side of each map a response template was shown.

9.1.2 Results and discussion

Over all, the outliers were selected with a mean of 66%. This result is statistically different from chance level (25%; $t(19)=5.589$, $p<.001$). However, across participants and all intersections a significant preference for one position can be seen (see Table 9.1). In 50% of the cases objects placed at the position before the intersection in the direction of turn are chosen, and the measured position preferences differ significantly from chance level. Another aspect is the difference between congruent (the visually salient object is located at the ideal landmark position) and incongruent (the outlier is located on one of the structurally suboptimal positions) configurations. In the congruent case the visuo-structural salient object is chosen in almost 100% of cases. In the incongruent cases the outlier is chosen on average in 55% and the object at the ideal landmark position in about 35% of cases. In Table 9.1 the object-position preferences for the four possible outlier locations are shown.

Table 9.1. Results of Experiment 5

Selected visual objects [in %]					
	Over all	Position of the outlier			
Preferred Position		Behind the intersection, opposite to the direction of turn	Behind the intersection, in the direction of turn	Before the intersection, opposite to the direction of turn	Before the intersection, in the direction of turn
Behind the intersection, opposite the direction of turn	13.75	**50.00**	02.50	02.50	00.00
Behind the intersection, in the direction of turn	20.31	08.75	**62.50**	08.75	01.25
Before the intersection, opposite the direction of turn	15.63	07.50	00.00	**53.75**	01.25
Before the intersection, in the direction of turn	50.31	33.75	35.00	35.00	**97.50**
	$\chi^2(3)=35.086$ $p<.001$[1]				
Mean decision times	*5347ms*	*6451ms*	*4738ms*	*6615ms*	*3538ms*

[1]testing against uniform distribution

The participants chose their preferred object on average after 5347ms (*SD*=2893). The fastest decision times occurred for the congruent condition (see Table 9.1), followed by outlier placement at the position behind the intersection and in the direction of turn. Across all four positions the decision times differ significantly ($F(1.796)=6.571$, $p=.005$). The post-hoc t-Tests only revealed a significant difference for the position before the intersection and in the direction of turn and the position opposite the direction of turn (see Appendix A). However, the decision times for the congruent condition (3538ms) are faster than for the incongruent one (5950ms) ($t(19)=-3.286$, $p=.004$).

Discussion

On the one hand, the results clearly show that the visual salience influences the participants' decision. The outlier object is preferred in at minimum 50% of the cases. However, here the outlier is preferred on average in 66% of the cases which differs significantly from the 92.50% outlier preference found in Chapter 6 ($t(33.266)=3.155$, $p=.003$). Also, I do not find a uniform distribution across the positions as predicted by a solely influence of the visual salience (Table 9.2).

Table 9.2. Results from Experiment 5 and position preference for the visual and structural salience.

	Results Exp. 5	Position preference visual salience	Position preference structural salience
Behind the intersection, opposite to the direction of turn	13.75	25	04.64
Behind the intersection, in the direction of turn	20.31	25	19.13
Before the intersection, opposite to the direction of turn	15.63	25	04.21
Before the intersection, in the direction of turn	50.31	25	72.02
Testing results against the position preferences		$\chi^2(3)=35.078$, $p<.001$	$\chi^2(3)= 55.481$, $p<.001$

On the other hand, the results show a significant position preference. The position before the intersection in the direction of turn is overall preferred in about 50% of the cases. However, the position preference also differs significantly from the position preference found in Chapter 8 (see Table 9.2). To summarize the results revealed that in the case of congruence of visual and structural salience the corresponding object is preferred almost always and is also chosen faster than in the incongruent cases.

This demonstrates that in a landmark preference task (wayfinding context) the participants' decision is not exclusively influenced by visual or the structural salience. It is a combination of both types of salience. This empirical finding supports my landmark-preference model which assumes that the landmark preference is influenced by all available saliences. Also, this fits the theoretical assumptions by Sorrows and Hirtle (1999) and Klippel and Winter (2005), who assume that both saliences in combination determine the participants' landmark preference. I will model and compute this interaction in Chapter 13.

The decision times underline the hypotheses that the visual and the structural salience interact. The fastest decision times occurs for the congruent condition in which the visually salient object is located at the structurally ideal landmark position. In these cases the cognitive effort is minimal, because both saliences lead to the same landmark position. The second fastest decision times are found for the position behind the intersection in the direction of turn. This is the structurally second ideal position. The decision times for the outlier placement opposite to the direction of turn are slower and very similar to each other. If the outlier is placed at these positions the participants had to decide between two saliences or have to weigh the influence of the saliences (incongruent condition). This interaction will be defined mathematically in Chapter 13.

9.2. The importance of contrast variation (Experiment 6)

In this section I will examine the interaction between the visual and the structural salience in more detail and will focus on some open questions (parts of this are published before in Röser & Hamburger, 2013).

In Chapter 6 I was able to show that the contrast to the surrounding is elementary for visual salience. However, in Chapter 8 I showed that the position of the object is important (structural salience) and in Experiment 5 I combined these two effects and found a deviating distribution from the visual as well as from the structural salience. How could these deviations be explained? Based on my experimental settings and designs, two explanations are possible:

1. In Experiment 1 empty intersections were presented, whereas in Experiment 5 an arrow indicated the direction of turn and enclosed the position before the intersection in the direction of turn. The first explanation could be that this arrow leads to a deviating distribution based on the fact that the intersection does not look symmetrical anymore. Or, in other words, one point of criticism could be that the arrow leads the participants to a form preference for this position (for this line of argument see also Chapter 8.4).
2. In Experiment 1 the task was to choose the object that stands out most, whereas the task in Experiment 5 was to choose the object they would prefer to give route directions. The second explanation could therefore be that the different tasks lead to different position preferences.

In addition, in Experiment 1 and Experiment 5 the maximum contrast between the outlier and the surrounding objects is used. The question, what happens if the contrast is not set to maximum, remains open.

Taken together, this results in five questions for the following experiment:

1. Does the availability of an arrow influence the participants´ decision?
2. Does a change of the task influence the participants’ decision?
3. Does a change of the contrast between the outlier and the surrounding influence the participants´ decision?
4. Is it possible to replicate the findings of Experiment 5?
5. How do visual and the structural salience interact?

9.2.1 Participants, material and procedure

A total of 32 students from the University of Gießen (21 female; *mean age*=27 years; *range*=19–56) participated. All participants provided informed written consent. All had normal or corrected-to-normal visual acuity and color vision (tested with isochromatic plates by Velhagen & Broschmann, 2003). They received course credits or money for participation.

Material

In this experiment I used screenshots of the standard intersection in an allocentric perspective as material. As before the objects/landmarks are located at the corners of the intersections. Due to the variation of the color contrast between the outlier and the remaining objects from 180° to 0° (in the color circle) intersections with four visually and/or perceptually identical objects are available. In this case the question "which one stands-out" could not be answered. To prevent this problem, the landmarks in the squares at the corners of the intersections are filled here with a cross and five thin lines in different arrangements so that they are physically distinct (Figure 9.3). Three of these landmarks had the same color (identical); one was different (outlier).

The first main factor in this experiment was the contrast. I created material with eight different levels of contrast between the outlier and the remaining three identical objects: 0°, 2°, 6°, 12°, 22°, 46°, 90°, and 180° (complementary color; each contrast level is approximately twice as high as the previous). The color gradient is visible in Figure 9.3 in the bottom right hand corner. The colors of the objects are shown in the color circle in Figure 9.3 in the bottom left hand corner, in the upper row examples for the intersections are presented.

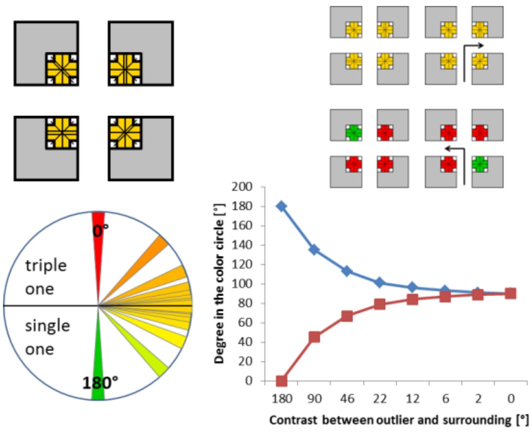


Figure 9.3. Top left: an example of an intersection with the thin lines. Top right: examples for intersections with and without an arrow and four different levels of contrast of the outlier. Bottom left: color circle with the used colors. Bottom right: color gradient.

The second main factor was the instruction. In Condition 1, only the intersection (without an arrow) with the four objects was presented and the participants were asked which one of the four stands out (similar to Experiment 1). The second, third and fourth condition all contain an arrow at each intersection pointing to the left or right side. The second condition had the same instruction as the first condition. In the third condition participants were asked which object they would prefer to find the route again later. In the fourth condition the participants were asked which object they would prefer to give route directions (as in the experiments of Chapter 8). In the first condition the outlier was presented twice at each position for each contrast, in the conditions with an arrow once at each position for a left and right turn, resulting in 64 different pictures/intersections which were presented in a randomized order.

This results in a 4 (instructions) x 8 (contrasts) factorial design with the between subject factor instruction and the within subject factor contrast.

The participants performed the experiment on a custom computer screen (19´´). Superlab 4.5 (Cedrus Coporation 1991–2006) was used for running the experiment and for data recording.

Procedure

Each participant was randomly assigned to one of four experimental instruction conditions. The instruction explained that the participants will see screenshots of intersections (Condition 3 and 4) or an environment with objects (Condition 1 and 2) (Figure 9.3) with four objects at the four corners and that they should choose one of them. According to the instruction condition the participants should either choose the object which stands out most (Condition 1 and 2), the object they would prefer to give route directions (Condition 3) or the object they would use to remember the route (Condition 4). Afterwards the response mode was explained. To select one object the participants had to press the corresponding key on the keyboard (keys 1, 3, 7 and 9; see Figure 5.2). Beside each intersection the corresponding keys are presented.

9.2.2 Results and discussion

In a first step, I analyze the findings for the factors contrasts and instructions. Over all conditions the outlier is preferred in 62% of the cases which differs significantly from chance level (25%; $t(42)=11.131$, $p<.001$). However, preferring the outlier differs significantly between the eight gradations ($F(3.058)=91.754$, $p<.001$; Fig. 6.4). In the 0° condition, in which the objects can not be differentiated, the participants chose each object equally often, which would be expected in term of an uniform distribution ($\chi 2(3)=1.660$, $p=.646$). If I analyze how often the positions are chosen on which the “outlier” should be located (following the location logic used in the remaining conditions), these positions are preferred in 26% of all cases. In Condition 2° the participants preferred the outlier on average in 33% of the cases, in Condition 6° in 49%, in Condition 12° in 67%, in Condition 22° in 77%, in Condition 46° in 79%, in Condition 90° in 81% and in Condition 180° in 81%. The differences and significances are shown in Table 9.3 and illustrated in Figure 9.4 (for the t-values see Appendix B). This means, an increasing contrast between the outlier and the identical objects is accompanied by an increase of the outlier preference.

Summarized over the eight different contrasts there are large differences between the four instructions (see Figure 9.4) and the main effect for the instructions was significant ($F(3)=24.746$, $p<.001$; see Figure 9.4). In Condition 1 the outlier was chosen on average in 79.55% of the cases (25%; $t(10)=41.217$, $p<.001$), in Condition 2 in 77.41% (25%; $t(10)=32.847$, $p<.001$), in Condition 3 in 43.61% (25%; $t(10)=3.506$, $p=.006$) and in Condition 4 in 44.38% (25%; $t(9)=3.267$, $p=.010$). In all of them the outlier preference differs significantly from chance level. The post-hoc tests for the main effect instructions revealed that Conditions 1 and 2, and 3 and 4 do not differ from each other, but Conditions 1 and 2 differ significantly from 3 and 4 (see Table 9.4). In Condition 1 and 2 the outliers were preferred significantly more often than in Condition 3 and 4. Finally, I found a significant interaction between the four conditions and the eight different contrasts ($F(9.173)=4.747$, $p<.001$; Figure 9.4). Here the post-hoc tests showed that there is no interaction between Condition 1 and 2 the eight contrasts ($F(7)=0.763$, $p=.619$). This means, that the participants will choose the outlier equally often in the eight contrast conditions across the two conditions. Or, in other words, the trend over the eight contrasts does not differ between Conditions 1 and 2. I found similar results for Conditions 3 and 4 ($F(7)=0.311$, $p=.948$). However, the interaction between the contrasts and Condition 1 and 3 ($F(3.463)=7.964$, $p<.001$), 1 and 4 ($F(2.451)=4.886$, $p=.008$), as well as 2 and 3 ($F(3.454)=9.323$, $p<.001$) and 2 and 4 ($F(2.339)=5.692$, $p=.004$) differed significantly. This is visualized in Figure 9.4. The outlier preference in Condition 1 and 2 increases strongly between 2° and 12° (contrast between the outlier and the surrounding). Then it reaches the 100% preference. The outlier preference in Condition 3 and 3 also increases between 2° and 22° (contrast between the outlier and the surrounding). However, it does not reach 100%. It reaches its maximum by around 60%.

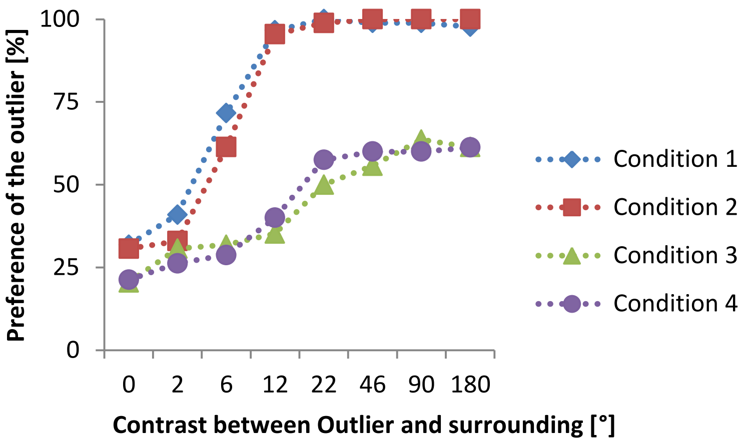


Figure 9.4. Results of Experiment 6. Preference of the outlier (%) for the four conditions of the main factor instruction. The colored lines represent the four conditions. The x-axis represents the single experimental variation (low difference on the left and high on the right). The y-axis represents the participants' relative object selection of the single object (outlier; relative frequency).

Table 9.3. How often was the outlier chosen? Mean differences between the contrasts [%]

	0°	**2°**	**6°**	**12°**	**22°**	**46°**	**90°**	**180°**
0°	XXX	06.69	22.67***	41.28***	*50.87****	*52.91****	*54.94****	*54.36****
2°		XXX	15.99**	34.59***	44.19***	46.2***	48.67***	47.67***
6°			XXX	18.60***	*28.20****	*30.23****	*32.27****	*31.69****
12°				XXX	09.59**	11.63**	13.66**	13.08*
22°					XXX	02.03	04.07	03.49
46°						XXX	02.03	01.45
90°							XXX	00.58
180°								XXX

Note. Significances after Bonferroni correction: *p<.05; **p<.01; ***p<.001
The differences show the difference between the specific contrasts. I measured for each contrast how often the outlier is chosen. The t-values are presented in Appendix B.

Table 9.4. How often was the outlier chosen? Mean differences between the conditions [%]

	Con. 1	**Con. 2**	**Con. 3**	**Con. 4**
Con. 1	XXX	*-02.13*	*-35.94****	*-35.17****
Con. 2	$t(20)=1.028$, $p=.316$	XXX	-33.81***	-33.04***
Con. 3	$t(11.329)=6.571$, $p<.001$	$t(11.794)=6.101$, $p<.001$	XXX	*00.77*
Con. 4	$t(9.897)=5.778$, $p<.001$	$t(10.302)=5.380$, $p<.001$	$t(19)=-0.967$, $p=.924$	XXX

Note. Significances after Bonferroni correction: * p<.05;** p<.01; *** p<.001
The values show the difference between the outlier preferences in the specific contrasts conditions.

The decision times showed a significant main effect for the contrasts ($F(3.996)=13.390$, $p<.001$). In the 0° condition the participants answered after 4887ms on average, in Condition 2° after 4717ms, in Condition 6° after 4277ms, in Condition 12° after 3125ms, in Condition 22° after 2789ms, in Condition 46° after 2501ms, in Condition 90° after 2873ms and in Condition 180° after 2550ms. An increase of the mean decision times with an increase of the contrast is observable (the corresponding t-values are presented in Appendix C). However, I did not find a significant main effect for the instructions ($F(3)=0.295$, $p=.829$). The mean decision time for Condition 1 was 3103ms, for Condition 2 3524ms, for Condition 3 3386ms and for Condition 4 3885ms.

Additionally, I found a significant interaction between the different instructions and the different contrasts levels ($F(11.98)=6.252$, $p<.001$). Figure 9.5 shows the corresponding results.

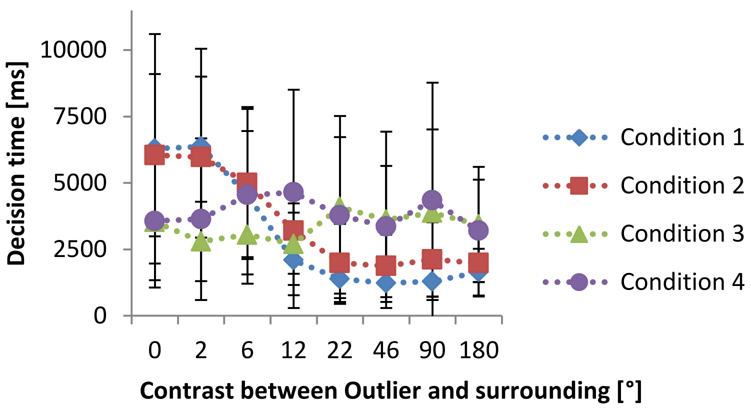


Figure 9.5. Results of Experiment 6. Interaction of decision times between the main factors instructions and contrasts. The colored lines represent the four conditions of the main factor introduction. The x-axis represents the experimental variation of the main factor contrast (low difference on the left and high on the right). The y-axis represents the participants' decision times (ms).

This result demonstrates that the decision times in both conditions with a landmark-preference task are stable whereas they decrease in the other two conditions. In Condition 1

($F(1.781)=16.830$, $p<.001$) and Condition 2 ($F(2.399)=19.619$, $p<.001$), the decision times decrease significantly with increasing contrast (for the mean value differences and the post-hoc t-values see Appendix D). In Condition 3 ($F(3.394)=0.691$, $p=.581$) and Condition 4 ($F(7)=1.041$, $p=.412$) the post-hoc ANOVA does not reveal a significant difference in the decision times between the contrasts.

In a next step I analyze the effect of the structural salience in combination with the contrasts. Here only the task condition in which I asked the participants which object they will use to give route directions is considered (Condition 4). This is the question I also asked in most of the other experiments presented here. The position preferences for the eight contrast conditions are shown in Figure 9.6 (and are listed in Table A.6 in Appendix E).

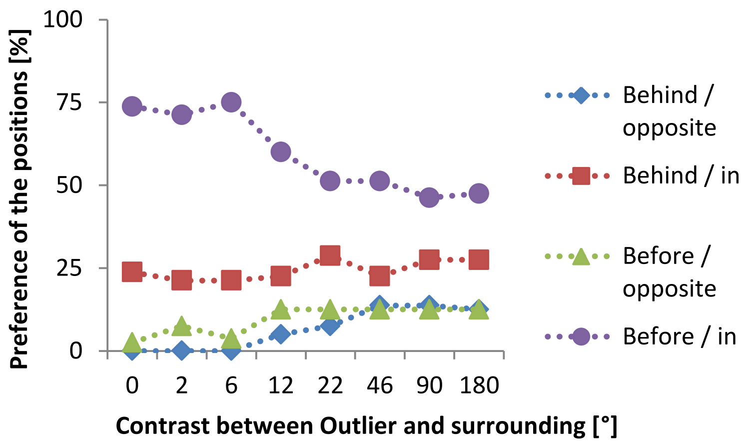


Figure 9.6. Results of Experiment 6 (Instruction Condition 4). Position preferences (%) for the four positions over the conditions of the main factor contrast. The colored lines represent the four positions of landmarks at an intersection. The x-axis represents the experimental variation of the main factor contrast (low difference on the left and high on the right).The y-axis represents the participants' relative object selection for the single positions (relative frequency).

It is visible that the preference for the ideal positions decreases from 74% (which is nearly the value presented in Chapter 8) to 48% for maximum contrast. The preference for the position behind the intersection in the direction of turn does not change and the preference for the remaining positions increases slightly with an increase of the contrast. The frequency of positions chosen in dependence of the position of the outlier is shown in Appendix E (Table A.7).

The following analyses show the preferences for the ideal landmark position considering the eight contrasts (only for Condition 4). The preference for objects located at the ideal landmark position vary significantly in dependence on the level of contrast between outlier and surrounding ($F(1.679)=4.605$, $p=.032$). Descriptively, a strong preference decrease for the outlier is observable between 6° and 22° of contrast. For the levels of contrast below and above the preferences are relatively stable. But, none of the post-hoc t-test reaches significant (see Appendix F). However, the decrease of the ideal position preference correlates significantly negative with the increase of the outlier preference ($r=-.978$, *Variables*=8, $p<.001$, two-tailed).

The next question is, whether the landmark preferences over all four positions differ between a contrast of 0° and one of 180°. In Table 9.5 the distributions for these two conditions are depicted, they differ significantly ($\chi 2(3)=38.613$, $p<.001$). Here the positions opposite to the direction of turn are of interest. In the Condition 0° where all landmarks had the same color, objects located at these positions will almost never be used for route directions. This distribution of object position preference does not differ significantly from the distribution found for the structural salience (Chapter 8). For the Condition 180° with a maximum contrast between the outlier and the surrounding, objects located at the positions opposite to the direction of turn are preferred in almost 30% of the cases. This distribution corresponds to the findings of Experiment 5, where the visual and the structural salience determine the participants' decision.

Table 9.5. Distribution of the landmark position preference

	Selected landmark positions [in %]			
	Results 0°	*Position preference structural salience*	**Results 180°**	*Results Exp. 5*
Behind the intersection, opposite the direction of turn	**00.00**	*04.64*	**12.50**	*13.75*
Behind the intersection, in the direction of turn	**23.75**	*19.13*	**27.50**	*20.31*
Before the intersection, opposite the direction of turn	**02.50**	*04.21*	**12.50**	*15.63*
Before the intersection, in the direction of turn	**73.75**	*72.02*	**47.50**	*50.31*

Note 0° and position preference structural salience $\chi 2(3)=6.492$, $p=.090$
180° and results Experiment 5 $\chi 2(3)=3.205$, $p=.350$

Discussion

The main finding of this experiment is again that the participants' decision in a landmark preference task is influenced by the visual as well as by the structural salience. Here, in contrast to Experiment 5, an increase of the visual saliences' with increasing contrast is visible. This consequently leads to a decrease of the structural salience influence. I replicated this experiment with a small variation of the saturations and found similar results, which highlights my findings here and shows that measures are stable and effects are solid.

Based on the previous parts' findings and their differences I proposed five questions for which I want to provide answers using this experiment's results.

The first question was whether the availability of an arrow influences the participants' decision. In the main experiments of Chapter 8 I, unlike Chapter 6, used an arrow to indicate the direction. One interpretation for the differences found between the experiments in these parts could be that the arrow leads to a preference of objects which are placed in the corner enclosed by the arrow. To examine this theoretical effect I created two conditions in the actual experiment by asking the participants which object stands out most from the environment – no reference to wayfinding. They only differ in the presentation of an arrow. The results, however, do not show a difference of outlier preference between these conditions. Therefore, presenting an arrow does not lead to different object preferences. This is in line with the findings from Chapter 8.4, where I showed that the position preference in a landmark preference task does not differ between intersections with an arrow indicating the direction and ones with words (left/right) indicating the direction. That means that the differences between results from Chapter 6 and 8 must accounted for somehow else.

The second question was whether changing the task influences the participants' decision or whether different tasks lead to different preferences. In Condition 1 and 2 the task was to choose the different object, in Condition 3 and 4 the task was to choose the preferred object for giving route directions. The results revealed a significant difference between these two types of conditions. In the first two conditions the participants chose the outlier as often as possible. Different results were found in the landmark preference tasks. Here another aspect influences the participants' decision: the structural salience. So it can be deduced that the different tasks measured different saliences, and in combination with the first question, not the availability of an arrow is responsible for the different results but rather the focus on perceptual (visual) characteristics on the one hand and decisions for landmarks (cognitive) on the other hand. Another interesting finding is that the position preference does not differ between the Condition 3 and 4. It seems that the participants preferred the same landmarks for giving route directions and for finding the path again for themselves, but this is beyond the scope of this Thesis.

The third question was whether the contrast between the outlier and the surrounding influences the participants' decision. The results show that the outlier is preferred in almost 100% of cases if the contrast to the surrounding is high enough (perceptually clear to identify) and if the task was to identify the outlier. Therefore it can be concluded that the participants can identify the outlier once it is sufficiently visible. This effect was weakened if I asked the participants about their landmark preference. However, even then an increase of the outlier preference with an increasing contrast is visible. But, this increase levels out at a mean preference around 60%. This seems to be a maximum for the influence of the visual salience (threshold). However, the chance level should be considered. When done, a weight for the visual salience of around 0.35 (0–1) occurs. I will return to this topic later in Chapter 13.

The fourth question was whether the findings of Experiment 5 could be replicated. In Experiment 5, I created outliers with a maximum contrast (180°) to the identical ones (surrounding). And I asked the participants which object they would chose to give route directions. In the present experiment I had this arrangement in the combination of task Condition 4 and contrast Condition 180°. When comparing these findings with those from the previous experiment, the same landmark preference distribution can be seen over the four positions. Therefore, I replicated the results and verified these findings.

The fifth question was how the visual and the structural salience interact. It is visible that an increase in the influence of the visual salience leads to a decrease of the influence of the structural salience. But, the visual salience does not eliminate the influence of the structural salience. Rather, the influence of the structural salience seems to be generally stronger. In Chapter 13 of my thesis this will be analyzed in more detail as a part of computing the weighting factors of visual and structural salience.

The decision times do not differ significantly between the different instructions, but, the contrasts lead to different decision times. However, this result could be explained by the interaction between the two saliences. In conditions where the participants had to choose the object that stands out, the decision times decreased with increasing contrast. This could be explained by the increasing simplicity of outlier identification. More interestingly, in the conditions where the participants had to choose a landmark no decrease occurred. Meaning, that the difficulty of identifying the outlier does not influences the participants' decision times. It seems that in this case the presence of a clear outlier does not lead to additional decision time and therefore not to an additional cognitive decision process. But this should be examined in more detail in further experiments.

9.3. Visual salience: how important is it?

At the beginning of this chapter I proposed the question how visual and structural salience interacts.

First, the visual salience could be defined as the contrast of an object to the surrounding, or in other words, as the contrast to other objects in the surrounding. That means on the one hand that if one object at an intersection stands out from other objects it will be chosen more frequently than expected by chance and if the contrast is high (over 22° distance in the color circle) it will be chosen almost always. The just noticeable difference for colors is around 3° as described by Mahy, Van Eycken, and Oosterlinck (1994). However, the experiments here do not focus on this perceptual issue and were not designed to detect such small differences. On the contrary, I want to investigate the just noticeable color difference for all participants under “normal” visual and experimental conditions.

Second, the effect of the visual salience differs between layouts which are labeled as intersections (including an arrow providing the direction) and intersections outside a wayfinding context. In a wayfinding context the effect of the visual salience is weakened in comparison to no context. If, at an intersection, one object visually stands out it will be chosen at about chance level but less often than the concept of visual salience would suggest. Here the structural salience, the position of an object, influences the participants’ decision as well. Generally, I conclude that the influence of structural salience is stronger than the influence of visual salience, because in nearly all conditions in which participants were asked which object they would use for route directions, the influence of the structural salience is visible. Further, the preference for the visual salient object never reaches the maximum value which I found for an influence of the visual salience in isolation. Even with the contrast set to a maximum, the visually salient object is not preferred in more than 60% of cases, whereas the objects located at the ideal landmark positions (before and behind the intersection in the direction of turn) are preferred in 75% of the cases.

However, the position of the outlier has to be taken into consideration. When the outlier is placed at the ideal landmark position the visual and structural salience are congruent, and then the object at this position is preferred almost always. The case when the visually salient object is placed at a position which is not the ideal one (e.g. behind the intersection and opposite to the direction of turn) is even more interesting. In this case the saliences are incongruent. How participants decide when the visual and structural saliences are incongruent is described in detail by Greger, Albrecht, Röser, and Ragni (in preparation). Recently, Greger (2015) described a process tree for the preference process. On the one side the participants could only look for the visually salient object (no reasoning). Or, on the other side the participants could consciously decide to either consider the visually salient object or not. If they decide to prefer one of the not visually salient objects they again had to decide if they prefer the object at the structurally salient position or one of the remaining. This process tree develops an approach to explain the cognitive decision process in landmark selection. Based on this and with an experiment inspired by Experiment 5, Greger et al. (in preparation) developed an ACT-R model to compute this salience interaction.

The general findings in this chapter are in line with the findings of Peters et al. (2010) who could show that the visual salience of an object (color difference) does not influence the participants' decision and landmark preference as much as other factors, for example the structural salience. Also, Ohm, Müller, Ludwig, and Bienk (2014) resumed in their eye-tracking study that not only the visual salience of objects should be considered for identifying the ideal landmark in a large scale indoor environment but also structural and contextual features should be taken into account.

10. The interaction of structural and viewpoint-based salience

In all previous experiments the intersections were presented in an allocentric perspective. My findings show that the structural salience (allocentric) of landmarks strongly depends on the specific route. When a receiver of a route instruction has to turn left the direction-giver prefers to mention landmarks on the left side of the street; if she has to turn right, the direction-giver prefers to mention landmarks on the right side of the street – most often the positions before the intersection are selected. But could the same results be found in an egocentric perspective, too? In this perspective the observer's point of view influence what she sees from the environment and which parts of the environment are visible: the objects differ in their degree of visibility (visible part), in their distance to the observer and the orientation in relation to the observer varies. Further, what are the implications of this viewpoint-based salience on the landmark-position preference? Thus, the main issue of this chapter is:

1. Does the position preference differ between an allocentric and an egocentric perspective?
2. Could this difference be explained by the components of the viewpoint-based salience?

10.1 Structural and viewpoint-based salience at an intersection (Experiment 7)

This experiment is a replication of Experiment 3 – with one essential difference, the environment is now presented in an egocentric perspective (parts of this are published in Röser, Krumnack, et al., 2012). Note that in an egocentric perspective, the landmarks at the four corners of the intersection vary in their viewpoint-based salience. The landmarks before the intersection are located closer to the observers' point of view than the landmarks behind the intersection and some facades of the landmarks are only visible in parts (as an illustration see Figure 10.1). Based on my landmark-preference model I expect that the landmark preferences in an egocentric perspective differ from those in an allocentric perspective.

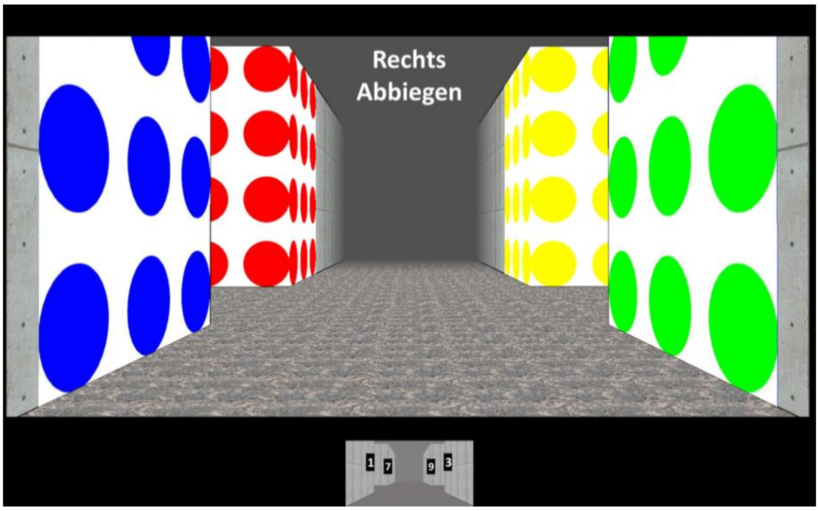
10.1.1 Participants, material and procedure

A total of 23 students from the University of Gießen participated in this experiment (15 females) with a *mean age* of 23.52 years (*range*= 18–33). All participants provided informed written consent and they received course credits or money for participation.

Material

As in the previous experiments, screenshots of the standard intersection were used, but now in an egocentric perspective. The 12 intersections included dark gray walls and floors and a light gray haze, which prevents the participants from seeing any further than the next intersection. The participant's position was located in the middle of the street before the intersection and with a viewing direction straight ahead and horizontal (neither looking up or down, nor to the left or right). As landmarks, the same objects as described in Experiment 3 were used: circles in the colors red, green, blue, and yellow. To ensure a good visual perceptibility and recognizability of the distinguishing landmark features, the facade of the landmark consisted of 12 circles of the same color and covered the wall from the bottom to the top (Figure 10.1). The route direction is presented by the letters "Rechts Abbiegen" ("turn right") or "Links Abbiegen" ("turn left") floating in midair in the middle of the intersection.

The screenshots were presented on a standard TFT computer screen (19´´), and Superlab 4.5 (Cedrus Corporation 1991–2006) was used for executing the experiment and data recording.



("Rechts abbiegen" = "Right Turn")

Figure 10.1. Exemplary intersection in the egocentric maze with the four landmarks at the four positions of the intersection and the answering instruction below the screenshot.

Procedure

The procedure was the same as in Experiment 3. The task was to choose the object participants would prefer to give route directions. After seeing the whole maze from an allocentric perspective each of the 12 intersections along the path in an egocentric perspective were shown. Below each intersection the corresponding answering instruction was presented (see Figure 10.1). The numeric keypad of a regular keyboard was used as an input device (see Chapter 5).

10.1.2 Results and discussion

With 93% a strong preference for landmarks located in the direction of turn was found. The mean percentage of the remaining landmark selections are presented in Table 10.1. As can be seen, the positions before the intersection were selected 2.02 times more often than the positions behind the intersection.

This position preference differs significantly from the position preference influenced only by the structural salience ($\chi 2(3)=10.972$, $p=.012$; Table 10.1). The positions opposite to the direction of turn do not change between an allocentric and egocentric perspective. However, an increase of preference for the position behind the intersection in the direction of turn is accompanied by a decrease of preference for the position before the intersection in the direction of turn.

The participants chose their preferred object on average after 5477ms (*SEM*=634ms).

Table 10.1. Results of Experiment 7

Selected landmark positions [%]		
	Results of Exp. 7	Structural salience
Behind the intersection, opposite to the direction of turn	**01.45**	04.64
Behind the intersection, in the direction of turn	**30.80**	19.13
Before the intersection, opposite to the direction of turn	**05.43**	04.21
Before the intersection, in the direction of turn	**62.32**	72.02

Discussion

As already mentioned before, the result here differs significantly from the findings of the structural salience (Chapter 8), which means that the decisions in an egocentric perspective are not only determined by the structural salience. In this experiment I found clear preferences for the positions in the direction of turn, but the positions before and behind the intersections do not differ as strongly as in the allocentric experiment. This higher preference of the landmarks behind the intersection could be explained by a larger visible part of the facades of the landmarks behind the intersection. The facade is only partially visible for the landmarks before the intersection, whereas for the landmarks behind the intersection one facade is fully visible and the other facade is again partially visible. Additionally the landmarks behind the intersection had a larger distance to the observers' point of view than the landmarks before the intersections. This also could explain the different preferences.

I replicated this experiment two times with variations of the landmark material and the kind of landmark selection to verify these results:

In the experiment "Video" (*N*=20; 11 females; 20 students; *mean age*=22.90 years; *range*= 19–29) the task was identical to the task in this experiment, with the difference that a video presented the path through the maze. The video stopped at each intersection and the participants then had to choose the landmark they would use to give route directions (for further details see Röser, Krumnack, et al. 2012). Moreover, I used different shapes in different colors as landmarks. In this experiment the landmarks in the direction of turn are also chosen in 89% of the cases. The position before the intersection in the direction of turn is chosen 1.44 times more often than the position behind the intersection.

In the experiment "landmark placement" (*N*=18; 9 females; all had at minimum a higher education entrance qualification; *mean age*=24.67 years; *range*= 20–48) the participants' task was to learn a written route direction (e.g. turn left at the church). Afterwards they saw blank intersections and were asked to indicate at which position of the intersection they would locate the landmark ideally to give route directions (for further details see Röser, Hamburger et al. 2012). In this experiment the locations in the direction of turn are also chosen in 93% of the cases. However, there the position before the intersection in the direction of turn is chosen only 1.13 times more often than the position behind the intersection. One explanation for the differences in the preferences for the position before and behind the turn could be a small variation in the distance between the observer and the middle of the intersection which will be described and examined in the following section.

The difference between Experiment 7 and the findings of Chapter 8 might be that the environment was presented in an allocentric perspective in Chapter 8 and in an egocentric here. Spatial cognition research has identified several important differences between the two perspectives (Klatzky, 1998). However, my present data indicate that the difference is also important when people select landmarks at an intersection when giving route directions. There could be two explanations for the different position preferences between the results of Chapter 8 and the results here:

1. Two different general position preferences can be found. The position preferences in the allocentric perspective are independent from the ones in the egocentric perspective.
2. Only one general position preference can be found. However, the position preference in the egocentric perspective is moderated by the viewpoint-based salience.

In the next sections I vary the parameters of the viewpoint-based salience. If they moderate the effect of the general structural salience, I should find differing position preferences. If there is an independent position preference in the egocentric perspective, I should find position preferences not correlated to the variation of the parameters.

10.2 Structural and viewpoint-based salience: variable distances (Experiment 8)

Experiment 8 is a replication of Experiment 7 – with one essential difference, now the observer's point of view varies. With this experiment I examine and vary one factor of the viewpoint-based salience in detail: the distance between the observer and the middle of the intersection. The assumption is that if the distance is an essential part of the viewpoint-based salience, the variation should influence the participants' landmark preference significantly.

10.2.1 Participants, material and procedure

A total of 20 students from the University of Gießen (15 females) with a *mean age* of 24.15 years (*range*= 19–43) participated in this experiment. All participants provided informed written consent and they received course credits or money for participation.

Material

As in the previous experiments, screenshots of the standard intersection in an egocentric perspective were used. The observer's point of view was always in the middle of the path with a viewing direction straight ahead and horizontal. However, the distance to the middle of the intersection was varied as follows: one with a larger distance to the middle of the intersection (far; Condition 1), one with a medium one (medium; Condition 2) and one with a short one (near; Condition 3). See Figure 10.2 for the three distances. In this experiment, colored circles (see Figure 10.2) served as landmarks and the colors were counterbalanced over all positions and conditions.

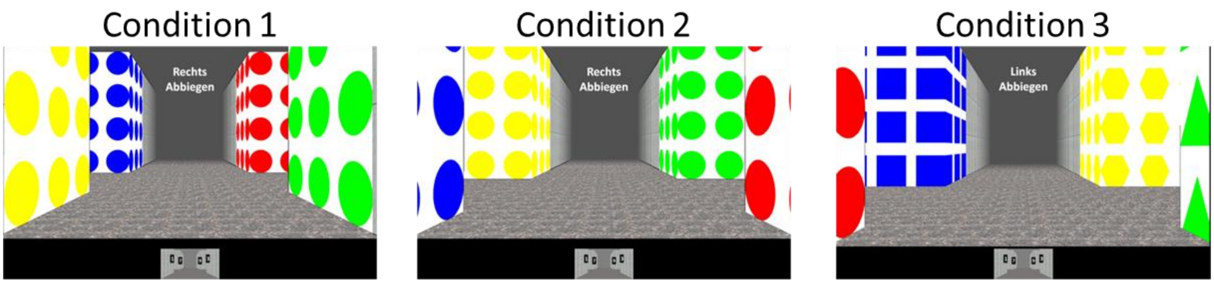


Figure 10.2. Examples of the conditions of Experiment 8. From left to right: far, medium, and near. In the middle of the intersections, floating in midair: route directions ("Links Abbiegen" = "Left Turn" and "Rechts Abbiegen" = "Right Turn"). Below the intersection: the corresponding response keys.

The screenshots were presented on a standard TFT computer screen (19´´), and Superlab 4.5 (Cedrus Corporation 1991–2006) was used for executing the experiment and data recording. The numeric keypad of a regular keyboard was used as an input device (see Figure 5.2).

Procedure

The task and general procedure was the same as in Experiment 7. Participants were informed they would see images of intersections representing a virtual path through a rectangular environment (here they did not see an allocentric map of the whole maze before the experiment). The instruction stated that the task was to decide which of the presented landmarks at each intersection they would prefer to give route directions. It was pointed out that the receiver of the directions is a person unfamiliar with the environment. At each intersection, the participants had to select their preferred landmarks by pressing corresponding keys on the keypad. Overall, 72 intersections were presented in random order.

10.2.2 Results and discussion

Five participants were excluded from the analysis due to software problems (no data recording) and idiosyncratic color preferences (preferences of the yellow objects were less than 6%). The landmark preferences of the remaining participants as a function of viewing distance are presented in Table 10.2. As shown in this table, in all three distance conditions, the two landmarks in the direction of turn were clearly preferred: “Far”, 99%; “Medium”, 97%; “Near”, 95%.

Table 10.2. Results of Experiment 8

	Selected landmark positions [%]			
	Far	**Medium**	**Near**	**General**
Behind the intersection, opposite to the direction of turn	00.28	01.39	03.06	01.57
Behind the intersection, in the direction of turn	33.89	54.17	55.83	47.96
Before the intersection, opposite to the direction of turn	01.11	01.67	01.94	01.57
Before the intersection, in the direction of turn	64.72	42.78	39.71	48.89

In addition, I found that the landmark preference varies as a function of the distance between participant and the middle of the intersection (Table 10.3). The position preference in the Condition “Far” differs significantly from those in the Condition “Medium”

($\chi^2(3)$=19.919, p<.001) and "Near" ($\chi^2(3)$=27.254, p<.001), but "Medium" does not differ significantly from "Near" ($\chi^2(3)$=1.236 p=.508).

The mean decision time was 3460ms. In the Condition "Far" the participants answered on average after 3444ms, in the Condition "Medium" after 3702ms and in the Condition "Near" after 3188ms. These decision times do not differ significantly ($F(2)$=.761, p=.477).

Discussion

The results seem quite robust and indicate that direction givers indeed prefer to describe a route by using landmarks which are located in the direction of turn. However, the preference for landmarks before or after the intersection was moderated by the participants' position within the environment. The farther away from the intersection the participant was, the more often a landmark before the intersection was selected. The closer to the intersection the participant was, the more often a landmark behind the intersection was selected. However, the visible part also varies with various distances. The farther away, the more of the landmark is visible before the intersection and vice versa (see Figure 5.2).

The findings are in line with my assumption – a variation of the distance leads to significant landmark preference differences, which means that the distance is an essential component of the viewpoint-based salience. How important the distance is in relation to the other factors of the viewpoint-based saliences and how they are related to each other will be described in Chapter 13.

10.3 Structural and viewpoint-based salience: variable orientations (Experiment 9)

Experiment 9 is a replication of Experiment 7 and Experiment 8 – with the essential difference that now the participants' position vary between the left and right side of the street. This variation results in different parallaxes, and thus in different spatial relations between the observer and the landmarks. In both previous experiments in this chapter the viewpoint-based salience was identical for the positions in and opposite to the direction of turn, although they differ in their viewpoint-based salience between the positions before and behind the intersection. If the viewing position is located in the middle of the path and the viewing direction is straight ahead along the middle of the path the distance to the landmarks opposite and in the direction of turn behind the intersection are identical. The same applies to the position before the intersection. Also both landmarks behind as well as both landmarks before the intersection had the same visible part. To examine different viewpoint-based saliences for all four landmark positions, the viewing direction of the observer is varied. This leads to different orientations of the landmarks in relation to the observers´ point of view and viewing direction. The assumption is that if the orientation is an essential component of the viewpoint-based salience, the variation should influence the participants' landmark preference significantly.

10.3.1 Participants, material and procedure

A total of 412 individuals started the online-experiment and 236 of them completed it (175 females; mean age=24.48, range=18–52). They were recruited via an email distributed among all students at the University of Gießen. All participants provided informed consent and participation was voluntary.

Material

As in the experiments before, screenshots of the standard intersection in an egocentric perspective were used. In this experiment I varied the viewing direction of the participants by varying the point of view to the left and right side of the path. This resulted in different orientations of the objects in relation to the viewing direction of the observer. The points of view were either in the middle of the street, in the direction of turn (standing either half-left on the street for a left turn or half-right on the street for a right turn), or opposite to the direction of turn (standing half-left on the street for a right turn or half-right on the street for a left turn). “In” and “opposite” to the direction of turn here means that the viewing position lies exactly between the middle of the intersection and the wall on this side of the path. The conditions are illustrated in Figure 10.3. In Condition 1 the participants look slightly towards the direction opposite to the turn, in Condition 2 they look straight ahead, and in Condition 3 they look slightly towards the direction of turn. Each point of view was presented three times for each direction, resulting in 24 intersections. LimeSurvey 2.05+ was used for material presentation and data collecting.

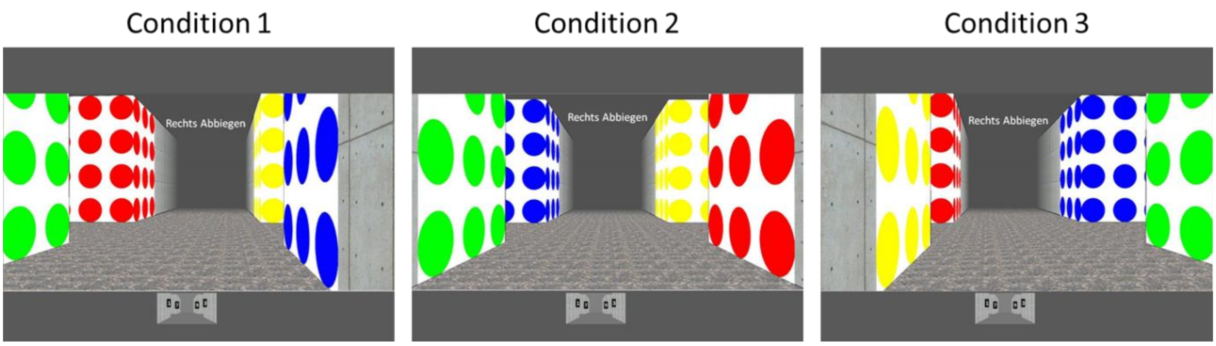


Figure 10.3. Example of the conditions of Experiment 9 for a turn to the right. From left to right: in the direction of turn, in the middle, opposite the direction of turn. In the middle of the path, floating in midair: route directions (“Rechts Abbiegen” = “Right Turn”). Below the intersection: the response template. For a turn to the left the positions are vice versa.

Procedure

The task and general procedure was the same as in Experiment 8. The instruction (which landmark will be preferred to give route directions), and the intersections and landmark material as described above (with the difference of the point of view). The participants saw screenshots of the intersections in a random order and below each intersection the numbers for the particulate object are presented (the numbers 1, 3, 7 and 9; see Chapter 5 for further details). To answer, which object they prefer, the participants had to enter the corresponding number in the appropriated field. Overall, the 24 intersections were presented in random order.

10.3.2 Results and discussion

The landmark preferences of the participants as a function of the point of view and viewing direction are presented in Table 10.3. As shown in this table, in all three orientation conditions, the two landmarks in the direction of turn were clearly preferred (Condition “in the direction of turn”, 82%; Condition “in the middle”, 92%; opposite the direction of turn, 94%).

Table 10.3. Results of Experiment 9

	Selected landmark positions [%]		
	In the direction of turn	In the middle of the street	Opposite the direction of turn
Behind the intersection opposite to the direction of turn	15.04	04.13	02.42
Behind the intersection, in the direction of turn	35.38	48.76	59.43
Before the intersection, opposite to the direction of turn	03.42	03.48	03.54
Before the intersection, in the direction of turn	46.17	43.63	34.61

The position preferences in the Condition “In the direction of turn” differ significantly from those in the Condition “In the middle of the street” ($\chi^2(3)=13.188$, $p=.004$) and “Opposite the direction of turn” ($\chi^2(3)=29.845$, $p<.001$). But the position preference “in the middle of the street” does not significantly differ from that in the Condition “Opposite the direction of turn” ($\chi^2(3)=4.910$, $p=.178$).

For analyzing the decision times the mean values for three participants had to be replaced by the mean value of the remaining sample because they had values about 3*SD* higher than the mean. In the Condition “In the direction of turn” they answered on average after 11278ms, in the Condition “In the middle of the street” after 10349ms and in the Condition “Opposite to the direction of turn” after 10129ms. This decision times differ significantly ($F(1.631)=6.722$, $p=.003$). The decision times in the Conditions “opposite to the direction of turn” is significantly faster than in the Condition “in the direction of turn” ($t(234)=-4.146$, $p<.001$). The Condition “in the middle of the street” does not differ from the other conditions (“middle” and “in” $t(234)=-2.305$, $p=.022$; “middle” and “opposite” $t(234)=0.722$, $p=.471$).

Discussion

Again, the results reveal that the viewpoint-based salience moderates the effect of the structural salience and that both influence the participants’ landmark preference. A variation of the point of view results in different viewing directions and different orientations of the landmarks in relation to the observer and leads to a variation in the participants’ landmark preference. The relatively high preference for the position behind the intersection opposite to the direction of turn, when the participants look towards this direction, is particularly interesting. This highlights the influence of the viewpoint-based salience. Also, the analyses of the decision times show faster decisions if the ideal landmark positions (the ones in the direction of turn) are located in the direction of view.

I replicated this experiment three times with a variation of the landmark material (different shapes in different colors or different gray colors) and/or a variation of the viewing position. In all cases I found shifts within the landmark preferences with a change of the viewing direction.

The findings are in line with my assumption that a variation of the orientation leads to significantly different landmark preferences, meaning that the orientation is an essential part of the viewpoint-based salience. How important the orientation is in relation to the other factors of the viewpoint-based saliences and how they are related to each other will be described in Chapter 163.

10.4 Do we prefer what we see?

At the beginning of this chapter I proposed two questions. First, does the position preference differ between an allocentric and egocentric perspective? The results revealed that the position preference in an egocentric perspective is significantly different from the preferences in an allocentric perspective. Second, could this difference between the allocentric and egocentric perspective be explained by the viewpoint-based salience? To investigate this issue I varied the distance between the observer and the middle of the intersection in Experiment 8 and the viewing direction (orientation) of the observer in Experiment 9. In both experiments the variations influenced the position preference significantly. The findings of the systematical variation of all three parameters of the viewpoint-based salience – distance, orientation and visible part – allow for the conclusion that the viewpoint-based salience moderates the effect of the structural salience. If this was not the case, the results should have been unsystematic. Additional I asked the question, whether the position preferences in the egocentric perspective are based on the same structural salience as in the allocentric perspective. The systematical variation of the position preferences in Experiment 8 and 9 allows the conclusion that it is the same structural salience, but moderated by the factors of the viewpoint-based salience in the egocentric perspective. However, whether all parameters of the viewpoint-based salience are necessary to compute the participants' position preference will be described in Chapter 13 of my thesis.

The empirical results underline the assumptions of Winter (2003) that the visibility – or my concept of viewpoint-based salience – influences the landmark position preference. Additionally, Winter (2003) stated that “when a subject moves along the right side of the street, she prefers facades on the left side, due to the more convenient observation distance and viewing horizon” (p. 359). However, Winter (2003) forgot to consider the route direction. If a subject moves along the right side of the street, she does not necessarily prefer landmarks on the left side. Which landmarks she will prefer also depends on the direction of turn at this intersection. Here, I demonstrated that neither the structural salience in isolation nor the point of view and viewing direction of the participant alone determine the ideal landmark (position). Only the combination of both factors represents the participants’ preference.

11. The interaction of visual, structural and viewpoint-based salience

In this chapter I present the experiment with this thesis' highest ecological validity, it represents an "artificial reality". The setting is an abstraction of a "real" environment: an intersection from an egocentric perspective with differently colored landmarks and it combines all three saliences described and examined before – the visual, structural and viewpoint-based salience. The experimental question remains the same: which is the preferred and most important salience for giving route directions? However, now a possible interaction of the three saliences shall also be investigated. At the end of this chapter I will additionally present an experiment by Schackow (2012) which shows how even more realistic experiments could be designed to consider the ecological validity.

11.1 Visual, structural and viewpoint-based salience (Experiment 10)

In this experiment the settings of Experiments 5 and 7 were combined. This resulted in screenshots of an egocentric intersection (viewpoint-based salience) with colored circles as landmarks at the four corners of the intersection (structural salience). Three of the landmarks had the same color (identical) and one of them differed (outlier) significantly (visual salience).

Based on my landmark-preference model and the previous findings, I assume that all three saliences interact and influence the participants' decisions.

11.1.1 Participants, material and procedure

In total 95 persons participated in this online-experiment. They were recruited via an email distributed among all students at the University of Gießen. All participants provided informed consent and participation was voluntary. A 56 people (28 females; 43 students; *mean age*=24.95; *range*=18–46) completed the experiment.

Material

As described this experiment combined the settings of Experiments 5 and 7. The screenshots of the single intersections (16 intersections in total) were presented in an egocentric perspective and the position of the observer was always located in the middle of the path with a fixed distance to the middle of the intersection; equivalent to the viewing position of the Condition “middle” in Experiment 9. Four colored circles served as landmarks; three of them had the same color, and one was different (the outlier; for further details see the material description in Experiments 5 and 6). To create 32 distinct colors for the 16 intersections I used a color circle and chose each color 11.25° away from the next one (see 9.1.1 for more details). As the outlier the complementary color was used, meaning that the outlier color had the maximum contrast (hue) to the three objects with the identical color (Figure 11.1).

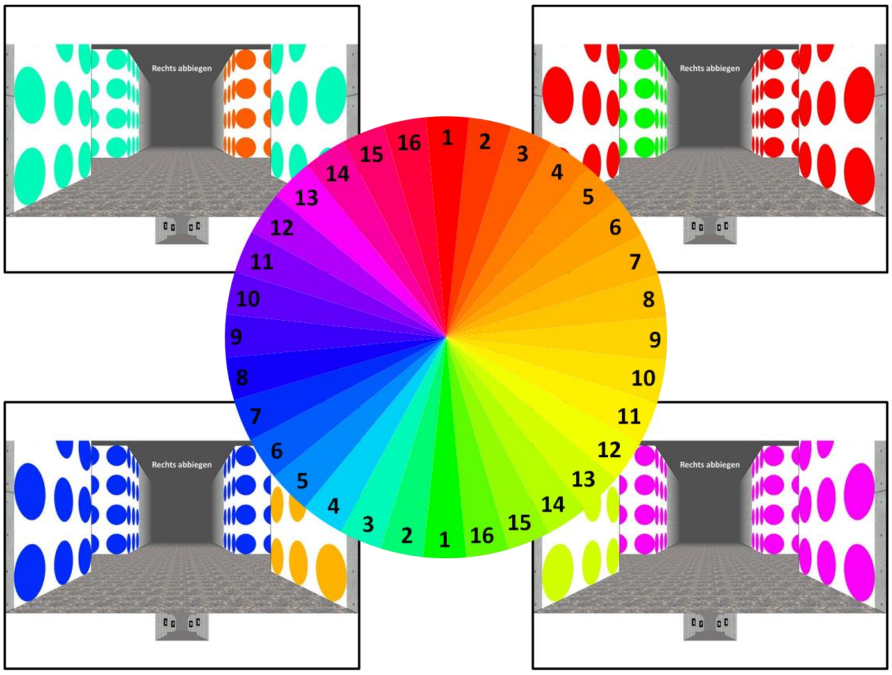


Figure 11.1. Exemplary intersections of Experiment 10 with the four outlier positions and different examples of color contrasts. Below the intersection the response template was presented. The center shows the color circle of the used landmark colors. Identical numbers in the color circle demonstrate the corresponding colors (identical ones and outlier) for one intersection.

At each position for a left and a right turn an outlier was presented, resulting in 16 intersections. I created two versions: each outlier color in the first version was the *identical* color in the second version and vice versa. For an example of the setting see Figure 11.1. LimeSurvey 2.05+ was used for material presentation and data collecting.

Procedure

On the first slide of the experiment it was explained that the participants would see a path through a maze where at each intersection four objects were presented. The participants were asked to imagine that they have to give route directions based on the given information. The instruction also stated that the participants had to decide/indicate which objects they were going to use for the route directions at every intersection. To select one object they had to press the corresponding key on the keyboard (the number 1, 3, 7 and 9 on the number block, see Figure 5.2). The response keys were presented below each slide in form of a schematic intersection (Figure 11.1) and an exemplary intersection with the corresponding numbers as landmarks was shown. Afterwards, the participants were randomly distributed to one of the two versions and the experiment started with the 16 intersections in a random order.

11.1.2 Results and discussion

Overall the outliers were preferred in 63% of cases which is significantly above than chance level ($t(55)=10.281$, $p<.001$). The landmark preferences in dependence on the position of the outlier are presented in Table 11.1.

Again I found preferences for the positions in the direction of turn (75% of all cases). The overall position preference in this experiment differed significantly from a uniform distribution (Table 11.1) and the position preference expected for the influence of visual salience ($\chi^2(3)=28.280$, $p<.001$), as well as the sole influence of structural salience ($\chi^2(3)=46.382$, $p<.001$). Also, it differed significantly from the position preference of

Experiment 7 (structural and viewpoint-based salience; $\chi^2(3)=95.173$, $p<.001$). The position preferences between the combination of structural and visual salience and the experiment here differed by trend ($\chi^2(3)=6.753$, $p=.080$).

Table 11.1. Results of Experiment 10

	Preferred landmarks [in %]				
	Overall	Position of the outlier			
Preferred Position		Behind the intersection, opposite the direction of turn	Behind the intersection, in the direction of turn	Before the intersection, opposite the direction of turn	Before the intersection, in the direction of turn
Behind the intersection, opposite to the direction of turn	12.28	**45.54**	01.79	01.34	00.45
Behind the intersection, in the direction of turn	30.69	20.98	**75.45**	16.52	09.82
Before the intersection, opposite to the direction of turn	12.50	01.34	00.89	**47.32**	00.45
Before the intersection, in the direction of turn	44.53	32.14	21.88	34.82	**89.29**
	$\chi^2(3)=28.280$ $p<.001$[1]				

Note. [1]testing against uniform distribution

The participants' average decision time was 9430ms. When the outlier was placed at the position behind the intersection opposite to the direction of turn the mean decision time was 9488ms, for the position behind the intersection in the direction of turn 8936ms, for the position before the intersection opposite to the direction of turn 10624ms and for the position before the intersection in the direction of turn 8674ms. These decision times differed significantly ($F(2.679)=3.017$, $p=.037$) from each other, but none of the post-hoc t-tests is significant (see Appendix G). However, descriptively faster decision times could be found for the positions in the direction of turn in comparison to positions opposite to the direction of turn.

Let us take a final detailed look at the descriptive distribution of the decision times. In a first step all decision times above three standard deviations of the mean decision time were replaced by the average decision time of this participant. Afterwards, I clustered these decision times in one second steps in order to provide a histogram (0–32 s.; minimal decision time: 1.94 s.; maximal decision time: 31.54 s.). The histograms over all decision times are presented in Figure 11.2 and show that most decisions were made in around 5 seconds. In 50% of the cases the participants answered after 2.00 – 7.33 seconds. Otherwise decision times between 7.34 and 31.54 seconds were found. The decision times for specific salience combinations are even more interesting. Therefore, I only considered decision times between 1.94 seconds (minimum) and 20 seconds (higher decision times occurred hardly ever). Additionally, the frequencies of the decision times are now presented as relative frequencies (%; all decision times between the minimum of 1.94 and 20 s. add up to 100%), which allows for comparability. The second histogram in Figure 11.2 shows the distribution of the decision times when the visually salient stimulus was located at the structurally salient position. It becomes clear that more than 50% of the landmark preference decisions were made between 1 and 7 seconds, which is comparable to the decision time distribution over all decision times. When the visual outlier was not located at the structurally ideal landmark position is even more interesting and the decision-time distributions can be seen in Histogram 3 of Figure 11.2. The decision times are separated for the cases in which the visually salient stimuli were preferred and where the structurally salient stimuli were preferred. The decision times of the preference for the structurally salient objects again show a peak around 5 seconds, in contrast, the decision times of the visually salient objects have their peak at around 9 seconds. Furthermore, a second peak occurred for the structurally as well as for the visually salient objects. This could indicate that two different processes are involved.

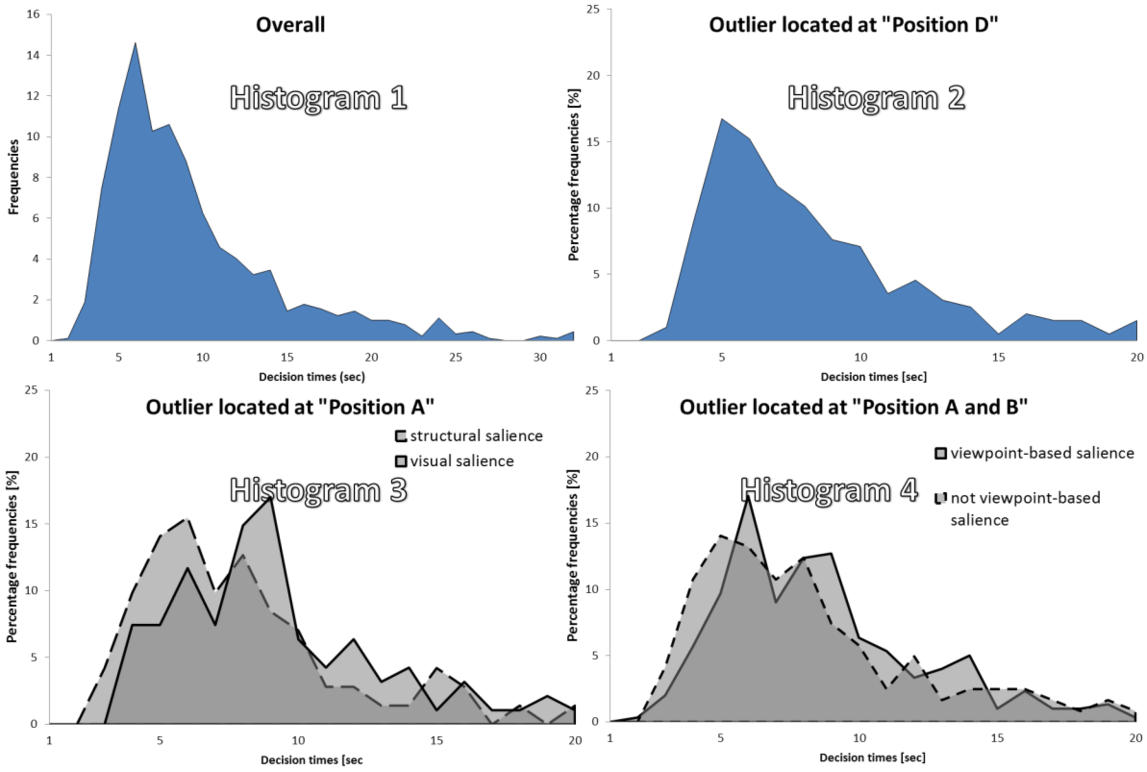


Figure 11.2. The four histograms show the decision time distributions. Overall conditions (Histogram 1) and the case that the visually salient object (the outlier) was located at the structurally salient position (Position D [see Figure 5.1], at the position before the intersection and in the direction of turn; Histogram 2). For Histogram 3 the decision time distributions are presented when the visually salient object is located at a position which is not the structurally salient one (Position A; behind the intersection and opposite to the direction of turn). Two distributions are shown, one for the case that the visually salient object is preferred and one for the preference of the structurally salient object. In Histogram 4 the decision time distributions for the preferences of landmarks located at the positions behind the intersection (viewpoint-based salient ideal object positions) and for objects at the positions before the intersections are shown (their only cases are considered in which the outlier was placed at the two positions behind the intersection).

The results of Experiment 7, 8 and 9 showed that in an egocentric perspective the positions behind the intersections were preferred more often than in an allocentric perspective. I concluded that this is due to the influence of the viewpoint-based salience. Therefore, I now present the decision times for the cases when the outliers are located at the positions behind the intersection. Then, I compare the decision times of the preferred objects at these positions to the decision times of the preferred objects at the positions before the intersection. This is shown in Histogram 4 of Figure 11.2. Again, two peaks are visible, the first at around 5 seconds and the second at around 8 seconds. However, this is difficult to interpret, as the saliences of the landmark positions are not clearly definable: the position behind the intersection in the direction of turn for example is the second most preferred structural position, but how the visual and the viewpoint-based salience interact in detail and which mechanisms are involved is not clear yet. Still, over all presented histograms it is visible that two separate mechanisms for landmark preferences at an intersection should be existent, when more than one salience is involved. The two possible processes are briefly discussed in Chapter 12.3 and are currently investigated and modeled by Albrecht, Ragni and myself.

Discussion

In this experiment I combined the influence of the visual salience (one outlier color), the structural salience (the four positions at the intersection), and the viewpoint-based salience (egocentric perspective). The distribution of the position preferences is different to the previous findings. The visually salient object is preferred more often than by chance just like objects at the ideal landmark position. Also, objects located at the viewpoint-based salient position (behind the intersection) are preferred more often compared to prior experiments. However, the effects of the visual salience as well as for the structural salience are diminished in contrast to the experiment where only one of the saliences was examined. Furthermore it is visible that if two saliences are congruent, they mutually reinforce each other. This is also visible within the decision times. Generally, the decision times are fast if the visually salient object was located at the structurally ideal landmark position. Moreover, this can also be seen in the decision time histograms. So, the overall landmark-position preferences could only be explained by considering the influence and the interaction of all three saliences. This interaction, including the weighting factors for the three saliences will be addressed in Chapter 13.

The presented environment is still artificial, however, of all my experiments presented here it is the one providing the most realistic image of a real world situation (for the transfer of experience and knowledge from virtual to real environments see Bailey & Witmer, 1994; Péruch, Belingard & Thinus-Blanc, 2000; Wallet, Sauzéon, Rodrigues & N'Kaoua, 2009): egocentric perspective of a four-way intersection with different objects in different colors and the question which one is the most preferred one for giving route directions. The results revealed that all three presented saliences should be considered to understand the cognitive process of landmark preference. However, how does the result look like if pictures of real environments are used instead of virtual environments?

11.2 Route descriptions and pictures of real intersections

In this section I want to briefly introduce how an examination of my assumptions could look like in any more realistic setting. One of my Diploma-students (Schackow, 2012) adopted my general environmental setting for her thesis (*N*=32; 24 females; 32 students; *mean age*=21.50 years; *range*= 19–27) to examine which landmarks participants' are using at real intersections. Therefore she presented pictures of 12 four-way intersections of an unknown environment (typical German downtown four-way intersections). To control for the influence of the visual as well as semantic salience the intersections are either presented in the original form or in the mirrored form (across a line in the plane) and all signs and placards or individual information (e.g. number plates) are deleted (see Figure 11.3). At each intersection (presented for 6 seconds) the task was to memorize the presented directions (by an arrow) and the landmark they would use to describe the path later on. Afterwards the participants had to write down the memorized way (handwritten), intersection by intersection. This was repeated three times. The analysis of the third and last created route direction revealed that, over all, landmarks at the position before the intersection and in the direction of turn are the most often described ones. However, when visually salient (e.g. red house) or semantically salient object (e.g. container) was located at one of the other landmark positions, the preference is more unspecific. In follow-up experiments it will be very important to find intersections with clearly definable visually or semantically salient objects to evaluate my model in detail. Or, to find a possibility to determine the object saliences for the intersections presented in this experiment. The aim is to compute the corresponding model and to compare it to the participants route directions. However, this explorative study showed that especially the effect of the structural salience could be found at a real four-way intersection (ecological validity).

Figure 11.3. Two examples of the pictures of an intersection used by Schackow (2012; left: p. 62; right: p. 63). The left picture shows an intersection with one visually salient object (the red facade), the left one represents an intersection without visual difference, but the viewpoint-based salience of the house in the back and to the left is low.

12. Comparison and interpretation of the empirical findings

In five chapters I examined the landmark position preferences for single saliences and combinations thereof. In the following I compare them for understanding the underlying mechanisms, to show similarities and differences, and to discuss and interpret the major points and their meaning.

12.1 Landmark-position preferences

The empirical findings of landmark-position preferences from the chapters above are summarized in Table 12.1.

Table 12.1. Comparison of the landmark-position preferences of the saliences and salience combinations

	Preferred positions in the experiments [%]				
	Visual Salience (derived distribution)	**Structural Salience (subsumed distribution)**	**Visual and Structural Salience (Exp. 5)**	**Structural and viewpoint-based Salience (Exp. 7)**	**Visual, structural and viewpoint-based Salience (Exp. 10)**
Behind the intersection, opposite the direction of turn	**25**	**04.64**	**13.75**	**06.66**	**12.28**
Behind the intersection, in the direction of turn	**25**	**19.13**	**20.31**	**36.25**	**30.69**
Before the intersection, opposite the direction of turn	**25**	**04.21**	**15.63**	**04.89**	**12.50**
Before the intersection, in the direction of turn	**25**	**72.02**	**50.31**	**52.45**	**44.53**

The comparison of the findings as shown in Table 12.1 reveals that the landmark-position preference between visual and structural salience differs significantly ($\chi 2(3)$=151.747,

$p<.001$). Additionally, the combination of visual and structural salience differs significantly from visual salience ($\chi2(3)=35.078$, $p<.001$) as well as from structural salience ($\chi2(3)=55.481$, $p<.001$). The combination of structural and viewpoint-based salience differs significantly from structural salience ($\chi2(3)=21.628$, $p=.001$). And, the combination of visual, structural, and viewpoint-based salience slightly differs from the combination of visual and structural salience ($\chi2(3)=6.753$, $p=.080$).

These results suggest that if only one salience was present, the participants will prefer one exclusive landmark or landmark position; if more than one salience was present, the participants will prefer more than just one landmark or landmark position and the distribution of landmark-preferences does not show a clear preference. For examined preference for the visual salience, it was very clear: the visually salient object was preferred in almost all cases. For the structural salience, one position was preferred in around 72% of the cases. This is less specific; however, if the two most salient positions were taken into account, the preferences run up to 91%. For the combination of two saliences, the preferences are even less specific. The preference for a single landmark or landmark position does not exceed 52%. And for the combination of three saliences, the highest single preference does not exceed 45%.

In summary, the more saliences have to be considered, the more unspecific were the landmark or landmark-position preference.

12.2 Decision times

Besides the preferences, the decision times for specific landmarks or saliences and also the combination of them are interesting. Additionally, conclusions about the underlying mechanism may be drawn by analyzing the distribution of decision times. The results of one relevant experiment per salience and salience combination are shown in Table 12.2. A statistical analysis of the decision times revealed significant differences between the experiments ($F(74)=37.145$, $p<.001$); the associated post-hoc t-tests are shown in Table 12.2.

Table 12.2. Average decision times for the saliences and salience combinations and relevant post-hoc t-tests

	Decision times [ms]				
	Exp. 1 (visual salience)	**Exp. 3 (structural salience)**	**Exp. 5 (visual and structural salience)**	**Exp. 7 (structural and viewpoint-based salience)**	**Exp. 10 (visual, structural and viewpoint-based salience)**
Mean	**1889**	**3302**	**5347**	**5477**	**9430**
Standard deviation	1419	1945	2893	3041	3134
Exp. 1	XXX				
Exp. 3	*t*(41)=-2.618, *p*=.012	XXX			
Exp. 5	*t*(28.263)= -4.749, *p*<.001***	*t*(43)=-2.828, *p*=.007*	XXX		
Exp. 7	*t*(39)= -4.619, *p*<.001***	*t*(46)=-2.976, *p*=.005*	*t*(41)=-0.143, *p*=.887	XXX	
Exp. 10	*t*(65.173)= -13.779, *p*<.001***	*t*(72.067)= -10.526, *p*<.001***	*t*(74)=-4.968, *p*<.001***	*t*(77)=-5.011, *p*<.001***	XXX

Note. Significances after Bonferroni-correction: * <.05; **<.01; ***<.001

Overall, with increasing number of saliences, an increase of the average decision times occurred. The fastest decision times were measured in the experiment of visual as well as structural salience, and they do not differ significantly. Significantly slower decision times were measured in the experiments with a combination of two saliences, and it does not matter whether visual and structural salience or structural and viewpoint-based saliences are combined: the decision times between these two experiments do not differ from each other. The slowest decision times were measured in the experiment with a combination of all three saliences. However, this last experiment was performed online and is to be treated with some caution. In summary, a more or less linear increase of the average decision times with each additional salience is visible. This is illustrated in Figure 12.1.

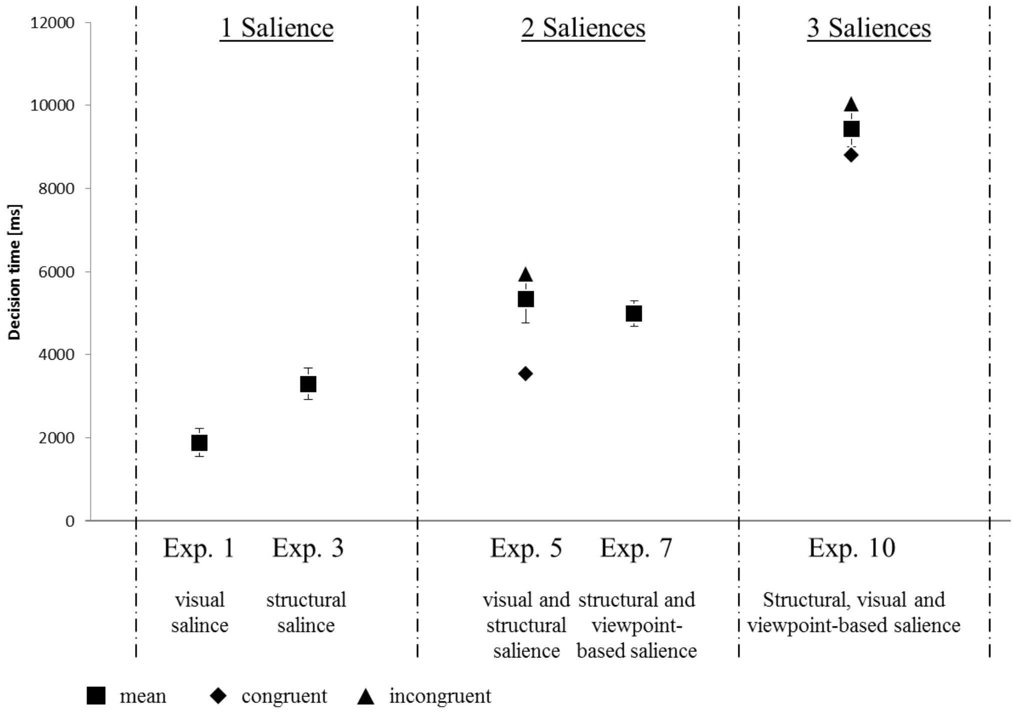


Figure 12.1. Decision times for the individual experiments. In addition to the mean decision times, the decision times for congruent saliences (Experiment 5 and 10: visual salient and position before the intersection in the direction of turn) and incongruent salience combinations (all remaining combinations) are presented.

12.3 Congruent and incongruent saliences

For experiments with more than one salience, two general combinations of the saliences exists: they could be congruent or incongruent. The assumption is that the effect of the saliences should mutually reinforce if they are congruent and mutually weaken if they are incongruent. In Experiment 5, the two saliences are congruent if the visually salient object is located at the position before the intersection and in the direction of turn. In this case, objects located at this position were almost always preferred. In all other cases the preferences are less specific. Also, the decision times were significantly faster in the congruent condition than in the incongruent one (see Figure 12.1). For Experiment 7 no real congruent condition exists. The structural salience highlights the position before the intersection and in the direction of turn, whereas the viewpoint-based salience highlights the positions behind the intersection (e.g., more of the landmarks are visible and the distance is higher; for more details see Chapter 13). For Experiment 10, no congruence of all three saliences exists; however, the visual and the structural salience could be congruent and the visual and the viewpoint-based salience. In the first case, a preference of almost 90% occurs, and in the second case a preference of 75% still occurs. The decision times for the combination of visual and structural salience are shown in Figure 12.1.

In summary, if the saliences were congruent they are mutually reinforcing, which means that in such cases almost always this highly salient object will be preferred.

12.4 What we learn from the experiments

The results revealed that for congruent saliences the decision times are faster than for incongruent ones. This effect is, for instance, very well examined for the Stroop-effect, where the participants should name the color in which a color word is written (Stroop, 1935). In the experiments on the Stroop-effect, two possible cases occur: either the color name is identical to the color of the letters (e.g., the word “red” written in red letters), or they are different (e.g., the word “red” written in green letters). As did Stroop (1935), Glaser and Glaser (1982) showed that congruent stimuli are named significantly faster than incongruent ones. This means that the congruence of saliences makes the decision easier and faster, or the other way around: if two (or more) types of information are incongruent, the decision is more difficult and takes longer. However, the classical Stroop-task measures fast responses (reactions; ~ 500ms) to overlearned stimulus material (~ 500ms) and does not consider complex (and more deliberate) decisions.

From the literature, it is well known that the working memory (e.g., Baddeley, 2012; Baddeley & Hitch, 1974; Cowan, 1999) is a central component in spatial cognition and the processing of information relevant for wayfinding (e.g., Davis, Therrien, & West, 2009; Gyselink, De Beni, Pazzaglia, Meneghetti, & Mondolino, 2006). However, working memory capacities are rather limited, and adding new and relevant information to a task leads to an increase in decision time (e.g., Smith & Kosslyn, 2014; Sternberg, 1967) due to additional processing demand (i.e., cognitive load; Paas & van Merrienboer, 1993; Sweller, van Merrienboer, & Paas, 1998; for an overview, see Paas, Touvinen, Tabbers, & Van Gerven, 2003). This means for my findings that an increase in the number of relevant information (saliences) induces a higher demand on working memory. But which working memory (sub)components are involved in processing landmark preferences?

It is suggested that the working memory consists of four sub-systems: the phonological-loop, the visuo-spatial sketchpad, the episodic buffer, and the central executive (Baddeley, 2000, 2003). Besides a large amount of research on the involvement of the sub-systems of working memory in spatial wayfinding tasks (De Beni, Pazzaglia, Gyselink, & Meneghetti, 2005; Garden, Cornoldi, & Logi, 2002; Gras, Gyselinck, Perrussel, Orriols, & Piolino, 2012; Wen, Ishikawa, & Sato, 2011, 2013), the work of Meilinger, Knauff, and Bülthoff (2008) is the most relevant one for my research. In addition to the verbal sub-system, they investigated the involvement of a visual and spatial sub-sub-system. The participants had to learn a route through a virtual environment and to simultaneously perform one of three different secondary tasks: either a verbal, a spatial, or a visual one. In a following wayfinding task, the authors measured the frequency of participants getting lost. The verbal secondary task in the learning phase led to the majority of errors in the wayfinding phase, followed by the spatial and the visual secondary task. They concluded that the working memory systems are relevant for the wayfinding process. Furthermore, they highlighted the importance of the verbal and spatial sub-system.

It is well established that landmarks are elementary for learning a path (e.g., Lynch, 1960; Presson & Montello, 1988; Raubal & Winter, 2002; Sorrows & Hirtle, 1999), meaning that in the learning phase of Meilinger’s et al. (2008) experiment the participants very likely learned landmarks in order to find their way again later. Which landmark participants are going to use to find the required path is the focus of this current Thesis. So I conclude that the described working memory processes (visual, verbal and spatial) should also be included in my landmark-preference task. The strong interference of the verbal secondary task with the wayfinding performance shows the high impact of the verbal system within this process. In my experiments, participants as well had to consider verbal information, including at minimum the information “left” and “right”. Moreover, it is conceivable that the observers transfer other information, just like the color of an object, into a verbal system. In general, two kinds of information are included in the landmark-preference task: a verbal one and a visuo-spatial one. The differentiation between these two types of information has first been described in the dual-coding theory by Paivio (1971, 1986, 1991).

Meilinger et al. (2008) stated that in a wayfinding context, the information are perceived mostly visually and will then be encoded verbally. In this verbal representation, the information could be encoded in an allocentric (survey) or an egocentric (landmark) perspective. Lee and Tversky (2001, 2005) showed in a series of experiments that the reading times for route directions increase if the perspective changes. In 2005, they summarized their findings in a way that “comprehension time costs in constructing on-line mental models when spatial descriptions change perspective” (p. 183) occur. This concept is also relevant for my model. The structural salience is represented in an allocentric perspective. The viewpoint-based salience depends on the viewpoint of the observer and her view direction and is therefore represented in an egocentric perspective (e.g., Klatzky, 1998). The visual salience is a characteristic of the object (the contrast to the surrounding) and should therefore be represented either in an egocentric perspective or detached from perspectives.

With the above described concepts, the increase of decision times by adding further saliences is explainable: the different perspectives – allocentric and egocentric (structural and viewpoint-based salience) – must be integrated to decide the landmark that is the ideal one. Additionally, this interpretation could also be transferred to the findings of landmark preferences. The information from the two different systems compete with each other and must be integrated into one preference, which then could lead to more than one salient object that can explain the empirically found preference distribution.

Part 3

The Mathematical Model of

Landmark Preference

$$S_t=(d^* o^* v_{vis})^* w_v s_v + w_s s_s + w_u s_u$$

13. Target of the mathematical model

This chapter covers the main ideas of my mathematical landmark preference model. A mathematical model to formalize and describe human preferences is part of the research about cognitive models, which are used to understand underlying cognitive processes and to define the parameters involved in order to understand and comprehend as well as to compute them (Cooper, Fox, Farringdon, & Shallice, 1996; Dörner & Schmid, 2011; Schmid & Kindsmüller, 1996; Strube, Ferstl, Konieczny, & Ragni, 2013). A mathematical definition of cognitive processes is a fundamental and clear approach in the field of cognitive modeling that describes and defines the involved factors and various processes (e.g., a decision process) and defines how these factors are related to each other. Also, such a mathematical model description help to compute predictions about decisions or preferences.

The aim of my mathematical landmark-preference model is to define and formalize the three saliences examined in the previous experiments, to analyze how they interact, and how they have to be weighted. The model is based on theoretical assumptions, and I will extend them and analyze if it fits my empirical findings or if modifications are necessary. The model includes the structural salience and formalizes what the structural salience is and what values it could contain. Also included is how the visual salience could be formalized, and which influence the perception of objects has on the landmark-preference. Additionally, the factors of the viewpoint-based salience are described and quantified. The overall questions are the following: How do the saliences interact, are all of them necessary to define the total salience of an object, and how are they weighted?

In the following, I (a) define and formalize the variables of my model; (b) compute the models for all possible combinations of saliences (visual, structural and viewpoint-based salience); and compare the model predictions with empirical findings. Within the different sections, I also analyze which adaptions of the model are necessary to minimize the deviations between the model and the findings. In (c) a next step, I describe and interpret the fit of the model, (d) show restrictions, and (e) discuss alternative models.

13.1 Defining variables

Many spatial cognition researchers explored what makes some landmarks more salient than others. They typically distinguish between three types of landmark salience: visual, structural and semantic.

The visual salience of landmarks is related to findings from visual perception and attention research showing that objects that stand out from their surroundings quickly reach the focus of attention (e.g., Treisman & Gelade, 1980). Spatial cognition researchers have extensively investigated how these factors affect landmark or object selection (e.g., Appleyard, 1969; Itti & Koch, 2001; Jin, Gillner, & Mallot, 2004). Some researchers found that the visual characteristics (i.e., contrast to the surroundings) have a significant effect on landmark selection, while I here showed that these effects are moderate at best (Chapter 9). The findings in Chapter 8 as well as in Chapter 9 showed that people's landmark preferences were not affected by landmark color and/or shape if four differently colored objects are available at an intersection.

A second type of salience is usually referred to as semantic salience (Caduff & Timpf, 2008; Sorrows & Hirtle, 1999). A description of the methodological definition problems of this is described and discussed in Chapter 14.3. However, I did not examine the influence of semantic salience in the experiments presented in this Thesis. Such influences have been addressed in related studies (Hamburger & Röser, 2011; 2014). To control for any influence of the semantic salience, I had used almost meaningless geometrical figures as landmark-objects.

A third important factor that guides landmark selection is the location of the potential landmarks in the environment. These location-related aspects of landmarks are referred to as structural salience. Many researchers have emphasized the importance of this kind of salience for spatial cognition (Caduff & Timpf, 2008; Hamburger & Knauff, 2011; Klippel & Winter, 2005; Sorrows & Hirtle, 1999). However, the effects of structural salience on landmark preferences are still widely unexplored and were thus in the present focus. This Thesis is the first work to present a series of experiments that examines a wide range of aspects of the structural salience at a four-way intersection.

Also, the viewpoint-dependent location of a landmark from the perspective of the observer is considered here. To obtain these ratios, I used an egocentric perspective of the direction giver in my experiments in Chapter 10. In the literature, many researchers differentiate between an egocentric (self-to-object) and allocentric (object-to-object) perspective (Bryant, 1997; Coluccia et al., 2007; Klatzky, 1998; Nadel & Hardt, 2004). The findings in Chapter 10 showed that the structural salience of landmarks strongly depends on the specific route and the position of the person within the environment. When a receiver of a route instruction has to turn left, the direction-giver prefers to mention landmarks on the left side of the street; if she has to turn right, the direction-giver prefers to mention landmarks on the right side of the street. This robust finding is combined with the effects of the landmarks' visible portion. If, for instance, the direction-giver stands far to the left or the right side of the street, this might result in the invisibility (i.e., total occlusion) of some landmarks (Winter, 2003). They might be covered by other buildings, for instance, and thus the competent direction-giver selects more visible landmarks.

Raubal and Winter (2002) introduced a mathematical model of landmark salience that consists of three parameters (Sorrows & Hirtle, 1999) and three weighting factors for each of the three parameters. The three parameters are thought as empirical measures for the visual, semantic, and structural salience of landmarks. These individual measures are combined in the following equation:

$$s_o = w_v s_v + w_s s_s + w_u s_u \quad (1)$$

with s_v, s_s, s_u €[0,1] and w_v, w_s, w_u €[0,1] with w_v+w_s+w_u=1, which results in s_o€[0,1]. In the equation, s_o stands for the joint salience, s_v for the visual salience, s_s for the semantic salience, s_u for the structural salience, and w_v; w_s; w_u are the corresponding weighting factors.

The results in Chapter 6 revealed that an outlier color attracts attention and leads to a higher preference for being a landmark. In Chapter 8, a clear position preference for the position before the intersection in the direction of turn was found. Based on these empirical findings, I could determine the values for two factors of the joint salience. As mentioned above, the semantic salience does not influence the participants' decision in this context here and will be neglected in the following, or, mathematically speaking, the value of the semantic salience is identical for all relevant objects and does therefore not influence the joint salience.

Winter (2003), however, stated that his concept of "advanced visibility" needs to be taken into account as well in this research context. Klippel and Winter (2005) picked up this concept and combined it with the assumptions of Raubal and Winter (2002). The model by Klippel and Winter (K&W model, 2005) consists of the three parameters, the three weighting factors for each of the three parameters, and the visibility. All of these parameters result in the total salience of an object:

$$s_t = v * s_o \quad (2)$$

with s_o €[0,1] and v €[0,1], which results in s_t €[0,1]. In the equation, s_t stands for the total salience, v for the visibility of the landmark, and s_0 for the joint salience from (1).

I think that this is the point where the K&W model needs some revision. My main assumption is that the landmark selection always takes place at a specific point in the environment. The observer is located somewhere in the environment and sees the surroundings and the potential landmarks from her specific egocentric perspective. My results showed that this is an important factor in landmark selection and goes beyond an abstract visibility measure, which is independent from the observer. I therefore suggest referring to this observer-perspective-dependent visibility of a landmark as viewpoint-based salience. This concept implies the distance between the observer and the landmark, the orientation of the landmark in relation to the observer's point of view, and the visible portion (for my definition of visibility; see below). This results in the following modeling suggestion:

$$vp = d * o * v_{vis} \tag{3}$$

$$s_t = vp * s_o \tag{4}$$

with d, o, v_{vis} €[0,1], vp €[0,1] and s_o €[0,1], which results in s_t €[0,1]. In the equation, s_t stands for the total salience of a landmark, v_p for the viewpoint-based salience, s_o for the joint salience according to K&W, d for the distance between observer and landmark, o for the landmark's orientation, which results from the observer's perspective, and v_{vis} for the visible part of the landmarks.

The first new factor in my model is the distance between the observer and the landmark and is defined as the distance from the person's point of view to the object's center on a straight line. The measuring point is the center of the visible parts (see below) of each facade at ground level, and each measured distance is divided by the largest value ($d = \frac{|d|}{|d_{max}|}$). Since the largest value is set to 1, all other values are consequently smaller (d €[0,1]).

The second factor in my model is the orientation of the landmark from the observers' perspective. Winter (2003) first described the concept of landmark orientation during the wayfinding process. I added landmark orientation to my model, but I simplified it. This concept here describes the orientation of an object in relation to an observer. On the left side of Figure 13.1, the viewpoint, viewing direction, and landmark positions are depicted. A fixed viewpoint and a fixed viewing direction are used. The viewing axis is positioned at a right angle to the viewing direction, and this axis is relevant for the concept of landmark orientation. To calculate the orientation the angle (α) between the potential landmark and the view axis is relevant:

$$o = 1 - \sqrt{(1 - \frac{\alpha}{180})^2}\text{, for } o \in [0,1]. \quad (5)$$

In the equation, o stands for the orientation, and α stands for the angle between the landmark and view axis.

I define the orientation to have values between 0 and 1; 0 means the landmark is parallel to the viewing axis with the same orientation as the viewing direction (0°) and therefore not visible, whereas 1 implies that the landmark is parallel to the viewing axis but orientated towards the viewing direction and point of view (180°). Furthermore, a linear increase between these two extreme values is assumed, for which the angles are specified on a circle in clockwise rotation. Each facade of an object will be considered separately:

The idea behind this basic calculation is that a landmark oriented in the observer's line of sight (frontal view) scores a higher orientation value, because it should be recognized more easily in comparison to an object oriented along the observer's viewing direction (perspective distortion). The different approaches are depicted in Figure 13.1.

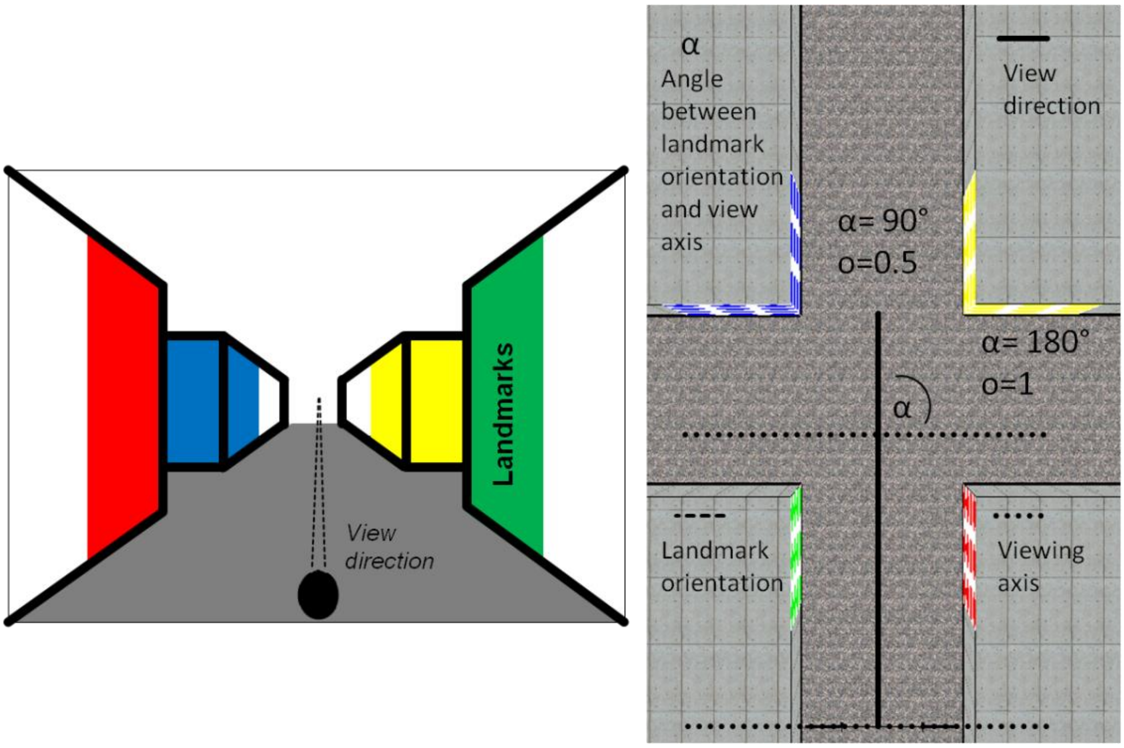


Figure 13.1. Schematic figure of the concept orientation. On the left side, the egocentric view of an intersection including the point of view and the view direction is shown. On the right side, an allocentric perspective of the intersection shows the point of view, the view direction, and the view axis. The angle between the view axis and the landmark represents the concept of orientation.

The last and central factor in my model is the visible part of the landmark for the observer, which is a new definition of the classical "visibility" concept. It is important to note that this is not the visual salience of the landmark, as viewpoint-based salience does not rely on visual features such as color, shape, texture, or size of the landmark. In general, quite a few theories consider the visibility of an object with different definitions (Elias & Brenner, 2004; Nothegger et al., 2004; Peters et al., 2010; Raubal & Winter, 2002; Richter, 2007; Winter, 2003; Winter, Raubal, & Nothegger, 2005). But, these theories and definitions do not consider the viewpoint of the observer; also, they are very complex and do not offer a detailed modeling account or a cognitive approach. I define visibility as the visible part of a landmark from a certain point of view. In vision research, this concept is known as occlusion culling, which means which objects or which parts of objects are within the “visible shadow” of other objects (Wonka et al., 2000). The question is then how much of a landmark must be visible for it to be “identified” by the observer with a high probability? This uses a cognitive definition of “visibility”. It implies besides the perceptual aspect – view field and view direction – the evaluation of the object: is enough of the object visible to identify the object and to use it as a landmark? Moreover, although only a part of the landmark or landmark facade is visible, the entire landmark must be considered for the preference decision. This forms my measurement of visibility:

$$v_{vis} = \frac{vp_l}{ts_l}, \text{ for } v_{vis} \in [0,1]. \qquad (6)$$

In the equation, v_{vis} stands for the visibility, vp_l is the visible part of the landmark, and ts_l is the total size of the landmark.

13.2 The mathematical model

Based on my definitions above, the mathematical landmark model consists of the following equation:

$$s_t = vp * s_o \qquad (7)$$

$$s_o = w_v s_v + w_s s_s + w_u s_u \qquad (8)$$

$$vp = d * o * v_{vis} \qquad (9)$$

$$s_t = (d * o * v_{vis}) * (s_v + w_s s_s + w_u s_u) \qquad (10)$$

with d, o, v_{vis}, s_v, s_s, s_u $\in[0,1]$ and w_v, w_s, w_u $\in[0,1]$ with $w_v+w_s+w_u=1$, which results in s_t $\in[0,1]$.

In the equations s_t is the total salience of an landmark object, vp is the viewpoint-based salience, s_o is the joint salience, s_v is the visual salience, s_s is the semantic salience, s_u is the structural salience, w_v; w_s; w_u are the corresponding weighting factors, d is the distance between the observer and the landmark, o is the landmarks' orientation that results from the observer's perspective, and v_{vis} is the visible part of the landmarks.

Let me illustrate the influence of the single saliences presented in the equation with the initial example on which fast-food restaurant you are likely to prefer for giving route directions:

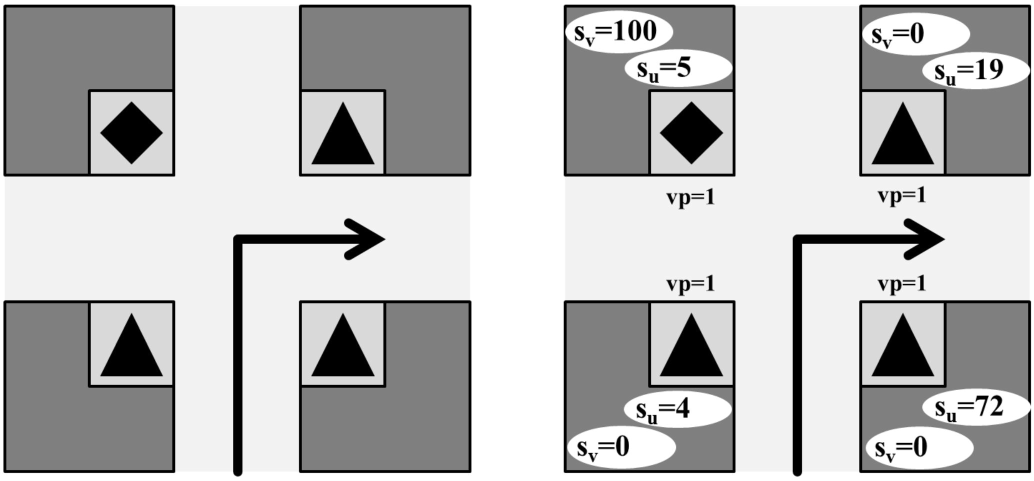
Imagine that you want to describe a direction change at an intersection where there are four fast-food restaurants, but you do not know where they are located. You only know that three of them have the same color and one is differently colored (ignoring their true colors and your personal preferences for one of the restaurants, which represents the semantic salience). Which of the four restaurants will you prefer? You should prefer the restaurant with the different color; it is the visually salient one.

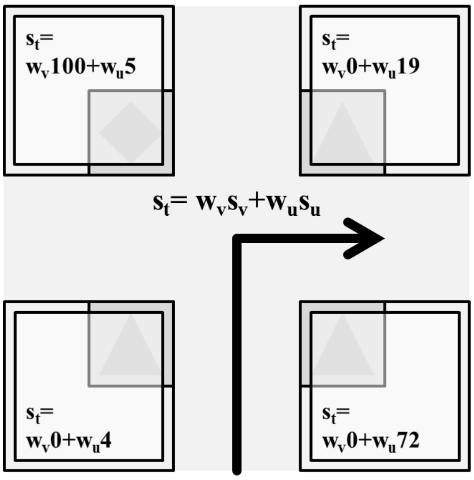
The next step is to imagine the intersection with the fast-food restaurants from an allocentric perspective (as in my structural salience experiments) and all restaurants having the same color (again ignoring the true colors). In this case, you could see all restaurants equally well; they all have the same distance and orientation to you. Hence, the viewpoint-based salience is identical for all of them. Which one will you prefer? In this case, only the structural salience influences your decision; your preference should be, "Turn right at the Wendy´s", if you want to describe a turn to the right, and Wendy´s is placed before the intersection and on the right side of the street. But, what happens if three restaurants have the same color, one is differently colored, and you know the position at the intersection? Or you see the intersection from an egocentric perspective and some of the restaurants are only partially visible? How would you then decide? Which restaurant (i.e., landmark) would you prefer for giving route directions? This preference decision is defined in the above equation. How the total salience of the single landmarks is computed will now be described in detail.

13.2.1 Proceeding

In the following sections, I describe the mathematical model for the combination of visual and structural salience, structural and viewpoint-based salience, and visual, structural, and viewpoint-based salience. For a better comparability of the modeled total salience and the empirical findings, I use for the visual and the structural salience percentage distributions which results in s_t Є[0,100]. For each case, only the relevant saliences are considered in the corresponding equation. For example, if I compute the interaction of visual and structural salience, the equation only includes these two components. My assumption for this case is that the viewpoint-based salience is equivalent for all potential landmarks (e.g., presentation of the environment in an allocentric perspective) and does not influence the participants' decision.

Let me first introduce the modeling procedure with an example. In Figure 13.2 (upper left), one of my typical four-way intersections with four landmarks at the corners is shown. The path proceeds to the right at this particular intersection and the question is the following: Which landmarks are participants going to use for describing the direction change to somebody unfamiliar with this intersection? In this example, geometrical shapes serve as landmarks: three identical ones and an outlier at the position behind the intersection and opposite to the direction of turn. The first question is concerned with the salience of each of these potential landmarks. Due to the allocentric representation of the environment, each of them has the same viewpoint-based salience, so that I may ignore this salience in the following. From the experiments in Chapter 6, we know that the visually salient object is preferred in 100% of the cases, so here the outlier landmark possesses a visual salience of 100, and all others have the value 0. Furthermore, from Chapter 8 we already know which positions the participants prefer if only the structural saliences influence the decision. These values for the structural salience are presented in Figure 13.2 on the upper right side. On the lower left side of Figure 13.2, the computation of the total salience for each object is presented, and the modeling results are shown in the lower right.





	Visual salience	Structural salience	Total salience (s_t= $0.5s_v$+$0.5s_u$)	Total salience. Linear transformation (sum 100)
Behind the intersection, opposite the direction of turn	**100**	**5**	**52.5**	**52.5**
Behind the intersection, in the direction of turn	**0**	**19**	**9.5**	**9.5**
Before the intersection, opposite the direction of turn	**0**	**4**	**2.0**	**2.0**
Before the intersection, in the direction of turn	**0**	**72**	**36.0**	**36.0**

Figure 13.2. This figure shows the computation steps of the mathematical model. On the upper left side, a four-way intersection with three identical landmarks and one outlier landmark is shown. On the upper right side, the saliences for each potential landmark are represented, and in the lower left the total salience for each landmark is computed. At the lower right, an overview for the modeling steps is given (the weighting factors are set to 0.5 each).

Now, we have a value for the total saliences for each object and can compare them with each other. The landmark with the visually salient object has the highest total salience followed by the landmark at the structurally salient position. For a better comparability with empirical findings (and to have an equivalent to a percentage representation), the total saliences of the four landmarks at an intersection will be transformed (linearly) if necessary (which is not the case in the actual example) so that they sum to 100. This is shown in Figure 13.2 in the lower right side and represents the modeled percentage distribution of landmark preferences at this intersection with a turn to the right.

In the following, I present computations for the relevant combinations of saliences. For this the total salience will be computed for each landmark-position at the four-way intersection, and the total salience of each position will be compared with each other as described. For models in an egocentric perspective, some landmarks have two visible facades. Here I define the saliences for each visible facade and compute the model for each of them separately. Afterwards, I use the mean of the two facades for the total salience of this landmark; therefore, I will have four total saliences for the four landmarks at each intersection.

This computation will be repeated for all measured landmark arrangements in the respective experiments, and I compare the modeled landmark-preferences with the landmark-position preferences of the participants in the corresponding experiment. To determine a model fit, I run a linear regression for the model and empirical findings. One open question remains. I did not say anything about the weighting factors so far. From the literature, only theoretically determined weighting factors are known. To analyze whether they are necessary or not, I will adjust the weighting factors in each model as long as the model fits the empirical findings best. If the weighting factors are necessary, an improvement of the model fit should be visible; if they are not necessary, the weighting factors should be removed from the model in order to provide simple and parsimonious models.

13.2.2 Visual and structural salience

In this section, I now model the combination of visual and structural salience and compare this model with the empirical results of Experiment 5 and Condition 4 of Experiment

6. In this experiment and experimental condition, the landmark preferences at intersections with one outlier and three identical objects were examined, and the task was to choose the preferred landmarks for providing route directions. The setting of these experiments consisted of the four-way intersections in an allocentric perspective, so that the viewpoint-based salience is equivalent for all four landmark positions; also, the landmarks consist of circles in different colors so that they do not have different semantic meanings. This reduces the equation to the following:

$$s_t = w_v s_v + w_u s_u \tag{11}$$

with s_v, s_u €[0,100] and w_v, w_u €[0,1] with $w_v + w_u = 1$, which results in s_t €[0,100]. In the equation s_t is the total salience of a landmark, s_v is the visual salience, and s_u is the structural salience, and w_v, w_u are the corresponding weighting factors.

The equation includes two unknown variables, the structural and the visual salience:

1. For the structural salience, I use the empirical findings of Chapter 8, which provide the position preference for each position at the intersection.
2. For the visual salience I had on the one hand the findings of Chapter 6. There, results showed that if the visual salience is maximal, the participants preferred this visually salient object in almost 100% of the cases. This means the outliers at an intersection have the value 100, and all others have the value 0 if a maximum contrast (180°) between outlier and surrounding is present. The landmarks in Experiment 6 consisted of different contrasts between the visually salient object and the surrounding environment. To define the value for the visual salience, I use the results of Experiment 6 Condition 1 in which I asked which one stands out most from the surrounding (visual salience).

Consequently, I now possess values for both unknown variables. Based on this, I model the landmark preference for all experimental conditions (placement of the outlier at the intersection and contrast between the outlier and the surrounding). For the purpose of process illustration, I show all model predictions for the settings of Experiment 5 in detail in Table 13.1. Additionally, the participants' preferences are shown in this table as well.

Table 13.1. Comparison of model and empirical results of Experiment 5

Preferred object position [in %]								
	Position of the outlier							
Preferred position	Behind the intersection, opposite the direction of turn		Behind the intersection, in the direction of turn		Before the intersection, opposite the direction of turn		Before the intersection, in the direction of turn	
	Model (s_t)	Results	Model (s_t)	Results	Model (s_t)	Results	Model (s_t)	Results
Behind the intersection, opposite the direction of turn	**52.30***	**50.00**	02.32	02.50	02.32	02.50	02.32	00.00
Behind the intersection, in the direction of turn	09.56	08.75	**59.95***	**62.50**	09.56	08.75	09.56	01.25
Before the intersection, opposite the direction of turn	02.10	07.50	02.10	00.00	**52.05***	**53.75**	02.10	01.25
Before the intersection, in the direction of turn	36.01	33.75	36.01	35.00	36.01	35.00	**85.70***	**97.50**

Note *outlier was placed on this position
The model values (s_t) are the transferred ($s_t \in [0,1] \rightarrow s_t \in [0,100]$) values of the mathematical model computed for each landmark at the intersection. The result values are the empirical findings reported in the corresponding experiment above.

As becomes clear from Table 13.1, the model predicts the empirical findings very well. In all cases (i.e., outlier positions), the model reveals the highest values for the same landmarks as the empirical findings. Moreover, in three of the four cases the ranking sequence between the model and the empirical findings is identical. This descriptively demonstrates the good fit of my model.

I follow this procedure for all examined conditions – the position of the visually salient object and different contrasts in Experiment 6, Condition 4 – and compare the model values with the empirical findings (see Appendix H). With this model (for Experiment 5 and

Experiment 6, Condition 4) I can explain 92% of the variance as indicated by a linear regression (R^2=.847; *F(1)*=788.111, *p*<.001), which represents a very good fit.

However, in this model the weighting factors for the visual and the structural salience were not considered; instead, they were set equal ($w_v = w_u$; $w_v + w_u = 1$; $w_v = w_u = 0.5$; Duckham, Winter, & Robinson, 2010; Klippel and Winter, 2005; Raubal & Winter, 2002). To analyze whether one of the two saliences has a higher influence, I adjusted the weighting factors. Due to the interdependence of the two ($w_v = 1-w_u$), an increase in one indicates a decrease for the other. In an iterative procedure (Newton), I adapted the weighting factors up to a maximum R^2. This procedure determines weightings of w_v=0.384 and w_u=0.616 for the visual and structural salience. Using these weightings, the model fit further increases to 94.24%. The linear regression with these two weighting factors is depicted in Figure 13.3 (R^2=.888; *F*(1)=1126.927, *p*<.001). The figure shows the empirical data on the x-axis and model values on the y-axis; the straight line represents the linear regression, and all values lie relatively close to the linear regression line.

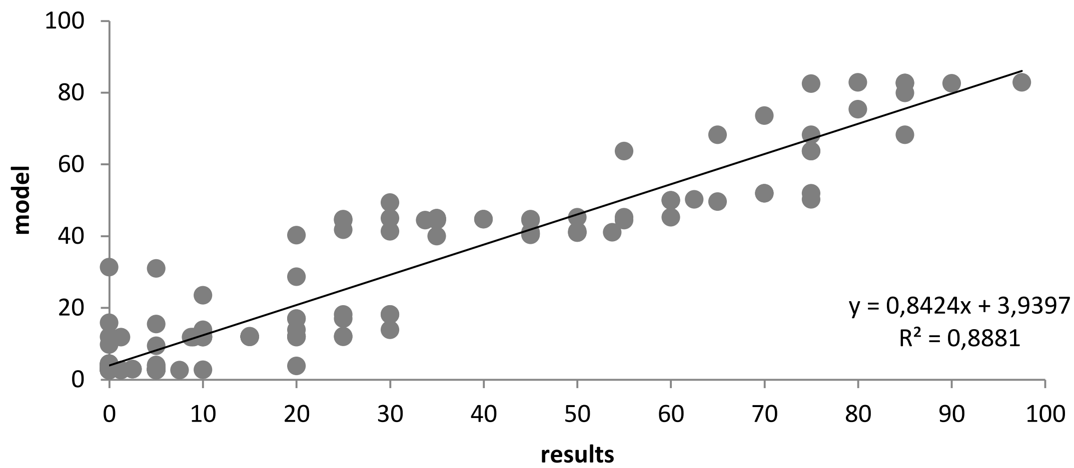


Figure 13.3. Linear regression between the model and the empirical findings. The x-axis represents the empirical results and the y-axis the model. The line shows the linear regression between the model and the empirical data. The equation shows the definition of the line and the coefficient of determination.

The first conclusion for this section is that I could verify the assumptions of Raubal and Winter (2002) and Klippel and Winter (2005) that the visual and structural salience are connected in an additive way. Based on this assumption and the equations, it is possible to compute the empirical findings very well. The second conclusion is that I am among the first who provide empirical values for defining the weighting factors. Sadeghian and Kantardzic (2008) as well as Duckham et al. (2010) stated that the weighting factors should be analyzed with human subjects. Raubal and Winter (2002) as well as Klippel and Winter (2005) used hypothetic values for the weighting factors in their model. However, my model showed a better model fit with a stronger weight of the structural salience.

This verification of the model challenges another assumption from Winter et al. (2005). They showed in their experiment that at day and night different objects will be preferred as landmarks. Based on this, they assumed that generally for day and night conditions different weighting factors should be taken into account. I challenge this interpretation. I would assume that no additional weighting factor for a night condition is necessary. It is obvious that the environment looks different at night than during day. However, the possible different preferences of participants at night (e.g. illuminated building at night vs. another colored building at day) could be explained by the visual salience without considering additional weighting factors. This should be examined in further experiments (for a first experiment, see Trillmich, Röser, & Hamburger, 2012).

13.2.3 Viewpoint-based and structural salience

In this section I model the results presented in Chapter 10. In these experiments, the environment was presented in an egocentric perspective. However, in Experiment 7 the view position was always in the middle of the intersection; in Experiment 8, the distance between the observer and the middle of the intersection was varied (i.e., multiple view positions); and in Experiment 9, the view direction of the observer was varied, which resulted in different orientations of the landmark objects with respect to the observer. All of these variations are components of the viewpoint-based salience, which determined the participants' decision in these experiments. Overall, due to the use of four differently colored circles as landmarks, the visual as well as the semantic salience may not influence the participants' decisions. All this results in the following equation:

$$s_t = d * o * v_{vis} * w_u s_u \qquad (12)$$

with o, d, v_{vis}, s_u €[0,1] and w_u =1] which results in s_t €[0,100]. In the equation s_t is the total salience of a landmark, s_u is the structural salience, d is the distance, o is the orientation, v_{vis} is the visible part, and w_x are the weighting factors.

This equation consists of four unknown variables: distance, orientation, visible part, and structural salience. For the structural salience, I inserted the empirically determined values described in Chapter 8. The variables distance, orientation, and visible proportions are physical variables and could reliably be determined at the four-way intersection, as described in Chapter 13.1. The values for all variables are listed in Appendix I.

To compute the model, I follow again the procedure described in Chapter 13.2.1. Notice that for some landmarks, two facades are visible. In this case, the total salience of the facade is defined by the mean of the total saliences of each facade. Furthermore, to figure out which model fits the data best, I computed all possible and suitable combinations of saliences. The mean squared deviation between the model values and the empirical values are shown in Table 13.2. The first column gives the description of the model in natural language, and the second column gives the mean-squared deviation between the model and the empirical findings. A low value indicates a better explanation of the empirical data.

Table 13.2 reveals significantly different model fits. As shown in line 2 of the table, the model "structural salience x orientation" cannot account for the empirical data appropriately.

The model "structural salience x distance" is even worse, followed by the models "structural salience x visible part", "structural salience x visible part x orientation", and "structural salience x visible part x distance". The best model fit was obtained for the model "structural salience x visual proportions x distance x orientation". This model can explain 93% of the variance as indicated by a linear regression (R^2=.858; $F(1)$=152.208, p<.001).

Table 13.2. Mean-squared deviation between the model and the empirical findings

	Mean-squared deviation
structural salience × distance	*167*
structural salience × orientation	*244*
structural salience × visible part	*154*
structural salience × visible part × orientation	*108*
structural salience × visible part × distance	*86*
structural salience × visible part × distance × orientation	*77*

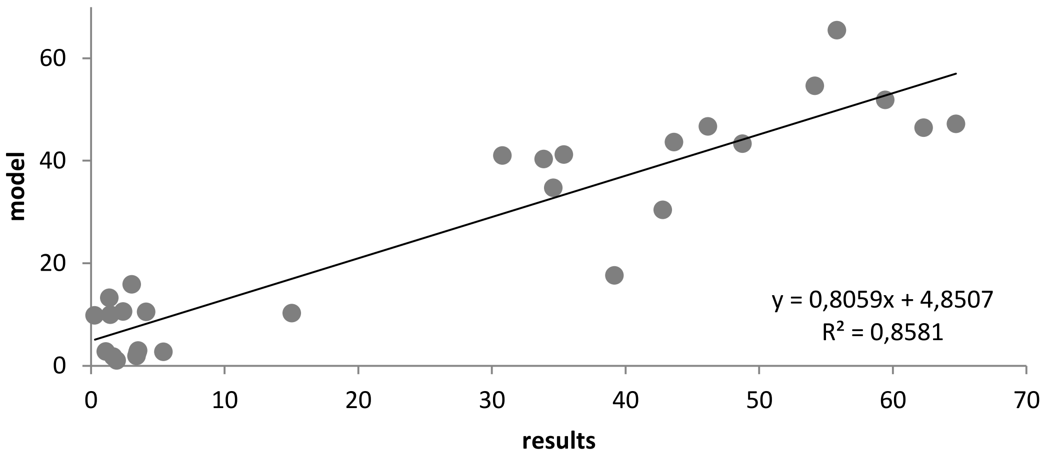


Figure 13.4. Linear regression between the model and empirical findings. The x-axis represents the results and the y-axis the model. The line shows the linear regression between the model and the empirical data. The equation shows the definition of the line and the coefficient of determination.

The fit between the best model and the empirical findings is depicted in Figure 13.4. The figure shows the empirical data on the x-axis and the model values on the y-axis; the straight line shows the linear regression. The figure demonstrates that all of the values lie relatively close to the linear regression line.

This finding additionally reveals that my extension of the K&W assumption models the empirical data very well; the parameters of the viewpoint-based salience (distance, orientation, and visible part) are needed to determine the participants' decision.

13.2.4 Visual, structural, and viewpoint-based salience

In a last model, I now compute the interaction of visual, structural, and viewpoint-based salience and compare the model with the empirical findings of Experiment 10. In this Experiment, the visual salience (outlier) as well as the structural salience (landmark positions) and the viewpoint-based salience (egocentric perspective) influence the participants' landmark-preference. The computation follows the steps described in the previous sections, and as before the influence of the semantic salience is excluded.

Until now, I followed the assumptions of the K&W model about the composition of the saliences: the visual and structural saliences added up and are moderated by the viewpoint-based salience to define the total salience. However, there are two other possible compositions, which are represented in the following equations:

$$s_t = d * o * v_{vis} * (w_v s_v + w_u s_u) \quad (13)$$

$$s_t = (d * o * v_{vis} * w_u s_u) + w_v s_v \quad (14)$$

$$s_t = (d * o * v_{vis} * w_v s_v) + w_u s_u \; . \quad (15)$$

with o, d, v_{vis}, s_v, s_s, s_u Є[0,100] and w_v, w_u Є[0,1] with $w_v + w_u = 1$, which results in s_t Є[0,100]. In the equation, s_t is the total salience of a landmark, s_u is the structural salience, s_v is the visual salience, d is the distance, o is the orientation, v_{vis} is the visible part, and w_x are the weighting factors.

Equation 13 represents the composition as described in the K&W model, Equation 14 represents a model in which only the structural salience is moderated by the viewpoint-based salience, and Equation 15 represents a model in which only the visual salience is moderated by the viewpoint-based salience. To figure out which model fits the data best, I compare them with each other, as shown in Table 13.3. Additionally, I first use equal values for the weighting factors of visual and structural salience (w_v=0.5 and w_u=0.5), and second I use weighting factors as computed in Chapter 13.2.2. This is also shown in Table 13.3 (the three models with all parameters and values are listed in Appendix J).

Table 13.3. Linear regressions for the models, including equal or unequal weightings

	$w_v = 0.5; w_u = 0.5$		$w_v = 0.384; w_u = 0.616$	
	R^2	F	R^2	F
$s_t = d * o * v_{vis} * (w_v s_v + w_u s_u)$	.792	*F(1)*=53.321, *p*<.001	.779	*F(1)*=49.332, *p*<.001
$s_t = (d * o * v_{vis} * w_u s_u) + w_v s_v$	.784	*F(1)*=50.736, *p*<.001	.818	*F(1)*=63.927, *p*<.001
$s_t = (d * o * v_{vis} * w_v s_v) + w_u s_u$	.627	*F(1)*=23.515, *p*<.001	.493	*F(1)*=13.590, *p*=.002

The linear regressions showed the best fit for the model in which the viewpoint-based salience only moderates the structural salience and the structural salience gets a higher weighting than the visual salience. For this model, the fit could be increased (iterative procedure [Newton]) if the structural salience gets an even stronger weighting (w_u=0.862; R^2=.935; *F(1)*=201.943, *p*<.001). For the linear regression of the original model and the new model with the adjusted weightings, see Figure 13.5. This again underlies the importance of the structural salience. Whether the viewpoint-based-salience only influences the structural salience or the visual and structural salience should be examined and computed in further experiments; ideally, a combination of the settings of Experiment 6, 8, and 9 should be carried out. This will lead to an experiment with a variation of all parameters of the viewpoint-based salience and a variation of the influence of the visual salience. At this point, however, it can only be concluded that the model should be modified as described in equation 14.

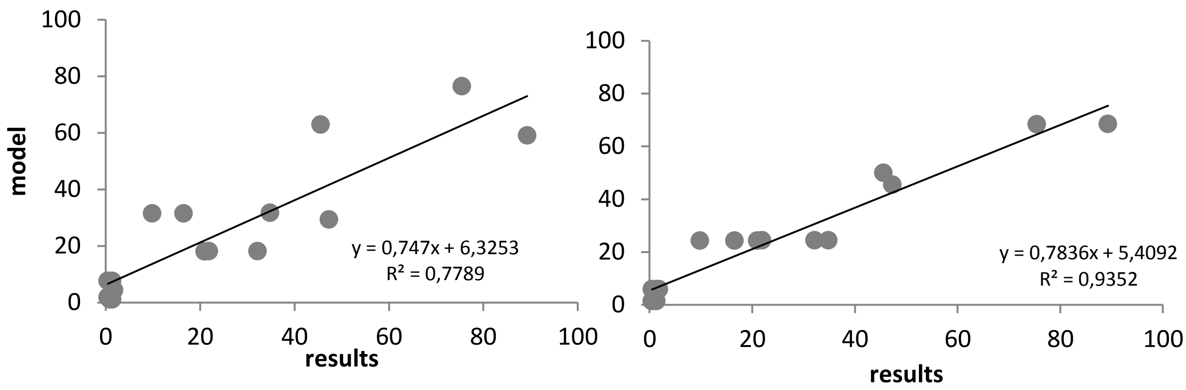


Figure 13.5. Linear regression between the model and empirical findings. On the left is the model in which the viewpoint-based salience moderates the visual and structural salience and the weighting factors for visual and structural salience are computed as done in Chapter 13.2.2. On the right is the model in which the viewpoint-based salience only moderates the structural salience and the weighting factors for visual and structural salience are computed as done in Chapter 13.2.2. The x-axis represents the empirical results, and the y-axis represents the model. The line shows the linear regression between the model and empirical data. The equation shows the definition of the line and the coefficient of determination.

13.3 Model fits and interpretation: the mathematical model

In the previous computations, I showed that the viewpoint-based salience is an essential part for modeling landmark preferences, and therefore an extension of the K&W model was necessary. However, the computations showed that one of the basic assumptions in the K&W model is correct: both the visual and structural salience must be considered to explain the participants' preferences, and they are additively linked. Furthermore, the K&W model assumes that the visibility – or here the viewpoint-based salience – moderates the effect of the joint salience consisting of the visual and structural salience. The computation revealed that only the structural salience – the position of the landmark at the intersection – is moderated by the viewpoint-based salience. The visual salience remains unaffected. The conclusion therefore is that the viewpoint-based salience influences which landmark position we prefer, but not which landmark-object. This results in the following revision of the model:

$$s_t = w_u(d * o * v_{vis} * s_u) + (w_v s_v) \quad (16)$$

with o, d, v_{vis}, s_v, s_s, s_u Є[0,1] and w_v, w_u Є[0,1] with $w_v + w_u=1$, which results in s_t Є[0,1]. In the equation s_t is the total salience of a landmark, s_u is the structural salience, s_v is the visual salience, d is the distance, o is the orientation v_{vis} is the visible part, and w_x are the weighting factors.

In the description of the theoretical background of my work, I assumed that the viewpoint-based salience should include the visible part of the object, the distance between the observer, and the object as well as the orientation of the object with respect to the observer's view direction. But are they all equally important? Generally the computations showed that considering all three factors leads to the best model fit. However, as could be seen in Table 13.3, the model including structural salience, the visible part, and distance and the model with structural salience, the visible part, distance, and orientation are the best and differ only slightly. This suggests that the orientation is less significant. However, Winter (2003) pointed out that the object relation to the observer should be an important factor. One explanation for the difference between the findings and the assumptions could be that I only considered a short variation of the orientation, and I do not break up the symmetries of the intersections – in my experiments the intersections are still orthogonal, but they are rotated towards or away from the observer's view direction. In further experiments, the relevance of the orientation at different and more asymmetric intersections should be considered. One starting point could be Hexatown by Gillner and Mallot (1998), which does not use orthogonal intersections. I assume that in more asymmetric environments, the influence of the orientation increases.

Considering all computations described above (Chapter 13.2.2, 13.2.3, and 13.2.4), the values for the visible part and the distance correlates significantly ($r(64)=.553$, $p<.001$), and the values for visible part and orientation correlate significantly negatively ($r(64)=-.514$, $p<.001$). This means that the distance enhances the influence of the visible part, whereas the orientation reduces its influence. Both aspects could also be explained with the findings from the research of Chieffi and Allport (1997). In their experiment, participants had to memorize the location of a light in a dark environment and had to point with closed eyes and with the finger to the position they thought they had seen the light. The results showed that the errors for distance and orientation were uncorrelated. They concluded that they found "evidences for a dissociation between memory for the distance and direction of spatial location to point to" (p. 248; see also Frank, 1996).

Another important issue is how the distance is represented. Generally, the mental representation of space is a central research aspect in spatial cognition (e.g., Bryant, 1997; Cheng & Newcombe, 2005; Montello, 1992, 1997; Tenbrink, Wiener & Claramunt, 2014). For example, the discussion whether the distance between objects or the distance between the observer and the object are represented in a physical (i.e., Euclidean) manner, or in an abstract and relational manner (e.g., Montello, 1992) is central. It is difficult to differentiate between these two approaches. My results pointed into the direction that the distance is essential for the landmark-preference. However, if the cognitive processing is relational or Euclidean, this may not be answered. This will be one of the topics for further experiments and analyses.

Additionally, I computed weighting factors for the visual and structural salience; this has not been done before. Overall, the models for the interaction of visual and structural as well as for visual, structural, and viewpoint-based salience had a better fit if the weighting factor for the structural salience is higher than for the visual salience. Due to the general assumption that they are interdependent, the weighting factors for the visual and structural salience should be defined as followed:

$$w_u + w_v = 1 \quad (17)$$

$$1 - w_u = w_v; \quad (18)$$

$$w_u > w_v \quad (19)$$

$$w_u \geq 0.616 \quad (20)$$

with w_v, w_u €[0,1]. In the equation, w_u is the weighting factor of structural salience and w_v is the weighting factor of visual salience.

What is the benefit of my model? Raubal and Winter (2002) were the first to describe the total salience as a function of visual, semantic, and structural salience factors (Sorrows & Hirtle, 1999). Based on “Digital city maps, […] Navigation graphs for the actual means of travel, […] Rectified, geo-referenced images of facades of each single building located at elements of the navigation graph [and] Accessible databases such as yellow pages […]” (Raubal & Winter, 2002; p. 253), they defined the factors and computed the ideal landmark at an intersection. However, first they did not examine how the single saliences should be weighted, and second they did not consider the visibility as a moderating factor. Two years later, Nothegger et al. (2004) presented an experiment that used a similar procedure as I did here. They asked the participants, “Which is, in your opinion, the most prominent facade?” and “The facades in the panoramas are marked with numbers. Find the most prominent facade. It could also be the one that you would quote when giving directions, or the one that is the easiest to describe” (p. 128). The participants had to choose the most salient object on a picture of intersections in Vienna, Austria. They found a significant correlation between their model and the empirical findings. However, they only considered the visual and semantic salience in their model and excluded the structural salience as well as the visibility or the viewpoint-based salience. Winter (2003) added his concept of “advanced visibility” to the concept of Raubal and Winter (2002) and used the same general setting as Nothegger et al. (2004). He found that the implementation of the visibility factor enhances the model qualitatively. Klippel and Winter (2005) used the model of Raubal and Winter (2002) and combined it with the advanced visibility concept of Winter (2003), but they focused on the structural salience only. They differentiated between landmarks that will not be passed (i.e., behind the intersection, opposite the direction of turn), landmarks that will be passed after the change of direction (i.e., behind the intersection and in the direction of turn), and landmarks being passed before the change of direction (see also Hansen, Richter, & Klippel, 2006). However, here they did not differentiate between the positions in and opposite to the direction of turn. They mentioned that both positions will be ideal locations for landmarks. Furthermore, they described their assumptions about the benefit of their model, but they did not provide empirical data for it.

The benefits of my model can be summarized in the following four points:

1. I defined empirical values for the structural salience. Until now, the structural salience could only be estimated or theoretically defined. Based on these data, I demonstrated the high importance of the structural salience and found that only the position before the intersection and in the direction of turn is the ideal landmark position.
2. I used a prototypical intersection layout and prototypical and clear landmarks; this is in contrast to real intersections or pictures as in several previous experiments. By using this setting, I was able to vary and compare the different saliences systematically. Based on this, I presented a computation of the weighting factors of visual and structural salience and show their influence on the whole model.

3. I implemented the concept of viewpoint-based salience, which includes a simpler and more pragmatic definition of visibility: the visible part of the landmark. This is based on the position of the observer before the intersection where she decides the landmark she prefers. Additionally, I implemented the factor of the distance between the observer and the object, and the orientation was also implemented.
4. I verified my model with a series of experiments and determined the factor combination that leads to the best fit.

13.4 Model restrictions

Two possible restrictions could be described: the first deals with the “real world” restriction (ecological validity), and the second deals with the inter-individual restriction (personality).

The first restriction refers to the fact that our every-day environment is more complex than the SQUARELAND setting and is influenced by more than the defined model parameters. Caduff and Timpf (2008) described in their model similar approaches and indicated that our every-day perception is not only influenced by visual characteristics. I address this problem of definition in Chapter 14.1, and I also address the question how multimodal processing influences the participants’ landmark-preference. How this complex environmental perception could be integrated into the model should be analyzed in the future. Nevertheless, my model describes how the landmark-preference decision works in an artificial environment that represents the underling structure of landmark-preferences. It should, with few restrictions, also work in real environments.

The second restriction refers to inter-individual preferences. It is always difficult to conclude individual preferences from a general model. It could be that a specific person only prefers street names or something else; for the issues of cognitive styles in spatial cognition research, see, e.g., Pazzaglia and Moè (2013). This problem could be solved by including the last salience: the semantic salience. However, how inter-individual preferences could be quantified is unclear until now. Nevertheless, the factors described in my model, especially the structural salience, are general factors, and my findings showed that they are very stable and applicable. I return to this issue in Chapter 14.3.

13.5 Alternative models

There is a long tradition of landmark salience research: research on saliences in route directions (Daniel & Denis, 1998; Michon & Denis, 2001; Richter, 2007; Tom & Tversky, 2012), eye-tracking studies on landmark preferences (Schwarzkopf et al., 2013; Wiener, de Condappa, & Hölscher, 2011), studies on neuronal correlates of landmark use, ideal landmark representation and spatial abilities (Committeri et al., 2004; Epstein & Vaas, 2013; Janzen, Jansen, & van Turennout, 2008; Janzen & van Tourennout, 2004; Schinazi & Epstein, 2010), and research about automatic landmark detection systems (e.g., Sadeghian & Kantardzic, 2008). One of the most used models is the extension from Sorrows and Hirtle's (1999) and Raubal and Winter's (2002) model by Klippel and Winter (2005), which form the basis of my mathematical landmark-preference model as well. In the following, I present some alternative models and compare their assumptions with my model assumptions.

The theory of Sorrows and Hirtle (1999) define the landmark saliences as a distinct aspect of the landmark itself (inherent property). However, in my definition, the landmarks are embedded in the environment and can not be interpreted separately. Additionally, the environment by definition is a spatial one (Benedikt, 1979; Kitchin & Blades, 2002; Knauff, 2013); therefore, the characteristics of a potential landmark have to be defined in relation to each other and in relation to the observers' point of view (Caduff & Timpf, 2008; Gärling, Böök, & Lindberg, 1986). This "observer-based" and environmental approach brings a new aspect into the spatial landmark research area and supplements most of the older definitions that ignore human cognition and the observers' point of view (Sorrows & Hirtle, 1999;

Presson & Montello, 1988). The model of the trilateral relation between the observer, the object, and the environment illustrates this "observer-based" approach very well (Figure 13.6).

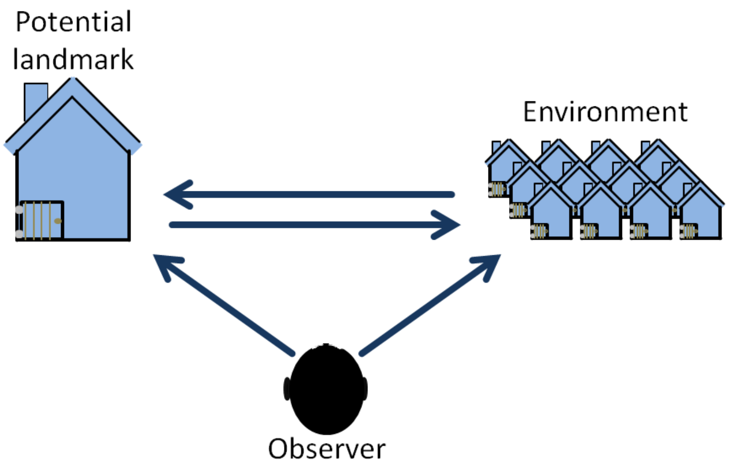


Figure 13.6. Trilateral relation between observer, potential landmark and the environment (based on Caduff & Timpf, 2008).

This model precisely describes that the selection of a potential landmark is only adequate if the object, the environment, the observer, and the relation between these three aspects are taken into account. The potential landmark object interacts with the environment, and the observer considers both the landmark and the environment. This model implies a few aspects that are central for landmark theories. First, the visual salience of a potential landmark could not be defined by itself as an inherent property of the landmark (Röser et al., 2011). The visual saliences of the surrounding potential landmarks must also be considered, and consequently the one with the highest visual salience in a specified environment is the "visually salient" object. This "bottom-up" mechanism (visual stand-out effect) is in a spatial context and landmark preference decision highly influenced and moderated by top-down processes (Chen, You & Chiou, 2003; Desimone & Duncan, 1995; Enger, Monti, Trittschuh, Wieneke, & Mesulam, 2008; Hamburger & Knauff, 2011; Itti & Koch, 2001; Smith &

Kosslyn, 2014). Second, the trilateral relation highlights the importance of the structural salience. The position of the object in relation to the other objects and in relation to the surroundings is one of the three relations (i.e., the relation between the object and the environment). This aspect should therefore be central in every landmark salience theory (Klippel & Winter, 2005; Raubal & Winter, 2002). Third, in this concept the importance of the viewpoint of the observer is clearly visible (viewpoint-based salience) and considers indirectly the concept of the visible part, the distance, and the orientation. This is represented by the relationship between observer and object (distance and orientation), observer and environment as well as of object and environment (visible part).

That the aspects of a potential landmark (e.g., its visual or structural aspects) could not be estimated in isolation was also described in later concepts. Winter (2003) presented his concept of advanced visibility, which considers the visibility of the landmarks by walking a segment of a path. Klippel and Winter (2005) integrated this within their mathematical model. In addition to the “advanced visibility”, other definitions of visibility exist, including a wide range of concepts (Elias & Brenner, 2004; Nothegger et al., 2004; Peters et al., 2010; Raubal & Winter, 2002; Richter, 2007; Winter, 2003; Winter et al., 2005; see Chapter 3.3). In my model, I summarize these relational aspects between observer and landmark and environment in the concept of the viewpoint-based salience. It includes the visible part of potential objects, the distance between them and the observer, and the orientation of them in relation to the observer view direction.

Another important model is the one by Caduff and Timpf (2008), which describes a salience assessment process with a Bayesian network. They also distinguish between three landmark characteristics: the perceptual, cognitive, and contextual salience (Figure 13.7). The perceptual salience is defined as the “bottom-up guidance of attention as it is derived from the part of the environment that is perceived by the navigator from one specific position" (p. 255). This concept integrates the definition of visual, structural, and viewpoint-based salience described above. For them, cognitive salience "in contrast to the perceptual salience, modulates attention in a top-down manner, as it is dependent on the observer's experience and knowledge" (p. 267); this is similar to the concept of semantic salience of Sorrows and Hirtle (1999). Caduff and Timpf´s (2008) contextual salience is a new and interesting concept. They define it as "how much attention can be allocated to the recognition and assessment of potential landmarks" (p. 258). This concept is considered in the description and assumptions for describing the return path (see Chapter 14.2). Caduff and Timpf (2008) call their saliences "High-level Components". How these components are determined and how the humans' evaluation is taking place starting with the perception of the environment is described in their model. In a first pre-attentive step, low-level components such as distance or orientation of objects are discriminated from the environment. These low-level components are processed in the so called auxiliary components. At this level, Caduff and Timpf (2008) postulated seven different components: idiosyncratic relevance, degree of recognition, object-based attention, location-based attention, scene context, task-based context, and modality. These components interact, but how they interact and which component influences which is actually only based on their theoretical assumptions (Figure 13.7). These auxiliary components define in a last step the high-level components, i.e., the saliences of the landmark. The complete model is visualized in Figure 13.7.

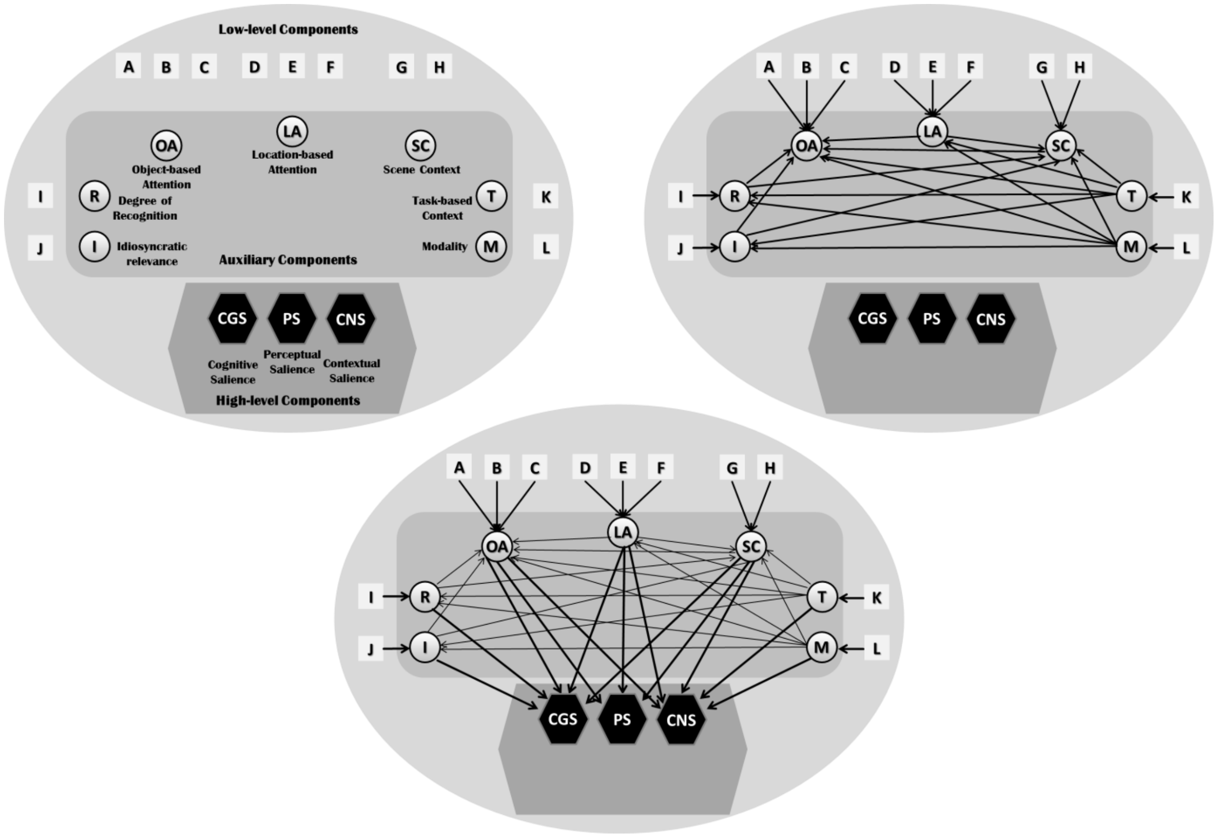


Figure 13.7. Caduff and Timpf's (2008) Bayesian network for simulation the salience assessment process (adopted from Caduff & Timpf, 2008). Components of the model (upper left). Interactions between the low-level components and the auxiliary components and the auxiliary components among themselves (upper right). The full model is shown at the bottom.

Another model is that of Lloyd (1997). In his original model, he represents a schematic neural process of landmark identification and differentiated between four different neuronal areas: one for color, size, category and location. All of them include more specific neuronal areas for specific identification mechanism, e.g., "red" and "green" or "large" and "small". His assumptions could be transferred very well into my model assumptions as shown in Figure 13.8.

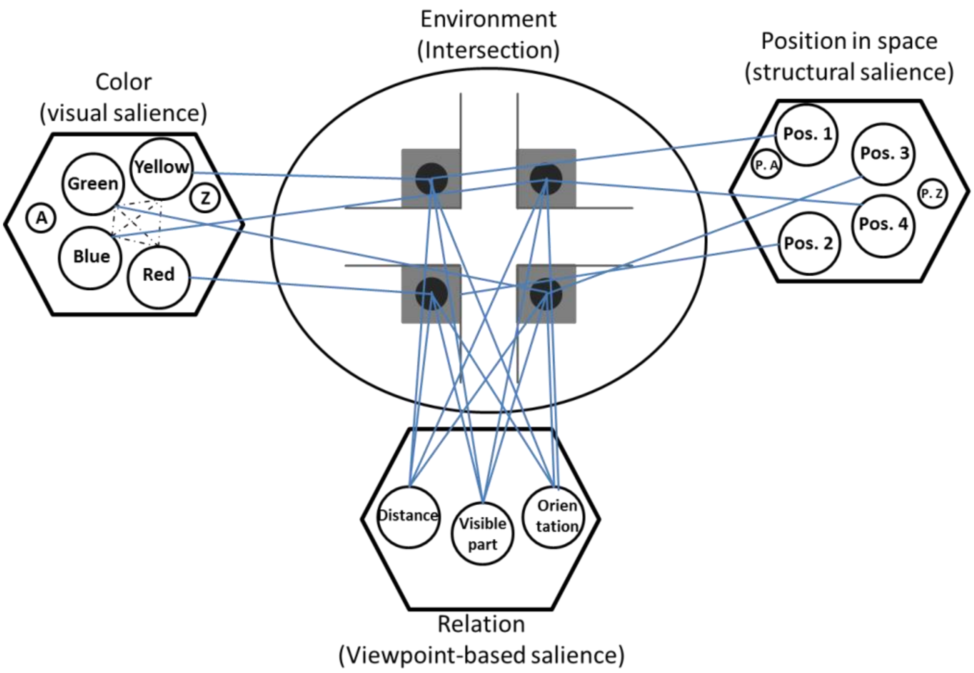


Figure 13.8. Neuronal network for the landmark-preference model (adapted from Lloyd, 1997). The blue lines represent the connections between the module parameters and the potential landmarks. The black dotted lines represent the contrast of the visual stimuli between each other. The black circles in the landmarks (gray squares) represent the competition of the single factors.

In this adapted "neuronal" model, each object in the environment in the focus of attention is preceded in the modules visual, structural, and viewpoint-based salience. Based on the findings above, the assumption is that in each module the aspects compete with each other. This model would suggest that the landmark-preference is based on the combination of the "decisions" in each module. This will be a very interesting assumption for further fMRI-studies about landmark-preference.

In summary, these three models are mainly theoretical and are not solidly built on empirical findings. Moreover, they are either very simple (trilateral relationship), which makes predictions difficult, or they are quite complex. It is unclear whether these models could explain more variance than my model and whether they predict the empirical findings significantly better.

14. Further factors and possible further research

In this section, I present some further relevant factors of landmark-preference. The first is a broader definition of visual salience, the second treated the question of what happens if the task is to describe the return path and how this influences the structural salience. In a last section, I describe some ideas for further research questions and shortly discuss their relevance.

14.1 Perceptual salience

In this work I used the term “visual salience” to describe the visual aspects of the landmark such as color. Sorrows and Hirtle (1999) as well as Klippel and Winter (2005; Raubal & Winter, 2002; Wolfe & Horowitz, 2004) also used this term. However, not only visual landmarks could be used for finding the way to a goal. Imagine you walk through the woods in the night and hear a river lapping. This river is a salient landmark for you. You could now remember that you have to go to the right if you hear the river or something else. Caduff and Timpf (2006; 2008) therefore consequently used the term “perceptual salience” and label it as “the bottom-up guidance of attention” (Caduff & Timpf, 2008; p. 256). Unfortunately, in their follow-up definition they also only consider visual characteristics.

To examine whether other stimulus modalities could also be helpful for retrieving a way through a virtual environment we – Hamburger and Röser (2014) – used in addition to visual stimuli, acoustic and written landmarks (*N*=30; 25 females; *mean age*=21.7, *SD*=2). The participants saw a path through the maze (SQUARELAND) presented via a video and at each intersection (12 in total), one of the landmarks was presented. In the first condition, we used pictures of animals as landmarks; in the second one, we used the written names of the animals and in the third one, the noises (sounds) of the animals are audible. The task was to memorize the landmarks and the path. We had two test phases: in the first phase (recognition), we presented the landmarks and distractors in random order, and the participants had to decide which of them they had perceived in the maze; in the second phase (wayfinding), the participants saw the video again, but now it stopped in front of each intersection, and the participants had to decide in which direction (left or right) the learned path had gone. The sequences of the video followed the correct path independent of the participants' decision. The results of this experiment are presented in Table 14.1.

Table 14.1. Results of the Experiment of perceptual salience

	Recognition (correct classification; landmarks and distractors [%])	**Wayfinding (correct turning decisions [%])**
Pictures	55.00	83.33
Sounds	73.33	74.17
Words	85.83	77.50

The results showed for the recognition task a significant difference between the three conditions ($F(2, 27)=8.34$, $p=.002$). Pictures and sounds differ marginally but significantly ($t(18)=-2.20$, $p=.071$; all critical values are corrected with Scheffé). Pictures and words differ significantly ($t(18)=-3.65$, $p=.002$); however, sounds and words did not differ significantly ($t(18)=-2.20$, $p=.275$; pictures < sounds = words). For the wayfinding test, we did not find significant differences ($F(2, 27)<1$).

We concluded that stimuli in other modalities than visual ones could also be used as landmarks. Interestingly, sounds and words were accompanied by better recognition performance and equal wayfinding performance. In a set of other experiments from Hamburger and Röser (2011; Experiment 1: $N=20$ students of the University of Gießen; 19 females; *mean age*=25.7, *SD*=7.1; Experiment 2: $N=20$ students of the University of Gießen; 19 females; *mean age*=22.05, *SD*=2.3; Experiment 3: $N=10$; 5 students of the University of

Gießen; 8 females; *mean age*=28.2, *SD*=9.2), we "switched" the modalities between the learning and the recognition phase. For example, if the participants learned a route with animal sounds as landmarks, they had animal pictures in the recognition as well as in the wayfinding phase, and vice versa. In these experiments, the participants did not show any "switching costs" between the modalities. This could be interpreted as evidence for a modality unspecific representation of landmarks in human cognition. However, this experiment was only a first step in the direction of a multimodal landmark representation model.

Conclusion

The inherent aspects of landmarks should be labeled in the general literature about landmarks as "perceptual salience" because not only visual facts and objects could be used as landmarks. However, in our every-day life we normally use visual stimuli as landmarks. And in the most research about landmarks (except of blind people; e.g., Gaunet, 2006; Loomis et al., 1993) visual objects and pictures were used in the experiments. Here the term "visual salience" describes the research issue much better.

14.2 Return path

Research about finding your way back to the point of origin is another interesting topic in spatial cognition (Gondorf & Jian, 2011; Lawton, Charlston, & Zieles, 1996; Silverman, et al., 2000). In our everyday life, it could happen that we have to describe a return path to someone else. Let's imagine you are at a party in an unknown part of your city and you remember the path from the train station to this building. But now you need to describe to someone the way back to the train station, i.e., the "return path". Does the position (structural salience) of your used landmarks differ with respect to those you would have used for describing the initial path (train station to party)?

The question whether the landmark preferences differ between an initial and a return path is still widely unexplored until today (Hamburger et al., 2013; Hinterecker, Röser, & Hamburger, 2014; Hinterecker, Strickrodt, Röser, & Hamburger, 2014; Strickrodt, Röser, & Hamburger, 2015). In two online experiments we – Hamburger and Röser (in press) – examined this question in more detail. To make the landmark positions clearer, I will here use the following terminology and shortcuts. As shown in Figure 14.1, I use the letters A, B, C, and D to describe the four positions at the intersection. In the following two experiments, the participants had to learn a path through a maze (presented by screenshots) illustrated by the blue solid line. Then they had to write down route directions, either for the initially learned path (blue solid line) or for the return path, as presented by the red dotted line. The letters representing the landmark positions are not changed for describing the results of the initial or return path.

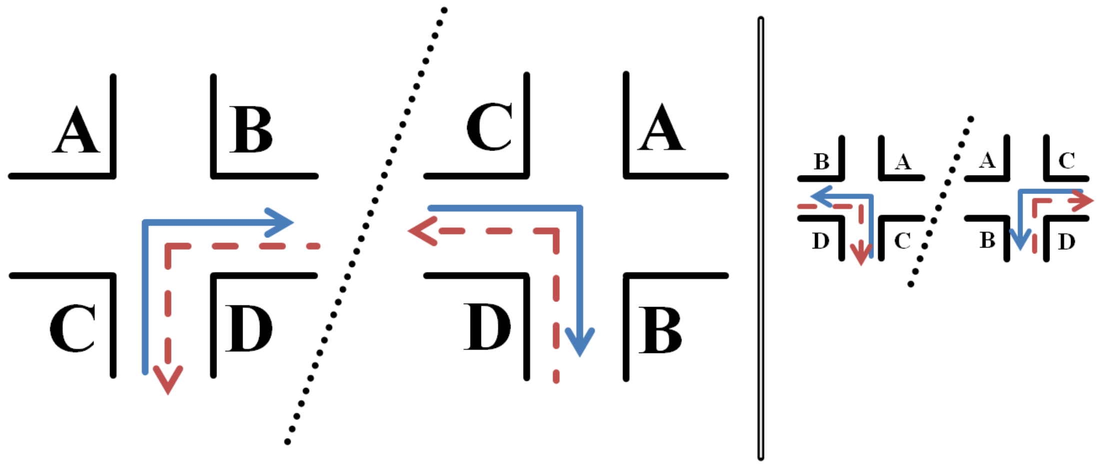


Figure 14.1. Return path. The four possible positions at an intersection and the two walking directions are shown. The blue line (solid) indicates the initial path and the presentation in the learning phase. The red line (dotted) indicates the return path. The large-scaled intersections on the left shows a turn to the right on the initial path. The left side here shows the perspective from the initial path and the right side from the return path. The small picture on the right shows the corresponding intersections for a turn to the left.

In the first experiment (*N*=127; [79 females] *mean age*= 23.96 years [*range*= 18–46]) the participants saw intersections in an allocentric perspective with words as landmarks (from start [s] to finish [f]), and afterwards they had to create route directions. In the first experimental condition, they had to describe the initial part (in the learned order: s to f); in the second, they had to describe the return path (from the end to the start: f to s). The results for the initial part (as well as a more detailed description of the setting for this and the following experiment) are the results of Experiment 4 (route directions; see also Table 8.4). The results for the initial as well as for the return path are shown in Table 14.2.

Table 14.2. Results of the Experiment's "return path" in the allocentric perspective

	Describe landmark positions [in %]	
	Initial path	**Return path**
Position A	05.22	03.36
Position B	07.46	07.38
Position C	03.73	00.67
Position D	83.58	88.59

Note: Shown are the distribution of the describe landmark positions in the route directions

In both conditions, landmarks located at position "D" are most often used. For the initial path, landmarks at this position ("D") are described 5.1 times more often than the remaining three positions together. For the return path, this happens 7.8 times more often. However, descriptively there are no large differences visible between describing the initial and the return path.

But how does this look for an egocentric perspective? To examine this, the same setting as before was used, but now with an egocentric perspective (for further details see Hamburger & Röser, in press). The results for this second experiment (*N*=191; [142 females] *mean age*= 24.53 years [*range*= 17–77]) are shown in Table 14.3.

Table 14.3 Results of the Experiment's "return path" in the egocentric perspective

	Describe landmark positions [in %]	
	Initial path	Return path
Position A	00.50	02.34
Position B	42.71	43.27
Position C	01.01	28.07
Position D	55.78	26.32

Note: Shown are the distribution of the describe landmark positions in the route directions

Here, a large difference between the results of the initial and the return path is visible. For the initial path, the results are similar to the results described in Chapter 10 (landmark-preference in an egocentric perspective). Both positions in the direction of turn ("B" and "D") are the most preferred ones. However, for describing the return path, the distribution of the described landmark positions is significantly different ($\chi^2(3)=60.532$, $p<.001$). Here landmarks at the position "C" are described in 28% of the cases. This means that for describing the return path, the participants cognitively transfer the learned intersection. But, do participants take other parameters into account than described in the mathematical model in Chapter 13? How could this shift to the position "C" be explained?

In a first model, Hamburger et al. (2013) focused on the landmark positions in relation to the walking direction, i.e., initial versus return path. Here we differentiated between variant and invariant positions. Positions "A" and "D" in Figure 14.1 are invariant. This means that position "A" is seen from the perspective of the initial path as well as from the perspective of the return path at the position behind the intersection and opposite to the direction of turn. Position "D" is in both cases at the position before the intersection and in the direction of turn. The remaining two positions ("B" and "C") change their position relative to the perspective of the observer. Position “B” is from the perspective of the initial path at the position before the intersection and opposite to the direction of turn and from the perspective of the return path at the position behind the intersection and in the direction of turn, and vice versa. The assumption is that the positions “A” and “D”, due to their invariant character, should be the preferred positions. However, the findings do not fit this assumption. But it is possible to combine this assumption with my model (Chapter 13). An assumption based on the viewpoint-based and the structural salience would predict the following: if I assume that the participants will make a mental transformation to the perspective of the return path, landmarks at the positions “C” and “D” should be used for describing the return path about 7 times more often than landmarks at the other two positions. But if I assume that the participants consider the perspective of the initial path as well as of the return path, the model prediction is that all landmarks located at all positions except for positions “A” should be used for route directions. This fits the empirical data quite well.

So I conclude that the participants will take both perspectives into consideration. Quite interestingly, it is also possible to model the return path results in an even simpler geometrical way. If I draw a circle around the corner of position “D” (the structurally ideal and the most often described one for the return path), this circle includes all corners of the landmark position that will be used for describing the return path. In Chapter 8, I already presented my idea that a rope fixed to the corner of the Position D (before the intersection and in the direction of turn) will lead the wayfinder always in the correct direction. If this rope is replaced by a circle, it describes what is demonstrated in Figure 14.2.

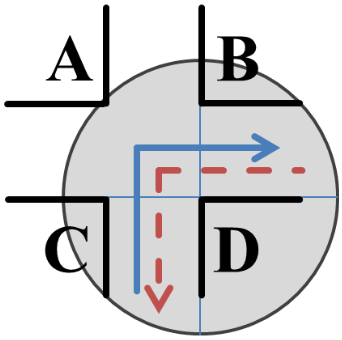


Figure 14.2. Prototypical intersection with the four positions. The circle with the middle at the corner of position "D" could resemble a rope which always leads the participants into the correct direction and additionally covers all landmark positions that were used for route directions.

Conclusion

Research about describing the return path is a relatively new field in spatial cognition. However, I presented first findings that lead to a better understanding of landmark preferences in such a task. Again, as described above, the position before the intersection in the direction of turn is the ideal landmark position. In an egocentric perspective, however, this effect is moderated by the viewpoint-based salience. And for describing the return path, the participants partially consider the perspective of the wayfinder to find the path with the given route directions. It is also possible to model the findings with the assumptions described above and without implementing an additional factor.

14.3 Possible further research

Besides the experiments presented above and the described further factors, existing overlaps with other research areas are a possible starting point for further research.

One interesting additional aspect is the question whether different cognitive styles influence the participants' landmark preferences (e.g., Pazzaglia & Moè, 2013). One well known example for the influence of cognitive styles on the wayfinding process is the sense of direction (Kozlowski & Bryant, 1977), for which Wen, Ishikawa, and Sato (2011, 2013) could show that differences in the sense of direction lead to different strategies of landmark processing. Another aspect for giving route directions and the preference of landmarks is the differentiation between “visualizers” and “verbalizers” (Richardson, 1997; see also Blajenkova, Kozhevnikov, & Motes, 2006 and Blazhenkova & Kozhevnikov, 2008). Visualizers are people who prefer visual material and seem to prefer visual representations of space. Verbalizers are people who prefer verbal material and seem to prefer verbal representations of space. For a modified screening tool to differentiate between these two cognitive styles, see the German version of the Visualizer-Verbalizer-Questionnaire (Richardson, 1977) from Wedell, Röser, and Hamburger (2014). How these styles influence the participants’ preference in detail is the subject of current research.

Another question is how route directions are cognitively represented. In detail, how is the spatial relation between the landmark and the route direction represented and memorized? The information “red house, turn right” includes two separate information: the object and the direction. In contrast, the information “in the direction where the red house is located” includes only a single information: the object. The latter one is quite longer from a lingual point of view, but only a single amount of information (“red house”) and no additional directional information must be memorized. That is, you know that you will have to go in the direction of the house; if you follow this strategy, it is possible to reduce the amount of information to be processed. A first study for the differentiation between direction specific information (“turn right/left”) and direction unspecific information (“turn into direction/in the opposite direction”) was presented by Hinterecker et al. (2014). We found different landmark position preferences between these two kinds of information (direction specific versus direction unspecific). Also this kind of belief revision of spatial landmark information in a route direction task can serve as an experimental paradigm to examine spatial cognitive representations in humans. For a first study about the combination of belief revision and spatial landmark cognition, see Bucher, Röser, Nejasmic & Hamburger (2014).

The semantic salience is part of the K&W model (see also Raubal & Winter, 2002 and Sorrows & Hirtle, 1999). In this Thesis, I focused on the effect of visual and structural landmarks and did not implement a variation of semantic landmarks. However, the semantic salience is essential in some areas of wayfinding (Hamburger & Röser, 2014; Quesnot & Roche, 2014; Raubal & Winter, 2002; Rosch, 1978; Rosch et al., 1976). One methodological problem with the semantic salience is that the quantification of it is quite unclear and vague. Sorrows and Hirtle (1999) defined semantic salience through historical and cultural importance and mentioned the prototypicality and implicit semantic as further factors. Raubal and Winter (2002) used the same classification but added "explicit marks" such as signs on the front of buildings. Schroder, Mackaness, and Gittings (2011) also used the classification of Sorrows and Hirtle (1999) but added the function of the object as another point. Elias (2003) highlighted only the function of buildings. All of these classifications use a view on the semantic that is based on "external" and "artificial" classifications, and they do not or only in part consider the individual cognitive classification and preference. Caduff and Timpf (2008) give credit to this issue with their concept of "idiosyncratic relevance". This considers the personal, individual, and perhaps the emotional reference to objects (Balaban, Röser, & Hamburger, 2014). This concept of Caduff and Timpf (2008) describes the cognitive process of semantic landmark preference best. However, it is the most difficult one to quantify and to examine.

Additionally, further eye-tracking studies could help to get a deeper understanding of the mechanisms of landmark-choice. There is literature available in which general landmarks and landmark salience are investigated with eye-tracking (Ohm et al., 2014; Schwarzkopf et al., 2013; Wiener et al., 2011); however, tracking eye-movement while presenting systematic variations of salience combinations are still unexplored (e.g., how much attention received a visually different object, and does the ideal landmark position correlate with the view duration?). My experiments are suitable to examine the question of how the view duration and view distribution over the landmarks at an intersection differ between the presentation of potential landmarks with single saliences or combination of saliences. A similar question arises for the neuronal representation of the single saliences and salience combinations. Here brain imaging experiments (fMRT) would be useful for a better understanding of the neural correlates of landmark-based wayfinding.

A great advantage but also disadvantage of the environment SQUARELAND is its strict symmetry. The advantage is that it is possible to vary and measure the different saliences in detail, in particular the structural and viewpoint-based salience. The disadvantage is that our every-day environment is normally much more complex and less symmetrical. In all of the experiments, I used the setting SQUARELAND with an orthogonal street grid. Although the first data of actual experiments look as if this representation of space complies with an early representation of space (e.g., kindergarten kids). Additionally, this checkerboard layout is quite common in many cities around the world. However, the natural environment is often more complex and includes different types of intersections. In a first step it will be useful to transfer the setting to other well-established research environments like Hexatown (Gillner & Mallot, 1998; Steck & Mallot, 2000). There, every intersection is a Y-intersection, which offers new possibilities. The last step will be a transformation to real-world pictures and environments.

15. Practical applications

What are the practical applications of this Thesis? With my work, I could show the preferred landmark (positions) at an intersection for giving route directions. This provides extensive practical applications. First, my findings could be well combined with the findings from Daniel & Denis (1998) or Denis et al. (1999). They could show how an ideal route direction should be conceptualized and formalized to be understandable and memorable. Combined with my findings and mathematical model for finding the perfect landmark at each intersection along the path, nearly perfect route directions could be created. My findings could also be used for the installation of signs. For example, if you want to know at which position at an intersection you have to place your sign ideally, you could use my mathematical model or at least consider the three relevant factors. You should use a sign that stands out at the intersection where it has to be placed (visual salience). If you generally prefer a red sign (signal color), you may face the problem that at the intersection where you want to place it, there are additional red signs. In this case, your sign does not have any visual salience. The sign should, if possible, ideally be located in the direction of turn and before the intersection (structural salience). And finally, it should be oriented in the view direction of the observer and totally visible. Also, for the programming of landmark-based navigation systems, my findings for the structural salience and my modified mathematical model could be used.

Taken together my research serves as a tool for widespread applications.

16. Corollaries and conclusions

This work was motivated by the ongoing debate in the spatial cognition community on what affects people's decisions to make use of a certain landmark instead of others when they are asked for route directions. The question is also important from an applied cognitive psychology point of view and for the development of technical spatial assistance systems that help people to navigate through unfamiliar environments. My studies provide new information on how landmarks are actually selected by direction-givers (empirical data) and how they should be selected in technical systems that seek to act in a human-like manner (theoretical and computational assumptions).

The main finding of my studies is that landmark selection is not random and may therefore be predictable. Landmark selection did not follow a uniform distribution in any of the experiments, except for the visual salience experiment with four different objects. In fact, in all of the other experiments, preferences for certain landmarks were found, and these preferences were affected by the position of the landmark at the intersection. There were methodological differences between the experiments, but irrespective of these variations participants overall had a strong bias towards landmarks that were located in the direction of turn. My work is part of a tradition of research about spatial cognition (for an overview see Allen, 2004; Dolins & Mitchel, 2014; Dudchenko, 2010; Waller & Nadel, 2012) and focuses on the use of landmarks for giving route directions (for an overview see Golledge, 1999; Richter & Winter, 2014). However, Duckham et al. (2010) asked for systematical human subject testing in the research field of wayfinding: "At several points we have highlighted the need for heuristics in selecting landmarks […]. Future work might empirically examine these heuristics with human usability studies, helping to parameterize the model […] e.g., changing relative weighting, generation of overall weights, module weights […]" (p. 18). I see this Dissertation as a contribution to this research area.

Let us return for a last time to the initial example: I asked you at the beginning which description and therefore which landmark (fast-food restaurant) you would prefer? Based on the findings of this Thesis you now know which landmark at this intersection is the ideal one, and it is now possible for you to compute the general human landmark preference. My assumptions and inferences provide a simple but sophisticated tool. My mathematical landmark-preference model is an expansion and specification of the preliminary work of Sorrows and Hirtle (1999), Raubal and Winter (2002), and Klippel and Winter (2005) and clarifies the question of which position at an intersection is the best one for the wayfinder. Additionally, it defines and formalizes the necessary factors and how they interact. The comparison of the model predictions of landmark-preference and the empirical findings reveals the best model structure. In summary, the preference for a landmark depends on two factors: the lower weighted visual characteristic of the landmark and the higher weighted position of the observer in combination with the position of the landmark.

To define and formalize this model was the main goal of this work. However, as usual, several new and additional questions have occurred in the meantime. With follow-up research, I hope to obtain a deeper understanding of the mechanisms of landmark preferences, landmark usage, and wayfinding procedures in general. To reach these goals, cooperations with other disciplines will be enriching. From a cooperation with *Cognitive Scientists* (experimental design and cognitive interpretations), *Linguists* (analyses of route directions and communications strategies), and *Computer Scientists* (review of the mathematical model and cognitive modeling), I hope for constructive and concentrated interdisciplinary research. Such collaborations have always been part of the cognitive science and lead to the success of the discipline.

"The ideal landmark position

is the position before the intersection and in the direction of turn."

Röser, 2015

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Appendix

Appendix A

Table A.1. Mean value differences between the outlier positions for the decision times [ms]

Position of the outlier	Behind the intersection, opposite the direction of turn	Behind the intersection, in the direction of turn	Before the intersection, opposite the direction of turn	Before the intersection, in the direction of turn
Behind the intersection, opposite the direction of turn	XXX	1668	-163	2913
Behind the intersection, in the direction of turn	*t*(19)=-1.738, *p*=.098	XXX	-1831	1245
Before the intersection, opposite the direction of turn	*t*(19)=0260, *p*=.798	*t*(19)=2.888, *p*=.009	XXX	3076***
Before the intersection, in the direction of turn	*t*(19)=-2.648, *p*=.016	*t*(19)=-2.132, *p*=.046	*t*(19)=-3.855, *p*=.001	XXX

Note. Significances after Bonferroni correction: * p<.05;** p<.01; *** p<.001
Post-hoc t-Tests for the decision times in Experiment 5
The values show the difference between the conditions with the different outlier positions.

Appendix B

Table A.2. Mean differences between the contrasts [%]

	0°	2°	6°	12°	22°	46°	90°	180°
0°	XXX	06.69	22.67***	41.28***	*50.87****	*52.91****	*54.94****	*54.36****
2°	*t*(42)= -1.916, *p*=.062	XXX	15.99**	34.59***	44.19***	46.2***	48.67***	47.67***
6°	*t*(42)= -5.645, *p*<.001	*t*(42)= -4.211, *p*<.001	XXX	18.60***	*28.20****	*30.23****	*32.27****	*31.69****
12°	*t*(42)= -8.620, *p*<.001	*t*(42)= -7.413, *p*<.001	*t*(42)= -5.854, *p*<.001	XXX	09.59**	11.63**	13.66**	13.08*
22°	*t*(42)= -11.385, *p*<.001	*t*(42)= -9.848, *p*<.001	*t*(42)= -8.040, *p*<.001	*t*(42)= -4.222, *p*<.001	XXX	02.03	04.07	03.49
46°	*t*(42)= -11.162, *p*<.001	*t*(42)= -9.580, *p*<.001	*t*(42)= -7.487, *p*<.001	*t*(42)= -3.938, *p*<.001	*t*(42)= -1.155, *p*=.254	XXX	02.03	01.45
90°	*t*(42)= -11.903, *p*<.001	*t*(42)= -10.311, *p*<.001	*t*(42)= -7.991, *p*<.001	*t*(42)= -4.018, *p*<.001	*t*(42)= -1.858, *p*=.070	*t*(42)= -1.069, *p*=.291	XXX	00.58
180°	*t*(42)= -11.694, *p*<.001	*t*(42)= -10.408, *p*<.001	*t*(42)= -7.927, *p*<.001	*t*(42)= -3.843, *p*<.001	*t*(42)= -1.549, *p*=.129	*t*(42)= -0.777, *p*=.441	*t*(42)= -0.573, *p*=.570	XXX

Note. Significances after Bonferroni correction: *p<.05; **p<.01; ***p<.001
Post-hoc t-Tests for the decision times in Experiment 6

Appendix C

Table A.3. Mean differences between the contrasts for the decision times [ms]

	0°	2°	6°	12°	22°	46°	90°	180°
0°	XXX	-170	-611	-1763*	-2098*	-2386**	-2014	-2337**
2°	*t*(42)= .538, *p*=.593	XXX	-440	-1592*	-1928	-2216**	-1843	-2167**
6°	*t*(42)= 1.639, *p*<.109	*t*(42)= 1.478, *p*=.147	XXX	-1152*	-1488	-1776**	-1403	-1727**
12°	*t*(42)= 3.621, *p*=.001	*t*(42)= 3.459, *p*=.001	*t*(42)= 3.704, *p*=.001	XXX	-336	-624	-251	-575
22°	*t*(42)= 3.510, *p*=.001	*t*(42)= 3.311, *p*=.002	*t*(42)= 3.282, *p*=.002	*t*(42)= .993, *p*=.326	XXX	-288	85	-239
46°	*t*(42)= 4.103, *p*<.001	*t*(42)= -3.996, *p*<.001	*t*(42)= 4.060, *p*<.001	*t*(42)= 1.857, *p*=.071	*t*(42)= .851, *p*=.400	XXX	372	49
90°	*t*(42)= 3.192, *p*=.003	*t*(42)= 3.055, *p*=.004	*t*(42)= 2.905, *p*=.006	*t*(42)= .655, *p*=.516	*t*(42)= -.207, *p*=.837	*t*(42)= -1.770, *p*=.084	XXX	-323
180°	*t*(42)= 4.291, *p*<.001	*t*(42)= 4.116, *p*<.001	*t*(42)= 4.298, *p*<.001	*t*(42)= 1.683, *p*=.100	*t*(42)= .651, *p*=.518	*t*(42)= -.202, *p*=.841	*t*(42)= 1.021, *p*=.313	XXX

Note. Significances after Bonferroni correction: *p<.05; **p<.01; ***p<.001
Post-hoc t-Tests for the decision times in Experiment 6

Appendix D

Table A.4. Mean differences between the contrasts for the decision times [ms] in Condition 1

	0°	2°	6°	12°	22°	46°	90°	180°
0°	XXX	78	-1751	-4196	-4901	-5058*	-4996	-4642
2°	*t*(10)= -.092, *p*=.928	XXX	-1829*	-4274**	-4979**	-5136**	-5074*	-4720*
6°	*t*(10)= 1.748, *p*=.111	*t*(10)= 4.845, *p*=.001	XXX	-2445	-3150	-3306	-3244	-2891
12°	*t*(10)= 4.175, *p*=.002	*t*(10)= 5.877, *p*<.001	*t*(10)= 4.506, *p*=.001	XXX	-705	-862	-800	-446
22°	*t*(10)= 4.144, *p*=.002	*t*(10)= 5.304, *p*<.001	*t*(10)= 4.055, *p*=.002	*t*(10)= 2.503, *p*=.031	XXX	-156	-94	260
46°	*t*(10)= 4.284, *p*=.002	*t*(10)= 5.330, *p*<.001	*t*(10)= 4.022, *p*=.002	*t*(10)= 2.570, *p*=.028	*t*(10)= 1.687, *p*=.122	XXX	62	416
90°	*t*(10)= 4.164, *p*=.002	*t*(10)= 5.273, *p*<.001	*t*(10)= 3.899, *p*=.003	*t*(10)= 2.240, *p*=.049	*t*(10)= .822, *p*=.430	*t*(10)= -.806, *p*=.439	XXX	354
180°	*t*(10)= 3.610, *p*=.005	*t*(10)= 4.501, *p*=.001	*t*(10)= 3.120, *p*=.011	*t*(10)= .938, *p*=.370	*t*(10)= -.944, *p*=.344	*t*(10)= -1.789, *p*=.104	*t*(10)= -1.858, *p*=.093	XXX

Note. Significances after Bonferroni correction: *p<.05; **p<.01; ***p<.001
Post-hoc t-Tests for the decision times in Experiment 6

Table A.5. Mean differences between the contrasts for the decision times [ms] in Condition 2

	0°	**2°**	**6°**	**12°**	**22°**	**46°**	**90°**	**180°**
0°	XXX	-75	-1047	-2845*	-4055**	-4170*	-3927*	-4064*
2°	*t*(10)= .125, *p*=.903	XXX	-973	-2770	-3980**	-4095*	-3852*	-3989**
6°	*t*(10)= 2.591, *p*=.027	*t*(10)= 1.613, *p*=.138	XXX	-1798	-3008**	-3123*	-2880	-3016*
12°	*t*(10)= 4.389, *p*=.001	*t*(10)= 3.418, *p*=.007	*t*(10)= 3.050, *p*=.012	XXX	-1210	-1325	-1082	-1218
22°	*t*(10)= 6.627, *p*<.001	*t*(10)= 6.026, *p*<.001	*t*(10)= 6.354, *p*<.001	*t*(10)= 3.141, *p*=.010	XXX	-115	128	-9
46°	*t*(10)= 5.166, *p*<.001	*t*(10)= 4.949, *p*=.001	*t*(10)= 4.994, *p*=.001	*t*(10)= 3.497, *p*=.006	*t*(10)= .414, *p*=.688	XXX	243	107
90°	*t*(10)= 4.743, *p*=.001	*t*(10)= 4.461, *p*=.001	*t*(10)= 4.157, *p*=.002	*t*(10)= 2.451, *p*=.034	*t*(10)= -.330, *p*=.748	*t*(10)= -.988, *p*=.342	XXX	-136
180°	*t*(10)= 4.977, *p*=.001	*t*(10)= 5.665, *p*<.001	*t*(10)= 4.626, *p*=.001	*t*(10)= 2.466, *p*=.033	*t*(10)= .032, *p*=.975	*t*(10)= -.480, *p*=.641	*t*(10)= 1.021, *p*=..448	XXX

Note. Significances after Bonferroni correction: *p<.05; **p<.01; ***p<.001
Post-hoc t-Tests for the decision times in Experiment 6

Appendix E

Table A.6 Position preference over all outlier positions in dependence of the contrasts [%]

		Over all	Contrasts							
			0°	**2°**	**6°**	**12°**	**22°**	**46°**	**90°**	**180°**
Over all outlier positions	Behind the intersection, opposite the direction of turn	**06.56**	0.00	0.00	0.00	5.00	7.50	13.75	13.75	12.50
	Behind the intersection, in the direction of turn	**23.75**	23.75	21.25	21.25	22.50	28.75	22.50	27.50	27.50
	Before the intersection, opposite the direction of turn	**02.50**	2.50	7.50	3.75	12.50	12.50	12.50	12.50	12.50
	Before the intersection, in the direction of turn	**73.75**	73.75	71.25	75.00	60.00	51.25	51.25	46.25	47.50

Table A.7 Position preference in dependence of the position of the outlier and the contrasts [%]

		Over all	Contrasts							
			0°	**2°**	**6°**	**12°**	**22°**	**46°**	**90°**	**180°**
Position of the outlier	**Behind the intersection, opposite the direction of turn**	**24.38**	0.00	0.00	0.00	20.00	30.00	50.00	50.00	45.00
	Behind the intersection, in the direction of turn	**16.88**	25.00	25.00	30.00	20.00	10.00	0.00	10.00	15.00
	Before the intersection, opposite the direction of turn	**5.00**	0.00	20.00	0.00	5.00	5.00	5.00	0.00	5.00
	Before the intersection, in the direction of turn	**53.75**	75.00	55.00	70.00	55.00	55.00	45.00	40.00	35.00
Position of the outlier	Behind the intersection, opposite the direction of turn	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Behind the intersection, in the direction of turn	**43.13**	10.00	20.00	25.00	30.00	75.00	60.00	60.00	65.00
	Before the intersection, opposite the direction of turn	**3.75**	5.00	5.00	5.00	10.00	0.00	0.00	5.00	0.00
	Before the intersection, in the direction of turn	**53.13**	85.00	75.00	70.00	60.00	25.00	40.00	35.00	35.00
Position of the outlier	Behind the intersection, opposite the direction of turn	**1.88**	0.00	0.00	0.00	0.00	0.00	5.00	5.00	5.00
	Behind the intersection, in the direction of turn	**19.38**	30.00	20.00	20.00	15.00	10.00	15.00	25.00	20.00
	Before the intersection, opposite the direction of turn	**28.75**	5.00	5.00	5.00	35.00	45.00	45.00	45.00	45.00
	Before the intersection, in the direction of turn	**50.00**	65.00	75.00	75.00	50.00	45.00	35.00	25.00	30.00

(continued)

Table A.7 Position preference in dependence of the position of the outlier and the contrasts [%] (continued)

		Over all	Contrasts							
			0°	**2°**	**6°**	**12°**	**22°**	**46°**	**90°**	**180°**
Position of the outlier	Behind the intersection, opposite the direction of turn	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Behind the intersection, in the direction of turn	**18.13**	30.00	20.00	10.00	25.00	20.00	15.00	15.00	10.00
	Before the intersection, opposite the direction of turn	**0.63**	0.00	0.00	5.00	0.00	0.00	0.00	0.00	0.00
	Before the intersection, in the direction of turn	**81.25**	70.00	80.00	85.00	75.00	80.00	85.00	85.00	90.00

Appendix F

Table A.8. Mean differences of ideal landmark position preference over the contrasts [%] and corresponding t-tests.

	0°	**2°**	**6°**	**12°**	**22°**	**46°**	**90°**	**180°**
0°	XXX	2.50	-1.25	13.75	*22.50*	*22.50*	*27.50*	*26.25*
2°	*t*(9)= 1.500, *p*=.168	XXX	-3.75	11.25	20.00	20.00	25.00	23.75
6°	*t*(9)= -0.429, *p*=.678	*t*(9)= -1.152, *p*=.279	XXX	15.00	*23.75*	*23.75*	*28.75*	*27.50*
12°	*t*(9)= 2.538, *p*=.032	*t*(9)= 1.784, *p*=.108	*t*(9)= 3.674, *p*=.005	XXX	8.75	8.75	13.75	12.50
22°	*t*(9)= 2.332, *p*=.045	*t*(9)= 1.922, *p*=.087	*t*(9)= -2.967, *p*=.016	*t*(9)= 1.210, *p*=.257	XXX	00.00	5.00	3.75
46°	*t*(9)= -2.047, *p*=.071	*t*(9)= 1.714, *p*=.121	*t*(9)= -2.349, *p*=.043	*t*(9)= 0.938, *p*=.373	*t*(9)= 0.000, *p*=1.000	XXX	5.00	3.75
90°	*t*(9)= 2.467, *p*=.036	*t*(9)= 2.095, *p*=.066	*t*(9)= -2.815, *p*=.020	*t*(9)= 1.673, *p*=.129	*t*(9)= 0.667, *p*=.522	*t*(9)= 0.937, *p*=.373	XXX	-1.25
180°	*t*(9)= 2.739, *p*=.023	*t*(9)= 2.273, *p*=.049	*t*(9)= -3.161, *p*=.012	*t*(9)= 1.677, *p*=.128	*t*(9)= 0.758, *p*=.468	*t*(9)= 1.152, *p*=.279	*t*(9)= -0.318, *p*=.758	XXX

Note. Significances after Bonferroni correction: *p<.05; **p<.01; ***p<.001
Post-hoc t-Tests for the decision times in Experiment 6

Appendix G

Table A.9. Mean value differences between the outlier positions for the decision times [ms]

Position of the outlier	Behind the intersection, opposite the direction of turn	Behind the intersection, in the direction of turn	Before the intersection, opposite the direction of turn	Before the intersection, in the direction of turn
Behind the intersection, opposite the direction of turn	XXX	552	-1135	814
Behind the intersection, in the direction of turn	$t(55)=1.074$, $p=.287$	XXX	-1687	262
Before the intersection, opposite the direction of turn	$t(55)=-1.640$, $p=.107$	$t(55)=-2.839$, $p=.020$	XXX	1950
Before the intersection, in the direction of turn	$t(55)=1.084$, $p=.283$	$t(55)=.364$, $p=.717$	$t(55)=2.420$, $p=.019$	XXX

Note. Significances after Bonferroni correction: * $p<.05$;** $p<.01$; *** $p<.001$
Post-hoc t-Tests for the decision times in Experiment 10
The values show the difference between the conditions with the different outlier positions

Appendix H

Table A.10. Explanation of the Positions

Behind the intersection, opposite the direction of turn	Position “A”
Behind the intersection, in the direction of turn	Position “B”
Before the intersection, opposite the direction of turn	Position “C”
Before the intersection, in the direction of turn	Position ”D”

Table A.11 Model parameters, model computation and empirical results for Experiment 5 and Condition 4 in Experiment 6

Exp. number	Contrast condition	Position of the outlier	Position at the intersection	Visual salience	Structural salience	w_v	w_u	Intermediate step ($w_v s_v + w_u s_u$)	Model (sum 100)	Empirical results
Exp. 5		A	A	100.00	04.64	00.50	00.50	52.32	52.32	50.00
Exp. 5		A	B	00.00	19.13	00.50	00.50	09.57	09.57	09.00
Exp. 5		A	C	00.00	04.21	00.50	00.50	02.11	02.11	07.50
Exp. 5		A	D	00.00	72.02	00.50	00.50	36.01	36.01	33.75
Exp. 5		B	A	00.00	04.64	00.50	00.50	02.32	02.32	02.50
Exp. 5		B	B	100.00	19.13	00.50	00.50	59.57	59.57	62.50
Exp. 5		B	C	00.00	04.21	00.50	00.50	02.11	02.11	00.00
Exp. 5		B	D	00.00	72.02	00.50	00.50	36.01	36.01	35.00
Exp. 5		C	A	00.00	04.64	00.50	00.50	02.32	02.32	02.50
Exp. 5		C	B	00.00	19.13	00.50	00.50	09.57	09.57	08.75
Exp. 5		C	C	100.00	04.21	00.50	00.50	52.11	52.11	53.75
Exp. 5		C	D	00.00	72.02	00.50	00.50	36.01	36.01	35.00
Exp. 5		D	A	00.00	04.64	00.50	00.50	02.32	02.32	00.00
Exp. 5		D	B	00.00	19.13	00.50	00.50	09.57	09.57	01.25
Exp. 5		D	C	00.00	04.21	00.50	00.50	02.11	02.11	01.25
Exp. 5		D	D	100.00	72.02	00.50	00.50	86.01	86.01	97.50
Exp. 6	90	A	A	09.09	04.64	00.50	00.50	06.87	12.59	00.00
Exp. 6	90	A	B	00.00	19.13	00.50	00.50	09.57	17.54	25.00
Exp. 6	90	A	C	00.00	04.21	00.50	00.50	02.11	03.86	00.00
Exp. 6	90	A	D	00.00	72.02	00.50	00.50	36.01	66.02	75.00
Exp. 6	91	A	A	21.21	04.64	00.50	00.50	12.93	21.33	00.00
Exp. 6	91	A	B	00.00	19.13	00.50	00.50	09.57	15.78	25.00
Exp. 6	91	A	C	00.00	04.21	00.50	00.50	02.11	03.47	20.00
Exp. 6	91	A	D	00.00	72.02	00.50	00.50	36.01	59.42	55.00
Exp. 6	93	A	A	62.12	04.64	00.50	00.50	33.38	41.18	00.00
Exp. 6	93	A	B	00.00	19.13	00.50	00.50	09.57	11.80	30.00
Exp. 6	93	A	C	00.00	04.21	00.50	00.50	02.11	02.60	00.00
Exp. 6	93	A	D	00.00	72.02	00.50	00.50	36.01	44.42	70.00
Exp. 6	96	A	A	95.45	04.64	00.50	00.50	50.05	51.21	20.00
Exp. 6	96	A	B	00.00	19.13	00.50	00.50	09.57	09.79	20.00
Exp. 6	96	A	C	00.00	04.21	00.50	00.50	02.11	02.15	05.00
Exp. 6	96	A	D	00.00	72.02	00.50	00.50	36.01	36.85	55.00

(continued)

Table A.11 Model parameters, model computation and empirical results for Experiment 5 and Condition 4 in Experiment 6 (continued)

Exp. number	Contrast condition	Position of the outlier	Position at the intersection	Visual salience	Structural salience	w_v	w_u	Intermediate step ($w_v s_v + w_u s_u$)	Model (sum 100)	Emprirical results
Exp. 6	101	A	A	100.00	04.64	00.50	00.50	52.32	52.32	30.00
Exp. 6	101	A	B	00.00	19.13	00.50	00.50	09.57	09.57	10.00
Exp. 6	101	A	C	00.00	04.21	00.50	00.50	02.11	02.11	05.00
Exp. 6	101	A	D	00.00	72.02	00.50	00.50	36.01	36.01	55.00
Exp. 6	113	A	A	98.48	04.64	00.50	00.50	51.56	51.96	50.00
Exp. 6	113	A	B	00.00	19.13	00.50	00.50	09.57	09.64	00.00
Exp. 6	113	A	C	00.00	04.21	00.50	00.50	02.11	02.12	05.00
Exp. 6	113	A	D	00.00	72.02	00.50	00.50	36.01	36.28	45.00
Exp. 6	135	A	A	98.48	04.64	00.50	00.50	51.56	51.96	50.00
Exp. 6	135	A	B	00.00	19.13	00.50	00.50	09.57	09.64	10.00
Exp. 6	135	A	C	00.00	04.21	00.50	00.50	02.11	02.12	00.00
Exp. 6	135	A	D	00.00	72.02	00.50	00.50	36.01	36.28	40.00
Exp. 6	180	A	A	96.97	04.64	00.50	00.50	50.80	51.59	45.00
Exp. 6	180	A	B	00.00	19.13	00.50	00.50	09.57	09.71	15.00
Exp. 6	180	A	C	00.00	04.21	00.50	00.50	02.11	02.14	05.00
Exp. 6	180	A	D	00.00	72.02	00.50	00.50	36.01	36.56	35.00
Exp. 6	90	B	A	00.00	04.64	00.50	00.50	02.32	04.25	00.00
Exp. 6	90	B	B	09.09	19.13	00.50	00.50	14.11	25.87	10.00
Exp. 6	90	B	C	00.00	04.21	00.50	00.50	02.11	03.86	05.00
Exp. 6	90	B	D	00.00	72.02	00.50	00.50	36.01	66.02	85.00
Exp. 6	91	B	A	00.00	04.64	00.50	00.50	02.32	03.83	00.00
Exp. 6	91	B	B	21.21	19.13	00.50	00.50	20.17	33.28	20.00
Exp. 6	91	B	C	00.00	04.21	00.50	00.50	02.11	03.47	05.00
Exp. 6	91	B	D	00.00	72.02	00.50	00.50	36.01	59.42	75.00
Exp. 6	93	B	A	00.00	04.64	00.50	00.50	02.32	02.86	00.00
Exp. 6	93	B	B	62.12	19.13	00.50	00.50	40.63	50.12	25.00
Exp. 6	93	B	C	00.00	04.21	00.50	00.50	02.11	02.60	05.00
Exp. 6	93	B	D	00.00	72.02	00.50	00.50	36.01	44.42	70.00
Exp. 6	96	B	A	00.00	04.64	00.50	00.50	02.32	02.37	00.00
Exp. 6	96	B	B	95.45	19.13	00.50	00.50	57.29	58.62	30.00
Exp. 6	96	B	C	00.00	04.21	00.50	00.50	02.11	02.15	10.00
Exp. 6	96	B	D	00.00	72.02	00.50	00.50	36.01	36.85	60.00
Exp. 6	101	B	A	00.00	04.64	00.50	00.50	02.32	02.32	00.00
Exp. 6	101	B	B	100.00	19.13	00.50	00.50	59.56	59.56	75.00
Exp. 6	101	B	C	00.00	04.21	00.50	00.50	02.11	02.11	00.00
Exp. 6	101	B	D	00.00	72.02	00.50	00.50	36.01	36.01	25.00
Exp. 6	113	B	A	00.00	04.64	00.50	00.50	02.32	02.34	00.00
Exp. 6	113	B	B	98.48	19.13	00.50	00.50	58.81	59.26	60.00
Exp. 6	113	B	C	00.00	04.21	00.50	00.50	02.11	02.12	00.00
Exp. 6	113	B	D	00.00	72.02	00.50	00.50	36.01	36.28	40.00
Exp. 6	135	B	A	00.00	04.64	00.50	00.50	02.32	02.34	00.00
Exp. 6	135	B	B	98.48	19.13	00.50	00.50	58.81	59.26	60.00
Exp. 6	135	B	C	00.00	04.21	00.50	00.50	02.11	02.12	05.00
Exp. 6	135	B	D	00.00	72.02	00.50	00.50	36.01	36.28	35.00

(continued)

Table A.11 Model parameters, model computation and empirical results for Experiment 5 and Condition 4 in Experiment 6 (continued)

Exp. number	Contrast condition	Position of the outlier	Position at the intersection	Visual salience	Structural salience	w_v	w_u	Intermediate step ($w_v s_v + w_u s_u$)	Model (sum 100)	Emprirical results
Exp. 6	180	B	A	00.00	04.64	00.50	00.50	02.32	02.36	00.00
Exp. 6	180	B	B	96.97	19.13	00.50	00.50	58.05	58.94	65.00
Exp. 6	180	B	C	00.00	04.21	00.50	00.50	02.11	02.14	00.00
Exp. 6	180	B	D	00.00	72.02	00.50	00.50	36.01	36.56	35.00
Exp. 6	90	C	A	00.00	04.64	00.50	00.50	02.32	04.25	00.00
Exp. 6	90	C	B	00.00	19.13	00.50	00.50	09.57	17.54	30.00
Exp. 6	90	C	C	09.09	04.21	00.50	00.50	06.65	12.19	05.00
Exp. 6	90	C	D	00.00	72.02	00.50	00.50	36.01	66.02	65.00
Exp. 6	91	C	A	00.00	04.64	00.50	00.50	02.32	03.83	00.00
Exp. 6	91	C	B	00.00	19.13	00.50	00.50	09.57	15.78	20.00
Exp. 6	91	C	C	21.21	04.21	00.50	00.50	12.71	20.97	05.00
Exp. 6	91	C	D	00.00	72.02	00.50	00.50	36.01	59.42	75.00
Exp. 6	93	C	A	00.00	04.64	00.50	00.50	02.32	02.86	00.00
Exp. 6	93	C	B	00.00	19.13	00.50	00.50	09.57	11.80	20.00
Exp. 6	93	C	C	62.12	04.21	00.50	00.50	33.17	40.91	05.00
Exp. 6	93	C	D	00.00	72.02	00.50	00.50	36.01	44.42	75.00
Exp. 6	96	C	A	00.00	04.64	00.50	00.50	02.32	02.37	00.00
Exp. 6	96	C	B	00.00	19.13	00.50	00.50	09.57	09.79	15.00
Exp. 6	96	C	C	95.45	04.21	00.50	00.50	49.83	50.99	35.00
Exp. 6	96	C	D	00.00	72.02	00.50	00.50	36.01	36.85	50.00
Exp. 6	101	C	A	00.00	04.64	00.50	00.50	02.32	02.32	00.00
Exp. 6	101	C	B	00.00	19.13	00.50	00.50	09.57	09.57	10.00
Exp. 6	101	C	C	100.00	04.21	00.50	00.50	52.10	52.10	45.00
Exp. 6	101	C	D	00.00	72.02	00.50	00.50	36.01	36.01	45.00
Exp. 6	113	C	A	00.00	04.64	00.50	00.50	02.32	02.34	05.00
Exp. 6	113	C	B	00.00	19.13	00.50	00.50	09.57	09.64	15.00
Exp. 6	113	C	C	98.48	04.21	00.50	00.50	51.35	51.74	45.00
Exp. 6	113	C	D	00.00	72.02	00.50	00.50	36.01	36.28	35.00
Exp. 6	135	C	A	00.00	04.64	00.50	00.50	02.32	02.34	05.00
Exp. 6	135	C	B	00.00	19.13	00.50	00.50	09.57	09.64	25.00
Exp. 6	135	C	C	98.48	04.21	00.50	00.50	51.35	51.74	45.00
Exp. 6	135	C	D	00.00	72.02	00.50	00.50	36.01	36.28	25.00
Exp. 6	180	C	A	00.00	04.64	00.50	00.50	02.32	02.36	05.00
Exp. 6	180	C	B	00.00	19.13	00.50	00.50	09.57	09.71	20.00
Exp. 6	180	C	C	96.97	04.21	00.50	00.50	50.59	51.37	45.00
Exp. 6	180	C	D	00.00	72.02	00.50	00.50	36.01	36.56	30.00
Exp. 6	90	D	A	00.00	04.64	00.50	00.50	02.32	04.25	00.00
Exp. 6	90	D	B	00.00	19.13	00.50	00.50	09.57	17.54	30.00
Exp. 6	90	D	C	00.00	04.21	00.50	00.50	02.11	03.86	00.00
Exp. 6	90	D	D	09.09	72.02	00.50	00.50	40.56	74.35	70.00
Exp. 6	91	D	A	00.00	04.64	00.50	00.50	02.32	03.83	00.00
Exp. 6	91	D	B	00.00	19.13	00.50	00.50	09.57	15.78	20.00
Exp. 6	91	D	C	00.00	04.21	00.50	00.50	02.11	03.47	00.00
Exp. 6	91	D	D	21.21	72.02	00.50	00.50	46.62	76.92	80.00

(continued)

Table A.11 Model parameters, model computation and empirical results for Experiment 5 and Condition 4 in Experiment 6 (continued)

Exp. number	Contrast condition	Position of the outlier	Position at the intersection	Visual salience	Structural salience	w_v	w_u	Intermediate step ($w_v s_v + w_u s_u$)	Model (sum 100)	Emprirical results
Exp. 6	93	D	A	00.00	04.64	00.50	00.50	02.32	02.86	00.00
Exp. 6	93	D	B	00.00	19.13	00.50	00.50	09.57	11.80	10.00
Exp. 6	93	D	C	00.00	04.21	00.50	00.50	02.11	02.60	05.00
Exp. 6	93	D	D	62.12	72.02	00.50	00.50	67.07	82.74	85.00
Exp. 6	96	D	A	00.00	04.64	00.50	00.50	02.32	02.37	00.00
Exp. 6	96	D	B	00.00	19.13	00.50	00.50	09.57	09.79	25.00
Exp. 6	96	D	C	00.00	04.21	00.50	00.50	02.11	02.15	00.00
Exp. 6	96	D	D	95.45	72.02	00.50	00.50	83.74	85.68	75.00
Exp. 6	101	D	A	00.00	04.64	00.50	00.50	02.32	02.32	00.00
Exp. 6	101	D	B	00.00	19.13	00.50	00.50	09.57	09.57	20.00
Exp. 6	101	D	C	00.00	04.21	00.50	00.50	02.11	02.11	00.00
Exp. 6	101	D	D	100.00	72.02	00.50	00.50	86.01	86.01	80.00
Exp. 6	113	D	A	00.00	04.64	00.50	00.50	02.32	02.34	00.00
Exp. 6	113	D	B	00.00	19.13	00.50	00.50	09.57	09.64	15.00
Exp. 6	113	D	C	00.00	04.21	00.50	00.50	02.11	02.12	00.00
Exp. 6	113	D	D	98.48	72.02	00.50	00.50	85.25	85.90	85.00
Exp. 6	135	D	A	00.00	04.64	00.50	00.50	02.32	02.34	00.00
Exp. 6	135	D	B	00.00	19.13	00.50	00.50	09.57	09.64	15.00
Exp. 6	135	D	C	00.00	04.21	00.50	00.50	02.11	02.12	00.00
Exp. 6	135	D	D	98.48	72.02	00.50	00.50	85.25	85.90	85.00
Exp. 6	180	D	A	00.00	04.64	00.50	00.50	02.32	02.36	00.00
Exp. 6	180	D	B	00.00	19.13	00.50	00.50	09.57	09.71	10.00
Exp. 6	180	D	C	00.00	04.21	00.50	00.50	02.11	02.14	00.00
Exp. 6	180	D	D	96.97	72.02	00.50	00.50	84.49	85.79	90.00

Appendix I

Table A.12. Explanation of the Positions

Behind the intersection, opposite the direction of turn	Position “A”
Behind the intersection, in the direction of turn	Position “B”
Before the intersection, opposite the direction of turn	Position “C”
Before the intersection, in the direction of turn	Position ”D”

Table A.13 Model parameters, model computation and empirical results for Experiment 5 and Condition 4 in Experiment 6

Exp. number	View position	Position at the intersection	Visible part of the facade	Structural salience	Distance	Orientation	Visible part	Intermedia step I (vpbs*$w_u s_u$)	Intermedia step II (mean of visible facades)	Model (sum 100)	Empirical results
Exp. 7		Pos. A	Front	04.64	0.90	1.00	0.50	02.08	02.20	09.94	01.45
Exp. 7			Side	04.64	1.00	0.50	1.00	02.32			
Exp. 7		Pos. B	Front	19.13	0.90	1.00	0.50	08.56	09.06	40.96	30.80
Exp. 7			Side	19.13	1.00	0.50	1.00	09.57			
Exp. 7		Pos. C	Side	04.21	0.43	0.50	0.67	00.60	00.60	02.71	05.43
Exp. 7		Pos. D	Side	72.02	0.43	0.50	0.67	10.26	10.26	46.39	62.32
Exp. 8	Con. 1	Pos. A	Front	04.64	0.90	1.00	0.50	02.08	02.20	09.77	00.28
Exp. 8	Con. 1		Side	04.64	1.00	0.50	1.00	02.32			
Exp. 8	Con. 1	Pos. B	Front	19.13	0.90	1.00	0.50	08.58	09.07	40.28	33.89
Exp. 8	Con. 1		Side	19.13	1.00	0.50	1.00	09.57			
Exp. 8	Con. 1	Pos. C	Side	04.21	0.48	0.50	0.62	00.62	00.62	02.76	01.11
Exp. 8	Con. 1	Pos. D	Side	72.02	0.48	0.50	0.62	10.63	10.63	47.19	64.72
Exp. 8	Con. 2	Pos. A	Front	04.64	0.89	1.00	0.56	02.32	02.32	13.25	01.39
Exp. 8	Con. 2		Side	04.64	1.00	0.50	1.00	02.32			
Exp. 8	Con. 2	Pos. B	Front	19.13	0.89	1.00	0.56	09.55	09.56	54.61	54.17
Exp. 8	Con. 2		Side	19.13	1.00	0.50	1.00	09.57			
Exp. 8	Con. 2	Pos. C	Side	04.21	0.43	0.50	0.34	00.31	00.31	01.78	01.67
Exp. 8	Con. 2	Pos. D	Side	72.02	0.43	0.50	0.34	05.31	05.31	30.37	42.78
Exp. 8	Con. 3	Pos. A	Front	04.64	0.89	1.00	0.59	02.43	02.31	15.88	03.06
Exp. 8	Con. 3		Side	04.64	1.00	0.50	0.94	02.18			
Exp. 8	Con. 3	Pos. B	Front	19.13	0.89	1.00	0.59	10.03	09.51	65.47	55.83
Exp. 8	Con. 3		Side	19.13	1.00	0.50	0.94	08.99			
Exp. 8	Con. 3	Pos. C	Side	04.21	0.44	0.50	0.16	00.15	00.15	01.03	01.94
Exp. 8	Con. 3	Pos. D	Side	72.02	0.44	0.50	0.16	02.56	02.56	17.62	39.17

(continued)

Table A.13 Model parameters, model computation and empirical results for Experiment 5 and Condition 4 in Experiment 6 (continued)

Exp. number	View position	Position at the intersection	Visible part of the facade	Structural salience	Distance	Orientation	Visible part	Intermedia step I (vpbs*$w_u s_u$)	Intermedia step II (mean of visible facades)	Model (sum 100)	Empirical results
Exp. 9	Con. 1	Pos. A	Front	04.64	0.88	1.00	0.48	01.97	02.14	10.51	04.13
Exp. 9	Con. 1		Side	04.64	1.00	0.50	1.00	02.32			
Exp. 9	Con. 1	Pos. B	Front	19.13	0.88	1.00	0.48	08.10	08.83	43.32	48.76
Exp. 9	Con. 1		Side	19.13	1.00	0.50	1.00	09.57			
Exp. 9	Con. 1	Pos. C	Side	04.21	0.41	0.50	0.60	00.52	00.52	02.55	03.48
Exp. 9	Con. 1	Pos. D	Seite	72.02	0.41	0.50	0.60	08.90	08.90	43.63	43.63
Exp. 9	Con. 2	Pos. A	Front	04.64	0.61	0.99	0.36	01.01	01.68	10.22	15.04
Exp. 9	Con. 2		Side	04.64	1.00	0.51	1.00	02.35			
Exp. 9	Con. 2	Pos. B	Front	19.13	0.83	0.99	0.28	04.44	06.77	41.20	35.38
Exp. 9	Con. 2		Side	19.13	0.96	0.49	1.00	09.10			
Exp. 9	Con. 2	Pos. C	Side	04.21	0.52	0.51	0.28	00.31	00.31	01.88	03.42
Exp. 9	Con. 2	Pos. D	Side	72.02	0.37	0.49	0.58	07.67	07.67	46.69	46.17
Exp. 9	Con. 3	Pos. A	Front	04.64	0.83	0.99	0.26	01.00	01.60	10.52	02.42
Exp. 9	Con. 3		Side	04.64	0.96	0.49	1.00	02.21			
Exp. 9	Con. 3	Pos. B	Front	19.13	0.90	0.99	0.36	06.13	07.90	51.83	59.43
Exp. 9	Con. 3		Side	19.13	1.00	0.51	1.00	09.67			
Exp. 9	Con. 3	Pos. C	Side	04.21	0.37	0.49	0.58	00.45	00.45	02.94	03.54
Exp. 9	Con. 3	Pos. D	Side	72.02	0.52	0.51	0.28	05.29	05.29	34.71	34.61

Note. w_u is here always 05. and can therefore be ignored.
The conditions (Con.) are described and defined in the corresponding experimental sections.

Appendix J

Table A.14. Explanation of the Positions

Behind the intersection, opposite the direction of turn	Position “A”
Behind the intersection, in the direction of turn	Position “B”
Before the intersection, opposite the direction of turn	Position “C”
Before the intersection, in the direction of turn	Position ”D”

Table A.15. Model parameters, model computation and empirical results for Experiment 10 for $s_t = d * o * v_{vis} * (w_v s_v + w_u s_u)$

Position of the outlier	Position at the intersection	Visible part of the facade	Visual salience	Structural salience	wv	wu	Distance	Orientation	Visible part	Intermedia step I	Intermedia step II (mean of visible facades)	Model (sum 100)	Empirical results
A	A	Front	100.00	04.64	00.38	00.62	00.88	01.00	00.48	17.48	19.05	62.89	45.54
A		Side	100.00	04.64	00.38	00.62	01.00	00.50	01.00	20.63			
A	B	Front	00.00	19.13	00.38	00.62	00.88	01.00	00.48	04.99	05.44	17.96	20.98
A		Side	00.00	19.13	00.38	00.62	01.00	00.50	01.00	05.89			
A	C	Side	00.00	04.21	00.38	00.62	00.41	00.50	00.60	00.32	00.32	01.06	01.34
A	D	Side	00.00	72.02	00.38	00.62	00.41	00.50	00.60	05.48	05.48	18.09	32.14
B	A	Front	00.00	04.64	00.38	00.62	00.88	01.00	00.48	01.21	01.32	04.36	01.79
B		Side	00.00	04.64	00.38	00.62	01.00	00.50	01.00	01.43			
B	B	Front	100.00	19.13	00.38	00.62	00.88	01.00	00.48	21.26	23.17	76.49	75.45
B		Side	100.00	19.13	00.38	00.62	01.00	00.50	01.00	25.09			
B	C	Side	00.00	04.21	00.38	00.62	00.41	00.50	00.60	00.32	00.32	01.06	00.89
B	D	Side	00.00	72.02	00.38	00.62	00.41	00.50	00.60	05.48	05.48	18.09	21.88
C	A	Front	00.00	04.64	00.38	00.62	00.88	01.00	00.48	01.21	01.32	07.63	01.34
C		Side	00.00	04.64	00.38	00.62	01.00	00.50	01.00	01.43			
C	B	Front	00.00	19.13	00.38	00.62	00.88	01.00	00.48	04.99	05.44	31.44	16.52
C		Side	00.00	19.13	00.38	00.62	01.00	00.50	01.00	05.89			
C	C	Side	100.00	04.21	00.38	00.62	00.41	00.50	00.60	05.06	05.06	29.26	47.32
C	D	Side	00.00	72.02	00.38	00.62	00.41	00.50	00.60	05.48	05.48	31.67	34.82
D	A	Front	00.00	04.64	00.38	00.62	00.88	01.00	00.48	01.21	01.32	07.63	00.45
D		Side	00.00	04.64	00.38	00.62	01.00	00.50	01.00	01.43			
D	B	Front	00.00	19.13	00.38	00.62	00.88	01.00	00.48	04.99	05.44	31.44	09.82
D		Side	00.00	19.13	00.38	00.62	01.00	00.50	01.00	05.89			
D	C	Side	00.00	04.21	00.38	00.62	00.41	00.50	00.60	00.32	00.32	01.85	00.45
D	D	Side	100.00	72.02	00.38	00.62	00.41	00.50	00.60	10.22	10.22	59.08	89.29

Note. w_u and w_v here are obtained from the computation of Chapter 9.
Intermedia step I: computation the total salience for each visible facade.

Table A.16. Model parameters, model computation and empirical results for Experiment 10 for $s_t = (d * o * v_{vis} * w_u s_u) + w_v s_v$

Position of the outlier	Position at the intersection	Visible part of the facade	Visual salience	Structural salience	wv	wu	Distance	Orientation	Visible part	Intermedia step I (vpbs*$w_u s_u$)	Intermedia step II (mean of visible facades)	Model (sum 100)	Empirical results
A	A	Front	100.00	04.64	00.38	00.62	00.88	01.00	00.48	15.51	15.66	49.90	45.54
A		Side	100.00	04.64	00.38	00.62	01.00	00.50	01.00	15.82			
A	B	Front	00.00	19.13	00.38	00.62	00.88	01.00	00.48	06.98	07.61	24.25	20.98
A		Side	00.00	19.13	00.38	00.62	01.00	00.50	01.00	08.24			
A	C	Side	00.00	04.21	00.38	00.62	00.41	00.50	00.60	00.45	00.45	01.43	01.34
A	D	Side	00.00	72.02	00.38	00.62	00.41	00.50	00.60	07.67	07.67	24.43	32.14
B	A	Front	00.00	04.64	00.38	00.62	00.88	01.00	00.48	01.69	01.85	05.88	01.79
B		Side	00.00	04.64	00.38	00.62	01.00	00.50	01.00	02.00			
B	B	Front	100.00	19.13	00.38	00.62	00.88	01.00	00.48	20.80	21.43	68.27	75.45
B		Side	100.00	19.13	00.38	00.62	01.00	00.50	01.00	22.06			
B	C	Side	00.00	04.21	00.38	00.62	00.41	00.50	00.60	00.45	00.45	01.43	00.89
B	D	Side	00.00	72.02	00.38	00.62	00.41	00.50	00.60	07.67	07.67	24.43	21.88
C	A	Front	00.00	04.64	00.38	00.62	00.88	01.00	00.48	01.69	01.85	05.88	01.34
C		Side	00.00	04.64	00.38	00.62	01.00	00.50	01.00	02.00			
C	B	Front	00.00	19.13	00.38	00.62	00.88	01.00	00.48	06.98	07.61	24.25	16.52
C		Side	00.00	19.13	00.38	00.62	01.00	00.50	01.00	08.24			
C	C	Side	100.00	04.21	00.38	00.62	00.41	00.50	00.60	14.27	14.27	45.44	47.32
C	D	Side	00.00	72.02	00.38	00.62	00.41	00.50	00.60	07.67	07.67	07.67	34.82
D	A	Front	00.00	04.64	00.38	00.62	00.88	01.00	00.48	01.69	01.85	05.88	00.45
D		Side	00.00	04.64	00.38	00.62	01.00	00.50	01.00	02.00			
D	B	Front	00.00	19.13	00.38	00.62	00.88	01.00	00.48	06.98	07.61	24.25	09.82
D		Side	00.00	19.13	00.38	00.62	01.00	00.50	01.00	08.24			
D	C	Side	00.00	04.21	00.38	00.62	00.41	00.50	00.60	00.45	00.45	01.43	00.45
D	D	Side	100.00	72.02	00.38	00.62	00.41	00.50	00.60	21.49	21.49	68.44	89.29

Note. w_u and w_v here are obtained from the computation of Chapter 9.
Intermedia step I: computation the total salience for each visible facade.

Table A.17. Model parameters, model computation and empirical results for Experiment 10 for $s_t = (d * o * v_{vis} * w_v s_v) + w_u s_u$

Position of the outlier	Position at the intersection	Visible part of the facade	Visual salience	Structural salience	wv	wu	Distance	Orientation	Visible part	Intermedia step I ($vpbs*w_u s_u$)	Intermedia step II (mean of visible facades)	Model (sum 100)	Empirical results
A	A	Front	100.00	04.64	00.38	00.62	00.88	01.00	00.48	09.85	10.38	11.21	45.54
A		Side	100.00	04.64	00.38	00.62	01.00	00.50	01.00	10.91			
A	B	Front	00.00	19.13	00.38	00.62	00.88	01.00	00.48	16.49	16.49	17.81	20.98
A		Side	00.00	19.13	00.38	00.62	01.00	00.50	01.00	16.49			
A	C	Side	00.00	04.21	00.38	00.62	00.41	00.50	00.60	03.63	03.63	03.92	01.34
A	D	Side	00.00	72.02	00.38	00.62	00.41	00.50	00.60	62.07	62.07	62.07	32.14
B	A	Front	00.00	04.64	00.38	00.62	00.88	01.00	00.48	04.00	04.00	04.32	01.79
B		Side	00.00	04.64	00.38	00.62	01.00	00.50	01.00	04.00			
B	B	Front	100.00	19.13	00.38	00.62	00.88	01.00	00.48	22.34	22.87	24.70	75.45
B		Side	100.00	19.13	00.38	00.62	01.00	00.50	01.00	23.40			
B	C	Side	00.00	04.21	00.38	00.62	00.41	00.50	00.60	03.63	03.63	03.92	00.89
B	D	Side	00.00	72.02	00.38	00.62	00.41	00.50	00.60	62.07	64.07	67.06	21.88
C	A	Front	00.00	04.64	00.38	00.62	00.88	01.00	00.48	04.00	04.00	04.55	01.34
C		Side	00.00	04.64	00.38	00.62	01.00	00.50	01.00	04.00			
C	B	Front	00.00	19.13	00.38	00.62	00.88	01.00	00.48	16.49	16.49	18.76	16.52
C		Side	00.00	19.13	00.38	00.62	01.00	00.50	01.00	16.49			
C	C	Side	100.00	04.21	00.38	00.62	00.41	00.50	00.60	05.34	05.34	06.07	47.32
C	D	Side	00.00	72.02	00.38	00.62	00.41	00.50	00.60	62.07	62.07	70.62	34.82
D	A	Front	00.00	04.64	00.38	00.62	00.88	01.00	00.48	04.00	04.00	01.55	00.45
D		Side	00.00	04.64	00.38	00.62	01.00	00.50	01.00	04.00			
D	B	Front	00.00	19.13	00.38	00.62	00.88	01.00	00.48	16.49	16.49	18.76	09.82
D		Side	00.00	19.13	00.38	00.62	01.00	00.50	01.00	16.49			
D	C	Side	00.00	04.21	00.38	00.62	00.41	00.50	00.60	03.63	03.63	04.13	00.45
D	D	Side	100.00	72.02	00.38	00.62	00.41	00.50	00.60	63.78	63.78	72.56	89.29

Note. w_u and w_v here are obtained from the computation of Chapter 9.
Intermedia step I: computation the total salience for each visible facade.

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Gießen, den ________________ ___________________________
Florian Röser