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The influence of perceptual and structural salience

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The influence of perceptual and structural salience

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Abstract

Spatial cognition research has recently made much progress in understanding the cognitive representations and processes underlying human wayfinding. Many theoretical assumptions about the concept of landmark salience have been established. In this context it is important to define perceptual (or visual) and structural landmark salience. Structural salience is defined as the position of a landmark at an intersection. Perceptual salience is defined as the visual characteristic of a landmark. It must "stand out" from its surrounding to be perceptually salient. We investigated the influence of perceptual salience and the combination of perceptual and structural salience in landmark selection. We show for a spatial arrangement of four objects that the different object is preferred almost always. If the same spatial arrangement is interpreted as an intersection with a directional information, the participants' preference is influenced by structural as well as perceptual salience. Findings are discussed within the context of landmark salience.

Keywords: landmark; perceptual salience; structural salience

Introduction

Human wayfinding is a particularly active field of spatial cognition research. People often have to navigate through new or familiar environments and that they, of course, do not want to get lost. Another reason is that wayfinding research is important for many basic and applied research fields, for instance, the study of spatial long-term memory and the development of user-friendly navigation systems.

One of the central concepts in spatial cognition research is the *landmark* and the question how it can be defined. Consequently, several definitions and theories about the nature of landmarks and their characteristics exist. The most common assumption is that the potential landmark must have a high contrast to its immediate or wider surrounding (e.g., Presson & Montello, 1988; Janzen & van Turennout, 2004; Caduff & Timpf, 2008). Anything can serve as a landmark; natural, artificial, or man-made objects along a route that help us to find the way. Landmarks are helpful in wayfinding because they "stand out" of the environment, can serve as anchors (Couclelis, Golledge, & Tobler, 1987), are better remembered if a change of direction is required (Lee, Tappe & Klippel, 2002; Lee, Klippel & Tappe, 2003), and increase the quality of a route description (Denis, Pazzaglia, Cornoldi, & Bertolo, 1999).

The present paper is concerned with the *salience* of landmarks. The term "salience" is mostly referred to perceptual psychology (e.g., Treisman & Gelade, 1980) and means that a salient object needs to stand out compared to other objects (e.g., different color or orientation). We here distinguish two kinds of landmark salience: *structural salience* and *perceptual salience*.

Structural salience

Structural aspects of landmarks refer to the contexts of landmarks in navigational tasks and may be divided into different aspects or gradations. It is generally accepted that landmarks must have a "prominent location in the environment" (Sorrows & Hirtle, 1999; p. 46). Furthermore, they can be separated into global and local landmarks (Steck & Mallot, 2000). Local landmarks are situated directly along the path and intersections (Klippel & Winter, 2005). Those at an intersection may again be divided, based on the route in the navigational task, into landmarks at a decision point or non-decision point, where a direction change is necessary/possible (Michon & Denis, 2001).

Here we concentrate on landmarks directly located at an intersection were a decision is required (Lee et al., 2002; Peters, Wu, & Winter, 2010). In this context we define structural salience as a preference of a wayfinder for a landmark to be located at a specific position at an intersection. Strictly speaking structural salience is thereby not a property of a landmark itself but of its position at an intersection. Therefore we have to address the question how an intersection can be defined. A typical or even prototypical intersection is a cross intersection. At such intersections four possible positions for landmarks are available (figure 1).

The true (physical) position of a landmark, *on the right* or *on the left* of the observer, is less important than the position in dependence to the direction of the turn to be made at the intersection. So the four positions can be defined as the positions *before* and *behind the intersection* and *in direction* or *opposite to the direction of turn* (see also Hamburger, Dienelt, Strickrodt, & Röser, 2013) and will be abbreviated as "turn based" in the following. The preferred positions for a landmark at such a prototypical intersection from an allocentric perspective are *in direction of the turn* with the main focus *before* the intersection (figure 2). These results serve as our reference for the influence of structural salience at the positions of a four-way-intersection.

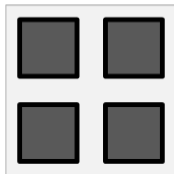

Figure 1: Schematic visualization of a prototypical intersection with two orthogonal streets.

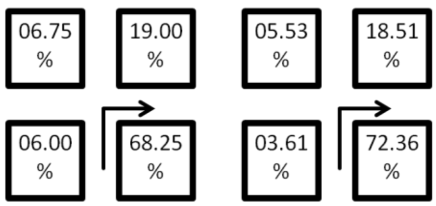

Figure 2: Results (landmark position preference over all intersections) for the structural salience (optimal landmark position) from two previous experiments (only position preference without landmarks: Röser, Hamburger, Krumnack, & Knauff, 2012 [left]; shape-color-combinations as landmarks: Röser, Krumnack, Hamburger, & Knauff, 2012 [right]). Here the turn based positions are depicted.

Perceptual salience

Sorrows and Hirtle (1999) defined visual (perceptual) 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 they understood perceptual salience as a bottom-up salience with the components location-based and attention-based attention, and the scene context. Other authors demonstrated that, for example, different colors, orientations, and shapes deploy attention (Raubal & Winter, 2002; Wolfe & Horowitz, 2004) what implies that these features could have a high visual salience. Also Treisman and Gelade (1980) showed that objects that stand out from their environment quickly reach the focus of attention.

Based on these concepts our definition of perceptual salience is a contrast-based approach where the observer-based contrast to the surrounding of the object is central. Strictly speaking an object is perceptually salient if it is an *outlier*, meaning that it is sufficiently different in comparison to the other objects available.

In our prior experiments (Röser, Hamburger, et al., 2012; Röser, Krumnack, et al., 2012) all landmark material was created to have the same perceptual salience and therefore the perceptual salience of a landmark should not have had an effect on landmark choices. In such a setting the perceptual contrast between the objects should be equal, no object should stand out.

Cognitive salience

The focus of this study is not on cognitive (also defined as semantic) salience but it should not be neglected. It can be defined as the meaning or prototypically of an object (Sorrows & Hirtle, 1999). Again the contrast is important or the degree of recognizability and the idiosyncratic relevance (Caduff & Timpf, 2008). We assume that these factors do not play any role if the material is simple enough and is related to a single perceptual/cognitive category, like colors or simple geometrical shapes (by the same argument as for the perceptual salience, see above).

Experiments

The main aim of the present paper is to explore which object in an environment people prefer to use as a landmark in wayfinding. In particular we want to answer the following questions: How important is a high perceptual contrast for the choice of a landmark at a decision point? And, what is the influence of the position of an object on landmark choices in a setting where one object clearly stands out? We investigated two independent factors: To vary the *perceptual salience* of potential landmarks we used objects in different *colors, shapes, and different orientations*. To vary the *structural salience* of potential landmarks the objects were located at different *positions* at an intersection. In a pilot study we examined how *visual aspects* of objects influence their perceptual salience in an arrangement similar to figure 1 but without any navigational context. In the main experiment we combine perceptual and structural salience by adding a navigational context to the arrangement.

Pilot Study – Perceptual salience

We investigated the distribution of perceptual salience of an array of objects. Therefore, we presented groups of different stimuli and asked the participants which of them stands out most in contrast to the other ones (which one is the outlier?). This is based on our definition of perceptual salience as the contrast of an object to its surrounding. The goal was to establish a baseline of perceptual salience to use as a reference for further experiments.

Methods

Participants

A total of 20 students (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 color vision. They received course credit or money for participation.

Material

For this study we used a basic setting with four objects placed in a square with the same distance between each other (see figure 3). This setting resembles an intersection, but participants were not explicitly made aware of the resemblance and were not given any navigational context.

To vary the *perceptual salience* of potential landmarks we used objects in different *colors, different shapes, and different orientations*. The colors were always presented using the same shape, a simple cross (figure 3). 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; half of them with three crosses of the first color and one cross of the second color and vice versa. The position of the outlier was counter-balanced over the four positions.

For the different shapes we used the same logic: 24 items with three identical shapes (e.g., a square; always in black, see figure 3) and one outlier shape (e.g., a triangle), again balanced over the four positions. For the different orientations of shapes four identical forms were used (see figure 3). Here the difference lies in the orientation: Either three shapes are orientated vertically and the outlier is rotated 15 deg to the right or the three identically oriented objects are rotated 15 deg to the right and the outlier is orientated vertically. Again, the outliers are shown once at each of the four positions.

Distractors were presented in addition. Twelve identical colors or shapes and twelve different ones served as distractors. For the different orientations twelve items with identical forms in different orientations (+/- 15 deg, +/- 30 deg) and twelve with different shapes in different orientations served as distractors.

In sum this resulted in 144 images of different stimulus material, 72 as experimental material and 72 distractors. All images were presented in succession in a random order on a custom computer screen (22´´). Superlab 4.0 (Cedrus Corporation 1991-2006) was used for running the study and for data recording.

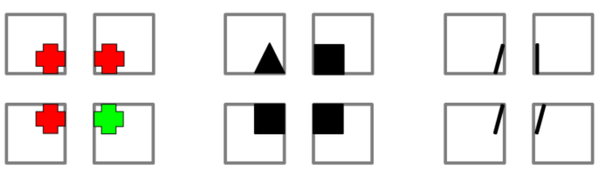

Figure 3: Example for the color material (left), different shapes (center), and shapes with different orientations (right).

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 stands out most to them. To select any object they should press the according response key on the keyboard.

Results

Distributions

The analysis of the distribution, preference of the objects over all variations, showed no significant variation from an equal distribution ($\chi^2(3)=0.281$, $p=.963$; each is preferred in 25% of the cases; we here used not a per 100 system, due to the fact, that the chi-square test is highly sensitive to the sample size, but rather a per 20 system, based on the sample size [$N=20$]; that means that each participant is weighted with one and the individual distribution is correspondingly adjusted).

Outliers

The follow-up data analysis is based on the preference of the outlier compared to the other three objects (equal). For this we merged the preferences of all participants over all images with three equal and one different stimulus and for all positions of the outliers (table 1).

Table 1: Results of the statistical analyses. Chance level (25%) would mean that every position is preferred equally often, or one position is chosen all the time.

	Preference of single one	t-test (df=19), against chance level	
Over all	86%	t=14.551	p<.001
Colors	92.5%	t=14.312	p<.001
Different shapes	91%	t=13.578	p<.001
Different orientations*	75%	t=11.446	p<.001

* Sum of outlier preferences differ significantly for colors ($t(19)=4.186$, $p<.001$) and shapes ($t(19)=3.964$, $p<.001$)

Discussion

With the present study we investigated whether participants prefer to indicate objects that differ perceptually from the surrounding in the display similar to an intersection. As our results indicate, participants prefer to indicate the object with different perceptual properties, the outliers. Based on our definition of perceptual salience as a contrast to the surrounding, the results may be considered as a measurement of perceptual salience. Colors and shapes had the highest perceptual salience in this study in contrast to the different orientations. This could be due to the fact that the contrast to the surrounding is for the different orientations not as high as for the colors and shapes.

In the main experiment we examine the effect of perceptual differences in a wayfinding context.

Main experiment – Perceptual and structural salience

With the main experiment we aim to examine how perceptual and structural saliences affect each other.

Based on the pilot study we now used the objects with the highest perceptual salience: colors in combination with different positions at an intersection in a navigational context. In this way we intend to investigate whether perceptual differences of landmarks influence the position preference or structural salience as determined by earlier experiments (see Figure 2).

Methods

Participants

A total of 20 students (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

The navigational task used for this experiment was based on the virtual environment SQUARELAND (Hamburger & Knauff, 2011). We used a 5×6 square setting from an allocentric (bird-eye) perspective (figure 4).

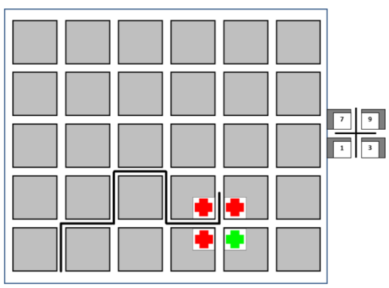

Figure 4: Maze including the path from the start to the sixth intersection. At the intersection four landmarks are depicted. On the right the answer instruction (which key to press) is given.

The route through the maze consisted of sixteen intersections: with equal numbers of left and right turns. This represented a route length people can imagine and remember in a virtual setting (e.g., Hamburger, Röser, Bukow, & Knauff, 2011). The arrangement of the four objects was equivalent to the pilot study (equal distance between them and in the corners of the four squares).

As before, at each intersection (array) four colored objects were used including one outlier. In order to ensure that each combination of colors was presented only once, we needed a total of sixteen color combinations with sufficiently different hues. So we used the color circle and chose each color 22.5 deg away from the next one. The respective complementary color was used as the outlier. Color combinations were distributed randomly over the path. The positions of the outlier objects were systematically varied based on the turn direction. A second version of the maze with inversed colors (identical and outlier) was created. Additionally, for both versions the direction of turn was switched for each intersection, resulting in overall four different mazes. Each participant was randomly assigned to one of them. The participants performed the experiment on a custom computer screen (22´´). Superlab 4.0 (Cedrus Corporation 1991-2006) was used for running the experiment and for data recording.

Procedure

The instruction explained that the participants would see a path through a maze where at each intersection four different objects are presented. They should imagine that they have to give a route description based on the information they see. They were instructed to decide/ indicate at each intersection which object they are going to use for the route description. To select one object they had to press the corresponding key on the keyboard. The response keys were presented next to each slide at an exemplary intersection (figure 4). Subsequently, the instruction was repeated and supplemented with a pictorial explanation. After this example the experimental phase started with the path being presented from the start to the first intersection, including the route direction for this intersection and four colored crosses placed at the four positions. After each decision participants saw the next intersection and again the path from the start to this intersection and direction of turn and the four colors became visible and so on.

Results

Outliers

To find whether outliers were selected more often as landmarks compared to the other objects, participants´ responses were analyzed. The outliers were selected with a mean of 66% and therefore significantly more often, compared to the remaining objects ($t(19)$=2.281, p=.034). This result is also statistically different from chance level (25%; $t(19)$=5.589, p<.001).

Distributions

In figure 5 (center) the turn based positions are presented. The distribution over all positions and intersections in the maze revealed a marginally significant variation from an equal (each is preferred in 25% of the cases) distribution ($\chi^2(3)$=7.016, p=.071; again we used a per 20 system, based on the sample size [N=20], see above).

For each of the four positions the outlier is chosen in at least 50% of the cases if the outlier is located at that position (figure 5 left). If the outlier is not to be found at that position, the position without the outlier is chosen in at least 2% of the cases (figure 5 right).

In a last step the distributions for the four variations of outlier positions were analyzed separately. Here, for all four variations a significant difference from chance level was obtained (see figure 5 bottom; position: top, opposite to the direction of the turn: $\chi^2(3)$=10.175, p=.017; position: top, in the direction of the turn: $\chi^2(3)$=12.100, p<.001; position: bottom, opposite to the direction of the turn: $\chi^2(3)$=13.575, p<.001; position: bottom, in the direction of the turn: $\chi^2(3)$=56.075, p<.001). In summary, for the single positions it could be emphasized that for each position the outliers were chosen in a minimum of 50% of the cases and furthermore the ideal position, *before* the intersection *in the direction of the turn*, is minimally preferred in 1/3 of the cases. If the outliers were placed on this ideal position it was almost always chosen.

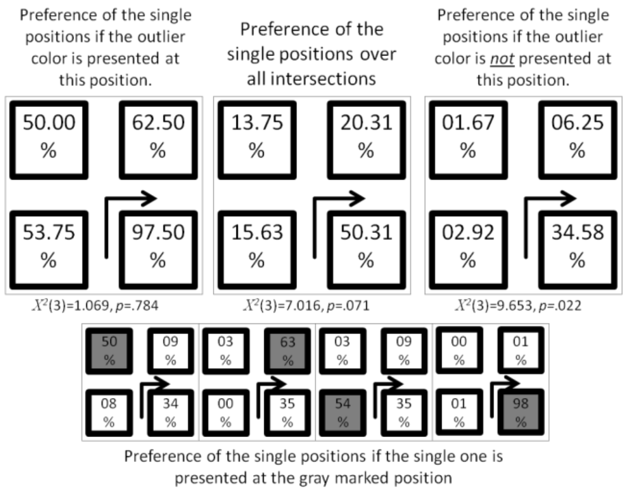

Figure 5: Results for the different analyses. On the left and the right side (top section) each position could reach a value of 100%. The four positions in the middle add up to 100%.

Discussion

The results could be interpreted from two different perspectives. On the one hand they revealed a clear preference of the perceptually salient object. The single outliers are preferred in 66% of the cases, which is much higher than chance (25%). This represents the importance of the perceptual salience for landmarks. On the other hand, the preference over all positions and intersections (merged for all single positions) are not distributed equally (see figure 5, middle). There is a preference for the position *before* the intersection and *in the direction of the turn*. Thus, the perceptual salience as well as the structural salience influence the preference of the positions. How they interact will be analyzed in the following section.

General Discussion

Our previous findings revealed a position preference which we presented as the structural salience. The position *before* the intersection and *in the direction of the turn* was preferred. The pilot study revealed an object preference depending on the perceptual salience. There, the outlier colors were preferred in 92.5% which is more or less equally distributed over the four positions. Here the objects differ from each other and the positions are unimportant. In the main experiment the combination of the perceptual (object preference) and the structural salience (position preference) influenced the participants´ selections. In figure 6 these results are contrasted.

It is very interesting that the results do not reveal the same distribution as in the pilot study (figure 6, left), because it is –from a perceptual point of view– inconsequential not to prefer the outliers. The preference for the outliers decreased from 92.5% in the pilot study to 66% in the main experiment. Therefore it seems that navigational context, in particular the turn based position of a landmark, also influenced the participants' preferences. In other words, not only the differentiation between objects plays an important role in landmark selection but also the position of the object.

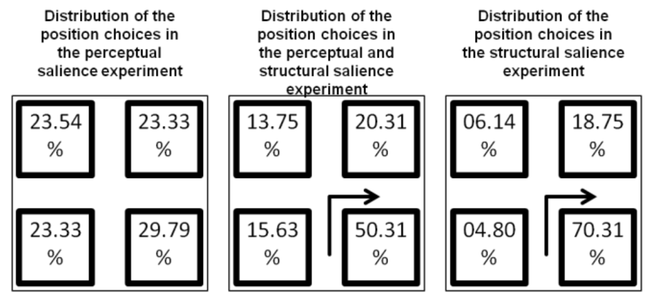

Figure 6: Object preferences of the pilot study with colors (left); data of the main experiment (center); data of the previous experiments (Röser, Hamburger et al., 2012; Röser, Krumnack et al., 2012) for position preference (right).

In this work we used one fixed factor of perceptual salience, outliers consisting of complementary colors (the contrast to the surrounding could not be higher) to observe its interaction with structural aspects of wayfinding. In further experiments we will address the possibility to vary the perceptual salience and take a look at the effects on the resulting distributions. Two possibilities remain: on the one hand the perceptual salience of a landmark has a simple *yes* or *no* (existing or non-existing) character. Then the results should be similar. Or, on the other hand the perceptual salience of a landmark is gradual. Then the results should change continuously. Whatever the case may be, it seems clear that the influence of the perceptual salience could hardly be increased by using other colors, because the contrast used here with the complementary colors, is the strongest color contrast possible. Additionally, the pilot study showed that the contrasting color is preferred in almost all cases. We may therefore conclude that the perceptual salience of the outlier object was as high as possible and any variation probably leads to a lower impact (at least its influence may not be higher). But even if an object is extremely "eye-catching" in a non-navigational setting, once we enter a navigational task it seems that the structural salience provides a strong and almost permanent influence on the choice of landmarks at an intersection. The position of an object at an intersection might therefore be as important for it being chosen as landmark as the contrast to its surrounding.

The comparison of the results of the two experiments clearly shows that the question which object is the most appropriate landmark cannot be reduced to the question which object is the most noticeable. The fact that an object has a high contrast to its surrounding does not guarantee its choice as a landmark. This supports Sorrows and Hirtle's (1999) concept of "prominence of spatial location" (p. 45) as a factor of visual salience and Caduff and Timpf's (2008) scene context of visual salience and/or contextual salience.

Obstacles in wayfinding research

Because of the abstract and artificial setting of our experiments, transfers to other wayfinding research is difficult. Nothegger, Winter, and Raubal (2004) for example used real environments for their wayfinding experiments. But, the experimental control in such experiments is difficult or even impossible (e.g., which information did participants pay attention to?). Particularly the structural aspects of intersections in real environments are determined by a lot of factors (visibility; view direction; occlusion, etc). This is why we chose to limit ourselves to such an abstract setting. Our study serves as a basic research approach, examining the underlying aspects and will serve as a basis for further and more realistic (but controlled) experiments.

Acknowledgement

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