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Memory for object location and route direction in virtual large-scale space

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Memory for object location and route direction in virtual large-scale space

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In everyday life people have to deal with tasks such as finding a novel path to a certain goal location, finding one's way back, finding a short cut, or making a detour. In all of these tasks people acquire route knowledge. For finding the same way back they have to remember locations of objects like buildings and additionally direction changes. In three experiments using recognition tasks as well as conscious and unconscious spatial priming paradigms memory processes underlying wayfinding behaviour were investigated. Participants learned a route through a virtual environment with objects either placed at intersections (i.e., decision points) where another route could be chosen or placed along the route (non-decision points). Analyses indicate first that objects placed at decision points are recognized faster than other objects. Second, they indicate that the direction in which a route is travelled is represented only at locations that are relevant for wayfinding (e.g., decision points). The results point out the efficient way in which memory for object location and memory for route direction interact.

Consider the problem of being in an unfamiliar place and having to find the way back to a certain location. Without additional help like city maps or global landmarks seen from far away people have to rely on their own memory for different locations, objects, and direction changes (for an overview on wayfinding behaviour see Freksa, Brauer, Habel, & Wender, 2000; Freksa, Habel, & Wender, 1998; Gallistel, 1990; Golledge, 1999; Kitchin & Freundschuh, 2000). When people acquire route knowledge in large-scale space local landmarks such as buildings or post boxes are extremely helpful for wayfinding (for a discussion on local and global landmarks see Steck & Mallot, 2000). Whereas small-scale space (e.g., looking at a map or a model) can be perceived as a whole or from one single viewpoint (Montello, 1998; Roskos-Ewoldsen, McNamara, Shelton, & Carr, 1998) large-scale space (e.g., cities) can only be experienced sequentially and by integrating different route segments. It is not only important to know which objects you have to pass, it is also necessary to remember where to make a turn and walk in a different direction. Thus both memory

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for object location and memory for the direction in which a route is travelled are needed for successful wayfinding. This paper focuses on the interaction of these two memory functions. One experiment investigated the representation of object locations. Two other experiments focused on how these representations of objects were associated with the representation of the travelling direction (route direction effect). Subsequently, the role of different object locations and the effect of route direction are discussed before outlining the present experiments.

Object locations

There is evidence that objects at different locations along a route are not equally important for complex cognitive tasks such as route descriptions and navigational behaviour. Several studies showed that objects placed at decision points (i.e., intersections) are named more frequently than other objects when describing a route (see, e.g., Ward, Newcombe, & Overton, 1986). The term decision point refers to route intersections where alternative routes can be chosen. That is, whereas going straight at a two-road intersection would count as a decision point, simple turns without the possibility to move on to another path do not. Blades and Medlicott (1992) found that route descriptions are easier to give if a decision point is marked with landmarks. Investigations of Ward et al. (1986) showed that in route descriptions objects associated with direction changes are named more often than others. The authors reduced this result to the fact that in route descriptions it is important that a person knows which object he or she has to expect when finding the way. Daniel and Denis (1998) reported that participants who had to rate route descriptions regarded objects at decision points as more important than objects along the route.

Further evidence comes from developmental psychology. Cohen and Schuepfer (1980, see also Cornell, Heth, & Broda, 1989, as well as Cornell, Heth, & Alberts, 1994) showed that compared to adults, children were particularly dependent on objects that were placed at decision points. They were more likely to choose a wrong path at an intersection when objects were not present. Additionally, in a later recall task, adults as well as children named objects at decision points more often than other objects.

These results show that objects placed at decision points are preferably used for spatial orientation. Accordingly, a decision about the further route is more difficult if no objects are available that can be connected to the place of decision (Blades & Medlicott, 1992). Empirical evidence in this field is either derived from verbal data or directly collected from navigation through real-world environments. Verbal utterances depend on the speech production process and are therefore susceptible for controlled processes such as wayfinding strategies (e.g., orientation on compass directions or right or left turns) or considerations about which objects are especially useful for the listening person (Buhl, 1996; Franklin & Tversky, 1990; Taylor & Tversky, 1992; for wayfinding strategies see also Janzen, Herrmann, Katz, & Schweizer, 2000; Janzen, Schade, Katz, & Herrmann, 2001). The same holds for data from navigation (Lawton, 1996). Furthermore most studies were carried out without a time limit so that participants were especially encouraged to reason about which object to choose or which way to go. In summary, the results suggest that objects placed at decision points play a specific role for wayfinding. However, these experiments do not rule out the influence of higher cognitive reasoning.

Route direction

Earlier studies have shown that the direction in which a route is travelled and objects along the route are learned is part of the spatial representation (route direction effect). Using a spatial priming paradigm (e.g., McNamara, 1992; McNamara, Ratcliff, & McKoon, 1984) Schweizer, Herrmann, Janzen, and Katz (1998) found an effect of route direction in an object recognition task (see also Herrmann, Buhl, & Schweizer, 1995). In a learning phase participants sequentially perceived different objects along a route. In a later testing phase, target objects were presented preceded by prime objects. Participants reacted faster to the question "Was the target object part of the learned route?" when prime and target objects were previously learned in the travelling direction (in-route items) than when they were learned the other way around (against-route items). This effect of route direction occurred even though all objects in the recognition task were shown from a canonical perspective without route-related information.

The route direction effect has a specific spatial component. The effect can only be evoked with objects placed in a spatial environment and not when the same sequence of objects is shown in a purely temporal order (Schweizer, 1997; Schweizer & Janzen, 1996; Schweizer et al., 1998). The route direction effect can also not be reduced to an effect of object salience. Schweizer and Janzen (1996; see also Schweizer, 1997) presented a U-shaped spatial configuration with objects along the route. Participants were presented with one of two film sequences each starting from a different end of the environment. Prime–target combinations with objects previously perceived in the travelling direction (in-route items) in one film sequence turned into against-route items for participants presented with the second film sequence. These conditions were set up in order to rule out any influence of object salience or familiarity. The route direction effect could be evoked for both film sequences (for further supporting evidence see Herrmann et al., 1995, who used two different routes through the same spatial layout).

The response time advantage for in-route items can be taken as evidence that route direction is part of the acquired spatial knowledge. When acquiring route knowledge spatial and temporal contiguity is usually confounded in such a way that locations close in space are also perceived together in time. Clayton and Habibi (1991) showed that spatial distance effects are due to serial learning (see also Clayton, Habibi, & Bendele, 1995) whereas the route direction effect cannot be evoked with a serial learning task.

Overview of experiments

The present experiments address the following questions: First, is the specific role of objects at decision points related to a different representation of those objects compared to objects placed along the route? In order to assess the spatial knowledge without confounding effects of wayfinding strategies and reasoning about the relevance of different locations, an object recognition task is used. Participants indicated whether they recognized a presented object from a previous learning phase, and object recognition latencies were recorded. A time advantage for decision point objects compared to other objects is predicted.

Second, is memory for object location independent of memory for route direction? In other words is there an interaction between the representation of route direction and the representation of objects placed in different locations (Experiments 2 and 3)? It is hypothesized that route direction is particularly represented at locations that are relevant for wayfinding. A route direction effect should only be observed at decision points. To test this hypothesis a spatial priming paradigm is used (Experiments 2 and 3). Differential effects of route direction priming for decision and non-decision point objects would indicate an interaction between the representations of decision points and route direction.

Third, can the results be replicated with a masked spatial priming method? In spatial priming paradigms primes are usually presented fully visible. However, in order to completely rule out possible influences of strategies even in a recognition task, a masked priming paradigm was used in Experiment 3. For a recent discussion on masked (or unconscious) priming processes see, for example, Vorberg, Mattler, Heinecke, Schmidt, and Schwarzbach (2003), Naccache and Dehaene (2001), and Klinger, Burton, and Pitts (2000), as well as Greenwald, Draine, and Abrams (1996), Forster (1998), and Kiefer and Spitzer (2000). Shorter recognition times for in-route items when the prime object is masked, and therefore not consciously perceivable, would strongly rule out the influence of strategic reasoning.

EXPERIMENT 1

In Experiment 1 it was investigated whether representations of objects placed at decision points were accessed more quickly than those of objects that were not placed at locations with a specific relevance for successful wayfinding. Objects at decision points should be recognized faster than others.

Method

Participants

Participants were 20 undergraduate students from the University of Mannheim. They either were paid volunteers or participated in exchange for fulfilment of study requirements. The data from an equal number of males and females were analysed. The mean age was 23.95 years (range 20–28 years).

Apparatus and stimuli

The virtual world, a maze, was constructed with the computer graphic software "Superscape Vrt". The environment was a labyrinth of paths with eight right-angled intersections that subjects viewed in colour and from a traveller's viewpoint. Four intersections had three paths, and two intersections consisted of four paths. A total of 22 objects, all articles from an office such as a chair and a drawing board, were placed in the maze. Figure 1 shows a simplified sketch map of the maze.

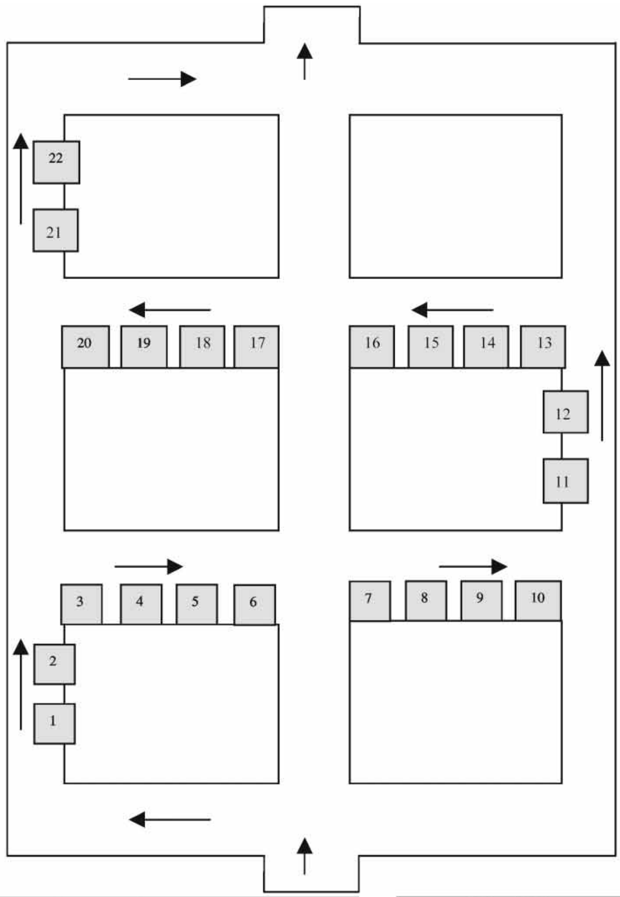
In real-world dimensions, the environment had a length of 60 m and was 39 m wide in relation to the simulated eye level of an observer from 1.70 m. Two film sequences with a frame rate of 14 frames/s were generated. The film sequences and the objects in the recognition task were presented on a 17-in., 60-Hz, VGA colour monitor. Sequence A showed the objects in the order depicted in Figure 1; Sequence B showed the objects in an order so that objects placed at decision points in Sequence A were placed along the route in Sequence B. This was done to rule out any influence of familiarity and salience of objects. Both film sequences lasted for 5.27 min, and each object was in the visual focus for 8 s. All objects were sequentially focused in the film sequence. Participants could see that more tables with objects were placed in the hallways. However, they could only identify the objects one by one to ensure that each object was shown for the same amount of time. All adjacent objects were placed with the same Euclidean distance. Figure 2 shows objects placed at decision and at non-decision points from the viewpoint that participants had during learning and recognition.

Procedure

The experiment was divided into three phases: a learning phase, a testing phase, and a debriefing phase. All participants were tested individually and randomly allocated to one of the two film sequences. Participants were told that they were trained to be a guide in a museum that exhibits office supplies of famous people. They were instructed to remember the objects in the spatial layout shown in the film. During the *learning phase*, participants saw the same film sequence five times. The film sequence was shown five times to ensure that participants reached a high level of encoding and could remember all objects.

As a learning check, after the fifth viewing of the film sequence participants were asked to draw a sketch of all objects. To give participants the possibility of encoding the objects without naming them a line drawing task was chosen. They were instructed to give a fast sketch of each object to identify the object. Thus, they did not need to give a complete and detailed drawing of the objects. The sketch was included as a treatment check to ensure that all participants in the experiments knew the objects regardless of their location in the environment.

In the *testing phase*, participants performed a recognition task. They had to decide whether each object displayed on the screen was part of the film sequence or not. The objects were not shown in the perspective from which they were viewed during the film sequence but were presented as pictures from a canonical perspective



Sequence A		
1 potted plant	9 phone	17 picture
2 case	10 clock	18 pens
3 camera	11 cup	19 staplers
4 calculator	12 lamp	20 stool
5 gramophone	13 crate	21 bottle
6 monitor	14 books	22 printer
7 notepad	15 flashlight	
8 tape-dispenser	16 shelf	

Sequence B		
1 potted plant	9 monitor	17 flashlight
2 cup	10 gramophone	18 crate
3 tape-dispenser	11 case	19 shelf
4 notepad	12 bottle	20 books
5 clock	13 pens	21 lamp
6 phone	14 picture	22 printer
7 calculator	15 stool	
8 camera	16 staplers	

List of Distractors
1. armchair
2. folding table
3. tin
4. commode
5. oven
6. closet
7. keyboard
8. desk
9. chair
10. keys
11. drawing board
12. television
13.toy roboter
14. matches
15. dongle
16. table

Figure 1. *Sketch map of the maze with objects ordered according to Sequence A used in all experiments.*

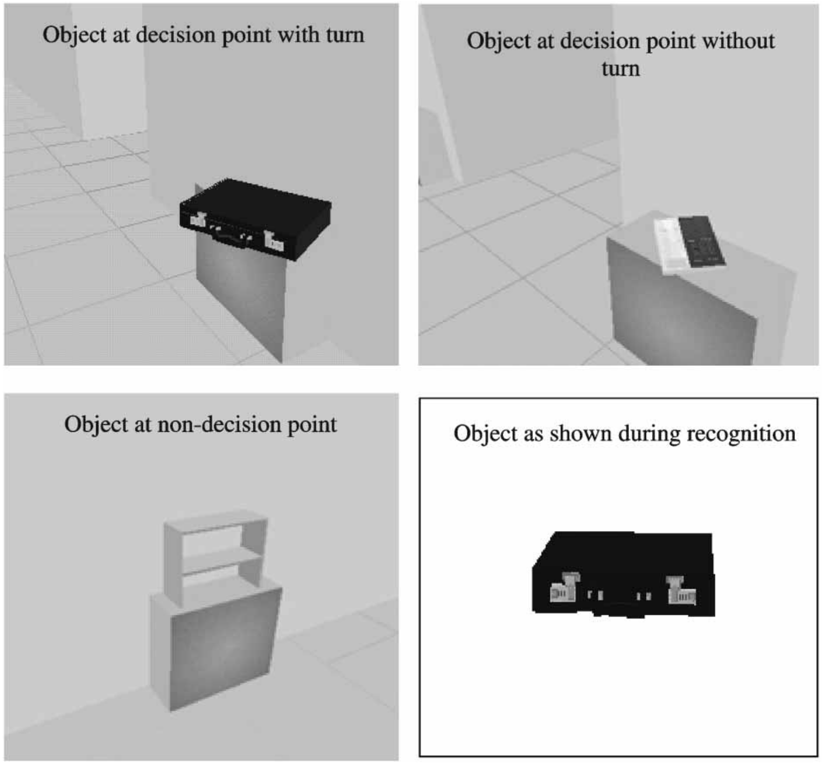


Figure 2. *Objects as seen during learning and recognition.*

on a white background without any maze-related information (see Figure 2). Participants were instructed to respond as accurately and as quickly as possible by pressing either a yes or a no response key. One trial consisted of a fixation cross centred on the screen for 100 ms followed by a blank white screen for 250 ms. Thereafter followed the object that remained on screen until participants responded. Participants saw 38 objects altogether. Objects were only shown once during the recognition task randomly intermixed with distractor objects. A total of 22 objects were old objects where the correct response was "yes", and 16 objects were distractor objects where subjects had to respond with "no". Distractor objects were similar in nature to the objects learned along the route. The first and the last object on the route (Objects 1 and 22 in Figure 1) were not included in the analyses; thus 20 critical items (only with old objects) remained. These items were subdivided into three item groups. One item group consisted of eight items with objects placed at decision points (D-objects) where a turn was made in the film sequence (Objects 2, 3, 10, 11, 12, 13, 20, and 21 in Figure 1, Sequence A). The second item group consisted of four items with objects at decision points where no turn was made, which meant that participants moved straight on (Objects 6, 7, 16, and 17 in Figure 1, Sequence A). The third item group consisted of eight items with objects placed along the route (N-D-objects) without a decision point (Objects 4, 5, 8, 9, 14, 15, 18, and 19 in Figure 1, Sequence A).

Finally, there was a *debriefing phase*. Participants were given a white sheet of paper (37 by 37 cm), and they were asked to draw a map of the environment including the objects. This task was performed in order to check whether participants could remember the objects.

Afterwards, participants were asked about their experience with virtual environments—for example, whether they had moved through virtual mazes before—and whether they played video or computer games or had any other skills in relation to spatial performance. The next questions concerned the strategies that they usually used for wayfinding and whether it was difficult for them to solve the learning and the verification tasks. One complete experimental session lasted for about 40 minutes.

The debriefing phase was first analysed by classifying different wayfinding strategies and second by subdividing the participants according to their experience with virtual computer graphic software. A total of 12 participants used a purely semantic strategy (remembering the objects by connecting them with a story or grouping into semantic categories), 2 participants used a purely spatial strategy (remembering different locations and the spatial layout), and 5 participants used a mixed strategy. One participant could not specify a strategy. A total of 9 participants reported having experience with virtual computer graphic software whereas 11 participants had no experience. Response times did not differ with regard to different strategies and computer experience.

Design

The three object types (D-objects with turn, D-objects without turn, and N-D-objects) were entered as within-subjects factor in an analysis of variance (ANOVA). Dependent variables were the individual mean response times (RTs) computed for each object type.

Results and discussion

Prior to analysis, response times for outliers and errors were excluded. Each response time larger or smaller than three standard deviations from the mean value of all response times for that specific item was treated as an outlier (1.18% of all response times were excluded). All wrong responses (false "yes" as well as "no" answers) were defined as errors. A total of 1.32% of the data were excluded as errors. Only critical items (20 items with old objects) were analysed. Film sequences A and B were analysed together. No differences between the two film sequences could be observed. Figure 3 presents the mean response times and standard errors for the three object types.

The within-subjects factor object type was entered in an ANOVA. There was a significant main effect of this factor, $F(2, 38) = 5.74$, $MSE = 4{,}348.71$, $p < .01$. Post hoc tests exhibit that D-objects with turn ($M = 704.38$ ms) differed significantly from N-D-objects, $M = 771.46$ ms, $p < .01$, HSD Tukey test. The effect size estimated using Cohen's d was .567 (Cohen, 1988). Also D-objects without turn

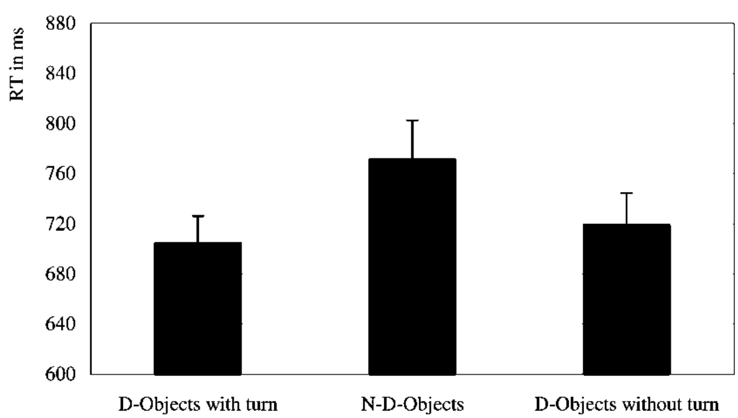


Figure 3. *Mean response times (and standard errors) of Experiment 1 for all three object types.*

($M = 718.69$ ms) differed significantly from the N-D-objects ($p < .05$, HSD Tukey test, Cohen's $d = .413$).

The results confirmed the assumptions. Objects at decision points were recognized faster than objects previously placed at non-decision points. No significant response time differences were found for D-objects associated with a turn compared to D-objects placed at an intersection with moving straight on. The use of different wayfinding strategies had no influence on the representation of object locations. Even participants who used a purely semantic strategy in the learning phase showed the described effect in the recognition task. Participants performed a recognition task in which they indicated whether they recognized an object. The results show that objects at locations with different wayfinding relevance are also represented differently. It can be suggested that objects placed at decision points are automatically strongly associated with this specific place. Presumably, this association accelerates access to object memory, and therefore objects located at decision points are recognized faster than others. Other objects along the route are not linked to their specific location to the same extent. In accordance with this idea are the results for objects placed at a decision point without a turn. Response times for D-objects without a turn did not differ from responses to D-objects with a turn, showing that the navigational relevance of a decision point facilitates object recognition independently from the actual movement.

EXPERIMENT 2

The results of Experiment 1 provide evidence for the impact of object locations on memory access. The second experiment investigates whether an effect of route direction can only be evoked with objects located at decision points. Therefore, planned comparisons are in- compared to against-route items at decision points (with and without turn) as well as at non-decision points. As the effect of route direction refers to a relation between two objects that are asymmetrically associated in and against the travelling direction during learning the paradigm of spatial priming is used.

Method

Participants

Participants were 21 students from the University of Mannheim. They participated as paid volunteers. One participant was excluded from the data analyses. Data from 6 males and 14 females were analysed. The mean age was 26.1 years (range 22–35 years).

Apparatus and stimuli

Apparatus and stimuli were the same as those in Experiment 1.

Procedure

The procedure was the same as that in Experiment 1 except for the testing phase where participants performed a primed recognition task. The learning phase was identical to that in Experiment 1 as was the debriefing phase. Participants were randomly allocated to one of the two film sequences (see Experiment 1). The replacement of objects at decision and at non-decision points in both film sequences ruled out the influence of object salience on the effect of route direction. In the paradigm, route direction was operationalized through items consisting of a prime object that either preceded the target object (in-route items) or succeeded the target object (against-route items) in the learned route.

In the *testing phase*, participants indicated whether they had seen a target object in the former film sequence. They had to decide whether this object was already presented during the learning phase or not. Instructions stressed both speed and accuracy. One trial consisted of a prime object that was always an old object (presented in the learning phase) centred on the screen for 100 ms followed by an interstimulus interval for 250 ms. Thus, the stimulus onset asynchrony (SOA) was 350 ms. Immediately thereafter the target object appeared and remained on screen until participants responded. The interitem interval was 1,000 ms. The target object disappeared after 5,000 ms if no response occurred. Prime and target objects for each item were directly placed side by side along the route and had the same Euclidean distance. Before the start of the testing phase participants performed five practice items in order to ensure that the instruction was understood correctly.

The participants responded to 80 items. Of these, 44 were items with objects from the maze for which the correct response was "yes", and 36 were distractor items for which participants had to respond with "no". To increase the number of items objects were repeated in the testing phase. A total of 16 target-objects were repeated twice, and 4 objects were repeated three times.

The 44 items consisted of 20 items with prime and target objects coming both from decision or both from non-decision points. From these analysed 20 items there was a group of 8 items where prime and target object were placed at a decision point with a turn in the film sequence, 4 items were decision point items without a turn, and 8 items were included with prime and target placed along the route (N-D-objects). All object types consisted of an equal number of in- and against-route items. A total of 24 heterogeneous items consisted of prime and target objects coming from a decision point and a non-decision point. These items were included in order to rule out the possibility that the participants could presume the intention of the test and were not further analysed.

The debriefing phase was comparable to that in Experiment 1. The phase was analysed by classifying wayfinding strategies and by subdividing the participants according to their experience with virtual computer graphic software. A total of 10 participants used a purely semantic strategy (see Experiment 1), 3 participants used a purely spatial strategy, and 7 participants used a mixed strategy. Participants reported that they had no specific strategy during the priming task. A total of 8 participants reported to have experience with virtual computer graphic software whereas 12 had no experience. Response times did not differ with regard to different strategies and computer experience.

Design

A 3×2 within-subjects design was used. Within-subjects factors were the factor object type with three levels (items consisting of D-objects with turn, items with D-objects without turn, and items with N-D-objects) and the factor route direction with two levels (in- and against-route items). Dependent variables were the individual mean RTs computed for each object type.

Results and discussion

Response times were corrected for outliers and errors as in Experiment 1. A total of 1.19% of the response times were excluded as outliers. A total of 1.75% of the data were excluded as errors. Only critical items were included in the analyses. Figure 4 presents the mean response times for the three object types in and against the route direction.

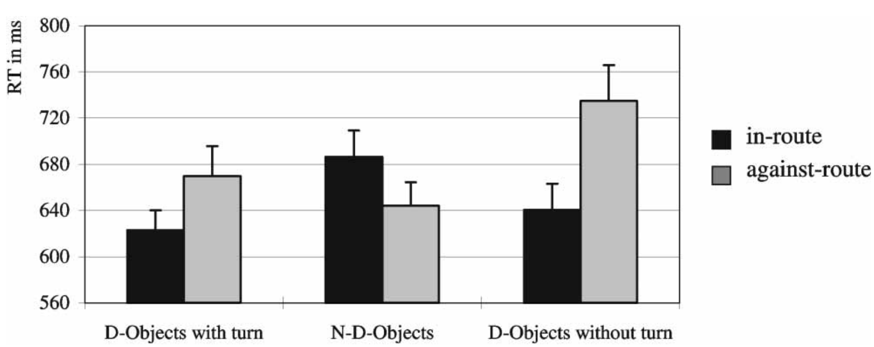


Figure 4. *Mean response times (and standard errors) of Experiment 2 for all three object types.*

Both within-subjects factors object type and route direction were entered in an ANOVA. There was a significant main effect of the factor object type, $F(2, 38) = 4.18$, $MSE = 4{,}081.93$, $p < .05$, and a significant main effect of the factor route direction, $F(1, 19) = 7.76$, $MSE = 4{,}220.52$, $p < .05$. The interaction between both factors was also significant, $F(2, 38) = 8.12$, $MSE = 5{,}914.11$, $p < .05$. Single one-tailed t tests showed that a route direction effect could only be evoked for decision point items regardless of a turn. Decision point items at which a turn was made (in-route items, $M = 622.74$; against-route items, $M = 669.74$) showed a reliable route direction effect, $t(19) = -2.90$, $p < .01$; Cohen's $d = .487$, as did decision point items without a turn, $t(19) = -3.15$, $p < .01$; in-route items, $M = 640.33$; against-route items, $M = 734.69$; Cohen's $d = .784$. For non-decision point items no route direction effect could be evoked (in-route items, $M = 686.30$; against-route items, $M = 644.05$). A trend in the reversed direction, $t(19) = 2.01$, $p = .059$, could be observed.

The results confirm the hypothesis. The route direction effect could only be evoked between objects placed at decision points. The representation of route direction occurs regardless of whether participants actually turn at an intersection or walk straight on. Surprisingly, a trend of a reversed result pattern was observed at non-decision points. This result might be due to a stronger association in the direction of the previous object, which could serve as an indicator for the correct route. However, further evidence is needed to demonstrate whether the representation against the simulated travelling direction at non-decision points is a substantial effect. The conclusion can be drawn that the relevance of a certain location (decision or non-decision point) for successful wayfinding is essential for the representation of direction.

EXPERIMENT 3

Experiment 3 investigated whether strategic, conscious processes evoked through a visible prime object had influenced the results of Experiment 2. This experiment is a replication of Experiment 2 using a subliminal or masked priming method instead of the previously used conscious priming. This method rules out the possibility that the results of Experiment 2 were due to predictions made by participants when perceiving the prime. A subliminal method should further validate that faster access to memory for object locations is automatic and occurs without the involvement of strategically controlled processes.

Method

Participants

Participants were 23 students from the University of Mannheim. They participated as paid volunteers. A total of 3 participants were excluded from data analyses. The data of 8 males and 12 females were analysed. The mean age was 22.35 years (range 17–33 years).

Apparatus and stimuli

Apparatus and stimuli were the same as those in Experiments 1 and 2.

Procedure

In Experiment 3 participants performed a subliminal priming task. The learning phase was identical to that in Experiments 1 and 2. Participants were randomly allocated to one of the two film sequences. The testing phase was similar to that in Experiment 2. Participants were told that shortly before the target object a few pictures were shown in a very fast sequence (see Figure 5). Before the start of the testing phase participants performed five practice items.

The used masking method consisted of the same backward and forward pattern mask for the prime object, called sandwich masking of primes (see, e.g., Debner & Jacoby, 1992; Klinger et al., 2000). The mask was a scrambled picture of all used objects. The preceding forward mask was presented for 150 ms, directly followed by a prime object for 40 ms and then a backward mask for 60 ms. Before the target object was

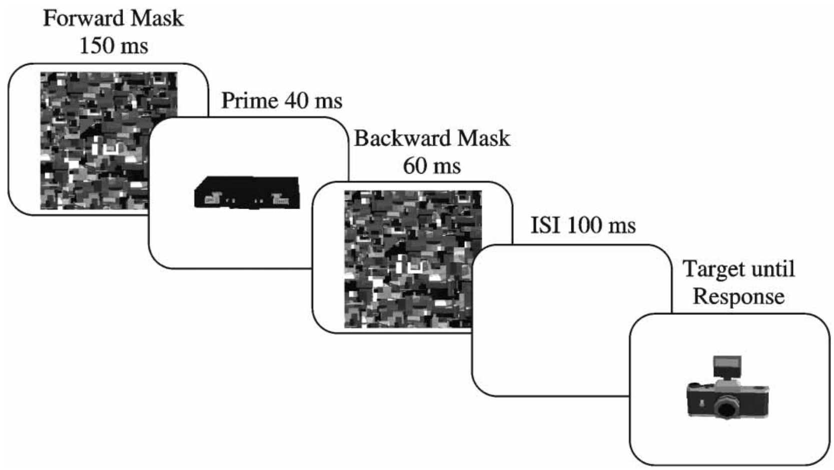


Figure 5. *Timing of a single item of Experiment 3.*

displayed a blank screen was shown for 100 ms. The target object remained on screen until the participant's response. The interitem interval was 1,000 ms. The target object disappeared after 5,000 ms if no response occurred. The timing of a single item is presented in Figure 5.

At the end of the priming phase a treatment check followed. Participants saw the first part of the priming phase again except for the target picture. Their task was to name the object shown between the two masks. This was done to rule out participants being able to perceive the masked objects. The cut-off was two or more correct responses. None of the participants was excluded due to this treatment check. In a following debriefing phase participants were asked whether they had noticed objects between the masks. All participants reported that they did not notice that an object was shown between the two masks in the former priming phase.

Design

The design was the same as that in Experiment 2.

Results and discussion

Response times were corrected for outliers and errors as in Experiments 1 and 2. A total of 1.78% of the response times were replaced as outliers. A total of 2.27% of the data were replaced as errors. Only critical items were analysed. Figure 6 presents the mean response times for the three object types.

Both within-subjects factors object type and route direction were entered in an ANOVA. There was a significant main effect of the factor object type, $F(2, 38) = 3.74$, $MSE = 6{,}535.47$, $p < .05$, and a significant main effect for the factor route direction, $F(1, 19) = 7.87$, $MSE = 5{,}789.91$, $p < .05$. The interaction between both within-subjects factors was also significant, $F(2, 38) = 3.5$, $MSE = 6{,}444.13$, $p < .05$. Single one-tailed t tests showed that a route direction effect could only be evoked with decision point items regardless of whether a turn occurred or not. Decision point items with a turn (in-route items, $M = 645.59$; against-route items, $M = 697.48$; Cohen's $d = .576$, showed a reliable route direction effect, $t(19) = -2.428$, $p < .05$. Decision point items without a turn (in-route items $M = 627.72$; against-route items $M = 706.39$) also show a route direction effect, $t(19) = -2.289$, $p < .05$; Cohen's $d = .624$. For non-decision point items the effect of route direction was not significant (in-route items, $M = 718.77$; against-route items, $M = 705.09$).

The results of Experiment 2 could be replicated with a subliminal priming method. The result

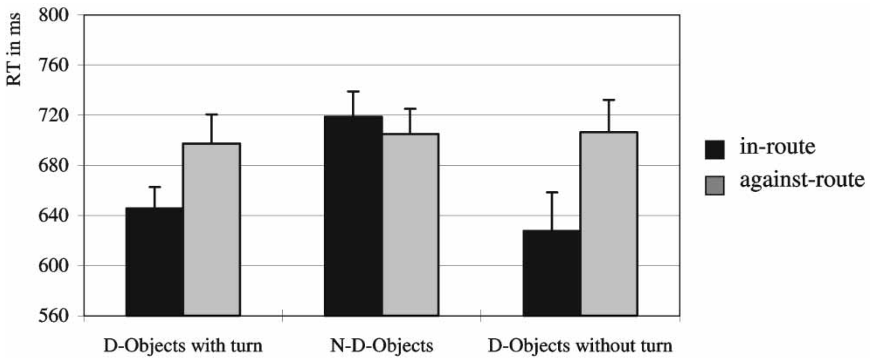


Figure 6. *Mean response times (and standard errors) of Experiment 3 for all three object types.*

pattern corresponded basically to the one of Experiment 2. This means that the impact of strategic, controlled processes can be ruled out. A conscious comparison between prime and target object is not responsible for the results. The faster recognition of objects at decision points and the associated representation of route direction can be attributed to a more salient representation in spatial memory.

GENERAL DISCUSSION

Several studies (see, e.g., Blades & Medlicott, 1992; Ward et al., 1986) concerning the acquisition of route knowledge show that objects—for example buildings—help to find one's way in an environment. Such landmarks are most helpful and can be recalled better if they are placed near an intersection or decision point. Moreover, it has been shown that humans recognize objects faster if the order in which they are presented is identical to the travelled direction during acquisition of route knowledge (Herrmann et al., 1995; Schweizer & Janzen, 1996). This route direction effect shows that the travelling direction is part of the resulting spatial representation.

In three experiments the interrelation of spatial representations of object locations with different relevance for wayfinding (decision points and places where no decision can be made) and the direction in which route knowledge is acquired was investigated. These issues were assessed in experiments using measurement of response times in a recognition task (Experiment 1) and in a spatial priming task (Experiment 2 as well as Experiment 3 with subliminal spatial priming). Prior to these tasks participants learned a route through a virtually simulated museum. Although real-life environments usually contain more objects and are more complex, a museum environment can consist of an almost empty setting in which a few objects are viewed sequentially. Further experiments using more complex virtual and real-world environments should provide additional evidence. (For a comparison of results from experiments using virtual and real environments see Ruddle, Payne, & Jones, 1997; for an overview, see Maguire, Burgess, & O'Keefe, 1999.)

Response times were generally shorter for objects at decision points than for other objects (Experiment 1), and an effect of route direction could only be observed if objects were placed near a decision point (Experiments 2 and 3). These results depend on the location of an object (decision related vs. not decision related). Locations relevant for successful wayfinding such as decision points do not only improve the performance in object recognition, but also determine whether or not route direction is represented in memory. In the following, the results are discussed in detail.

Memory for object locations

In Experiment 1 it was investigated whether decision-related objects were recognized faster than other objects that were not located at decision points. Previous experiments underline that objects at decision points play a specific role for navigation and route descriptions (see, e.g., Brewster & Blades, 1989; Daniel & Denis, 1998; Ward et al., 1986). However, these experiments involved complex cognitive processes such as speech production or wayfinding. A very recent functional magnetic resonance imaging (fMRI) study by Janzen and van Turennout (2004) showed that objects at decision points were represented differently from objects in locations with less navigational relevance. A region in the parahippocampal gyrus showed selectively increased responses for objects previously placed at decision points. This region showed the same increased activation for decision point objects even when participants could not remember that they had seen the object before. The results of Experiment 1 provide behavioural confirmation of the results of Janzen and van Turennout (2004) with a different virtual environment.

In Experiment 1 participants solved an implicit task in which they only decided whether they had seen an object or not. The results provide evidence for a distinguishable representation of objects dependent on their location. Objects located at decision points are represented in such a way that they can be recognized faster than other objects. It is assumed that a linkage between the representation of an object placed at a decision point and the representation of this specific location is responsible for the differences in recognition time. The finding that objects at decision points are named more frequently than others (Blades & Medlicott, 1992) not only is due to higher cognitive processes but has a counterpart in their representation. This time advantage of memory retrieval can also be the basis for the previous results on decision points.

Memory for route direction

When people first acquire knowledge about an unknown route they encounter objects along this route sequentially in the travelling direction. The route direction effect demonstrates that this direction is part of the spatial representation of the environment. Within a network theory approach, the effect of route direction can be explained as a specific asymmetry in spread of activation.

Previous results came to the conclusion that an asymmetrical (faster) spread of activation in versus against the route direction can be observed among all objects placed along a route (Schweizer et al., 1998). However, in these experiments navigational relevance was not considered. The present experiments systematically contrasted objects placed at navigationally relevant locations with other locations along a route and led to different results.

Experiment 3 provides further evidence for an interaction between decision points and route direction. The results replicated the findings of Experiment 2 with the method of subliminal priming. The prime objects were masked and not consciously available. The results show that the faster spread of activation for in-route direction with decision point objects is an automatic process without contribution of conscious and strategic considerations.

Previous masked priming experiments used semantic tasks to demonstrate activation of unconscious cognitive processes (see, e.g., Naccache & Dehaene, 2001). The present results show that masked prime objects can also facilitate unconscious processes that are due to spatial relations. Dehaene et al. (1998) could show that perceptual, semantic, and motor processes can occur without awareness of prime stimuli. With measurement of event-related potentials and fMRI they demonstrated covert brain activity in the motor cortex due to unconscious semantic processes. Klinger et al. (2000) could also observe large priming results that are consistent with claims of unconscious perception using the masked priming paradigm although they could not show a semantic priming effect. They argued that the absence of semantic priming is more likely due to their short response window than to the masked priming procedure. In the present experiment a sandwich masking procedure was used without a short response window.

Experiment 3 rules out an impact of strategic processes. The results provide strong evidence for a faster access to objects placed at decision points when prime and target object follow each other in the direction of the route. An advantage of object pairs presented in the direction of the route could not be observed for objects placed at non-decision points. The results reveal that the travelling direction is corepresented only at objects placed at decision points. It is assumed that a masked prime object placed at a decision point initiates a faster spread of activation in the route direction than against the route direction. This asymmetrical spread of activation is responsible for a faster recognition of the target object.

Interaction of memory systems

Distinct but interacting spatial memory systems are included in the spatial semantic hierarchy model by Kuipers (2000). He proposes that representation of locations in a spatial environment is separated from the procedures to get from one place to the other. The present data are in line with this memory model, providing evidence for a memory system representing route direction that is separate but interacting with a memory for object location.

Further support for an interaction of separated memory systems comes from the field of cognitive neuroscience. Several studies demonstrate evidence for distinct memory systems for object locations, object identity, and location alone (for an overview of the neural basis of spatial cognition see Burgess, Jeffery, & O'Keefe, 1999). An occipito-temporal pathway (ventral stream) for object identity and an occipito-parietal pathway (dorsal stream) for spatial location of objects can be divided (Mishkin, Ungerleider, & Macko, 1983). More recent data show that the parietal lobe is associated with representations of object locations in an egocentric reference frame whereas the right medial temporal area is associated with a memory for object locations in an allocentric frame of reference (see, e.g., Burgess, 2002; Maguire, Frith, Burgess, Donnett, & O'Keefe, 1998; O'Keefe & Nadel, 1978; Pigott & Milner, 1993). Büchel, Coull, and Friston (1999), using simple line drawings of objects presented on different locations on a computer screen, could show that a connection between dorsal and ventral stream exists. Correlated with the learning performance of individuals an increase in effective connectivity between the distinct areas occurred. Such a pathway shows the efficient way of interaction of distinct memory systems. The interaction of object placed at decision points and the representation of route direction, most likely represented in an egocentric reference frame, might be due to an effective connectivity of the parietal and the hippocampal areas. Experiment 1 provided supporting evidence along these theoretical assumptions. Access to objects placed at decision points is superior regardless of the actual behaviour (i.e., turning or not). Objects at decision points compared to objects located at other points result in differential pattern of neural activity in the parahippocampal gyrus (Janzen & van Turennout, 2004). This area is known to be involved in object–place associations (Maguire et al., 1998; Owen, Milner, Petrides, & Evans, 1996). Further results from the field of cognitive neuroscience are needed to allow strong claims about the precise brain areas of distinct memory systems and their way of interaction.

In short, three main results were obtained from the present experiments. First, objects located at decision points are recognized faster than objects in other places. Second, an effect of route direction can only be evoked at decision point objects, regardless of whether a turn was made or not. Third, the results can be replicated with a subliminal priming method where the prime object is masked and therefore not consciously available. An impact of strategic processes can be ruled out. It can be concluded that the present experiments provide evidence for a distinct representation of object location and route direction and a specific interaction of both memory functions dependent on the specific relevance of a spatial location for wayfinding.

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