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Hierarchical coding in the perception and memory of spatial layouts

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Abstract Two experiments were performed to investigate the organization of spatial information in perception and memory. Participants were confronted with map-like configurations of objects which were grouped by color (Experiment 1) or shape (Experiment 2) so as to induce cognitive clustering. Two tasks were administered: speeded verification of spatial relations between objects and unspeeded estimation of the Euclidean distance between object pairs. In both experiments, verification times, but not distance estimations, were affected by group membership. Spatial relations of objects belonging to the same color or shape group were verified faster than those of objects from different groups, even if the spatial distance was identical. These results did not depend on whether judgments were based on perceptually available or memorized information, suggesting that perceptual, not memory processes were responsible for the formation of cognitive clusters.

Introduction

Spatial cognition is of central importance for a wide range of human everyday activities, because most of our actions rely on the perception and memories of spatial relations, such as in reaching and grasping an object, typing on a keyboard, or finding one's way home. To perform successfully in such tasks, our cognitive system not only needs to register and integrate relevant portions of the available spatial information, but also retrieve and use already acquired and stored information from short-term and long-term memory. Interestingly, there is strong evidence that spatial information undergoes considerable changes on its way from the sensory surface to memory, often distorting the original information in systematic ways (for overview see McNamara, 1991; Tversky, 1981). In the literature, such distortions have been often attributed to memory processes, such as the encoding of spatial information (e.g., McNamara & LeSueur, 1989), its retrieval (e.g., Sadalla, Staplin, & Burroughs, 1979), or both (Tversky, 1991). However, here we entertain the hypothesis that at least some distortions might originate already from perception, not memory, hence much earlier in the processing stream that hitherto assumed. There is some evidence that complex visual structures are coded in a hierarchical fashion in both perception and memory. Memory distortions are often ascribed to hierarchical representation, so that such a commonality suggests that memory distortions may merely reflect the perceptual organization of stimulus information. We report two experiments that investigated whether and how perceptual similarities between perceived and to-be-memorized elements of a map-like display affect perception- and memory-based judgments of spatial relations. Our data provide evidence that the structure of memory representations is already formed in perception, a finding that calls for a reinterpretation of a considerable part of previous observations.

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Hierarchical coding in memory

There are quite a number of studies supporting the idea that spatial relations are coded hierarchically in memory. Maki (1981) had participants verify sentences describing the spatial relation between pairs of American cities ("City A is west of City B" or "City A is east of City B"), and observed that, as one might expect, verification time was a decreasing function of Euclidean inter-pair distance. However, this was only true for cities that belonged to the same state (e.g., Alamo and

Burlington, North Dakota), but not for cities located in different states (e.g., Jamestown, North Dakota, and Albertville, Minnesota). Such findings might indicate that information about cities and states is hierarchically organized, so that cities are stored as elements of superordinate state categories. If so, comparing elements from the same category should be in fact easier the more discriminable (i.e., distant) the elements are; however, judgments about elements from different categories might be often based on category membership, hence influenced by the spatial relationship between categories (i.e., states), so that within-category discriminability does not (or not that much) come into play.

Further evidence for hierarchical structures in memory comes from the experiments of Stevens and Coupe (1978). These authors presented their subjects with to-be-memorized artificial maps each containing two cities (e.g., city x and city y) that fell in different superordinate regions (e.g., Alpha county, Beta county). In a congruent condition, the spatial relation between the cities matched the relation between the counties, e.g., city x (located in Alpha county) was to the west of city y (located in Beta county) and Alpha county was to the west of Beta county. In an incongruent condition, the relationship between cities was the opposite of that between counties, e.g., city x was to the west of city y and Alpha county was to the east of Beta county. When subjects made directional judgments about the two cities, systematic errors were observed with incongruent conditions producing more errors than congruent conditions. According to Stevens and Coupe, this is because participants used their knowledge about superordinate relations in judging the subordinated cities, so that the judged relations were distorted to conform with the relation of the superordinate geographical units.

A similar type of bias can also be demonstrated for real-world locations, as shown by the study of Hirtle and Jonides (1985) on the cognitive representation of landmarks in the city Ann Arbor, Michigan, (e.g., city hall, central cafe). Protocols of the free recall of landmarks were used to (re-) construct individual clusters, separately for each subject, and the validity of these clusters was then tested by means of a spatial-judgment task (i.e., distance estimation). As expected, distances within a cluster were judged smaller than distances across clusters.

In experiments reported by Hirtle and Mascolo (1986), participants memorized maps in which place names fell into two semantic cluster: names of recreational facilities (e.g., Golf Course or Dock) and names of city buildings (e.g., Post Office or Bank). Locations were arranged in such a way that, although places belonging to the same semantic cluster were spatially grouped on the map, the Euclidean distance of one recreational facility was shorter to the cluster of the city buildings than to any other recreational facility, and vice versa. However, when subjects were asked to estimate inter-object distances on the basis of memory information, they showed a clear tendency to (mis)locate these critical places closer to their fellow category members than to members of the other cluster.

Taken altogether, these results provide strong evidence that global nonspatial relations between objects induce the formation of hierarchical object clusters in memory, thereby distorting certain inter-object spatial relations, or at least the judgments made about these relations.

Hierarchical coding in perception

The available results from memory studies provide strong evidence for the assumption that information about spatial configurations is not cognitively represented in a one-to-one correspondence, but seems to be at least partly organized in a hierarchical fashion. However, it is far from being settled which processes are responsible for such an organization. Obvious candidates are memory processes, which may work to reduce the perceptual information to minimize storage costs, optimize later retrieval, and so forth. But hierarchical coding may also be a result of perceptual, or perceptually driven, processes, which may not only register sensory evidence but actively integrate it into a structured whole. If so, hierarchical coding in memory would tell us not so much about memory principles but about perceptual organization[1].

Several authors have argued that complex visual structures are perceptually coded in a hierarchical fashion. Navon (1977) tested the idea that global structuring of a visual scene precedes analysis of local features. Participants were presented with large letters (the global level) made of small letters (the local level), and they were to recognize either the global or the local letter level. There were two important outcomes: First, it

[1]According to the classical Gestalt-psychological view, perceptual organization proceeds preattentively and autonomously, hence before codes of perceptually available information are brought into contact with stored knowledge. If so, the rules according to which perceptual information is organized are hard-wired into the perceptual system and cannot be modified by experience, an assumption that draws a thick line between perceptual and memory systems and processes. In contrast, more recent approaches (e.g., Goldstone & Barsalou, 1998) propose a more continuous view on the relation between perception and memory that allows for interactions between perceptual and memory contents in the processing of perceptual input. We do not think that the logic of our study presupposes the acceptance of one or other view, or that our findings help to decide which one is more tenable. What we wish to investigate is (1) whether the cognitive clustering (i.e., the organization) of spatial- and location-related information about map-like layouts is affected, and can be experimentally induced, through purely perceptual, nonspatial characteristics of the layout, and (2) whether such clustering effects are restricted to memory-driven tasks (i.e., tasks requiring memory retrieval) or whether they can also be obtained *before* the layout has been memorized and stored, i.e., in a perceptually-driven task not relying on memory retrieval. However, even though our study does reveal clustering effects in perceptually driven tasks – an outcome suggesting an important role of perceptual organization – there is nothing in our data that would exclude (or suggest) experience- or memory-related contributions to perceptual organization.

took less time to identify the global than the local letter, showing that global identification is easier than local identification. Second, the congruence between global and local letter produced asymmetric effects, that is, global identification was more or less independent of the identity of the local letters, while local identification was much easier if global and local letters were identical than if they were incongruent. This latter finding supports the notion that local analysis is always preceded by global processing, while global information can be extracted without local analysis. Obviously, visual structures are perceptually represented in a hierarchical fashion and this hierarchy affects informational access.

More evidence for hierarchical clustering of visual information has been found by Baylis and Driver (1993), who had their subjects judge the relative height of object features that were part of the same or of different visual objects. Although the distance between the features was held constant, the judgments were made faster when both features were part of the same rather than different objects. The authors argued that codes of features of the same object, including their spatial relations, make up a single representational cluster, with different clusters (i.e., object representations) being hierarchically organized. If so, judging features of different objects requires switching between cluster levels, while judging features of the same object does not, so that between-level judgments are slower than within-level judgments. Obviously, these argument follow exactly the same lines as those of Maki (1981), although Baylis and Driver refer to perception, while Maki refers to memory. This strengthens our suspicion that the way complex configurations are represented in perception and memory may be similar, or even identical.

Gestalt principles in spatial cognition

Taken altogether, the literature reviewed so far suggests that perceptual coding processes do not only affect perceptually based judgments, but may also determine the way perceptual information is stored, thus indirectly affecting memory-based judgments. This implies that the distortions and clustering effects observed in memory tasks may not so much reflect organizational principles of memory processes, but be a more or less direct consequence of distortions and clustering tendencies in perception. Accordingly, we wanted to test whether experimental, stimulus-related factors that are known to affect perception can also be shown to affect memory-based performance, and whether their effects on perception and memory are comparable. In particular, we investigated whether Gestalt principles can be demonstrated to affect perception and memory the same way.

Gestalt principles are known to exert powerful effects on perception. Important for our study is the fact that elements tend to be grouped perceptually if they are similar in color, shape, or other attributes (see Rock & Palmer, 1990). Several investigators have shown that such perceptual-clustering phenomena are associated with biases and errors in spatial judgments analogous to visual-geometric illusions (e.g., Canter & Tagg, 1975; Coren & Girgus, 1980), suggesting that the perceived distance between items belonging to the same phenomenal group is contracted. That is, Gestalt principles and their effects on perceptual organization may lead to distortions of the perceived space or, more precisely, of the spatial characteristics of perceived configurations. Indeed, Canter and Tagg found evidence that Gestalt features of map-like stimuli can lead to measurable biases in performance: When facing a city with a river running through it, people seemed to mentally divide the city in halves, as expressed in their tendency to judge distances between places within a half of the city differently than across the river.

In the present two experiments, we used the Gestalt principle of *similarity*, that is, the tendency of people to perceive similar objects as belonging to a common group. Similarity between objects was expected to induce the cognitive clustering of the representations of these objects, which again should affect performance in perceptual and/or memory tasks. In Experiment 1, the stimulus layout was a visual map-like configuration of 18 objects (Fig. 1), namely houses of an artificial city. The coloring of the objects was chosen in such a way that the configuration was subdivided into three or four groups of adjacent objects with the same color. In Experiment 2, the same grouping of objects on the stimulus layout was achieved by using different shapes of the objects (Fig. 2).

To test whether the non-spatial factors color and shape would affect the coding of the spatial information between the objects, participants were asked to perform two "spatial" tasks: a speeded verification of sentences describing spatial relations (e.g., "Is house A above house B?") – a task often used in perceptual experiments – and an unspeeded estimation of Euclidean distances – a task very common in memory experiments. We had our participants perform these tasks under three conditions in three consecutive sessions. In the *perceptual* session, the configuration was constantly visible; in the *memory* condition, participants first memorized the configuration and then performed the tasks without seeing it; and in the *perceptual/memory* condition, the configuration was again visible, so that both perceptual and memory information was available.

We expected both tasks to reveal the same pattern of results, hence the cognitive clustering of the configuration should affect verification times as well as distance estimations. Our prediction for both experiments were as follows: Objectively identical Euclidean distances between two given objects should be estimated as being smaller when both objects were elements of the same (identical color or shape) rather than different visual groups. Such a result would suggest that the cognitive representations of the objects were in fact clustered as a consequence of Gestalt factors (e.g., similarity of color or shape) and that this clustering led to the distortion of

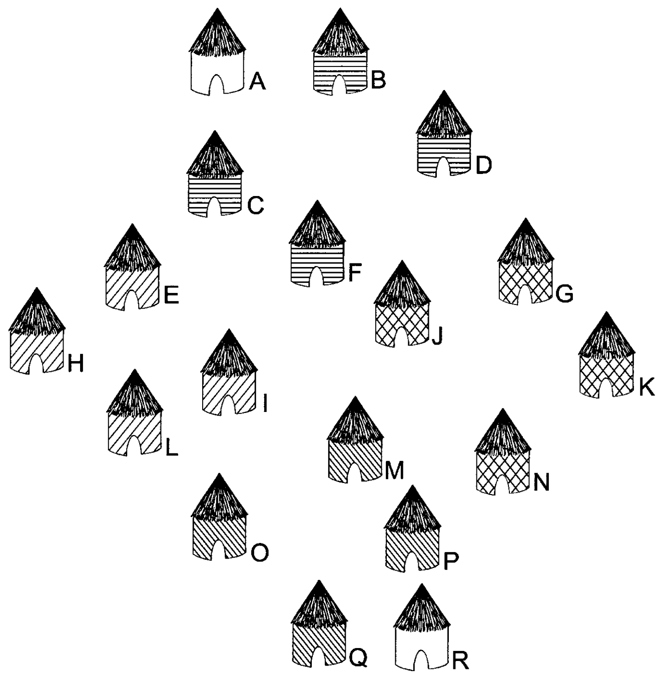

Fig. 1 Schematic graph of the layout used in Experiment 1 (example). The letters indicating the locations were not shown to the subjects; instead each house was identified by a nonsense "name" (i.e., a meaningless syllable like "MAW", omitted here) appearing in its center. Each configuration consisted of 18 colored houses (colors indicated here by *texture*). Three to four of them had the same color, this making up either three or four color groups (configurations *C3* and *C4*). For example, in *C4* houses in locations B, C, D and F might be red, houses in E, H, I, and L green, houses in G, J, K, and N blue, and houses in M, O, P and Q yellow. *White houses A* and *R*, that were not used in any task, were added to all configuration versions

the objective spatial information. We assumed that the visual grouping of objects by similarity would induce a similar kind of cognitive clustering as presenting or referring to abstract knowledge about category or group membership – the manipulation used in previous studies (e.g., Stevens & Coupe, 1978). Along the same lines, we expected the verification of spatial relations to proceed more quickly if the to-be-judged object pair belonged to the same as compared to different visual groups. If so, this would support the idea that (inter-)object information is hierarchically represented, so that within-cluster information can be accessed more quickly than between-cluster information. Finally, given the idea that memory effects may often merely reflect the outcome of perceptual organization, we expected that the same pattern of result for distance estimations and verification times should be present in all three conditions, that is, results to be independent of whether the perceptual information is available or not.

Experiment 1

Experiment 1 was conducted to provide a first test of our hypothesis that Gestalt factors of a stimulus layout (here: the color-based grouping of objects) induce the hierarchical coding or clustering of the objects making up this configuration, and that this effect influences perception and memory in comparable ways.

Methods

Participants. Eighteen adults (mean age 24 years), 11 females and 7 males, were paid to participate in the experiment. They reported having normal vision or corrected-to-normal vision, and were unaware of the purpose of the study.

Apparatus and stimuli. Stimuli were presented via a video beamer (BARCODATA 800) on a 140 × 110 cm projection surface and participants were seated in front of the surface with a viewing distance of about 180 cm. The data acquisition was controlled by a personal computer. Participants made their responses by pressing a left or right sensor key with the corresponding index finger.

Stimuli were two versions of map-like configurations of 18 colored houses, which were introduced to the participants as houses of a virtual city (Figs. 1, 2). The houses measured 15 × 15 cm and were arranged as shown in Fig. 1, plus a randomly determined jitter of up to 5 cm around the location centers. Each house was labeled by a consonant-vowel-consonant nonsense syllable without any obvious phonological, semantic, or functional relation to locations or location-related words. The name-to-house mapping varied randomly between participants. In one version of the configuration (C3), three different colors were used to subdivide the map into three perceptual groups (group $C3_1$: C, E, H, L, O; group $C3_2$: B, F, I, J, M, Q; and group $C3_3$: D, G, K, N, P). In the second version (C4) four groups were formed using four colors (group $C4_1$: B, C, D, F; group $C4_2$: E, H, I, L; group $C4_3$: G, J, K, N; and group $C4_4$: M, O, P, Q). The houses in locations A and R served as neutral items in both configurations; their only use was to avoid possible end or anchor effects on verification or estimation performance.

Eight vertical location pairs were chosen for location verifications and distance estimations. The members of each of these pairs were separated by 300 mm on average. Half the pairs were composed of elements which were located within a perceptual group (B–F, E–L, G–N, M–Q) and the other half consisted of elements of adjacent groups (C–I, D–J, I–O, J–P). A small set of diagonal and

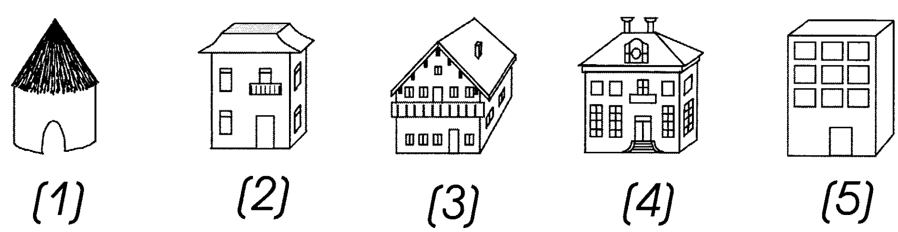

Fig. 2 Illustration of the objects used in Experiment 2. All objects were uncolored and varied in shape only. Three to four of them were of the same type, this making up either three or four shape groups (configurations *C3* and *C4*, respectively). Houses of type *3* served as neutral objects in locations *A* and *R*

horizontal pairs was used as fillers, but results for these pairs were not further analyzed.

Design. The experiment consisted of three experimental sessions (perceptual, memory, and perceptual/memory condition). Each session was divided into one experimental block for location judgments and another block for distance estimations, with task order being balanced across participants. A set of 320 judgments was composed of 10 repetitions for each possible combinations of eight experimental pairs, two relations (*under, above*), and two orders of location within the pair (*A–B, B–A*); 88 filler judgments were added to the set. Half of the participants responded yes and no by pressing the left and right response key, respectively, while the other half received the opposite response-key mapping. A set of 48 distance estimations comprised three repetitions of each of the possible combinations of eight experimental pairs and two orderings of location within the pair. Twelve further pairs served as fillers. Half of the participants worked on configuration *C3*, consisting three perceptual groups, and the other half worked on configuration *C4*, consisting four perceptual groups.

Procedure. Each participant participated in three experimental sessions on three consecutive days. The stimulus configuration for a given participant was the same in each session. In the first session (perceptual condition), the configuration remained visible while subjects worked through the distance estimation task and the location verification task. The second session (memory condition) started with an acquisition phase, in which the participants memorized the positions and syllables of the displayed houses. Then they performed the estimation and the verification tasks in front of a blank projection surface, hence without seeing the configuration. The third session (perceptual/memory condition) was identical to the first session, hence the configuration was visible while the two tasks were performed.

Distance estimations. Sixty pairs of house names (48 critical distance pairs and 12 filler pairs) were displayed one pair at a time in the upper center of the projection surface. The names were displayed in adjacent positions, separated by a short horizontal line. Another horizontal line of 70 cm in length was shown below the names and participants were told that this line represented the width of the whole projection surface (which actually spanned double the size). It was crossed by a vertical pointer of 5 cm in length, which could be moved to the left or right by pressing the left and right response key, respectively. For each indicated pair, participants were required to estimate the distance between the corresponding objects (center to center) by adjusting the location of the pointer accordingly, and then to verify their estimation by pressing the two response keys at the same time. They were instructed to take as much time as needed for each estimation. The critical dependent measure (i.e., estimated distance) was computed by taking the distance indicated on the screen in pixels, multiplied by 2, and transforming it into millimeters.

Location judgments. A series of 408 (320 critical and 88 filler) to-be-verified locational statements was presented to each participant, one statement at a time. In each trial, a fixation cross appeared for 300 ms in the top center of the display. Then the statement appeared, consisting of the names of two objects and a relation between them, such as "RUK under JOX" or "KAD above NOZ". Participants were instructed to verify (or falsify) as quickly and as accurately as possible by pressing the yes or no key accordingly; the assignment of answer and response key was counterbalanced across participants. The sentence stayed on the projection surface until the response key was made. After an intertrial interval of 600 ms the next trial appeared. In the case of an incorrect key being pressed, the error was counted without feedback and the trial was indexed. Such an indexed trial was incorporated into the rest of the series at a random position within the series. If the same error on the same trial was made for three times, this trial was excluded from the data.

Acquisition. The second session always started with the acquisition of the stimulus configuration. The configuration was presented to the participants, who had unlimited time to memorize the locations and names of the displayed objects. The configuration then disappeared and the participants were sequentially tested for each object. An object-size rectangle appeared in the lower right corner of the display, together with an object name in the lower left corner. Using a joystick, participants were asked to move the rectangle to the exact position of the named object. After pressing the left and right key simultaneously, the computer recorded the position of the rectangle, the projection surface was cleared, and the next test trial started. There were 18 such trials, one for each object, in a random order. If an object was mislocated for more than 2.5 cm, the whole procedure was repeated from the start[2].

The acquisition phase ended after the participant completed three correct positioning procedures.

Results

From the data of the distance-estimation task, mean estimates in millimeters were computed for each participant and condition. Over all conditions, the real distance was clearly underestimated: 237 mm instead of 300 mm. Estimates took about 15 s on average and there was no indication of any dependency of estimation latency on session. To test our hypotheses, comparisons were made between pooled estimates of the within-group pairs B–F, E–L, G–N and M–Q and pooled estimates of the between-groups pairs C–I, D–J, I–O and J–P. However, an ANOVA with the within-subject factors session/condition (perceptual, memory and perceptual/memory) and group membership (within-group vs between-groups) did not reveal any significant main effect or interaction. That is, no systematic distortions were observed for object pairs spanning two vs one group. Figure 3 shows the estimated distances for the pooled within-group pairs and between-groups pairs across sessions.

In the locational-judgment task, error rates were below 5% and the respective trials were excluded from

[2]This procedure might have provided subjects with feedback to improve and correct their spatial memory, which again might have worked against possible distortion effects. However, there are reasons why this should not represent a serious problem for interpreting our findings. First, every study on spatial memory requires some kind of check of whether the stimulus configuration has actually been learned. The previous studies described above also used some kind memory test that was repeated if too many errors were made. Despite this feedback, several of these studies found distortions in distance estimations. Second, even if repetitions of the test were used as feedback, the subjects could not attribute their failure to a specific object. Therefore, all that the repetitions offered was practice, which should have affected all objects – and, by implication, all object pairs – equally. This rules out specific effects of test repetitions on represented locations or distances between within- and/or between-groups pairs – apart from the fact that a tolerance of 25 mm still leaves room for some distortion effects.

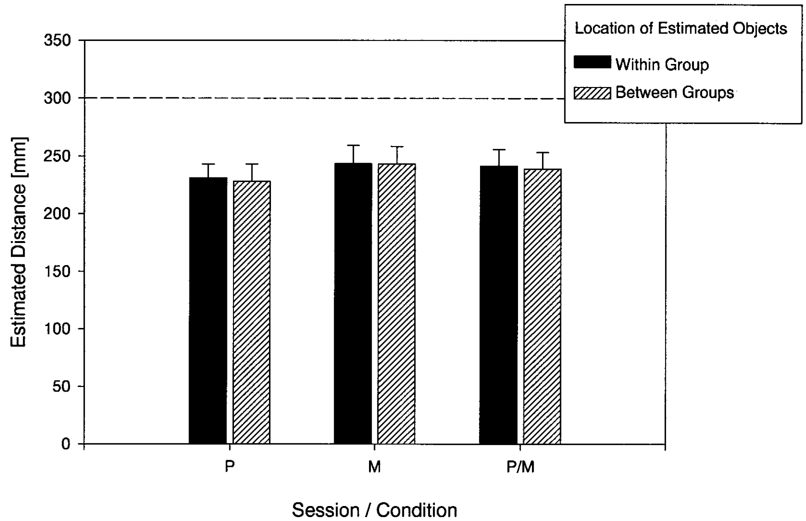

Fig. 3 Mean estimated Euclidean inter-object distance in Experiment 1 as a function of sessions/conditions (*P* perceptual condition, *M* memory condition, *P*/*M* perceptual/memory condition) and group membership of object pairs. The *dotted line* indicates real distances

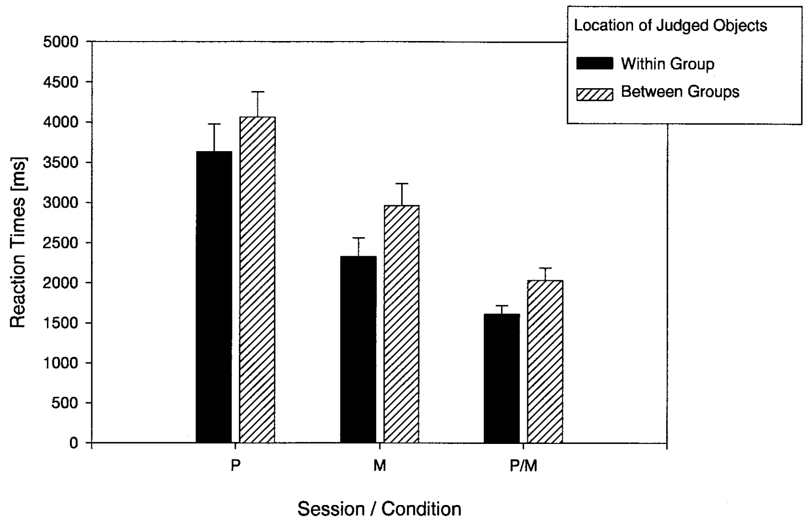

Fig. 4 Mean reaction times of judged spatial propositions in Experiment 1 as a function of session/condition (*P* perceptual condition, *M* memory condition, *P*/*M* perceptual/memory condition) and group membership of object pairs

analysis. In a first step, the remaining reaction times were analyzed as a function of configuration type (*C3* vs *C4*), spatial relation (above vs under), and response (yes vs no). The corresponding ANOVA revealed a highly significant main effect for response, $F(1, 16) = 39.98$, $p < 0.001$, indicating that positive responses were faster (2,656 ms) than negative responses (2,888 ms). The second significant source of variance was an interaction of relation and response, $F(1, 16) = 5.24$, $p < 0.05$. As revealed by a Scheffé test ($p < 0.05$), this was produced by an effect of relation restricted to positive reactions, where subjects verified "above" statements faster than "below" statements (2,588 vs 2,724 ms). Other sources of variance failed to reach the significance level.

Again, the most interesting analysis concerned the comparison of the reaction times within- and between-groups pairs (Fig. 4). In an ANOVA with the factors session/condition and group membership, the main effects of session/condition, $F(2, 16) = 38.74$, $p < 0.01$, and of group membership, $F(1, 17) = 54.36$, $p < 0.01$, were significant, while the interaction was not. In contrast to the distance estimation task, the grouping of the elements by color was quite effective: Faster reaction times were obtained within groups of identical colored objects (2,523 ms) than between groups (3,021 ms). Additionally, the reaction times decreased over sessions (critical difference of the Scheffé test: 661 ms, $p < 0.05$), but the type of session did not affect the grouping effect.

Discussion

The aim of Experiment 1 was to examine how a visual layout of objects is coded in perception and memory and, in particular, whether the color-induced grouping of objects leads to the hierarchical organization of their cognitive representations. We used two tasks which are very common in perception and memory studies. In contrast to our expectations of converging results in both tasks, the results turned out to depend on the measure taken.

On the one hand, performance in the verification task provided some strong evidence for hierarchical organization: Reaction times were shorter if the to-be-judged object pair belonged to the same rather than to different color groups. This suggests that objects of the same color were integrated into one cognitive cluster, and that this similarity-based clustering affected the access to representations of cluster members in judgments of relative location. Importantly, pronounced within-group benefits were found in all three sessions, that is, independent of whether perceptual information was available or not. This observation has two implications.

First, the fact that clustering effects appear in the first, perceptual session already demonstrates that these effects do not require memory storage and retrieval to show up. Apparently, the cognitive structuring of information can be induced by purely perceptual means like visual similarity manipulations. As mentioned above, this does not necessarily mean that the clustering is achieved by some autonomous, purely perceptual system without any top-down influence from memory – nor does it exclude this possibility. However, it does imply that when people perceive a relatively complex visual layout, they already integrate and cluster the perceptually available information in ways that show up in their location judgments. Second, the fact that the size of clustering effects does not increase if the judgments are made from memory at least suggests that processes of memory encoding and/or retrieval do not determine, and perhaps do not even contribute to, that and how the spatial information is coded and integrated. However, this second conclusion needs to be treated with caution as it rests on a statistical null effect (the absence of a session-by-group interaction). Moreover, Experiment 2 will show that there are situations where the size of the grouping effect can vary between sessions. What seems clear, though, is that, if anything, storage and retrieval adds very little to the clustering effect, suggesting that perceptual and memory-informed judgments are based on the same cognitive representations.

On the other hand, visual grouping did not produce any systematic distortion in distance estimations. Apart from the general tendency to underestimate physical distances, no differences could be observed between the estimates of within-group and between-groups pairs. There are at least four possible explanations for this finding. First, the absence of grouping effects on distance estimations might indicate that grouped objects were simply not cognitively clustered. Given that effects indicative of clustering were obtained in the verification latencies, this explanation is not very plausible unless one could come up with a reasonable story of why the two tasks were affected differently.

Second, and this may be such a story, estimating a distance and verifying a location require different types of judgments and make use of different measurement scales. Therefore, a dissociation of these two measures may simply reflect their different degrees of sensitivity to memory distortions. Although this possibility cannot be ruled out on the basis of the present findings, it would raise the question of why a discrete, relative judgment should be *more* sensitive than a continuous, absolute judgment that has already been shown to be affected by memory distortions in several previous studies.

Third, objects and their relations might have been represented in a distorted way but, in contrast to the verification task, the unspeeded nature of distance estimations allowed for correcting these errors before overt emission of the response[3].

Fourth, it may also be that verification latency and the reliability of distance estimations tap different cognitive processes. Distance estimations may more or less directly reflect the quality and representation of spatial information that is used in both verification and estimation tasks. If so, the fact that we did not find systematic distortions of estimations would indicate that this information was relatively reliable (i.e., of high quality) at least in our study. Yet, verification latencies need not reflect the quality of spatial information. Instead, they may depend on how *accessible* this information is, which again depends on how it is stored and organized. That is, Gestalt-induced grouping may lead to the hierarchical clustering of data entries (i.e., the formation of stronger links between codes of objects belonging to the same visual group) but not, or not necessarily, to the distortion of the data themselves.

On the basis of our results we are not able to distinguish between the last three of these possibilities. Importantly, however, each suggests that distance estimations and verifications of spatial relations measure different processes (or at least measure them to different degrees) and, therefore, tap into different aspects of spatial representations. Given that in the past distance-estimation and location-verification tasks have been used more or less interchangeably, such a possibility raises important implications for further research on spatial cognition apart from and beyond the present study.

The dissociation of verification and estimation performance notwithstanding, it is interesting to note that there were no systematic differences between estimations under perceptual and memory conditions, hence no main effect of session. In contrast to this finding, previous research has suggested that judgments made from the memory can differ systematically in the accuracy from those made perceptually (Kerst & Howard, 1978; Moyer, Bradley, Sorensen, Whiting, & Mansfield, 1978). For example, Kerst, Howard, and Gugerty (1987) reported that perceptual pair-distance judgments were more veridical than judgments made from memory after a brief (10 min) or a long (24 h) retention period.

[3]An obvious test of this idea would be to vary the time available for estimations. We actually did this in a follow-up experiment, where estimation time was either limited or unlimited – with little success (i.e., no impact on the estimations). However, as even in the limited condition the interval was as long as 7 s (which was the minimum to handle the input device), we do not consider this to represent a strong test of the correction hypothesis.

Interestingly, however, the properties of the used maps itself – the building sites on the left half of the map were labeled with dormitory names and those on the right were labeled with department names – had no effect on the accuracy of distance judgments. This latter observation is in line with our findings, thus supporting the view of a close correspondence between perception and memory-based estimates and, presumably, of the data these processes operate on.

Experiment 2

Experiment 1 provides the first evidence that nonspatial Gestalt factors like color grouping affect the coding and/or organization of spatial information in the perception and memory of map-like layouts. Also of interest, although the two measures we used yielded different outcomes, there was no evidence for session or condition effects, suggesting that perceptual and memory processes are based on the same representations. Experiment 2 was conducted to replicate and extend Experiment 1 for three reasons. First, we wanted to see whether our basic finding generalizes to other domains, i.e., whether a within-group benefit in verification times can be observed with another grouping factor than color. Second, given that the somewhat surprising dissociation of verification and estimation measures was based on a null effect in the estimation task, we were interested in whether this null effect can be replicated at all. Third, it seemed important to test whether the null interaction of group membership and session/condition can be replicated. After all, arguing on the basis of a null effect is problematic, so that we sought for converging evidence to strengthen our conclusions from Experiment 1. As a result of these considerations, we repeated Experiment 1 but, instead of color, attempted to induce similarity between objects by shape. That is, visual groups were formed using the same type of house for each subgroup of objects.

Method

Eighteen different adults (mean age 24 years), 11 females and 7 males, were paid to participate in the experiment. They fulfilled the same criteria as in Experiment 1. The apparatus was the same as in Experiment 1 as was the method, except that the 18 houses differed not in color (i.e., all were presented in black outline on white background) but shape (see Fig. 2).

Results

The data were analyzed as in Experiment 1. In the distance-estimation task, the real distance was again underestimated: 222 mm instead of 300 mm. Estimates took about 12 s on average, with no indication of any dependency of estimation latency on session. An ANOVA revealed only a significant main effect for the factor session/condition, $F(2, 15) = 5.96$, $p < 0.01$, due to participants estimating the Euclidean distances between objects as being shorter in the memory condition (217 mm) than in the perceptual condition (240 mm; critical difference of Scheffé test: 17 mm, $p < 0.05$) (Fig. 5).

In the locational-judgment task, error rates were again below 5%. An ANOVA with the factors configuration type (*C3* vs *C4*), spatial relation (above vs under), and response (yes vs no) revealed main effects of spatial relation, $F(1, 16) = 13.57$, $p < 0.01$, and response, $F(1, 16) = 42.28$, $p < 0.01$. Mean reaction times were shorter if a yes response was required (3,257 ms) as compared to a no response (3,550 ms). Furthermore, "above" judgments were faster (3,341 ms) than "below" judgments (3,466 ms). Other sources of variance failed to reach significance.

A further ANOVA with the factors session/condition and group membership yielded a highly significant main effect of session/condition, $F(2, 16) = 84.97$, $p < 0.01$, which showed a decreasing reaction time over sessions (perceptual condition: 4,272 ms; memory condition: 3,571 ms; perceptual/memory condition: 2,447 ms; critical difference of the Scheffé test: 489 ms, $p = 0.05$). The

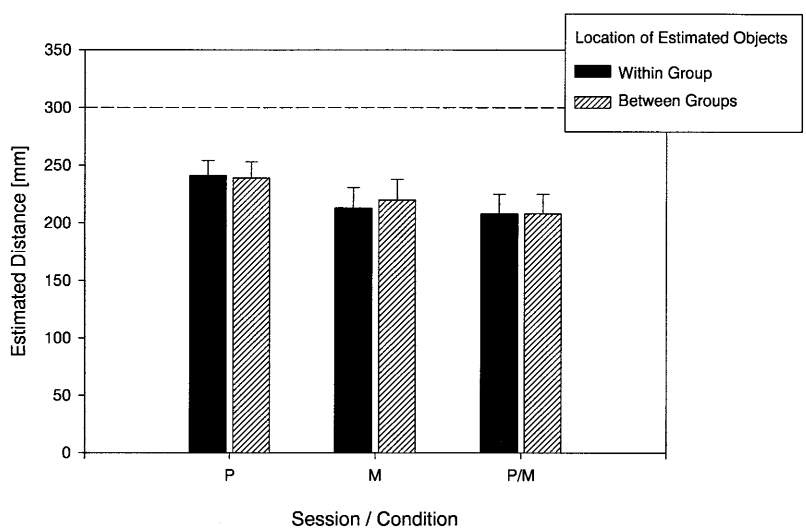

Fig. 5 Mean estimated Euclidean inter-object distance in Experiment 2 as a function of sessions/conditions (*P* perceptual condition, *M* memory condition, *P/M* perceptual/memory condition) and group membership of object pairs. The *dotted line* indicates real distances

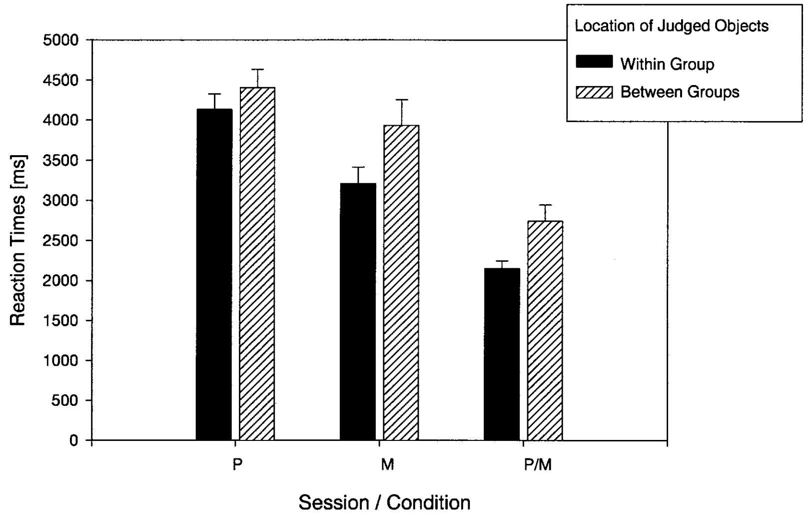

Fig. 6 Mean reaction times of judged spatial propositions in Experiment 2 as a function of session/condition (*P* perceptual condition, *M* memory condition, *P*/*M* perceptual/memory condition) and group membership of object pairs

second significant source of variance was the main group membership effect, $F(1, 17) = 15.34$, $p < 0.01$, that replicated the results from Experiment 1: faster reaction times for within-group pairs (3,165 ms) than for between-groups pairs (3,695 ms). This time, however, the two factors interacted, $F(2, 16) = 4.69$, $p < 0.05$, due to larger group-membership effects in the second and third session than in the first session. However, separate comparisons confirmed that the group-membership effect was significant in all sessions, $p < 0.05$ (Fig. 6).

Discussion

All in all, Experiment 2 represents a successful replication of Experiment 1. With regards to our first goal, this means that effects of inter-object similarity on verification performance is not limited to the domain of color but can also be demonstrated for shape. Although other types of similarity may also be interesting to investigate, we can safely conclude that the grouping effect seems to be fairly general. A second aspect of the present results is that the selective effect of group membership on verification times, but not on distance estimations, could be replicated as well. Even though one may still argue that the null effect in the estimation task merely reflects its less pronounced sensitivity, the replication strengthens our suspicion that verification and estimation tasks measure different things.

With regard to our third goal, the outcome is somewhat mixed. On the one hand, grouping affected performance from the first session on, which points again to a major role of cognitive clustering in a perceptually driven task. On the other hand, in contrast to Experiment 1, the effect of grouping on verification latencies increased from the first, perceptual session to the two following, memory-related sessions. There are at least three possible, partly related reasons for this increase.

First, it may be that storing and/or retrieving information about spatial layouts as such introduces further integration processes that strengthen the organization suggested or already achieved by perceptual or perceptually driven processes. Second, the need to memorize a complex spatial layout may lead subjects to make active, strategic use of the structured organization already offered by their perceptual system. Third, performance in the first, perceptual session may reflect a mixture of several, sometimes opposing effects of perceptual organization. Although our shape manipulation was quite effective, we cannot exclude the additional impact of other organizational tendencies. For instance, people may tend to organize our layouts into diagonal clusters, this way grouping, say, locations A, B, D, G, and K, locations C, F, J, and N, and so forth. Accordingly, the pair B–F, say, would represent a between-groups pair, which would conflict with the shape-induced coding as a within-group pair. Once coded and stored, however, one interpretation – presumably the shape-based one – might prevail, so that no coding conflict would occur from session 2 on. From this view, the interaction of session and group membership may merely reflect the fact that perceptual information can be organized in different ways.

At this point, we are unable to decide between these three possibilities. On the one hand, the fact that clustering effects varied with session in Experiment 2 but not in Experiment 1 seems to point to a more strategy-based interpretation, such as the second, memorizing-related hypothesis. On the other hand, it seems clear that a firmer conclusion regarding this issue would presuppose a direct manipulation of the individual encoding and/or retrieval strategies. Nevertheless, the most important message from Experiment 2 is that, whatever may have increased the clustering effect in the second session, it was reliably present before. This demonstrates that the hierarchical organization of information about map-like layouts appears in perceptually driven performance already and, therefore, does not require or rely on processes responsible for memory storage or retrieval.

Conclusions

Studies of human spatial cognition commonly focus on either the on-line use of perceptual information for ongoing action or on the representation and organization of spatial knowledge in memory. In contrast, the present experiments investigated and compared the ways spatial information is coded in perception and memory. In our view, three important conclusions can be drawn from our findings.

First, exogenous factors such as Gestalt characteristics of spatial layouts strongly affect the way spatial information is organized. In showing that, our results are in line with, and extend, previous demonstrations that spatial memories are influenced by nonspatial information such as linguistic information (Bower, Karlin, & Dueck, 1975; Daniel, 1972), semantic relations (Hirtle & Mascolo, 1986; McNamara & LeSueur, 1989; Sadalla et al., 1979), functional object information (McNamara, Halpin, & Hardy, 1992), or landmark-induced visual grouping (Gehrke & Hommel, 1998). These demonstrations are inconsistent with the idea that cognitive representations are mere copies of external stimulus arrays. Instead, spatial information seems to be integrated with nonspatial information in such a way that the retrieval of spatial information leads to the automatic activation of nonspatial information and, presumably, vice versa.

Second, there was very little evidence, if any, for coding differences in perception and memory. In Experiment 1 color grouping affected perception- and memory-based performance to the same degree, and the differences observed in Experiment 2 were more quantitative than qualitative in kind. In as much as exogenous grouping can be assumed to induce the cognitive clustering of spatial information, this implies that clustering arises in perception already instead of reflecting a process of memory organization. Accordingly, at least part of the demonstrated influences of nonspatial factors on spatial memory may tell us more about the principles of coding and organization in the perceptual system than about memory processes.

Third, the lack of converging results in the location-verification and the distance-estimation tasks raises the question of whether both tasks tap into different processes. Although we are reluctant to draw strong conclusions from the present data, it seems clear that these two measures should not be treated as equivalent. Possibly, distance estimations assess the quality of spatial information, while verification latencies indicate the way this information is organized.

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