The Impact of Exogenous Factors on Spatial Coding in Perception and Memory

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Abstract. In the course of acquiring knowledge about layouts and maps spatial information can undergo considerable changes and distortions, which systematically affect knowledge-based judgments of human observers. In the literature, these biases have been attributed to memory processes, such as memory encoding or retrieval. However, we present both theoretical reasons for, and first empirical evidence that at least some biases originate already in perception, that is, much earlier in the processing stream than commonly believed. Human subjects were presented with visual map-like layouts, in which objects were arranged to form two different spatial groups. When asked to estimate distances between object pairs and to verify statements about spatial relations, verification times, but not distance estimations, were affected by group membership: Relations between members of the same group were verified quicker than those between members of different groups, even if the Euclidian distance was the same. These results did not depend on whether judgments were based on perceptual or memory information, which suggests that perceptual, not memory processes were responsible.

1 Introduction

Spatial cognition is of central importance for a wide range of human everyday activities, such as reaching and grasping an object, typing on a keyboard, or finding one's way home. To achieve good performance in such tasks, our cognitive system does not only need to register and integrate relevant portions of the available spatial information, but also to 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 overviews 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 & LeSuer, 1989), its retrieval (e.g., Sadalla, Staplin, & Burroughs, 1979), or both (Tversky, 1991). However, in the present paper we entertain the hypothesis that at least some distortions might originate already from perception, not memory, hence much earlier in the processing stream than hitherto assumed. To motivate our hypothesis, we will briefly review some evidence for that complex visual structures are coded in a hierarchically 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 than report, as an example of our research, an experiment 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. To anticipate, our data will in fact provide preliminary 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.

1.1 Hierarchical Coding in Memory

There is a big deal of evidence supporting the idea that spatial relations are coded hierarchically in memory. For instance, Maki (1981) had participants to 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 Euclidian 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 experiments made by 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 was shown by Hirtle and Jonides' (1985) study 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-judgement 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 Euclidian 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 then 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.

1.2 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. An obvious candidate 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 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.

In fact, several authors have argued that complex visual structures are perceptually coded in a hierarchical fashion. For instance, 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 took more 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 the hierarchical clustering of visual information has been found by Baylis and Driver (1993), who had their subjects to 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 judgements 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 strenghtens our suspicion that the way complex configurations are represented in perception and memory may be similar, or even identical.

1.3 Present Study

Taken altogether, the evidence 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 so far in memory tasks may not so much reflect organizational principles of memory processes, but rather be a more or less direct consequence of distortions and clustering tendencies in perception.

The present study investigated this hypothesis by comparing perceptually-based and memory-based judgments of the same stimulus layout, a visual map-like configuration of eight houses and two ponds. As shown in Figure 1, these objects were visually grouped in such a way to induce a subdivision of the configuration into two perceptual (and/or memory) clusters. We asked participants to perform two “spatial” tasks, the unspeeded estimation of Euclidian distances—a task very common in memory experiments—and the speeded verification of sentences describing spatial relations (e.g., “is house A left of house B”)—a task often used in perceptual experiments. We had our participants to perform these tasks under three conditions in three consecutive sessions: In the *perceptual* condition, the configuration was constantly visible; in the *memory* condition, participants first memorized the configuration and then performed 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 distance estimations as well as verification times. In particular, our prediction was as follows: Objectively identical Euclidian distances between two given objects should be estimated smaller when objects were elements of the same than of different visual group. If so, this would suggest that the objects were in fact clustered and that this clustering led to the distortion of the objective spatial information. In the same vein, 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.

2 Method

2.1 Participants

Twenty adults, 11 females and nine 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.

2.2 Apparatus and Stimuli

Stimuli were presented via a video beamer (BARCODATA 700) on a 142 $\times$ 109 cm projection surface and participants were seated in front of the surface with a viewing distance of about 170 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 map-like configurations of eight houses, displayed at the same locations for each participant. The houses were 15 $\times$ 15 cm in size and were arranged into two groups, each centered around a pond (see Figure 1). Each house was named by a consonant-vowel-consonant nonsense syllable, such that there were no obvious phonological, semantic, or functional relations between the names associated with the to-be-judged location pairs. The name-to-house mapping varied randomly between subjects.

Eight horizontal location pairs were chosen for distance estimations and location judgements. Three of these pairs were separated by 300 mm (D_{300}: C-D, E-F, D-E), four by 600 mm (D_{600}: C-E, D-F, A-B, G-H), and one by 900 mm (D_{900}: C-F). Two of the pairs (C-D, E-F) had a pond in between. A small set of diagonal pairs was used as fillers; judgments for these pairs were no further analyzed.

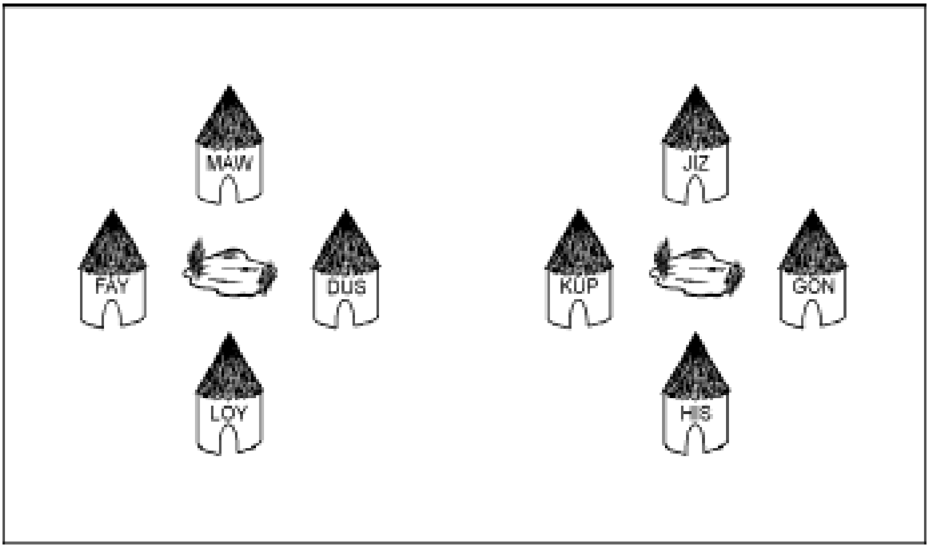

Fig. 1. Example of a stimulus configuration. Each configuration consisted of eight houses that were named by a nonsense syllable. For clarity we will in this paper use the letters A-H to indicate particular locations (location 'A': MAW; location 'B': JIZ; location 'C': FAY; location 'D': DUS; location 'E': KUP; location 'F': GON; location 'G': LOY; location 'H': HIS). Note that the house in a particular location had a different name for each participant.

1.3 Design

The experiment consisted of three experimental sessions (*perceptual*, *memory*, and *perceptual/memory* condition). Each session was divided into one experimental block for location judgements and another block for distance estimations, with task order being balanced across participants. A set of 256 judgements was composed of eight repetitions of each of the possible combinations of eight experimental pairs, two relations (*left of*, *right of*), and two orders of location within the pair (*A-B*, *B-A*). Forty-four judgments on distractor pairs 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 was composed of 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.

1.4 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 was visible throughout the whole experiment. The second session (*memory* condition) started with an acquisition phase, in which the participants first memorized the positions and syllables of the displayed houses and were then tested on their memory. This memory test was performed in front of a blank projection surface. The third session (*perceptual/memory* condition) was identical to the first session with respect to the display, hence the configuration was visible all the time.

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 explained that this line would represent the width of the whole projection surface. 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 time for each estimation of the distances was measured.

Location judgements. A series of 300 (256 critical and 44 filler) to-be-verified locational statements was presented to each participant, one statement at a time. In each trial, a fixation cross appeared for 500 msec 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 “FAY left of DUS” or “DUS right of FAY”. Participants were instructed to verify (or falsify) the sentence by pressing the ‘yes’ or ‘no’ key accordingly; the assignment of answer type and response key was counterbalanced across participants. The sentence stayed on the projection surface until the response was made, but instructions emphasized that participants should respond as quickly and as accurately as possible. After an intertrial interval of 1,000 ms the next trial appeared. In case of an incorrect keypress, the error was counted without feedback and the trial was indexed. All indexed trials were repeated immediately after the 300th trial until no indexed trial exists or until the same error on the same trial was made four times.

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. Then the configuration disappeared and the participants were sequentially tested for each object. A rectangle of an object’s size appeared in the lower right corner of the display, together with an object name in the lower left corner. Using a joystick, participants moved 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 eight 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.

3 Results

From the data of the *distance-estimation task*, mean estimates in cm were computed for each participant and condition. On average, estimates increased with real distance: 395 mm for D_{300} pairs, 782 mm for D_{600} pairs, and 1002 mm for D_{900} pairs. Figure 2 shows the estimated distances across sessions. Estimates took about 25 sec on average and there was no indication of any dependence of estimation latency on session or real distance.

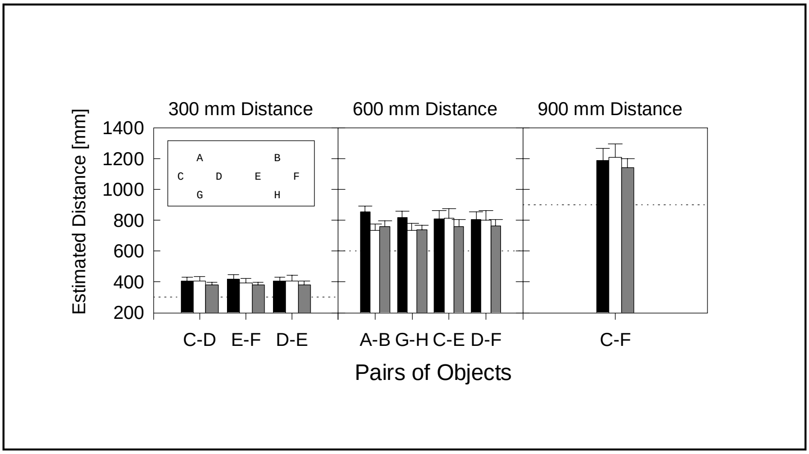

Fig. 2. Mean estimated Euclidian inter-object distance as a function of real distance across sessions/conditions (solid: perceptual condition; white: memory condition; hatched: perceptual/memory condition). The dotted line indicates real distances.

The relevant comparison was among the D_{300} pairs—the within-cluster pairs C-D and E-F and the between-cluster pair D-E—because these had identical Euclidian distances but different types of visual "cluster membership". However, an ANOVA with the factors session (condition) and pair did not reveal any significant main effect or interaction, hence, no systematic distortions were observed for object pairs spanning two vs. one clusters (see Figure 3).

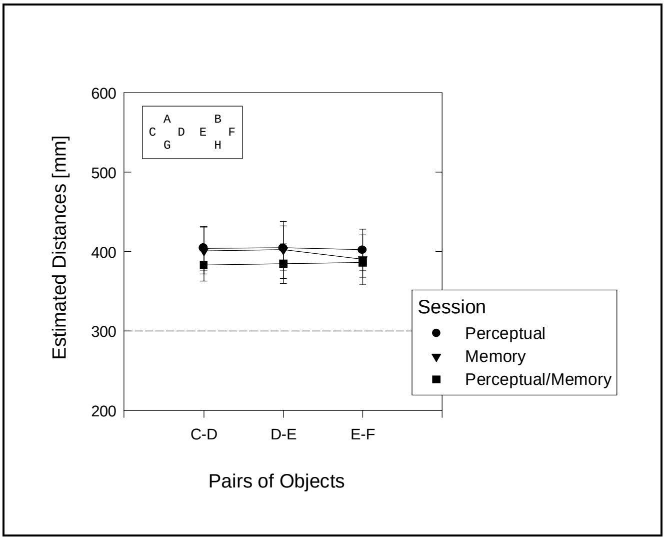

Fig. 3. Mean estimated Euclidian distances across session and equally-distant pairs of objects (C-D, D-E and E-F).

In the *location-judgement task*, error rates were low (< 4%) and the respective trials were excluded from analyses. Reaction times (RTs) from correct trials were analyzed by means of an ANOVA with the within-subjects factors session/condition and distance (D_{300}, D_{600}, and D_{900}). All three sources of variance were highly significant: the main effects of session, $F(2,18) = 133.25$; $p < .001$, and distance, $F(2,18) = 44.71$; $p < .001$, and the interaction, $F(4,16) = 6.68$; $p < .001$. As shown in Figure 4, verification times decreased over sessions and with increasing real distance. There was no difference between the inter-object distances D_{300} and D_{600} in the memory and perception/memory condition (critical difference of the Scheffé-test: 233 ms, $p < .05$).

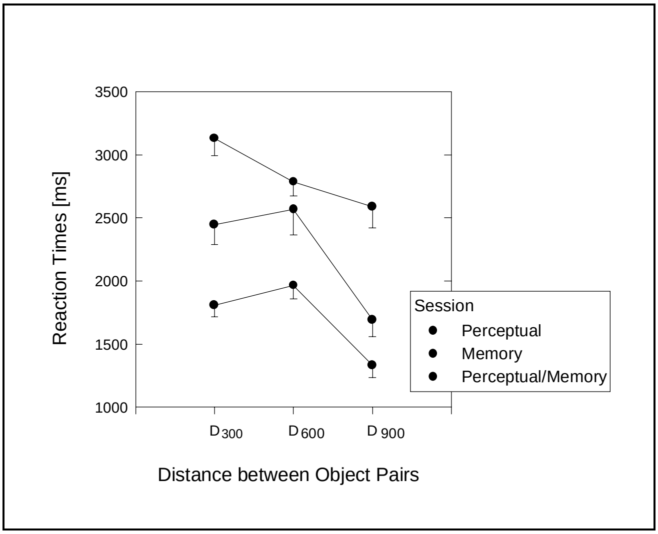

Fig. 4. Mean reaction times of judged spatial propositions across session/condition (perceptual condition, memory condition and perceptual/memory condition) and Euclidian distance between the judged objects (D_{300}: 300 mm; D_{600}: 600 mm; D_{900}: 900 mm).

As with distance estimations, an ANOVA was conducted on RTs for the equally-distant D_{300} pairs (C-D, E-F, and D-E) with session/condition and pair as within-subject factors. This time, two sources of variance were highly significant: the main effects of session, $F(2,18) = 102.27$; $p < .01$, and of pair, $F(2,18) = 73.37$, $p < .01$. The interaction failed to reach the significance level. Post-hoc analyses of the session effect (critical difference of Scheffé test: 238 ms) showed that RTs decreased from session to session (perceptual: 3132 ms; memory: 2446 ms; perceptual/memory: 1806 ms; see Figure 5). More interesting, however, was the analysis of differences between pairs. The Scheffé test yielded a critical difference of 218 ms, indicating significantly longer RTs for the between-clusters pair D-E (3041 ms) as compared to the within-cluster pairs C-D (2115 ms) and E-F (2227 ms).

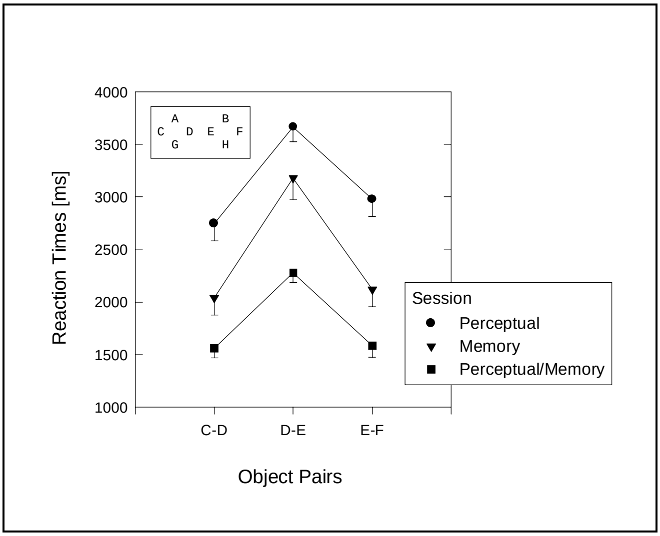

Fig. 5. Mean reaction times of judged spatial propositions across session/condition (perceptual condition, memory condition and perceptual/memory condition) and equally-distant object pairs.

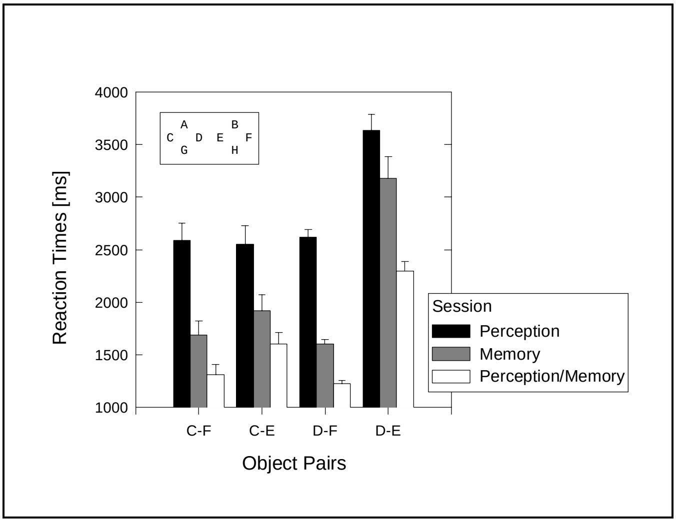

Fig. 6. Mean reaction times of judged spatial propositions across session/condition (perceptual condition, memory condition and perceptual/memory condition) and equally-distant objects pairs that consisted elements of two induced perceptual cluster.

One problem with this analysis is that the time to verify spatial propositions related to pairs C-D and E-F might be affected by the extreme left and right positions of the objects C and F. To control for this influence, we composed pairs consisting of elements of both perceptual clusters. The pairs C-E, D-F and C-F included at least one extreme spatial position, whereas the pair D-E contained adjacent object positions. If the spatial information is hierarchically organized then no differences in response times should occur ($RT_{C-E} = RT_{C-F} = RT_{D-E} = RT_{D-F}$) because judgements of each pair are based on the same path lenght within the hierarchy. On the other hand, if the organization of the spatial information would follow a linear formation, then RTs depended on the Euclidian distance between the elements of each pair ($RT_{C-F} < RT_{C-E}$, $RT_{D-F} < RT_{D-E}$). The ANOVA on the RTs for pairs C-F, C-E, D-F, and D-E yielded two significant main effects of session, $F(2,18) = 216.18$; $p < .001$, and pair, $F(3,17) = 60.83$; $p < .001$. Post-hoc tests revealed that RT constantly decreased across the three sessions/conditions (perception: 2849 ms; memory: 2098 ms; perception/memory: 1608 ms). Moreover, and this speaks to the spatial representation of the objects, the pair with adjacent elements (D-E: 3036 ms) was associated with higher RTs than the other pairs (C-F: 1863 ms; C-E: 2025 ms; D-F: 1816 ms). In addition, the interaction between session and pairs reached significance ($F(6,14) = 4.89$, $p < .01$) which is solely based on longer RTs for pair D-E under the perception, memory and perception/memory conditions (see Figure 6).

4 Discussion

The aim of this study was to examine how spatial information is coded in perception and memory and, in particular, to test the hypothesis that the spatial information is hierarchically organized in perception as well as in memory. We used two tasks which are very common in perceptual and memory studies and expected converging results in both tasks. The results we obtained are somewhat mixed.

First, the distance estimations showed that participants slightly overestimated the physical distances presented on the projection surface, which was true for all distances tested. This stands in opposition to previous observations that people tend to underestimate short as compared to long distances (McNamara, Ratcliff, & McKoon, 1984). In contrast to distance estimations, there was no reliable difference between estimation latencies in the D_{300}, D_{600} and D_{900} condition. This finding is inconsistent with some models of distance estimations from maps (e.g., Thorndyke, 1981), which propose that estimation time is a direct function of how long it takes to scan from one map element to the other. One reason for this inconsistency could have to do with the estimation procedure used in our experiment. Note that participants did not directly respond by pressing digits on a keyboard but they moved a vertical line back and forth on the projection surface without any time limit. Possibly, the time needed for this adjustment outlastet and, in a sense, overwrote the effect of scanning time.

Second, no difference was observed between estimations under perceptual and memory conditions. On the one hand, both the perceived and memorized distance between two objects increased linearly with their physical distance and the observed deviations were very similar under all conditions. This close correspondence between perceptually- and memory-based judgments suggests that the underlying processes and representation on which they operate are very similar if not identical. On the other hand, the visual grouping manipulation did not produce any systematic distortions of distance estimations. Although there are many possible explanations for this finding, three immediately come to mind. One is that the configuration simply induced no cognitive clustering of the objects. Given that clustering effects were obtained in the judgement latencies discussed below, this is an unlikely explanation. Another account might be based on the assumption that distance estimations and verifications of spatial relations are tapping into different processes. Although such an account would have important implications for research on spatial memory—where both measures are usually treated as equivalent—we are unable to judge its viability on the basis of the present results. Finally, one might assume that the strong symmetry of our stimulus display was responsible for the absence of systematic effects on distance estimations. In this context, the outcome of a recent experiment of ours (Heidemeier, Gehrke, & Hommel, in preparation) might turn out to be of considerable interest. There we used the same distance-estimation procedure as in the present experiment and had people judge vertical, horizontal, and diagonal inter-object distances. However, we added random spatial jitter to each object position, which resulted in a more asymmetrical configuration as compared to the present stimulus material. This time, we did observe cluster-related distortions in estimated Euclidian distance, suggesting that people use different estimation strategies for judging symmetrical and asymmetrical configurations.

The major aim of this study was to answer the question of whether spatial information is coded in the same—presumably hierarchical—way in perception and memory. The analysis of the time to verify spatial propositions provided some evidence for hierarchical organization induced by our visual-grouping manipulation: RTs were shorter for object pairs within (e.g., C-D and E-F) than between visual groups (e.g., D-E). Interestingly enough, this data pattern was found in all sessions, which can be taken to support the view that perceptually- and memory-based judgements were based on the same cognitive representation. A possible objection against such a conclusion could be based on the assumption that the shorter RTs for within-cluster judgments are mainly due to the inclusion of objects at extreme left and right locations (C and F), which because of their outstanding positions might facilitate the perception and/or retrieval of the corresponding object information. And, indeed, the verification times were shortest for distance D900 (see Fig. 4), which was related to the left- and rightmost object in the configuration. However, we have pointed out that this objection can be rejected on the basis that no RT differences were observed between the pairs C-E, C-F, and D-F under all conditions (see Fig. 6). Therefore, we think that there is some reason to maintain and pursue the idea that the coding of spatial configurations is—or at least can be—hierarchical, and that this is so in perception as well as in memory. If so, this suggests that phenomena of cognitive clustering as observed in studies on spatial memory may not so much reveal the logic of memory processes, but rather reflect the principles of coding and organization of spatial information in the perceptual system. If this argument is correct, then we can expect exogenous, perceptually relevant (Gestalt) factors, such as grouping by color or shape, to affect and possibly determine the way spatial information is coded and stored — a line of research we are pursuing in our lab. Figure 7 illustrates the theoretical framework that is suggested by the outcome of the present study. Perceptual processes come first and organize a given stimulus configuration into clusters that depend on feature-related similarities between objects. The emerging representation is then the basis for memory coding and other processes. That is, in contrast to traditional views, clustering is not a memory (-specific) process.

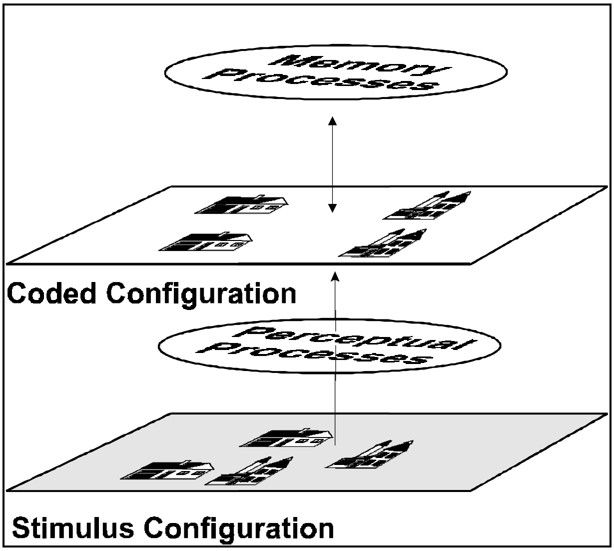

Fig. 7. Illustration of proposed relationship between perceptual and memory processes for the coding of spatial information. Perceptual processes come first and organize the stimulus configuration (indicated by the clustering of the objects within the coded configuration). The so far coded configuration is the basis for memory processes.

To conclude, our findings suggest a high degree of coherence between the processing of spatial information in perception and memory and therefore stress the importance of perceptual mechanism in the area of spatial cognition. However, more research is clearly needed to investigate the interdependence between perceptual and memory processes and representations.

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