Acquisition of Cognitive Aspect Maps

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Abstract. Two experiments investigated the cognitive consequences of acquiring different aspects of a novel visual scene. Subjects were presented with map-like configurations, in which subsets of elements shared perceptual or action-related features. As observed previously, feature sharing facilitated judging the spatial relationship between elements, suggesting the integration of spatial and non-spatial information. Then, the same configuration was presented again but both the features' dimension and the subsets defined by them were changed. In Experiment 1, where all spatial judgments were performed in front of the visible configuration, neither the novel features nor the inter-element relations they implied were acquired. In Experiment 2, where the configurations were to be memorized before the critical judgments were made, novel features were acquired, in part counteracting previous effects of feature overlap. Results suggest that different, subsequently acquired aspects of the same scene are integrated into a common cognitive map.

1 Introduction

Maps are media to represent our environment. They use symbols that are arranged in a particular fashion to represent relevant entities of the area in question and the way these entities are spatially related. However, as maps are not identical with, and not as rich as what they represent they necessarily abstract more from some features of the represented area than from others. For example, a road map contains information that a map of the public transportation network is lacking, and vice versa (Berendt, Barkowsky, Freksa, & Kelter, 1998). Thus, maps are always selective representations of the represented area, emphasizing some aspects and neglecting others.

The same has been shown to be true for cognitive representations of the environment. Far from being perfect copies of the to-be-represented area, cognitive maps often reflect attentional biases, internal correction procedures, and retrieval strategies. As with aspect maps this does not necessarily render them unreliable or even useless, they just do not represent picture-like duplications of the environment but are, in a sense, cognitive aspect maps. Numerous studies provide evidence that cognitive maps are tailored to the needs

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and attentional preferences, and sometimes also the cognitive limitations, of their owners (for overview see McNamara, 1991; Tversky, 1981). Our own research has focused onto the role of salient perceptual factors and of action-related information in the processing of visual arrays, such as shown in Figure 1. The most robust finding in several studies was that if people judge the spatial relations between elements of two-dimensional map-like arrays, they are substantially faster if these elements either share a salient perceptual feature, such as color or shape (Gehrke & Hommel, 1998; Hommel, Gehrke, & Knuf, 2000), or if they have been learned to signal the same action (Hommel & Knuf, 2000; Hommel, Knuf, & Gehrke, 2002). Moreover, these effects are independent of whether the judgments are given in front of a novel array or made from memory, ruling out factors having to do with memory organization, retrieval, or selective forgetting. Rather, perceptual or action-related commonalities between elements seems to induce the formation of cognitive clusters connecting the representations of the related elements via the shared feature code (Hommel & Knuf, 2000). Accordingly, accessing the codes of one element spreads activation to connected elements, thereby facilitating comparison processes. That is, people acquire cognitive maps the structure of which represented one particular, salient aspect of the to-be-represented environment—hence, cognitive aspect maps.

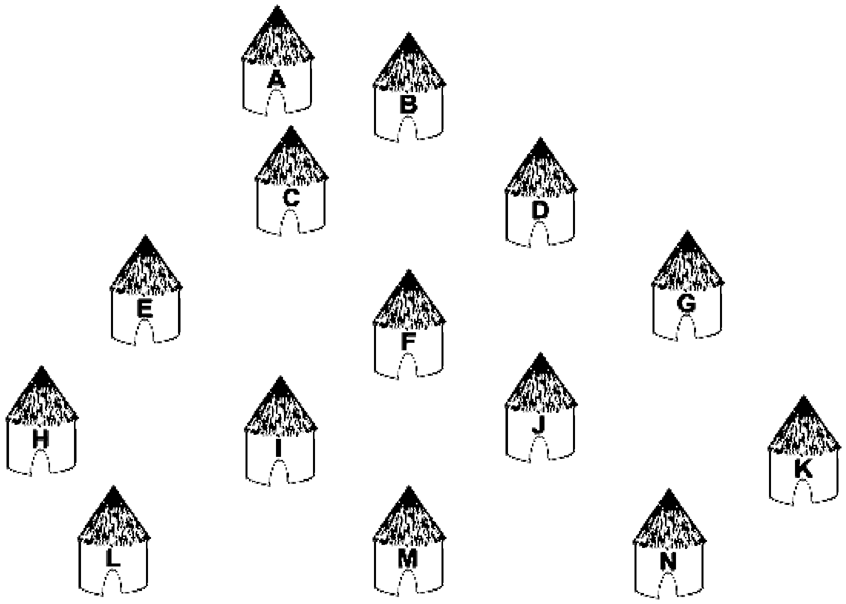


Fig. 1. Example of the stimulus layout used in all experiments. The huts were displayed at nearly the same locations for each participant, only differing by a small jitter of up to 5 cm per location (to counteract possible emerging figural properties of the display). The letters indicating the locations were not shown to the subjects; instead each hut was identified by a nonsense "name" (i.e., a meaningless syllable like "MAW", omitted here) appearing at the letter's position. Note that the hut in a particular location had a different name for each participant.

Previous studies were restricted in that they introduced only one dimension of similarity or feature sharing at a time, that is, there was only one salient aspect of the array. Yet, in everyday life we are often confronted with alternative aspects of the same environment. For instance, we go walking, ride a bike, take a subway, or drive by car in the same city, thereby following different tracks and routes, observing different constraints and, hence, focusing on different aspects of the same area. How are these different aspects cognitively represented? One possibility, suggested by computational approaches to aspect-map representation (e.g., Berendt et al., 1998) were to acquire and store independent cognitive maps and to retrieve them according to the current task and goal. Alternatively, people may begin with forming a cognitive map with respect to one aspect and fill in additional information, such as new links between locations, when focusing on another aspect (e.g., McNamara & LeSueur, 1989). That is, the same cognitive map may be used to represent all the acquired aspects—which may be differentially marked to relate them to the relevant aspect.

Importantly for both psychological and empirical reasons, the separate-maps and the integrative-maps view differ in their predictions with respect to the effect of acquiring information about a new aspect of an already known array. According to the separate-maps view there is no reason to assume that learning about aspect B of a given array X would change the representation of X with respect to another aspect A. Both aspects should be stored in different cognitive maps which should not interact. According to the integrative-maps view, however, learning about B should indeed be suspected to modify the map, especially if the implications of aspect B contradict the implications of aspect A. For example, assume subjects acquire a visual array as depicted in Figure 1. Assume that in a first trial the huts labeled B and F are presented in the same color, whereas F and M appear in different colors. If subjects would then verify spatial relations between hut pairs they should perform better when comparing B and F then when comparing F and M, indicating that perceptual grouping by color induced the creation of corresponding cognitive clusters. However, what would happen if, in a second trial, F and M were mapped onto the same response, while B and F required different responses (a condition that we know to induce action-based cognitive clustering)? This would change the similarity relationship between the three items: B and F would be alike with respect to one aspect but different with respect to another, and the same were true for F and M. Hence, the huts would be parts of aspect relations that are, in a sense, incongruent with each other.

According to the separate-maps approach, introducing different (and presumably differently-clustered) aspects would be expected to lead to the acquisition of two different cognitive aspect maps. If so, one map were used to perform in one part of the task and another map in the other part, so that the effects of inter-item similarity should be independent; i.e., subjects should perform better on B-F in the color condition and better on F-M in the action condition. According to the integrative-maps view, however, different aspects are integrated into the same cognitive map, so that learning about a new aspect might affect performance on the items in question. In our example, having learned that B and F are alike with respect to one aspect might facilitate comparing B and F even if, in the following, subjects learn that B and F are dissimilar regarding another, new aspect. If so, color-based similarity and action-based similarity would work against each other, which should decrease the effect of action-based similarity as compared to a condition where this type of similarity is acquired first. Inversely, later tests of the effect of color-based similarity should be reduced by exposure to the differing action-based similarity. Whether this is so we tested in two pairs of experiments.

2 Experiment 1

In Experiments 1A and 1B, subjects judged spatial relationships between houses of an imaginary village arranged as in Figure 1. All judgments were carried out vis-à-vis the visual array, hence, the task was purely perceptual in nature. Each of the two experiments 1A and 1B consisted of three blocks. The first blocks were closely modeled after our previous studies, where we found comparison speed to be affected by inter-item similarity based on color (Gehrke & Hommel, 1998; Hommel et al., 2000) and shared action (Hommel & Knuf, 2000; Hommel et al., 2002)—which we take to imply color- and action-induced cognitive clustering. That is, in Experiment 1A the houses of our imaginary village looked all the same except that they were colored in such a way that three (configuration C3) or four (C4) color groups were formed. Correspondingly, in Experiment 1B subjects learned that the houses were mapped onto three (C3) or four (C4) keypressing actions. On the basis of our previous findings we expected the time needed to verify a statement regarding the spatial relation of two given houses to be less if the two items share the color (in 1A) or action (1B) as if they do not.

In a second block we introduced a new aspect. In Experiment 1A the houses were no longer colored but now required particular keypressing actions. The configuration was changed from C3 to C4, or vice versa, so that the similarity relations implied by color and action agreed in some cases but not in others (B, F, and M). The crucial question was whether similarity effects would be as in the first block of Experiment 1B (where action served to induce similarity as well) or whether they would be affected by previously learning another aspect. Of special diagnosticity for this question was performance on B-F and F-M, the pairs with differing (*incongruent*) similarity relations in the blocks of the experiment. Analogously to Experiment 1A, 1B no longer required particular actions related to houses but introduced new color relationships as in the first block of 1A. Accordingly, the question was whether this would lead to performance equivalent to the first block of 1A, or whether some impact of previously learning another aspect in the first block would show up.

In the concluding third block of the experiments the first condition was rerun (ABA design). Here we were interested to see whether performance would be comparable to the first block, which would suggest that the two acquired aspects are stored in separate, non-interacting maps, or whether after-effects of learning about another aspect in the second block could be demonstrated, as the integrative-maps view suggests.

Apart from the relation-judgment task we also asked subjects to estimate Euclidean distances between pairs of objects. Although distance estimations and the verification of spatial relations are commonly thought to tap into the same cognitive processes, our previous studies consistently revealed a dissociation between these two measures. In particular, we did not obtain any hint that inter-item similarity affects distance estimation. In our view, this suggests that similarities affect the way information of spatial layouts is cognitively organized (a factor that impacts verification times) but not the quality of spatial representations itself, an issue we briefly get back to in the General Discussion. Accordingly, we did not expect interesting effects to show up in distance estimations (and, indeed, there were no such effects) but did include this task in Experiment 1 anyway just to be sure.

2.1 Method

Thirty-five naive male and female adults (mean age 24.5 years) were paid to participate; 23 took part in Experiment 1A, 12 in Experiment 1B. Stimuli were presented via a PC-controlled video beamer on a 144 x 110 cm projection surface, in front of which subjects were seated with a viewing distance of about 200 cm. They responded by pressing different arrangements of sensor keys with the index finger (see below).

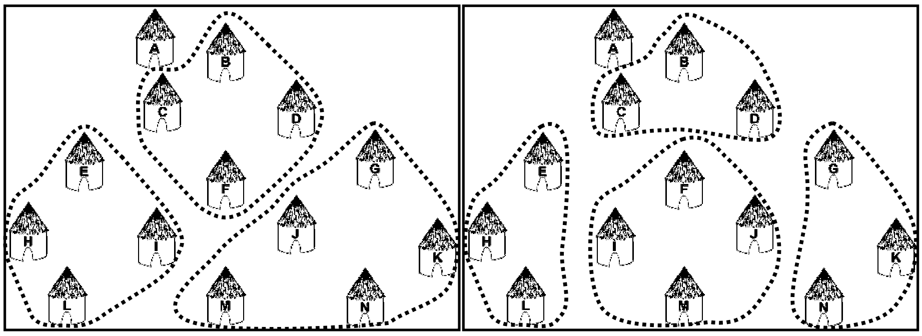
Stimuli were map-like configurations of 14 identically shaped houses, appearing as a virtual village (see Figure 1). Houses were displayed at nearly the same locations for each participant, only differing by a small jitter of 5 cm at maximum on each location (to avoid systematic spatial Gestalt effects). They were 15 x 15 cm in size and labeled by consonant-vocal-consonant nonsense syllables without any obvious phonological, semantic, or functional relations to each other or to location-related words—to exclude any cognitive chunking based on house names. The name-to-house mapping varied randomly between subjects.

Table 1. Design of Experiments 1 and 2. Experimental blocks differed in terms of grouping modality (i.e., houses were similar or dissimilar in terms of color or assigned action) and configuration (C3: three different colors or actions; C4: four different colors or actions; see Figure 2). Both modality and configuration alternated from block to block (C3→C4→C3 or C4→C3→C4).

	Experiments 1A and 2A		Experiments 1B and 2B	
Block	Modality	Configuration	Modality	Configuration
1	color	C3 / C4	action	C3 / C4
2	action	C4 / C3	color	C4 / C3
3	color	C3 / C4	action	C3 / C4

The experiment consisted of one experimental session of about 90 min., which was divided into three blocks differing in modality of grouping (Experiment 1A: color → action → color; 1B: action → color → action) and configuration sequence (C3/C4 vs. C4/C3), see Table 1. In the first block of Experiment 1A groupings were induced by color. In configuration C3, three different colors were used to induce three perceptual groups (group $C3_1$: B, C, D, F; group $C3_2$: E, H, I, L; and group $C3_3$: G, J, K, M, N; see Figure 2). In configuration C4, four colors were used to induce four groups (group $C4_1$: B, C, D; group $C4_2$: E, H, L; group $C4_3$: G, K, N; and group $C4_4$: F, I, J, M). The house in location A always served as neutral item; its only use was to avoid possible end or anchor effects on relation-judgment or estimation performance.

In the second block of Experiment 1A, color was removed from the objects, i.e., the homogenous stimulus layout shown in Figure 1 was presented. Also, the configuration was changed; i.e., subjects confronted with C3 in the first block were now confronted with C4 and vice versa (see Figure 2). Yet, the *spatial* stimulus arrangement for a given participant remained unchanged throughout the whole experiment. In contrast to the first block, subjects were to perform simple keypressing responses to induce cognitive clusters. In each trial, one of the houses would flash in red and the subject would press one of three or four response keys. The key-to-house mapping varied randomly between participants. As it was not communicated, they had to find out the correct mapping by trial and error. In case of a correct response the (red) color of the current object vanished and the next one was flashed. In case of an error an auditory feedback signal appeared and a different key could be tried out. Once subjects produced correct consecutive responses to all locations in a sequence, the mapping-induction phase ended. The third block was always exactly the same as the first one, i.e., groupings were induced by color and with the same, original configuration.



Configuration C3 **Configuration C4**

within groups	between groups		within groups	between groups
B-F	**F-M**	incongruent	**F-M**	**B-F**
E-L G-N	C-I D-J	congruent	E-L G-N	C-I D-J

Fig 2. Illustration of groupings by color and actions. Three to five of the huts were either displayed in the same color or assigned to the same keypressing response (groupings or assignments indicated by line borders, which were not shown in the experiments), this making up either three or four perceptual/action-related groups (C3 and C4). The sequence of configurations was always alternated between blocks (C3/C4/C3 vs. C4/C3/C4), as indicated in Table 1. As a consequence, the group membership of the location pairs B-F and F-M changed from block to block. The tables at the bottom indicate which comparisons entered the analyses of group-membership and congruency effects.

In Experiment 1B the method was exactly the same, only that the sequence of color and action blocks was interchanged (action → color → action).

In each experimental block subjects performed a relation-judgment task and a distance-estimation task in front of the visible stimulus configuration, task order being balanced across subjects. Six vertical location pairs were chosen for distance estimations and relation judgments, each pair being separated by ca. 300 mm. Half of the pairs were composed of houses within the same color or action group and the other half consisted of houses from different groups. In configuration C3, the pairs B-F, E-L, and G-N were assigned to the same color/key, while the pairs C-I, D-J, and F-M were assigned to different colors/keys (see Figure 2). In configuration C4, the respective within-group pairs were F-M, E-L, and G-N and the between-group pairs C-I, D-J, and B-F. As configurations varied between blocks (i.e., C3 → C4 → C3 or C4 → C3 → C4, see Table 1), group membership of some location pairs changed from 'between' to 'within' and vice versa. Those critical, *incongruent* location pairs were B-F and F-M.

Distance Estimations. Thirty-six critical pairs of house names (3 repetitions of the 6 critical pairs presented in the 2 possible orders) 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, serving as hyphen. Another horizontal line of 70 cm in length was shown above the names and participants were explained that this line would represent 150 cm (more than 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.

Relation Judgments. On basis of the 6 critical items a set of 128 judgments was composed, consisting of 4 repetitions for each item, 2 relations (*under, above*), and 2 presentation orders (*A-relation-B, B-relation-A*). 32 judgments on distractor pairs were added to the set. The to-be-verified relation statements were presented one at a time. In each trial, a fixation cross appeared for 300 ms centered on the top 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 the sentence as quickly and as accurately as possible by pressing the 'yes' or 'no' key accordingly, assignment of answer type and response key being counterbalanced across participants. The sentence stayed on the projection surface until response. After an inter trial interval of 1000 ms the next trial appeared. In case of an incorrect keypress an error tone appeared and the trial was repeated in a random position within the remaining series of trials. If the same error on the same trial was made for three times, this trial was excluded from the data.

2.2 Results and Discussion

Data were coded as a function of experimental block (*1-3*), group membership (*within-group vs. between-group*) and congruency (*congruent vs. incongruent*), as indicated in the scheme shown in Figure 2 (bottom). Thus, performance on distractor pairs was not analyzed. Analyses employed a four-way mixed ANOVA with the within-subjects factors group membership, congruency, and experimental block, and the between-subjects factor experiment (*1A* vs. *1B*). The significance level was set to $p < .05$ for all analyses.

From the data of the *distance-estimation task*, mean estimates in millimeters were computed. Across all conditions, the real distance of 300 mm was underestimated (Mean = 215 mm, SD = 46 mm). However, the ANOVA did not reveal any reliable effect or interaction, suggesting that there were no systematic distortions for object pairs spanning one vs. two groups, or for congruent vs. incongruent relations.

In the *locational-judgment task*, error rates were below 2% and the respective trials were excluded from analysis. The four-way ANOVA revealed a highly significant main effects of experiment, $F(1,22) = 16.862$, showing that RTs were generally slower in Experiment 1A than in 1B, and of block, $F(2,44) = 242.312$, indicating a decrease of RTs across blocks. More importantly, a highly significant main effect of group membership was revealed, $F(1,22) = 22.027$, indicating that relations between objects of the same color or action group were verified faster than relations between objects of different groups. However, this effect was modified by an interaction of group membership and block, $F(2,44) = 4.860$, indicating that grouping effects were reliable in Block 1 and 3, but not in Block 2. This effect was not further modulated by experiment ($p > .9$), suggesting that the way how groupings were induced did not play a role.

A main effect of congruency was also obtained, $F(1,22) = 18.922$, showing *slower* RTs for congruent object pairs than for incongruent ones. On first sight, this is a counterintuitive effect—it not only goes in the wrong direction, it also suggests that subjects were able to anticipate in the first block already which locations were rendered congruent or incongruent by the changes in the second block. Yet, note that it was always the same spatial locations that were used for the congruency manipulations (locations B, F, and M). Accordingly, a main effect of congruency merely reflects the relative difficulty to process information from these locations. As they occupied the horizontal center of the display, they may have been more difficult to find than more peripheral locations and/or processing the items presented there have suffered from the relatively high degree of masking from surrounding items.

At any rate, the more interesting question was whether grouping effects behaved differently for congruent and incongruent items. Indeed, besides an interaction with block, $F(2,44) = 7.547$, and with block and experiment, $F(2,44) = 3.531$, congruency entered a triple interaction with group membership and block, $F(2,44) = 4.925$; all further interactions failed to reach significance. To decompose the latter effect, separate ANOVAs were computed for congruent and incongruent trials. As suggested by Figure 3, no interaction effect was obtained for congruent trials. However, for incongruent trials group membership interacted with block, $F(2,44) = 6.989$, due to that standard grouping effects occurred in the first and the third block, but were reversed in the second block. As the status of within- and between-groups pairs changed under incongruence, this means that the original grouping effect from the first block persisted in the second block. In other words, subjects did not react to the grouping manipulation in the second block. (Indeed, membership no longer interacted with block when we reversed the sign of group membership in Block 2, that is, when we determined group membership for items in all blocks on the basis of their membership in Block 1.) As the critical interaction was not modified by experiment ($p > .9$), this lack of an effect can not be attributed to the way grouping was induced. Indeed, a look at the results from the first blocks shows that substantial grouping effects were induced by both color and action manipulations. Hence, commonalities with respect to both color and action seem to induce comparable cognitive clusters, but only if they are present the first time the stimulus configuration is encountered. Once the clusters are formed, so it seems, shared features are ineffective. In other words, acquiring one cognitive aspect map of an array blocks the acquisition of another aspect map.

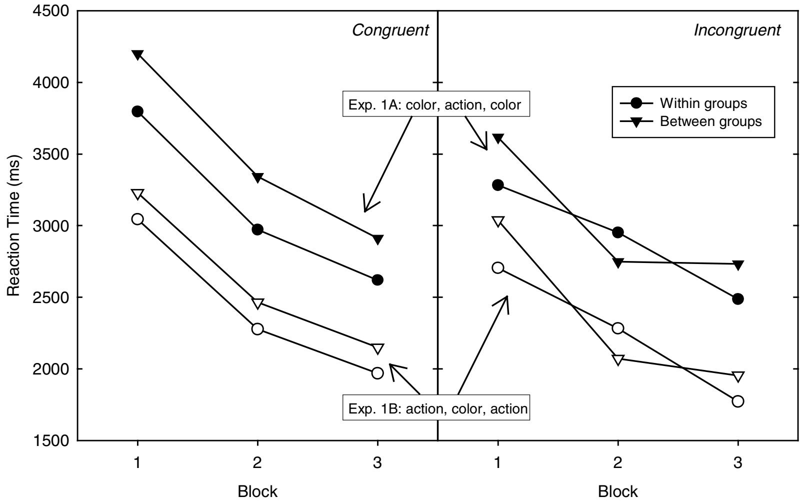


Fig. 3. Mean reaction times for verifying spatial relations between pairs of elements belonging to the same (within groups) or different (between groups) color- or action-induced group, as a function of block. Black symbols refer to Experiment 1A, white symbols to Experiment 1B.

To summarize, we see that the acquisition of perceptual or action-related aspects of a visual array strongly depend on previous experience. In particular, having experienced that the array items are similar with respect to one aspect—be it perceptual or action-related—prevents any further effect of other types of similarity. On the one hand, this is indicated by the fact that facing a novel aspect that supports an already acquired similarity relation, such as when items shared both color and action, does not increase the grouping effect. That is, in the left, congruency panel of Figure 3 there is not the slightest hint to an increase of the grouping effect in blocks 2 and 3 as compared to block 1, and this is so for 1A and 1B. On the other hand, there is also no hint to any grouping effect of the novel aspect in the incongruency condition. On the contrary, the pattern shown in the right, incongruency panel of Figure 3 shows that the grouping effect in block 2 entirely follows the old grouping encountered in the first block but shows no sign of effect by the present grouping. And finally, performance in the third block pretty much mirrored that in the first block, suggesting that the intermediate experience with another aspect had no effect.

3 Experiment 2

The outcome of Experiment 1 suggests that having structured a novel visual array with regard to one perceptual or functional dimension kind of immunizes the perceiver/actor against alternative ways to structure that array. It is as if perceivers/actors search for some obvious characteristic of the to-be-processed scene suited to provide the basic, internal structure of the scene's cognitive representation, and once a satisfying characteristic has been identified no other is needed. Yet, the situations in which we introduced and offered new features to induce some re-structuring of our subjects' scene representations were not too different from the previous ones and the tasks the subjects solved were rather similar. Hence, there was no real reason or motivation for subjects to re-structure their cognitive maps, so that our test for re-structuring effects was arguably weak. Moreover, all data we obtained were from purely perceptual tasks that, in principle, could be performed without any contribution from higher-level cognitive processes. Hence, our tasks arguably minimized, rather than maximized chances to find contributions from such cognitive processes.

Experiment 2 was carried out to provide a stronger test. Rather than merely confronting subjects with the visual arrays and asking them to carry out relation judgment we from Block 2 on required them to make these judgments from memory. In particular, we in Block 1 induced groupings by color (in Experiment 2A) or shared action (in Experiment 2B) and asked subjects to perform relation judgments in front of the visual array, just like in Experiment 1. Then, in Block 2, we introduced shared action or color as second grouping dimension, respectively, but here subjects were first to learn the spatial array before then making their judgments from memory. In Block 3 we switched back to the grouping dimensions used in Block 1 and tested again from memory. These design changes were thought to motivate subjects to establish new cognitive maps, or at least update their old ones, in Block 2 and, perhaps, in Block 3 as well. If so, we would expect an increasing impact of incongruent groupings in Block 2 and, perhaps, some impact on performance in Block 3.

3.1 Method

Twenty-four adults (mean age 23.1), 12 in Experiment 2A and 12 in 2B, were paid to participate. Apparatus and stimuli were the same as in Experiment 1, as was the sequence of blocks.

In contrast to Experiment 1, however, the mapping induction by keypressing responses in the second block of Experiment 2A was followed by an active learning phase. Following a 2-min study period, 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 the same keyboard as before, participants moved the rectangle to the estimated position of the named object and confirmed their choice by pressing the central key. Then the projection surface was cleared and the next test trial began. There were 14 such trials, one for each object, presented in random order. If in a sequence an object was mislocated for more than about 2.5 cm, the whole procedure was repeated from the start. The learning phase ended after the participant completed a correct positioning sequence.

Thereafter the mapping induction was repeated to prevent decay of information about the house-key mapping (Hommel et al., 2002). Since the stimulus layout was no longer visible, the name of a house appeared on the top of the screen and the correct key-to-house mapping had either to be recalled or again found out by trial and error. After having acquired the valid house-key mappings, subjects verified sentences about spatial relations between houses from memory. Distance estimations were not obtained.

Block 3 was also performed under memory conditions, so color-based grouping had to be reintroduced. The configuration of colored objects was therefore shown for about 2 minutes at the beginning of a new acquisition phase as well as at the beginning of each positioning sequence (see below). The rest of the procedure followed Experiment 1. Experiment 2B differed from 2A only in the sequence of grouping types (action → color → action) and was therefore a replication of Experiment 1B under mixed perceptual and memory conditions.

3.2 Results and Discussion

A four-way mixed ANOVA of verification times revealed a significant main effect of experimental block, *F*(2,44) = 68.562, indicating that RTs decreased across blocks (see Figure 4). This practice effect was more pronounced in Experiment 2A, which produced a block x experiment interaction, *F*(2,44) = 3.807. A main effect of congruency was obtained, *F*(1,22) = 5.487; it was again negative, showing slower RTs for congruent than

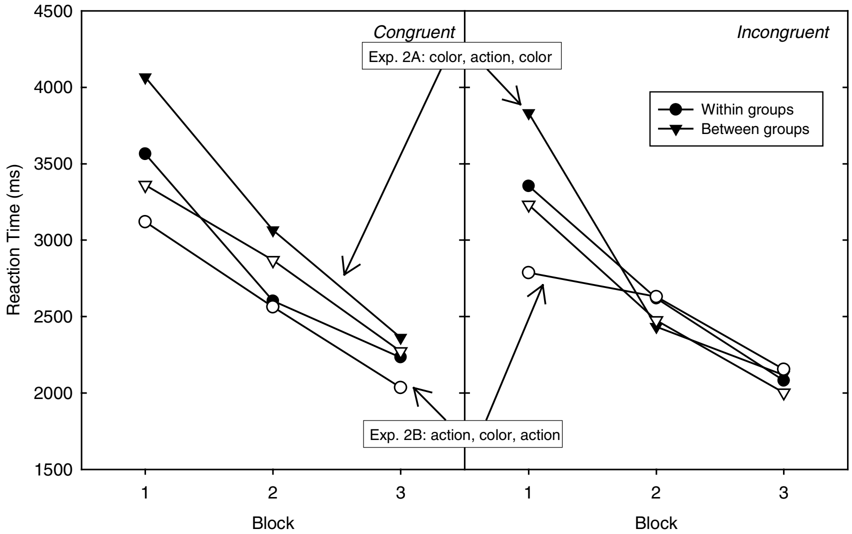


Fig. 4. Mean reaction times for verifying spatial relations between pairs of elements belonging to the same (within groups) or different (between groups) color- or action-induced group, as a function of block. Black symbols refer to Experiment 2A, white symbols to Experiment 2B.

incongruent pairs, and therefore is likely to reflect the general difficulty to process information from central locations.

More importantly, a highly significant main effect of group membership was obtained, $F(1,22) = 18.493$, indicating that relations between objects of the same color or action group were verified faster than relations between objects of different groups. This effect was modified by a group membership x block interaction, $F(2,44) = 4.408$, and a triple interaction of congruency, group membership, and block, $F(2,44) = 3.449$. Interestingly, these interactions did not depend on the experiment ($p > .9$). As shown in Figure 4, different grouping effects were obtained in Blocks 2-3 than in the first blocks of congruent and incongruent conditions.

In the first blocks of both experiments and under both congruency conditions grouping effects very much like in Experiment 1 were obtained. That is, both shared color and shared action facilitated the judgment of the spatial relations between object pairs to a comparable and replicable degree. In Block 2 the picture changes dramatically. Under congruency, the results again look very much like in Experiment 1, that is, grouping effects are pronounced in all three blocks and (statistically) unaffected by the block factor. Incongruency yielded a different pattern. The second block led to a reversal of the membership effect similar to Experiment 1, but now it was clearly reduced in size and no longer reliable (as revealed by t-tests, $p > .05$). The third block behaved quite differently than in Experiment 1. Rather than showing the same sign and size as in Block 1, here the membership effect more or less disappeared ($p > .05$). Thus, the two reversals of group membership in the second and third block clearly affected performance, suggesting that our memory manipulation was effective, indeed.

4 General Discussion

The guiding question of the present study was whether encountering information about a new aspect of an already known visual array leads the creation of a new cognitive aspect map that is stored separately from the original one, or whether the new information is integrated into the original cognitive map, thereby updating and transforming it. According to the separate-map view map acquisition should be unaffected by previously acquired knowledge and cognitive maps created thereof. From this view we would have expected that congruency between acquired and novel aspects has no impact on map acquisition, so that in Experiment 1 performance in congruent and incongruent conditions of Block 2 should have been comparable. However, performance clearly differed, in that novel aspects were not acquired if the grouping they implied was incongruent with the grouping induced by previous experience. In fact, previous experience with one group-inducing aspect seemed to have completely blocked out any effect of a novel aspect, so that performance in Block 2 perfectly matched performance in Block 1.

These results rule out the separate-maps approach, as it is unable to account for interactions between cognitive maps or side-effects of already existing maps. However, the findings are also inconsistent with the integrative-maps approach in demonstrating that new information was simply not integrated. Apparently, when encountering a new visual array people spontaneously pick up actually irrelevant features shared by subsets of its elements to create a clustered cognitive map; yet, once a map is created it does not seem to be spontaneously updated. However, the findings obtained in Experiment 2 suggest that updating does take place when people are given a reason to modify their cognitive maps. Not only is new information acquired under these conditions, it is also integrated into the existing cognitive map, as indicated by the disappearance of the membership effect under incongruency in Block 2 and 3. Thus, we can conclude that people do not under all circumstances store the aspects of a visual scene they come across, but if they do so they integrate them into a single, coherent cognitive map. This insight, together with the result pattern of the present study, has several implications, three of which we will discuss in turn.

4.1 Representing Aspect Maps

A first, theoretical implication relates to how spatial arrays are cognitively represented. Commonly, effects of nonspatial properties on spatial representations are taken to imply some kind of hierarchical representation, in which spatial information is stored within nested levels of detail with levels being organized by nonspatial categories (e.g., McNamara, 1986; McNamara, Hardy, & Hirtle, 1989; Palmer, 1977). To support such hierarchical representations authors often refer to known memory distortions, such as the relative underestimation of distances between cities belonging to the same state (e.g., Stevens & Coupe, 1978).

However, as we have pointed out elsewhere (Hommel & Knuf, 2000) effects of nonspatial relations on spatial judgments can be understood without reference to hierarchies. Consider the cognitive architecture implied by our present findings. Figure 5 shows an account of these findings along the lines of TEC, the *Theory of Event Coding* proposed by Hommel, Müsseler, Aschersleben, and Prinz (in press; Hommel, Aschersleben, & Prinz, in press). TEC makes two assumptions that are crucial for our present purposes. First, it assumes that perceived events (stimuli) and produced events (actions) are cognitively represented in terms of their features, be they modality-specific, such as color, or modality-independent, such as relative or absolute location. Second, TEC claims that perceiving or planning to produce an event involves the integration of the features coding it, that is, a binding of the corresponding feature codes.

Figure 5 sketches how these assumptions apply to our present study. Given the features each hut possessed in our study, its cognitive representation is likely to contain codes of its name, location, color, and the action it requires (cf., Hommel & Knuf, 2000). As TEC does not allow for the multiplication of codes (i.e., there is only one code for each given distal fact), sharing a feature implies a direct association of the corresponding event representations via that feature's code. That is, if two huts share a color or an action, their representations include the same feature code, and are therefore connected. Along these connections activation spreads from one representation to another, so that judging the relation between objects that have associated representations is facilitated. In congruent cases (i.e., if the current association is compatible with previously acquired associations) activation spreads to representations of only those objects that currently share some aspect (see panel A). However, in incongruent cases activation spreads to both objects currently sharing an aspect and objects that previously shared some aspect (see panel B).

As a consequence congruent, but not incongruent cases give rise to standard group-membership effects, just as observed in the present study.

Interestingly, along these (non-hierarchical) lines category-induced effects on spatial judgments can be explained as well. Consider, for instance, the three huts depicted in Figure 5 were all of the same color and not associated with different actions, but DUS and FAY were known to belong to a hypothetical "County A" while MOB belonged to "County B" (the category manipulation used by Stevens & Coupe, 1978). According to TEC, such a category membership is just another feature that, if it code is sufficiently activated and integrated, becomes part of the cognitive representation of the respective hut. Thus, instead of the code "red" or "green" the representations of DUS and FAY would contain the feature code "County A member", whereas the representation of MOB contained the code "County B member". If so, DUS and FAY were associated the same way as if they were of the same color, so that judging their spatial relation would be faster than judging that between FAY and DUS. Hence, category effects do not necessarily imply hierarchical representations but may be produced the same way as effects of perceptual or action-related similarities.

From comparing the outcomes of Experiments 1 and 2 it is clear that the when and how of feature integration depends on the task context. The results of Experiment 1 suggest that after having integrated the features available in the first block, subjects did not continuously update their event representations but went on operating with the already acquired ones. Accordingly, the new features introduced in the second block were not considered, their codes were not integrated, and therefore did not connect the representations of the objects sharing the particular feature. In contrast, asking subjects to memorize the display in Experiment 2 seems to have motivated (or even required) the update of the object representations, which provided a chance for the new features to get integrated. Thus, although the selection of features to be integrated does not seem to be determined intentionally (as indicated by color- and action-induced effects), the timepoint or occasion of integration is.

4.2 Assessing Aspect Maps

A second implication of our findings refers to method. Many authors have taken the speed of spatial judgments and distance estimations to reflect the same cognitive processes or structures and, hence, to measure the same thing. Yet, in our studies, including the present one, we consistently observed a dissociation between these measures, that is, systematic effects of grouping manipulations on reaction times of relation judgments but not on distance estimations (Gehrke & Hommel, 1998; Hommel et al., 2000, 2002; Hommel & Knuf, 2000). Although accounts in terms of strategies and differential sensitivity are notoriously difficult to rule out, we think it is worthwhile to consider that these measures reflect different cognitive functions. Along the lines of McNamara and LeSueur (1989) it may be that nonspatial information supports (or hinders) particular ways to cognitively structure information about visual scenes (assessed by the speed of comparative judgments) but does not modify its spatial content (assessed by distance estimations). In other words, feature sharing may affect the (ease of) access to cognitive codes but not what these codes represent.

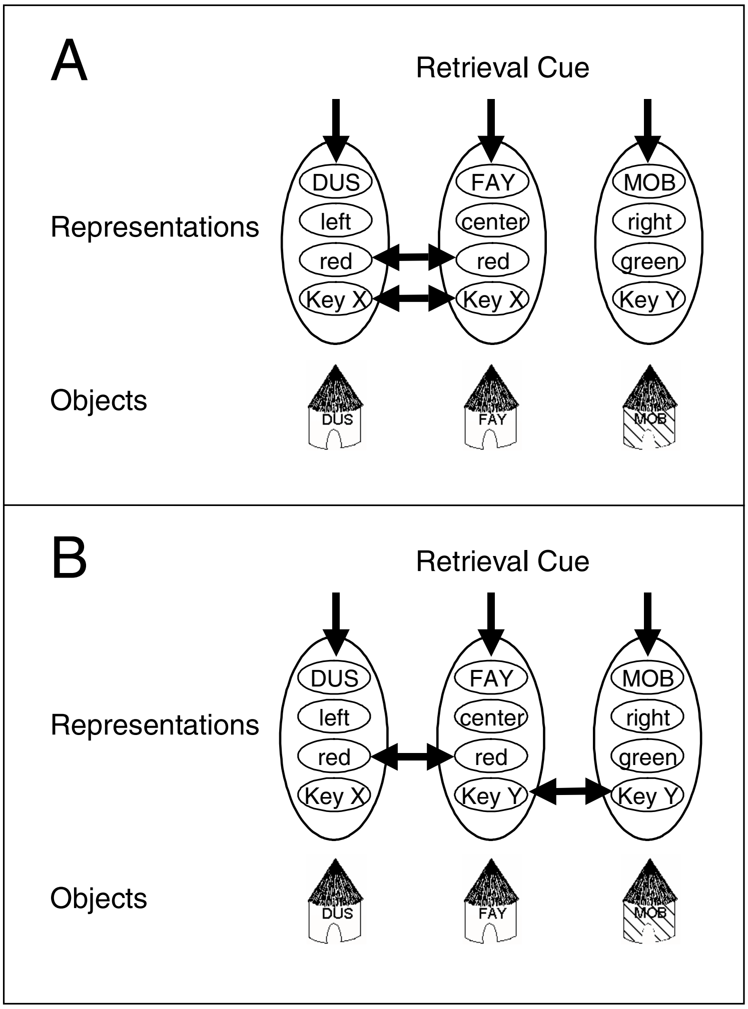


Fig. 5. A simplified model of how feature overlap between elements of a scene may affect the speed of verification judgments. Panel A shows an example of *congruent* learning, in which the hut FAY shared its color with DUS but not MOB on one occasion, and shared an action (response key) with DUS but not MOB on another occasion. This results in a strong association between the representations of DUS and FAY, so that activating the representation of FAY (e.g., in the course of retrieval) spreads activation to DUS, and vice versa. Panel B shows an example of *incongruent* learning, in which FAY shared its color with DUS but not MOB on one occasion, and shared an action with MOB but not DUS on another occasion. As a consequence, FAY becomes associated with both DUS and MOB, so that activating the representation of FAY spreads activation to both DUS and MOB.

Of course, this raises the question why other authors did find distortions of the content of spatial memories (e.g., Stevens & Coupe, 1978; Thorndyke, 1981; Tversky, 1981). We could imagine two types of causes that may underlie such findings. One is configurational, that is, purely visual factors—such as Gestalt laws—may distort the processed information during pick up, so that the memories would be accurate representations of inaccurately perceived information (Knuf, Klippel, Hommel, & Freksa, 2002; Tversky & Schiano, 1989). Another factor relates to response strategies. In many cases it may simply be too much to ask for precise distance estimations because the needed information is not stored. Under decision uncertainty people are known to employ "fast and frugal heuristics" (Gigerenzer & Todd, 1999), so that subjects may use the presence or absence of nonspatial relations, or the degree of mutual priming provided thereby, to "fine-tune" their estimations. How strongly this fine-tuning affects and distorts distance estimations is likely to vary with the degree of uncertainty, which may explain why distortions show up in some but not in other studies.

4.3 Acquiring Aspect Maps

A third implication of our findings is of a more practical nature. There is a growing number of demonstrations in the literature that humans fall prey to all sorts of biases and distortions when forming cognitive maps of their environment—even though we ourselves were unable to find such qualitative effects. Considering these observations one is easily led to adopt a rather pessimistic view on the quality and reliability of spatial representation in humans. However, the present findings suggest that biases and distortions are prevalent only in the beginning of forming a cognitive representation of a novel scene or array. Thus, if we create a new cognitive map we are attracted to and guided by only a few, currently relevant aspects of the represented environment, which is likely to induce one or another distortion under conditions of high decision uncertainty. However, with changing interests, tasks, and ways to get in touch with that environment information about additional aspects will be acquired and integrated into the same cognitive map. By integrating different aspects their possibly biasing and distorting effects will cancel out each other, the more likely the more aspects get integrated. Accordingly, rather than multiplying biases and distortions enriching one's cognitive map will lead to a more balanced, and therefore more reliable spatial representation.

4.4 Conclusion

To conclude, our findings suggest that when people create a cognitive map they are spontaneously attracted by perceptual features and actions (i.e., aspects) shared by subsets of the represented environment, and the way they organize their cognitive maps reflects these commonalities. However, once a scene is cognitively mapped novel aspects are acquired only if there is some necessity, such as posed by requirements of a new task. In that case the new information is integrated into the already existing cognitive representation, thereby modifying its behavioral effects. Hence, features of and facts about our spatial environment are not stored in separate aspect maps but merged into one common map of aspects.

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References

Berendt, B., Barkowsky, T., Freksa, C., & Kelter, S. (1998). In C. Freksa, C. Habel, & K. F. Wender (Eds.), *Spatial cognition: An interdisciplinary approach to representing and processing spatial knowledge* (pp. 313-336). Berlin: Springer.

Gehrke, J., & Hommel, B. (1998). The impact of exogenous factors on spatial coding in perception and memory. In C. Freksa, C. Habel, & K. F. Wender (Eds.), *Spatial cognition: An interdisciplinary approach to representing and processing spatial knowledge* (pp. 64-77). Berlin: Springer.

Gigerenzer, G., & Todd, P. (1999). Fast and frugal heuristics: The adaptive toolbox. In G. Gigerenzer, P. Todd and the ABC research group (Eds.), *Simple heuristics that make us smart* (pp. 3-36). Oxford: University Press.

Hommel, B., Aschersleben, G., & Prinz, W. (in press). Codes and their vicissitudes. *Behavioral and Brain Sciences, 24.*

Hommel, B., Gehrke, J., & Knuf, L. (2000). Hierarchical coding in the perception and memory of spatial layouts. *Psychological Research, 64*, 1-10.

Hommel, B., & Knuf, L. (2000). Action related determinants of spatial coding in perception and memory. In C. Freksa, W. Brauer, C. Habel, & K. F. Wender (Eds.), *Spatial cognition II: Integrating abstract theories, empirical studies, formal methods, and practical applications* (pp. 387-398). Berlin: Springer.

Hommel, B., Knuf, L., & Gehrke, J. (2002). Action-induced cognitive organization of spatial maps. Manuscript submitted for publication.

Hommel, B., Müsseler, J., Aschersleben, G., & Prinz, W. (in press). The theory of event coding (TEC): A framework for perception and action planning. *Behavioral and Brain Sciences, 24.*

Knuf, L., Klippel, A., Hommel, B. & Freksa, C. (2002). Perceptually induced distortions in cognitive maps. Manuscript submitted for publication.

McNamara, T.P. (1986). Mental representation of spatial relations. *Cognitive Psychology*, *18*, 87-121.

McNamara, T.P. (1991). Memory's view of space. *Psychology of Learning and Motivation, 27,* 147-186.

McNamara, T.P., Hardy, J.K., & Hirtle, S.C. (1989). Subjective hierarchies in spatial memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15,* 211-227.

McNamara, T.P., & LeSueur, L.L. (1989). Mental representations of spatial and nonspatial relations. *Quarterly Journal of Experimental Psychology, 41*, 215-233.

Palmer, S.E. (1977). Hierarchical structure in perceptual representation. *Cognitive Psychology*, *9*, 441-474.

Stevens, A., & Coupe, P. (1978). Distortions in judged spatial relations. *Cognitive Psychology, 10,* 422-427.

Thorndyke, P. W. (1981). Distance estimation from cognitive maps. *Cognitive Psychology, 13,* 526-550.

Tversky, B. (1981). Distortions in memory for maps. *Cognitive Psychology, 13*, 407-433.

Tversky, B., & Schiano, D.J. (1989). Perceptual and conceptual factors in distortions in memory for graphs and maps. *Journal of Experimental Psychology:General, 118*, 387-398.