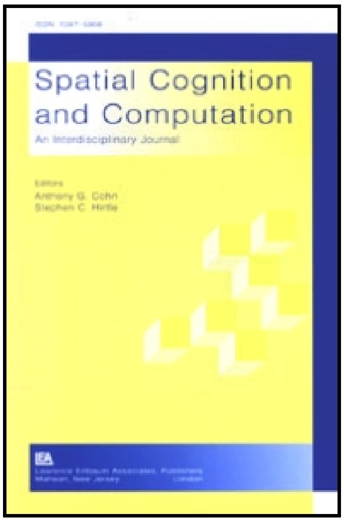
This article was downloaded by: *[University of Sussex]*
On: *15 December 2010*
Access details: *Access Details: [subscription number 906873701]*
Publisher *Taylor & Francis*
Informa Ltd Registered in England and Wales Registered Number: 1072954 Registered office: Mortimer House, 37-41 Mortimer Street, London W1T 3JH, UK



Spatial Cognition & Computation
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t775653698

Contributing Factors to Temporal and Spatial Associations in Mental Representations of Maps

Susan J. Naylor-Emlen[a]; Holly A. Taylor[b]
[a] Department of Psychology, Villanova University, Philadelphia, Pennsylvania, USA [b] Department of Psychology, Tufts University, Medford, Massachusetts, USA

Online publication date: 01 December 2009

To cite this Article Naylor-Emlen, Susan J. and Taylor, Holly A.(2009) 'Contributing Factors to Temporal and Spatial Associations in Mental Representations of Maps', Spatial Cognition & Computation, 9: 4, 262 — 286

To link to this Article: DOI: 10.1080/13875860903033472

URL: http://dx.doi.org/10.1080/13875860903033472

PLEASE SCROLL DOWN FOR ARTICLE

Full terms and conditions of use: http://www.informaworld.com/terms-and-conditions-of-access.pdf

This article may be used for research, teaching and private study purposes. Any substantial or systematic reproduction, re-distribution, re-selling, loan or sub-licensing, systematic supply or distribution in any form to anyone is expressly forbidden.

The publisher does not give any warranty express or implied or make any representation that the contents will be complete or accurate or up to date. The accuracy of any instructions, formulae and drug doses should be independently verified with primary sources. The publisher shall not be liable for any loss, actions, claims, proceedings, demand or costs or damages whatsoever or howsoever caused arising directly or indirectly in connection with or arising out of the use of this material.

Spatial Cognition & Computation, 9:262–286, 2009
Copyright © Taylor & Francis Group, LLC
ISSN: 1387-5868 print/1542-7633 online
DOI: 10.1080/13875860903033472

Contributing Factors to Temporal and Spatial Associations in Mental Representations of Maps

Susan J. Naylor-Emlen[1] **and Holly A. Taylor**[2]
[1]Department of Psychology, Villanova University, Philadelphia, Pennsylvania, USA
[2]Department of Psychology, Tufts University, Medford, Massachusetts, USA

Abstract: The present work explores an interactive model of spatial and temporal information in map memory. In four experiments, participants learned a map with temporal and spatial information confounded or unconfounded. Attentional and representational levels of information were made apparent through tasks that tap spatial, temporal, or other information. Learning criteria emphasizing sequential order or location imposed differential weighting of the information types in memory. Results indicate that map memory is spatial, but also interacts with the order in which map locations are encountered. Findings show flexibility in allocating attention and information indexing of location and sequential order information in map learning.

Keywords: cognitive mapping, environmental learning, memory, time, maps

1. INTRODUCTION

Imagine preparing for a visit to the Tufts University Psychology Department. In so doing, you examine the on-line campus map. Knowing you will be parking at the corner of College Ave. and Lower Campus Rd., you first locate this on the map. Next you locate the Psychology Department. Looking back at the parking lot, you plan your walk along College Ave. to the department, noting that you will first pass Hillside House on your right and then Bolles House on your left. Continuing, you will pass Robinson Hall, connected to Anderson Hall, on your right followed by Memorial Steps on your left. Finally, you see that you will reach the intersection of College Ave. and Boston Ave. at which point the department is across the street to your right.

While planning your path on the map, you will most likely form some kind of spatial mental representation, sometimes referred to as a *cognitive*

Correspondence concerning this article should be addressed to Dr. Susan J. Naylor-Emlen, Department of Psychology, Villanova University, Tolentine Hall, Villanova, PA 19085. E-mail: susan.naylor-emlen@villanova.edu

map. The term "map" within *cognitive map* suggests a spatial base to your representation; that is, your representation is structured by the relative spatial placement of landmark (e.g., buildings, intersections) locations (O'Keefe & Dostrovsky, 1971; O'Keefe & Nadel, 1978; Tolman, 1948). At the same time, the temporal sequence in which you gathered information makes clear that spatially proximal locations tend to be encountered in close temporal proximity. This co-occurrence of spatial and temporal information suggests the possibility that temporal information can structure your mental representation. A third, and more likely, possibility is that your representation includes spatial and temporal information. The two information sources may operate conjointly, or may be weighted by salience to accurately or efficiently represent the campus. The present studies examine factors contributing to spatial and temporal information in map memory, in particular learning goals, and the correlation or confounding of spatial and temporal information during learning.

The role spatial and temporal information play in the overall encoding and retrieval of a cognitive map remains in question. As our beginning example illustrates, we frequently experience adjacent locations in a spatially and temporally contiguous manner. However, this is not always the case and spatially adjacent locations may be encountered in separate time periods. Tufts' Ellis Oval, while spatially adjacent to our example parking lot, would not be processed in the same temporal episode involved with route planning to Psychology since the planned route does not pass it. Thus, spatial and temporal proximity of environment locations can be unconfounded. When unconfounded, spatially adjacent locations may be given membership to separate temporal intervals, defined by when they were experienced. Additionally with map learning, more so than navigation, spatially distant locations can be experienced in temporal succession through attentional shifts. In our example, you found the parking lot and then focused attention on the Psychology Building across campus. These spatially distant locations would be processed in the same or adjacent temporal intervals. Whether spatial or temporal information primarily structures memory may depend on learning goals, and/or whether this information is correlated or confounded during learning.

Previous research has examined spatial and temporal information interactions in map memory (Clayton & Habibi, 1991; Clayton, Habibi, & Bendele, 1995; Curiel & Radvansky, 1998, 2004; McNamara, Halpin, & Hardy, 1992; Sherman & Lim, 1991). These investigations into *memory content*, as opposed to *memory task performance*, question whether environment representations are predominantly spatial. Performance measures generally tell us whether a person's knowledge representation is sufficient for a particular task (Newcombe, 1985). Yet, information not needed for a task may still be present. In other words, multiple information types may exist in memory, but specific experimental tasks do not assess all types. Recognition priming should reflect associations in memory, but when multiple types of associations exist, may not reveal all such associations (Clayton & Habibi, 1991; Sherman & Lim, 1991). Similarly, location judgments (McNamara, Halpin, & Hardy, 1992) require spatial information, but may not tap temporal information. For fine distinctions about memory content, knowing what a task is measuring is important and employing multiple tasks that tap distinct information may best reveal the presence of different information types.

The effects of spatial distance found in recognition priming tasks (McNamara, Ratcliff, & McKoon, 1984), location judgments (Clayton & Chattin, 1989; Curiel & Radvansky, 2004; McNamara, Altarriba, Bendele, Johnson, & Clayton, 1989), and Euclidean and route distance estimations (Hirtle & Hudson, 1991; Taylor, Naylor, & Chechile, 1999; Thorndyke & Hayes-Roth, 1982) provide support for spatial models of environment memory. However, Clayton and Habibi (1991) pointed out that these effects could result from temporal sequences.

In most spatial memory studies, participants learn environments in a manner that confounds spatial and temporal information. Clayton and Habibi (1991) examined separate contributions of spatial and temporal information to map learning. Participants learned a fictitious town map in either a spatially and temporally confounded or unconfounded order. During study, all locations could be seen, but location labels appeared one at a time. The confounded presentation order followed a linear, spatial organization—roughly from top to bottom, left to right. Unconfounded presentation order appeared spatially random. After presentation, participants recalled each location name in the same temporal order as during learning. After learning to criterion, participants completed recognition priming. The unconfounded learning order showed temporal, but not spatial, priming. This finding, together with the fact that spatial and temporal information cannot be separated in the confounded learning order, suggests that previously interpreted spatial effects with confounded learning orders may, in fact, be temporal.

In a similar study, McNamara and colleagues (1992) found both temporal and spatial priming for temporally and spatially close locations, suggesting an additive effect of temporal and spatial closeness. More spatially driven tasks, including location judgments and distance estimations, also showed both spatial and temporal effects. While these results do not completely agree with Clayton and Habibi's (1991) findings, they support the notion that temporal information helps structure map memory.

Why might one study find temporal structuring and the other find influences of both information types? One explanation lies in the maps themselves. Clayton and Habibi's (1991) maps differed from McNamara et al.'s (1992) in two important respects—the number of locations and the spatial boundaries. Clayton and Habibi used 18 locations within a single map region; McNamara and his colleagues' had 30 locations, equally divided into two regions. People may strategically study a larger number of locations differently, thereby affecting memory associations. Eighteen locations, whether on a map or part of a list, may be amenable to a temporal learning strategy (e.g., remembering

Sedona is after Anderson). Clayton, Habibi, and Bendele (1995) support this contention. In a follow-up study, participants learned the same 18 town names, but in a list. Like Clayton and Habibi (1991), results showed temporal priming. In contrast, the 30 locations used by McNamara et al.'s (1992) may be too many for successful temporal learning, and spatial grouping strategies may be employed during study (McNamara et al., 1989). Second, spatial boundaries help structure spatial memory (Hommel, Gehrke, & Knuf, 2000; McNamara, 1986; McNamara et al., 1984).

These boundaries can be defined by roads (McNamara et al., 1984; Maddox, Rapp, Brion, & Taylor, 2008), artificial boundaries (McNamara, 1986), or landmarks grouped by shape or color (Hommel, Gehrke, & Knuf, 2000). Clayton and Habibi's map had no boundaries, McNamara et al.'s had a single boundary. In a study by Curiel and Radvansky (2004), participants learned a 28-location map, divided into four quadrants. Memory tasks requiring spatial information showed spatial effects, even when the learning task emphasized temporal order. Still, the spatial properties of these relatively sparse maps, because they lack features typical of geographic maps (MacEachren, 1995), may not be salient. Maps without clear spatial features may make a temporal learning strategy more amenable. In sum, the number of map locations and presence of spatial boundaries may influence learning strategies, which ultimately contribute to memory content. As such, the present experiments used a more naturalistic map depicting a 24-room building floor-plan and included building, hallway, and room boundaries (see Figure 1). Natural clusters of rooms emerged as a result of these boundaries (e.g., Blue Room, Copper Room, & Tan Room).

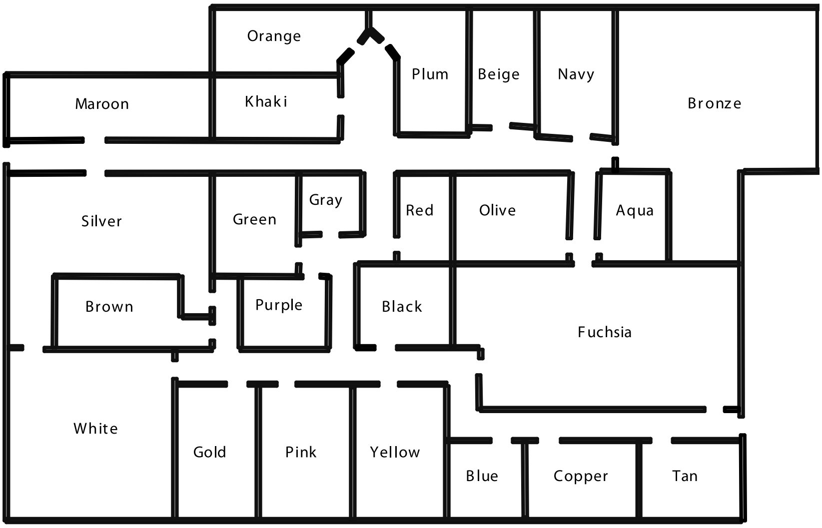


Figure 1. Floor-plan learned by participants. Participants viewed one label at a time.

Different learning goals may also help explain inconsistent findings on spatial and temporal contributions to map memory. In most spatial memory research, participants' learning is not driven by a specific learning goal. However, when learning an environment in everyday life, you generally have a goal, for example finding your way from the parking lot to the Psychology Department. Having a goal during spatial learning influences the type of information attended to and ultimately encoded in memory (Brunyé & Taylor, 2009; Gauvain & Rogoff, 1986; Magliano, Cohen, Allen, & Rodrigue, 1995; Taylor et al., 1999; van Asselen, Fritschy, & Postma, 2006). Brunyé and Taylor's (2009) results suggest that spatial learning goals manifest themselves at both attentional and representational levels. Eye-movements showed goal-consistent focus during early map study and memory tests showed goal-consistent information accessibility. More generally, behavioral goals constrain visual information selection (Maruff, Danckert, Camplin, & Currie, 1999).

Map learning studies that incorporate a learning criterion implicitly impose a learning goal—learn the map to meet the criterion. Thus, a specific learning criterion is in essence a learning goal. Clayton and Habibi (1991) and McNamara et al. (1992) used correct identification of location names as their criterion. Learning and test trials followed the same presentation order. However, this criterion could be met by remembering location names in order and spatial information need not even be processed (although Clayton and Habibi (1991) showed virtually perfect performance on a final map test). Curiel and Radvansky (1998, 2004) support this contention in studies examining the impact of learning criterion on map memory. Participants learned a map in an unconfounded order using either the standard *naming task* or a *pointing task* that emphasized absolute spatial location. The naming task led to temporal priming while the pointing task led to spatial priming (Curiel & Radvansky, 1998). The pointing task also boosted fine-grained spatial knowledge as evidenced on a direction judgment task (Curiel & Radvansky, 2004). These results suggest that our reasons for learning an environment influence how we represent it in memory. The present studies extend the examination of how learning goals affect memory structure by using criterion tasks that more strongly emphasized either spatial information, a *map drawing task,* or temporal information, a *sequential recall task.*

After learning, memory tasks may tap specific information, even when multiple types of information are represented in memory. Different information types, in one way or another, support performance on "spatial tasks": (a) temporal (Clayton & Habibi, 1991; Clayton et al., 1995; McNamara et al., 1992), (b) spatial (McNamara, 1992), and (c) landmark identity (Clayton & Habibi, 1991; Clayton et al., 1995; McNamara et al., 1992; Merrill & Baird, 1987). All of these information types are available in an environment, and all may be acquired during learning. However, these information types may be differentially weighted in memory and consequently contribute in different ways to memory task performance.

One focus of the present study was to evaluate memory content *beyond* what is needed for meeting task demands. Because multiple information types may exist in memory, but a specific experimental task may not assess all types, we hoped to better evaluate the differential weighting of information in memory through varied task demands. As such, the present studies used a variety of memory tasks. Participants performed either a recognition or a location-based priming task. Recognition priming should reflect the more strongly associated information (Clayton & Habibi, 1991; Sherman & Lim, 1991). During the location priming task participants assessed landmark location accuracy, thus necessitating spatial information retrieval. Participants also performed free-recall and Euclidean distance estimations. Free-recall order can reveal temporal and/or spatial organization (Clayton & Habibi, 1991). Euclidean distance estimation accuracy reflects spatial knowledge (Curiel & Radvansky, 2004; Hirtle & Hudson, 1991; Taylor et al., 1999; Thorndyke & Hayes-Roth, 1982). Results from all of these tasks, when considered together, should shed light on (a) the impact of learning criterion on differentially weighted contents of environmental memory, and consequentially, (b) the extent to which temporal and/or spatial information in memory is available for meeting task demands when temporal and spatial information is confounded or unconfounded during learning.

In summary, the present experiments aimed to further examine the presence of temporal and spatial information in map memory in light of specific learning goals (spatial or sequential). The studies extend the work of Curiel and Radvansky (1998, 2004) by pushing the spatial learning criterion to be more strongly spatial and by using a map that included more spatial boundaries. The second aim was to examine map memory under conditions of temporal and spatial confounded (Experiments 1 and 2) or unconfounded (Experiments 3 and 4) acquisition. Multiple tasks were employed to assess map memory. Some tasks require spatial information (location priming and distance estimation) and some could reveal both temporal and spatial information (recognition priming and free recall).

2. EXPERIMENTS

To assess the impact of a strongly temporally focused or spatially focused learning criterion, participants learned a floor-plan by reaching either a sequential criterion or a spatial criterion. Sequential learners had to correctly recall all location names in order on two consecutive trials. Spatial learners had to correctly reconstruct the map on two consecutive trials. Presentation order was maintained for both groups during learning.

Four tasks assessed spatial and temporal information availability in memory. Recognition priming (Experiments 1 and 3) and free-recall do not explicitly require spatial or temporal information, and therefore, could reflect either. In contrast, the location priming and distance estimation tasks both require spatial information and should reflect the strength of spatial information in memory (Curiel & Radvansky, 2004). The location priming task (Experiments 2 and 4) required participants to respond to room labels in a spatially explicit way. If sequential learners showed spatial effects in location priming or distance estimation, in addition to temporal effects, this would suggest the presence of spatial information in memory.

2.1. Confounded Learning (Experiments 1 and 2)

Clayton and Habibi's (1991) confounded learning condition revealed spatial priming, which could also be interpreted as temporal priming. We predicted sequential learners would strongly represent temporal information in memory. This prediction is based on the fact that the sequential learning criterion focuses on temporal order, but does not require participants to encode spatial information. Further, what was seen as spatial priming in Clayton and Habibi's study may have reflected salience of the spatially far pairs, as their far pairs lay at the upper and lower extremes of the array. This salience could have contributed to more distinct differences between spatially close and far pairs. In the present study, spatially far pairs are embedded in the overall floor-plan (see also McNamara et al., 1992), equating salience for spatially close and far pairs. Consequently, we expected recognition priming and free-recall to reveal temporal distance effects. To the extent that spatial information is also in memory, it should be seen in location priming and distance estimations. Spatial learners were expected to show primarily spatial memory organization. If a consistent temporal order during learning also influences the representation, then temporal effects may be found for recognition priming (Curiel & Radvansky, 1998, Study 3).

2.2. Unconfounded Learning (Experiments 3 and 4)

Although only in map learning can spatial and temporal information be completely unconfounded, examining learning under these conditions still informs spatial memory in general. Even during navigation some spatially close locations can be temporally separated. When spatial and temporal information is unconfounded during acquisition, we predicted that the learning goal would again influence memory, leading to differential weighting of temporal and spatial information. Spatial learning would result in a memory representation primarily structured by spatial information. Sequential learning would result in a memory representation primarily structured by temporal information. We also predicted that sequential learners' memory would be reinforced by spatial associations brought about by the spatial nature of the maps. If retrieving spatial information to meet demands of the location priming task serves to strengthen spatial associations in memory, then distance estimates made following the location based task may reflect this enriched spatial information in memory.

3. GENERAL METHOD

3.1. Participants

Tufts University undergraduates participated in partial fulfillment of a course requirement, Experiment 1 ($N = 39$), Experiment 2 ($N = 39$), Experiment 3 ($N = 50$), and Experiment 4 ($N = 50$). Participants had never had a class in the building depicted in the map. No one participated in more than one of these experiments.

3.2. Materials

3.2.1. Floor-plan. The floor-plan of the Psychology Research Building was modified to include 24 rooms (see Figure 1). The floor-plan measured 7.5 by 5.375 inches. Each room had a color label (e.g., Brown Room) appearing in its center. The same room and color pairings were used for all participants. Color labels avoided learning strategies based on sequentially ordered room numbers and held semantic associations constant.

3.2.2. Learning Packets. The sequential learning packet consisted of pages with a column of numbers (1–24) listed along the left-hand side. The spatial learning packet consisted of pages depicting an outline of the floor plan.

3.2.3. Standard Distance Line. The standard distance line equaled the distance between the center of the White room and the center of the Bronze room—the longest straight-line distance on the floor plan. The line was divided into 26 equal parts, labeled “a” to “z”.

3.3. Procedure

Participants were randomly assigned to either the sequential learning or spatial learning condition. They completed the experiment on Apple PowerMac computers using Superlab™ software. During learning, the floor plan remained visible and room labels appeared one at a time in a temporally and spatially confounded order (Experiments 1 and 2) or unconfounded order (Experiments 3 and 4) (see Table 1), 5 after which the participant completed the assigned criterion task (see description later). The study-test procedure repeated until the participant reached criterion, after which they completed free-recall, recognition priming (Experiments 1 and 3) or spatial priming (Experiments 2 and 4), and Euclidean distance estimations, in that order.

Table 1. Acquisition order for confounded and unconfounded learning

Confounded experiments 1 and 2	Unconfounded experiments 3 and 4
Silver room	Aqua room
Maroon room	Black room
Orange room	Khaki room
Khaki room	Copper room
Green room	Navy room
Gray room	Beige room
Red room	Blue room
Plum room	Orange room
Beige room	Maroon room
Navy room	Tan room
Bronze room	Purple room
Aqua room	Silver room
Olive room	Pink room
Fuchsia room	Red room
Tan room	Brown room
Copper room	White room
Blue room	Yellow room
Yellow room	Green room
Black room	Olive room
Purple room	Gray room
Brown room	Gold room
White room	Fuchsia room
Gold room	Bronze room
Pink room	Plum room

3.3.1. Sequential Learning Condition. Participants were instructed to learn the names and locations of all rooms. During presentation, they first viewed a floor plan without room labels. Then room labels appeared one at a time for 2.5 seconds each until all labels had been shown. For confounded learning, rooms were presented such that all rooms were spatially adjacent to the preceding one. For unconfounded learning, the learning order appeared to randomly sample map locations. Successive learning trials followed the same presentation order. Immediately following presentation, participants attempted the criterion test during which they saw the floor-plan without labels. Then, in sequential order, a number appeared in a room and participants wrote down the corresponding room name next to the number on the response sheet. The experimenter scored the response sheet, crossing out and replacing incorrect room labels, but leaving blanks. Participants could review the corrections for up to 30 seconds along with a floor-plan showing all 24 numbers in the room frames. After review, participants completed another study-test trial.

Participants reached criterion when they correctly listed all 24 labels on two consecutive trials.

3.3.2. Spatial Learning Condition. Presentation was identical to the sequential learning presentation. During test, participants received a floor-plan outline and drew and labeled all rooms, considering size and location. The experimenter scored the map using the following conventions. If the room was accurately located (within a $\frac{1}{2}$-inch), approximately sized and correctly labeled, it was considered correct. If the room was incorrectly labeled, located, or sized, the experimenter made one or more of the following corrections: If the room frame was incorrectly labeled, the experimenter corrected the label. If the room frame was incorrectly located, the experimenter crossed out the room frame. If the room frame was grossly mis-sized, the experimenter drew arrows pointing away from the room ("increase size"), or shaded in part of the room ("decrease size"). The experimenter also wrote down the number of missing room frames. Participants then reviewed map corrections for up to 30 seconds. After reviewing, the participant completed another study-test trial. Participants reached criterion when they drew a correct map on two consecutive trials.

3.3.3. Free Recall. Immediately after learning, participants completed free recall by writing the room names in any order in a single column on a blank page.

3.3.4. Recognition Priming (Experiments 1 and 3). For recognition priming, participants viewed color labels one at a time in the center of the screen. For each label, they responded whether or not the color label had appeared on the floor plan by pressing keys marked "yes" or "no." No feedback was provided. Following each response, a masking grid appeared for 200 ms. Participants first completed four practice trials.

Priming pairs were defined by spatial and temporal distance. Spatially close pairs consisted of adjacent rooms. Spatially far pairs consisted of rooms separated by at least two intervening rooms and/or at least 9 cm (from each room's midpoint). Temporally close pairs were rooms presented in succession during learning. Temporally far items were rooms separated by at least four intervening rooms during presentation. Based on the confounded presentation order, three types of pairs could be constructed: spatially close—temporally close (sctc), spatially close—temporally far (sctf), and spatially far—temporally far (sftf). Unconfounded presentation allowed for the fourth target-prime type, spatially far—temporally close (sftc).

Four priming lists were generated. The priming pairs were identical across lists, but the presentation order differed (see Table 2). For confounded acquisition, each list contained 30 color names, 18 correct items (colors found on the floor-plan) and 12 incorrect (new) items. The 12 incorrect

Table 2. Priming pairs and foils for confounded and unconfounded acquisition

Priming pairs	
1 and 2	3 and 4
fuchsia-tan (sctc)	brown-white (sctc)
brown-white (sctc)	navy-beige (sctc)
beige-navy (sctc)	red-olive (sctf)
yellow-black (sctc)	khaki-orange (sctf)
red-olive (sctf)	tan-purple (sftc)
orange-plum (sctf)	gold-fuchsia (sftc)
green-bronze (sftf)	green-bronze (sftf)
aqua-purple (sftf)	blue-silver (sftf)
copper-pink (sftf)	

Priming foils			
1 and 2		3 and 4	
Recognition	Spatial	Recognition	Spatial
creme	“khaki” (blue)	burgundy	“plum” (yellow)
turquoise	“gray” (gold)	creme	“maroon” (copper)
platinum	“gold” (gray)	turquoise	“gray” (aqua)
teal	“blue” (silver)	platinum	“black” (pink)
mint	“silver” (maroon)	teal	“aqua” (black)
chartreuse	“blue” (khaki)	mint	“pink” (gray)
rose	“maroon” (khaki)	chartreuse	“yellow” (copper)
charcoal	“gray” (maroon)	rose	“copper” (maroon)
burgundy	“maroon” (silver)	charcoal	“plum” (black)
taupe	“khaki” (gray)	taupe	“maroon” (yellow)
magenta	“silver” (gold)	magenta	“aqua” (gray)
coffee	“gold” (blue)	coffee	“pink” (plum)

Note: For spatial priming foils, room labels in quotes represent the color labels actually presented; and, room labels in parentheses represent the actual room location in which the label was presented.

items appeared in the same order for all lists. The 18 correct items were combined to form the nine critical priming pairs: 4 sctc, 2 sctf, and 3 sftf.[1] For unconfounded acquisition, each of the four priming list included 28 color names, 16 correct and 12 incorrect. The 16 correct items combined to form eight critical priming pairs, 2 of each pair type. Priming lists were bound by the following constraints: (a) prime-target pairs did not appear in the first

---

[1] The difference in the number of critical pairs for each of the three conditions results from an error in design.

two positions, (b) primes and targets appeared in immediate succession, and (c) the list appeared to sample randomly from the floor plan.

3.3.5. Location Priming Task (Experiments 2 and 4). Participants viewed a floor plan without labels. Labels then appeared one at a time and participants determined if the label was correctly located and responded using keys marked “yes” or “no.” Priming pairs were defined as in recognition priming. No feedback was provided. Following each response, a masking grid appeared for 200 ms. Participants completed four practice trials.

The location priming foils consisted of twelve color labels originally on the learned floor-plan, but incorrectly located (e.g., “gold room” in blue room, “gold room” in gray room).

3.3.6. Distance Estimation. All participants performed 36 Euclidean distance estimations using the standard distance line. Participants typed the letter corresponding to the distance between the midpoints of the two locations (e.g., “The center of the Khaki room to the center of the Pink room”). For each trial, participants anchored the first location at the beginning of the line (at “a”) and estimated the distance to the second location by typing the corresponding letter.

The distance estimation list consisted of 18 room label pairs. The critical pairs were the same as in the priming task. Filler pairs were generated by randomly pairing a room label from critical pairs with a previously unused room label. The 18 pairs were presented twice, with the second presentation reversing the pair order (e.g., gray-olive, olive-gray), resulting in 36 distance estimates.

3.3.7. Final Map-drawing Task. Sequential learners in Experiments 3 and 4 received a page depicting the outermost walls of the floor-plan and drew and labeled all rooms, considering room size and location.

4. RESULTS

For increased comparability across experiments, we present the results for all experiments, divided by task. Summary results can be found in Tables 3 and 4.

Data were trimmed as follows: (1) for the priming task, target trials showing errors and correct target trials preceded by incorrect primes were eliminated, (2) also for priming, response latencies greater than three standard deviations from the mean were trimmed, and (3) for distance estimation, we trimmed estimates 3 standard deviations above or below the group mean. Trimming eliminated less than 2% of the data. In individual experiments, we dropped participants from analyses as described here. In Experiment 1, one sequential learner’s free-recall was eliminated due to procedural irregularities.

Table 3. Summary of free-recall results

	Confounded learning		
	z-score	Temporal clustering	Spatial clustering
Expt. 1—sequential learning	.80	20.45	21.63
Expt. 1—spatial learning	.61	7.38	16.06
Expt. 2—sequential learning	.81	19.52	21.00
Expt. 2—spatial learning	.61	8.93	17.00
	Unconfounded learning		
	z-score	Temporal clustering	Spatial clustering
Expt. 3—sequential learning	.72	8.0	6.88
Expt. 3—spatial learning	.51	1.0	17.36
Expt. 4—sequential learning	.77	10.80	7.96
Expt. 4—spatial learning	.53	1.08	15.68

Note: temporal clustering values are out of 23 possible as there is only one way to achieve a "perfect" temporal clustering score. Spatial clustering values are not equivalent with temporal clustering values as there are a number of ways to achieve a "perfect" spatial clustering score.

This participant was included in all other analyses. In Experiment 2, one spatial learner failed to reach criteria within an hour and another did not complete the distance estimation task. The former was eliminated from all analyses; the latter was eliminated only from the distance estimation analysis. In Experiment 4, one sequential learner was eliminated due to procedural irregularities. We performed separate analyses for all tasks on trimmed and untrimmed data, the results of which did not differ. Trimmed results are reported.

4.1. Trials to Criterion During Learning

In both confounded and unconfounded learning, spatial learning participants took longer to reach criterion than those given the sequential learning goal. In all experiments, sequential criterion learners required between three and eight learning trials and sessions lasted between 30 and 60 minutes (Experiment 1: $N = 23$, M trials $= 4.83$, $SD = 1.03$; Experiment 2: $N = 23$, M trials $=$ 4.77, $SD = 1.15$; Experiment 3: $N = 25$, M trials $= 5.36$, $SD = 1.08$; Experiment 4: $N = 24$, $M =$ trials $= 5.33$, $SD = 1.01$). Spatial criterion learners required between four and fourteen trials to learn the map and sessions lasted between 45 and 90 minutes (Experiment 1: $N = 16$, M trials $= 7.94$, $SD = 1.53$; Experiment 2: $N = 15$, M trials $= 8.47$, $SD =$

Table 4. Summary of priming task results

	Confounded learning		Unconfounded learning	
	Sequential learn	Spatial learn	Sequential learn	Spatial learn
		Recognition priming		
Temporal at sc				
Ms difference	44-ms	−57-ms*	10-ms	8-ms
Effect size	.39	.52	.05	.08
Temporal at sf				
Ms difference			33-ms	16-ms
Effect size			.39	.07
Spatial at tc				
Ms-difference			17-ms	52-ms
Effect size			.07	.30
Spatial at tf				
Ms difference	48-ms	210-ms*	20-ms	63-ms
Effect size	.20	.99	.22	.37
		Location priming		
Temporal at sc				
Ms difference	153-ms	18-ms	350-ms*	81-ms
Effect size	.23	.07	.84	.36
Temporal at sf				
Ms difference			42-ms	26-ms
Effect size			.17	.10
Spatial at tc				
Ms difference			471-ms*	192-ms*
Effect size			1.14	.67
Spatial at tf				
Ms difference	190-ms	474-ms*	98-ms	226-ms*
Effect size	.36	.64	.19	.99

*Significant, $p < .05$.

1.96; Experiment 3: $N = 25$, M trials $= 8.24$, $SD = 2.39$; Experiment 4: $N = 25$, M trials $= 8.32$, $SD = 1.95$).

4.2. Free-recall

We analyzed free-recall for temporal and spatial organization. To examine temporal organization, we correlated free-recall order with learning order. To determine if this correlation differed as a function of learning criterion, we performed two-tailed independent *t*-tests on Fisher's z-transformed Spearman correlation coefficients. We also examined free-recalls for temporal and spatial clusters. For temporal clusters, we coded the number of times a recalled item immediately followed a temporally preceding item based on the presentation order. Temporal clustering values are out of 23 possible as there is only one way to achieve a "perfect" temporal clustering score. For spatial clusters, we coded the number of times a recalled item immediately followed a spatially adjacent item, based on room location within the floorplan, regardless of learning order. Because there are numerous ways to achieve a "perfect" spatial clustering score, spatial clustering values cannot be directly compared to temporal clustering. See Table 3 for free recall means.

In all experiments, sequential learners' recall order matched the learning order to a greater extent than did that of the spatial learners (Experiment 1: $t(36) = -3.79$, $p < .001$, $d = 1.23$; Experiment 2: $t(36) = -5.41$, $p < .0001$, $d = 1.78$; Experiment 3: $t(48) = -8.31$, $p < .0001$, $d = 2.48$; Experiment 4: $t(47) = -10.72$, $p < .0001$, $d = 3.06$). In all experiments sequential learners exhibited more temporal clustering than did spatial learners (Experiment 1: $t(36) = -8.60$, $p < .0001$, $d = 2.9$; Experiment 2: $t(36) = -5.30$, $p < .0001$, $d = 1.8$; Experiment 3: $t(48) = -6.16$, $p < .0001$, $d = 2.08$; Experiment 4: $t(48) = -6.16$, $p < .0001$, $d = 2.08$).

Confounding spatial and temporal information at acquisition affected spatial clustering. For confounded acquisition, sequential learners showed more spatial clustering than spatial learners (Experiment 1: $t(36) = -3.70$, $p < .001$, $d = 1.20$; Experiment 2: $t(36) = -2.70$, $p < .01$, $d = .89$). In this case, because the acquisition order confounded spatial and temporal information, the spatial clustering scores could largely reflect temporal information. When spatial and temporal information are examined separately as in unconfounded acquisition, spatial learners showed more spatial clustering than did sequential learners (Experiment 3: $t(48) = 8.53$, $p < .0001$, $d = 2.43$; Experiment 4: $t(47) = 4.79$, $p < 0001$, $d = 1.42$).

4.3. Recognition Priming (Experiments 1 and 3)

Analyses on recognition priming examined separated spatial and temporal contributions and used two-tailed paired t-tests. For confounded learning, this involved examining temporal effects on pairs held spatially close (sctc vs. sctf) and spatial effects on pairs held temporally far (sctf vs. sftf). In unconfounded learning, temporal and spatial effects could be examined at both levels of spatial and temporal distance (temporal effects: sctc vs. sctf, sftc vs. sftf; spatial effects: sctc vs. sftc, sctf vs. sftf). In both experiments, both sequential and spatial learners made few errors, the rate of which did not differ statistically within or between learning criteria.

For confounded learning, spatial learners' response latency showed effects of both temporal and spatial information. Spatially close pairs (sctf = 672-ms) had a 210-ms priming advantage over spatially far pairs (sftf =

882 ms), $t(15) = -3.95$, $p < .001$, $d = .99$. Temporal information showed an inverse 57-ms priming advantage, $t(15) = 2.09$, $p < .05$, $d = .52$. Participants responded faster to temporally far (sctf = 672 ms) compared to temporally close pairs (sctc = 729 ms). Sequential learners showed some influence of temporal information with a 44-ms priming difference between temporally close (sctc = 697 ms) and temporally far pairs (sctf = 741 ms), $t(22) = -1.88$, $p = .07$, $d = .39$, and no influence of spatial information.

In unconfounded learning, spatial learners showed a marginal 63-ms spatial priming advantage for spatially close pairs when temporal distance was held at far (sctf = 641 ms vs. sftf = 704 ms), $t(23) = -1.80$, $p = .09$, $d = .37$. No spatial priming occurred for pairs held temporally close and no temporal priming was evident. Sequential learners showed a marginal 33-ms temporal priming advantage for temporally close pairs when holding spatial distance at far (sftc = 626 ms vs. sftf = 659 ms), $t(23) = -1.89$, $p = .07$, $d = .39$. No temporal priming was found for spatially close pairs and no spatial priming was evident.

4.4. Location Priming (Experiments 2 and 4)

Data were examined as in recognition priming. Sequential and spatial learners made similarly few errors, and did not differ statistically. For confounded acquisition, spatial learners showed spatial priming with a 474 ms priming advantage for spatially close (sctf = 1060 ms) compared to spatially far pairs (sftf = 1534 ms), $t(14) = -2.47$, $p < .03$, $d = .64$. Sequential learners did not show either temporal or spatial effects on location priming.

For unconfounded acquisition, spatial learners showed spatial information effects at both levels of temporal distance. Holding pairs temporally close resulted in a 192-ms spatial priming advantage (sctc = 1008 ms vs. sftc = 1200 ms), $t(24) = -3.37$, $p < .003$, $d = .67$. Holding pairs temporally far showed a 226-ms priming advantage (sctf = 931 ms vs. sftf = 1157 ms), $t(23) = -4.84$, $p < .0001$, $d = .99$. Sequential learners showed effects of temporal and spatial information. The temporal effect occurred for pairs held spatially close, showing a 350-ms temporal priming advantage (sctc = 807 ms vs. sctf = 1157 ms), $t(21) = -3.96$, $p < .001$, $d = .84$. The spatial effect occurred for pairs held temporally close, showing a 471-ms spatial priming advantage (sctc = 810 ms vs. sftc = 1281 ms), $t(20) = -5.24$, $p < .0001$, $d = 1.14$.

4.5. Distance Estimation

Analyses on distance estimation results separated spatial and temporal contributions, as was done for both priming tasks. We examined both signed and absolute value distance estimates and results showed the same effects. For brevity, signed distance estimation errors are reported here. Two-tailed paired t-tests assessed mean signed distance estimation error, in inches, computed for each participant (estimated minus actual distance). In confounded learning, Experiment 1 spatial learners showed a spatial influence, overestimating spatially close pairs (sctf = 0.28) and underestimating spatially far pairs (sftf = –0.27), $t(14) = 3.70$, $p < .002$, $d = .95$. Sequential learners showed temporal and spatial effects and generally overestimated distances. The temporal distance effect showed greater overestimation for temporally far (sctf = 0.93) compared to temporally close pairs (sctc = 0.15), $t(22) = -5.15$, $p < .0001$, $d = 1.10$. In contrast, the spatial distance effect showed greater overestimation for spatially close (sctf = 0.93) compared to spatially far pairs (sftf = 0.03), $t(22) = 6.74$, $p < .0001$, $d = 1.40$.

In Experiment 2, both spatial and sequential learners overestimated spatially close and underestimated spatially far pairs, although for spatial learners the mean error differences were small and did not reach significance. As in Experiment 1, sequential learners showed influences of temporal, $t(21) = -5.29$, $p < .0001$, $d = 1.13$ (mean error differences: sctc = 0.07, sctf = 0.66), and spatial information, $t(21) = 5.52$, $p < .0001$, $d = 1.18$ (mean error differences: sctf = 0.66, sftf = –0.34).

For unconfounded learning in Experiment 3, spatial information influenced estimates after spatial learning for both temporally close (sctc = 0.18 vs. sftc = –0.83), $t(24) = 5.92$, $p < .0001$, $d = 1.18$, and temporally far pairs (sctf = 0.33 vs. sftf = –0.78), $t(24) = 6.62$, $p < .0001$, $d = 1.33$. Participants overestimated spatially close pairs and underestimated spatially far pairs. No effects of temporal distance were evident. Temporal and spatial information influenced sequential learners' distance estimates. With spatially close pairs, the temporal effect showed relatively accurate estimates with temporally close pairs (sctc = –0.05) and overestimation with temporally far pairs (sctf = 0.37), $t(23) = -3.43$, $p < .002$, $d = .70$. With spatially far pairs, participants underestimated both temporally far (sftf = –0.73) and temporally close pairs (sftc = –0.28), but more so for temporally far ones, $t(24) = 3.70$, $p < .001$, $d = .74$. The spatial effect appeared for pairs held temporally far with overestimation of spatially close (sctf = 0.37) and underestimation of spatially far pairs (sftf = –0.73) $t(23) = 7.96$, $p < .0001$, $d = 1.62$.

When distance estimations followed location priming in Experiment 4, only spatial information influenced distance estimates, regardless of learning criterion. Overall, participants overestimated spatially close pairs and underestimated spatially far pairs. Spatial learners showed this effect for pairs held temporally close (sctc = 0.21 vs. sftc = –0.48), $t(23) = 2.87$, $p < .009$, $d = .59$, and for pairs held temporally far (sctf = 0.28 vs. sftf = –0.53), $t(23) = 5.26$, $p < .0001$, $d = 1.07$. Sequential learners also showed this effect for pairs held both temporally close (sctc = 0.24 vs. sftc = –0.57), $t(23) = 3.94$, $p < .001$, $d = .80$, and temporally far (sctf = 0.36 vs. sftf = –0.56), $t(22) = 5.89$, $p < .0001$, $d = 1.25$.

4.6. Final Map-drawing Task (Experiments 3 and 4)

The final map-drawing task, completed by sequential learners in Experiments 3 and 4 (39 participants), examined whether sequential learners had acquired accurate spatial information (Clayton & Habibi, 1991). We scored each drawing for the percentage of (a) room labels included, (b) room labels correctly located, and (c) room frames correctly drawn. A room frame was considered correctly drawn if it was relatively sized, shaped, and located within one inch, regardless of room label. This one-inch criterion was more lenient than that used for the spatial learning criterion. Overall, maps were relatively complete and accurate with 96% of the labels recalled, 95% of labels correctly located, and 98% of the room frames drawn correctly. With this high accuracy, effects of interest were small.

5. DISCUSSION

In four experiments, participants learned a map with either a sequential or spatial learning goal. Our spatial goal involved accurately redrawing the map. Our temporal goal involved recalling locations in order (Clayton & Habibi, 1991; McNamara et al., 1992). During learning, the presentation order either confounded temporal and spatial information (Experiments 1 and 2) or unconfounded it (Experiments 3 and 4). After learning, participants completed free recall, priming (recognition or location), and distance estimation tasks. The tasks either specifically required spatial information (location priming and distance estimation) or could reveal either information type (recognition priming and free recall). From these tasks, we examined (a) effects of learning goals or criterion on the mental representation of a map, and (b) performance differences as they relate to task demands. Across studies, results indicate that learning goals affect memory representations in what seems best explained as differential weighting of temporal and spatial information, and that map memory maintains multidimensional content, evident through task demands. Although the absolute weighting of the two information types is not known, weighting appears to differentially match learning goals and also appears to be flexible in that information can be selectively retrieved to meet task demands.

5.1. Learning Goals

Learning goals guide attention to goal-related information and this information then gets encoded in memory (Brunyé & Taylor, in press; Gauvain & Rogoff, 1986; Magliano et al., 1995; Maruff et al., 1999; Taylor et al., 1999; van Asselen, Fritschy, & Postma, 2006). Learning goal effects manifest themselves at both attentional and representational levels (Brunyé & Taylor, 2009). Previous map memory studies have, seemingly unintentionally, used a strong temporal goal embedded in the learning criterion as the match between the learning and criterion presentation order (Clayton & Habibi, 1991; McNamara et al., 1992). Curiel and Radvansky (1998, 2004) compared an implicit spatial criterion (pointing to respond) to a naming criterion. The pointing task led to spatial priming, and the more typically used naming task led to temporal priming (Curiel & Radvansky, 1998). The pointing task also boosted fine-grained spatial knowledge as evidenced in direction judgments. The present studies support and extend this work to an explicit spatial learning goal, that of re-drawing the map.

Our spatial learning criterion of accurately re-drawing the map proved more difficult than the sequential learning criterion. In all experiments, participants required additional learn-test cycles to reach the spatial criterion compared to the sequential criterion. We believe, however, that performance on later tasks are due to differences in attentional focus and the resulting memory associations (as driven by the learning goal) and not due to the number of trials required to reach the learning criterion. Having 24 room locations on the floor plan served to equate the cognitive demands of the spatial and sequential learning tasks. Clayton and Habibi's map with 18 locations was thought to be more amenable to a temporal learning strategy.

McNamara and his colleagues' 30-location map, may lead to a strategy reliant less on temporal order (i.e., too many items to use a temporal learning strategy) and one based more on spatial properties of the map. As such, the present experiments used a map depicting a 24-room building floor plan that we believe helped to equalize cognitive load across learning tasks. Furthermore, if the increased difficulty of the re-drawing task contributed to results, we would see overall better performance for the spatial learning group, but this was not the case. Once learned, map memory indicated broad-based learning goal influences. Spatial learners showed spatial information effects on nearly all tasks; sequential learners showed temporal information effects on nearly all tasks. Learning goal effects remained evident (a) when spatial and temporal information were confounded and unconfounded during learning and (b) when tasks required spatial (distance estimation and location priming) or nonspatial information (free recall, recognition priming). However, results also suggest that goals alone do not fully guide map memory.

5.2. Task Demands

Different memory tasks can selectively demand and/or tap different types of information. A particular performance measure shows whether one's knowledge representation is sufficient for a particular task (Newcombe, 1985), but does not necessarily reveal the full complexity of that representation. As such, using different tasks when multiple information types may be present critically examines the overall nature of the mental representation. Of the tasks employed here, some should reflect primary associations (recognition priming and free recall), but may not reveal all associations when multiple ones exist (Clayton & Habibi, 1991; Sherman & Lim, 1991). In contrast, other tasks specifically required spatial information (location priming and distance estimation, final map drawing) in the form of landmark identity (color label) and location information (McNamara et al., 1992; Sherman & Lim, 1995). These latter tasks revealed the spatial nature of map memory, even when participants had a temporal learning goal.

The tasks that could reveal either information type generally reflected knowledge consistent with the learning goal. Sequential learners' free recall both adhered to the presentation order to a greater extent and had more temporal clustering than did that of spatial learners. Under conditions of unconfounded learning, sequential learners recall showed temporal *and* spatial influences. Spatial learners showed spatial organization with no evidence of temporal effects. Recognition priming performance also reflected the learning goal. For confounded learning, spatial learners showed spatial priming and sequential learners showed temporal priming. While spatial learners also showed an inverse temporal priming effect (faster response for temporally far pairs), this effect is difficult to explain and may reflect the spatial and temporal information confound. Unconfounded learning showed goal consistent priming, although marginal.

Tasks demanding spatial information (location priming and distance estimation) consistently showed spatial effects, sometimes combined with temporal effects for sequential learners. Further, the results suggest that consecutive spatial tasks may strengthen spatial associations and/or facilitate spatial information retrieval. Results of distance estimation following location priming for sequential learners support this contention. In Experiment 2, temporal and spatial information affected sequential learners' distance estimates. This differs from Experiment 1 where distance estimates followed recognition priming. In that case, sequential learners showed a temporal effect and an *inverse* spatial effect. A similar comparison between Experiments 3 and 4 showed an even stronger effect. Experiment 3 found temporal and spatial effects on distance estimates following recognition priming, Experiment 4 found only spatial effects for sequential learners when distance estimates followed location priming. One finding might seem to go against spatial task impact, although we suggest it does not. Distance estimates by Experiment 2 spatial learners did not show a spatial effect. We argue this occurred because their estimates were too precise.

Thus, comparing performance across different tasks suggests that multiple information types support map memory. Spatial task requirements elicit the spatial information present in sequential learners' memory, even though their memory is weighted toward temporal information. Although we would predict a similar effect with tasks requiring temporal information, the current studies did not include such tasks. The findings related to task requirements reiterate the point that when making fine distinctions about map memory, employing multiple tasks that tap distinct information may best reveal the presence of multiple and varied information types.

5.3. Other Effects

Although learning goals and task demands clearly affected weighting of spatial and temporal information in memory, some other influences on task performance should be noted. Two of these effects involve factors known to influence spatial memory performance, including spatial boundaries and regression to the mean.

People use spatial boundaries such as those defined by roads (McNamara et al., 1984), artificial boundaries (McNamara, 1986), and even landmarks grouped by color or shape (Hommel et al., 2000) to organize their mental representations (Friedman & Montello, 2006; McNamara et al., 1989). The floor plan used in the present studies included multiple boundaries in the form of room frames, hallways, and doorways. These boundaries may have affected performance, depending on the task. They may have reduced spatial effects on location priming. Findings from previous research show that a reduction in "spatial" priming may occur due to subjective or real boundaries in spatial environments (e.g., McNamara, 1986; McNamara, Hardy, & Hirtle, 1989). At the same time, they may have increased spatial clustering in free recall, although this point is admittedly somewhat speculative.

In addition to the goal and task effects, distance estimations also showed regression to the mean, wherein participants tended to overestimate short distances and underestimate long ones. The presence of this influence depended on accuracy. In cases of high accuracy, regression to the mean was weak and sometimes unidirectional (e.g., overestimation of spatially close pairs and relatively accurate estimation of far pairs). The demand for spatial information of this task can be seen even in unconfounded learning. In Experiment 3, the temporal distance effects on sequential learners' distance estimates appeared in seemingly opposite directions when spatial distance was held close versus far. The seemingly opposite directionality of the effect can be explained by a spatial distance influence. When held spatially close, temporal distance resulted in either accurate estimates (temporally close) or overestimation. When held spatially far, temporal distance resulted in underestimation and more so for temporally far pairs. Thus spatial distance exerted an overall effect, which again showed regression to the mean with overestimation of close pairs and underestimation of far pairs, and temporal distance exerted an effect within this.

5.4. Map Memory is Spatial

Hearing suggestions that map memory may not be spatial elicits a cognitive double-take, at least at first. Yet, research examining spatial and temporal contributions to map memory (Clayton & Habibi, 1991; Clayton, Habibi, & Bendele, 1995; Curiel & Radvansky, 1998, 2004; McNamara et al., 1992; Sherman & Lim, 1991) makes such a suggestion. Clayton and Habibi (1991) pointed out that the so-called spatial effects of map memory could result from temporal order sequences. An interactive memory model allowing both spatial and temporal associations would seem to make more sense than attributing map memory to one information type or the other.

A spatial and temporal interactive model has been proposed to account for animal neurological responses to location. Such a model provides a theoretical basis for spatial and temporal interactive account. Single-cell recording in rodents shows hippocampal place cells which fire when the animal is in a particular part of an environment (e.g., O'Keefe & Dostrovsky, 1971; Taube, 1995). Simultaneously firing place cells band together to form a network with neighboring place fields, referred to as a chart (Káli & Dayan, 2000; Muller, Kubie, & Saypoff, 1991; Muller, Stead, & Pach, 1996). Temporal aspects of behavior enter this network as theta phase precession, which codes temporal behavioral sequences as asymmetric connections within the chart (Skaggs, McNaughton, Wilson, & Barnes, 1996; Yamaguchi, Aota, McNaughton, & Lipa, 2002; Wagatsuma & Yamaguchi, 2004). Recent hippocampal research suggests that spatial and temporal processing work in parallel and contribute to environment representations, also incorporating episodic memory (Gorchetchnikov & Grossberg, 2007).

The present results suggest that map learning goals yield differential weighting of spatial and temporal information. The idea that the temporal information is coded within an established spatial structure suggests that even with a strong temporal learning goal, spatial memory is indeed spatial. The present findings support this contention, particularly when examining free recall and final map drawing results. Spatial learners showed strong spatial clustering in their free recall, which would be expected based on their learning goal. Sequential learners also consistently showed spatial influences, equivalent to the amount of temporal organization that their learning goal would predict.

In other words, spatial learning goals strengthen already present spatial associations; temporal learning goals add asymmetric temporal associations within an established spatial association network resulting in an admixture of spatial and temporal associations. This conclusion is supported in the present studies wherein spatial learners showed consistent spatial effects and sequential learners consistently showed both spatial and temporal influences. In sum, map memory maintains spatial properties even with a temporal learning goal.

Sequential learner's final map drawing accuracy also supports the notion that map memory is spatial. The final map-drawing task examined fine-grain spatial memory accuracy. Sequential learners accurately reconstructed the floor plan even though their learning criterion did not emphasize local spatial relations. The emergent spatial properties brought about through inherent boundaries on the floor plan, e.g., doorways, hallways, room boundaries, may have further enhanced attention to spatial information during study.

6. CONCLUSIONS

In conclusion, the present experiments suggest some basic information about map memory. First, map memory is inherently spatial, although not solely spatial. Second, learning goals influence the weighting of information in memory. Third, associations supporting map memory, even if not the primary associations, are made apparent through task demands. Spatial and temporal information appears to be differentially weighted. We suggest that the weighting of these information types is not fixed, rather it is flexible, and manipulated by learning goal and spatial context. The fact remains that environment locations in close spatial proximity tend to be visited in close temporal proximity. As such, understanding how the two information types interact can lead to an accurate interactive model of spatial memory.

REFERENCES

Brunyé, T. T., & Taylor, H. A. (2009). When goals constrain: Eye movements and memory for goal-oriented map study. *Applied Cognitive Psychology, 22*, 1–16.

Clayton, K., & Chattin, D. (1989). Spatial and semantic priming effects in tests of spatial knowledge. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15,* 495–506.

Clayton, K., & Habibi, A. (1991). Contributions of temporal contiguity to the spatial priming effect. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 17*(2), 263–271.

Clayton, K., Habibi, A., & Bendele, M. S. (1995). Recognition priming effects following serial learning: Implications for episodic priming effects. *American Journal of Psychology, 108*(4), 547–561.

Curiel, J. M., & Radvansky, G. A. (1998). Mental organization of maps. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 24,* 202–214.

Curiel, J. M., & Radvansky, G. A. (2004). The accuracy of spatial information from temporally and spatially organized mental maps. *Psychonomic Bulletin & Review, 11*(2), 314–319.

Friedman, A., & Montello, D. R. (2006). Global-scale location and distance estimates: Common representations and strategies in absolute and relative judgments. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 32*(3), 333–346.

Gauvain, M., & Rogoff, B. (1986). Influence of the goal on children's exploration and memory of large-scale space. *Developmental Psychology, 22,* 72–77.

Gorchetchnikov, A., & Grossberg, S. (2007). Space, time, and learning in the hippocampus: How fine spatial and temporal scales are expanded into population codes for behavioral control. *Neural Networks, 20,* 182–193.

Hirtle, S. C., & Hudson, J. H. (1991). The acquisition of spatial knowledge. *Journal of Environmental Psychology, 11*, 35–345.

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

Káli, S., & Dayan, P. (2000). The involvement of recurrent connections in area CA3 in establishing the properties of place fields: A model. *Journal of Neuroscience, 20*(19), 7463–7477.

MacEachren, A. M. (1995). *How maps work: Representation, visualization, and design*. New York: The Guilford Press.

Maddox, K. B., Rapp, D. N., Brion, S., & Taylor, H. A. (2008). Social influences on spatial memory. *Memory & Cognition, 36*(3), 479–494.

Magliano, J. P., Cohen, R., Allen, G. L., & Rodrigue, J. R. (1995). The impact of a wayfinder's goal on learning a new environment: Different types of spatial knowledge as goals. *Journal of Environmental Psychology, 15,* 65–75.

Maruff, P., Danckert, J., Camplin, G., & Currie, J. (1999). Behavioral goals constrain the selection of visual information. *Psychological Science, 10*(6), 522–525.

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

McNamara, T. P., Altarriba, J., Bendele, M., Johnson, S. C., & Clayton, K. N. (1989). Constraints on priming in spatial memory: Naturally learned versus experimentally learned environments. *Memory & Cognition, 17*, 444–453.

McNamara, T. P., Halpin, J. A., & Hardy, J. K. (1992). Spatial and temporal contributions to the structure of spatial memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 18*(3), 555–564.

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., Ratcliff, R., & McKoon, G. (1984). The mental representation of knowledge acquired from maps. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 10,* 723–732.

Merrill, A. A., & Baird, J. C. (1987). Semantic and spatial factors in environmental memory. *Memory and Cognition, 15,* 101–108.

Muller, R. U., Kubie, J. L., & Saypoff, R. (1991). The hippocampus as a cognitive graph (abridged version). *Hippocampus, 1*(3), 243–246.

Muller, R. U., Stead, M., & Pach, J. (1996). The hippocampus as a cognitive graph. *Journal of General Physiology, 107*(6), 663–694.

Newcombe, N. (1985). Methods for the study of spatial cognition. In R. Cohen (Ed.), *The development of spatial cognition* (pp. 277–300). Hillsdale, NJ: Lawrence Erlbaum Associates.

O'Keefe, J., & Dostrovsky, J. (1971). The hippocampus as a spatial map: Preliminary evidence from unit activity in the freely-moving rat. *Brain Research, 34*(1), 171–175.

O'Keefe, J., & Nadel, L. (1978). *The hippocampus as a cognitive map*. Oxford: Clarendon Press.

Sherman, R. G., & Lim, K. M. (1991). Determinants of spatial priming in environmental memory. *Memory and Cognition, 19*(31), 283–292.

Skaggs, W. E., McNaughton, B. L., Wilson, M. A., & Barnes, C. A. (1996). Theta phase precession in hippocampal neuronal populations and the compression of temporal sequences. *Hippocampus, 6*(2), 149–172.

Taube, J. S. (1995). Place cell activity recorded from the parasubiculum of freely-moving rats. *Hippocampus, 5,* 569–583.

Taylor, H. A., Naylor, S. J., & Chechile, N. (1999). Goal-specific influences on the representation of spatial perspective. *Memory and Cognition, 27*(2), 309–319.

Thorndyke, P. W., & Hayes-Roth, B. (1982). Differences in spatial knowledge acquired from maps and navigation. *Cognitive Psychology, 14,* 560–589.

Tolman, E. C. (1948). Cognitive maps in rats and men. *Psychological Review, 55*, 189–208.

Van Asselen, M., Fritschy, E., & Postma, A. (2006). The influence of intentional and incidental learning on acquiring spatial knowledge during navigation. *Psychological Research, 70*(2), 151–156.

Wagatsuma, H., & Yamaguchi, Y. (2004). Cognitive map formation through sequence encoding by theta phase precession. *Neural Computation, 16,* 2665–2697.

Yamaguchi, Y., Aota, Y., McNaughton, B. L., & Lipa, P. (2002). Bimodality of theta phase precession in hippocampal place cells in freely running rats. *Journal of Neurophysiology, 87*(6), 2629–2642.