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11 **When Goals Constrain: Eye Movements and Memory for**
12 **Goal-Oriented Map Study**
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21 SUMMARY

22 Perspective goals, such as studying a map to learn a route through an environment or the overall
23 layout of an environment, produce memory congruent with the goal-directed rather than the studied
24 perspective. One explanation for this finding is that perspective goals guide attention towards actively
25 gathering relevant information during learning. A second explanation is that information is
26 automatically organized into a goal-congruent spatial model that guides retrieval. Both explanations
27 predict goal-congruent memory, but only the former one predicts eye movement differences during
28 map study and the flexibility of resulting spatial memories. Results demonstrate eye movements
29 towards goal-congruent map elements during learning, and lasting memory effects at test. These
30 findings carry implications for the design of adaptive hand-held and in-vehicle navigation interfaces
31 that accommodate for varied user goals. Copyright © 2008 John Wiley & Sons, Ltd.

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33 College freshmen arriving on campus will need to know how to get from their dorm to the
34 dining hall, or for the more studious, the library. They may also want to know the layout of
35 the environment, such as where the athletic facilities are relative to the overall campus
36 structure. One common way of gathering such knowledge is to consult the campus map.
37 Some work has demonstrated that people's perspective goals while studying a map can lead
38 to pronounced spatial memory differences (Taylor, Naylor, & Chechile, 1999; van Asselen,
39 Fritschy, & Postma, 2006). For instance, when individuals study a map to find routes from
40 one place to another they subsequently perform better on first-person perspective tasks,
41 such as imagining themselves standing in the studied environment and pointing towards
42 distant landmarks; in contrast, they perform relatively poorly on external perspective tasks,
43 such as knowing the canonical relationship between two buildings. These findings strongly
44 support a growing body of evidence suggesting that spatial memory is not always
45 inextricably tied to the initial learning perspective (i.e. Brunyé, Ra  & Taylor, in press;
46 Brunyé & Taylor, 2008a,b; Taylor & Tversky, 1992; [Tversky, 1993](#); but see Shelton &
47 McNamara, 2004). They also point to the strong top-down influence of learner intentions
48 and strategies on spatial memory form and function. That is, whereas the map itself is
49 configural and always viewed from an external survey perspective, learner goals may play a
50 strong role in guiding the study and/or organization of map information in memory.
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The precise mechanisms responsible for goal-directed spatial memory differences, however, are unclear. The present work investigates whether these memory differences may be predicted by eye movements during map study. Such a result would suggest top-down control of attention in correspondence with perspective goals during map study; in contrast, if eye movements are not differentially affected by perspective goals, spatial memory differences may be due to perspective-guided retrieval (i.e. schema activation) alone.

Early work (Hasher & Zacks, 1979) suggested that spatial memory acquisition proceeds automatically and is not affected by learner state or environmental characteristics. More recent studies go against this early position by demonstrating that spatial knowledge acquisition and representation are affected by:

1. *Dual-tasking*, such as performing a verbal or spatial suppression task while studying a map or reading spatial texts (Brunyé & Taylor, 2008a; Coluccia, Bosco, & Brandimonte, 2006; Gyselinck, De Beni, Pazzaglia, Meneghetti, & Mondoloni, 2007; Hermer-Vazquez, Spelke, & Katsnelson, 1999; Pazzaglia, De Beni, & Meneghetti, 2007). In most cases, visuospatial secondary tasking interferes with gathering information from maps, survey descriptions, route descriptions and navigation. Articulatory secondary tasking, in contrast, interferes with gathering information from survey and route descriptions, but not maps.
2. *Environment density and complexity*, such as depicting landmarks at a high level of granularity or categorizing them by function (Brunyé, Taylor, & Worboys, 2007). Increases in the extent to which environments are presented in high detail lead to increased cognitive load and impoverished spatial memories.
3. *Experience*, such as having repeated exposures to a map, repeated travels *via* navigation and repeated reads of route-perspective spatial texts (Bosco, Filomena, Sardone, Scalisi, & Longoni, 1996; Brunyé et al., in press; Brunyé & Taylor, 2008b; Kuipers, Tecuci, & Stankeiwicz, 2001; Lee & Tversky, 2005; Sholl, 1987). In general, repeated or increased experience with navigation or route descriptions leads to spatial memories that are functionally similar to those acquired from map study or survey description reading; that is, the development of perspective-flexible memories that are readily applied to inference problems. Limited experience with navigation or route description reading, however, leads to perspective-specificity towards the first-person perspective and decreased flexibility at test (see also Shelton & McNamara, 2004).
4. *Goals and intentions*, such as studying a map with one of two goals: Learn the overall layout (survey goal) or the paths through the environment (route goal) (Magliano, Cohen, Allen, & Rodrigue, 1995; Taylor et al., 1999; van Asselen et al., 2006). Whereas maps are always presented and viewed from a survey and external perspective, respectively, the form and function of spatial memories varies dramatically as a result of perspective goals provided prior to learning.

The present work looks more specifically at the influence of perspective goals on the ability for map learners to gather and represent information in flexible memory forms. Rather than asking *whether* goals will influence eventuating memories for maps, we ask *why* and *how*, in a perceptual and cognitive sense, these influences affect map study and later application of memories.

In Taylor et al.'s work (1999), having a survey goal during map study increased performance on allocentric (bird's-eye perspective) tasks such as Euclidian distance

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6 estimation, whereas the route goal increased egocentric (first-person perspective) task
7 performance such as route distance estimation. There are several reasons why goals may
8 have influenced performance on these tasks. First, goals may cause an early development of
9 schemas that guide attention towards certain map elements during the study process
10 (Hayhoe & Ballard, 2005; Hopfinger, Buonocore, & Magnus, 2000; LaBerge, 1995;
11 Maruff, Danckert, Camplin, & Currie, 1999; Rayner, Rotello, Stewart, Keir, & Duffy,
12 2001; Yarbus, 1967); that is, effects of perspective goals may manifest themselves online
13 (during the study process). Schemas are mental models or knowledge structures that can
14 shape both information gathering and the structure of consolidated long-term memories
15 (Bartlett, 1932; Brewer, 2000; Kuipers, 1975; Minsky, 1975; Pichert & Anderson, 1977).
16 Schemas can be driven by existing knowledge, stereotypes and goals and intentions. Early
17 schema development can structure incoming information and then later guide retrieval (i.e.
18 schema activation at test; [Brewer & Nakamura, 1994^{Q2}](#)). For instance, with a route goal one
19 might focus visual attention on streets and street names, whereas a survey goal might lead
20 one to focus on landmark interrelationships and compass coordinates. The resulting
21 schema is shaped by the goal as a result, at least, of the visual processes during study. This
22 explanation predicts differential patterns of information gathering *during* map study as a
23 function of learner goals. Note that we will use the term 'schema development' to refer to
24 the influence of goals on the learning process, and 'schema activation' to refer to the
25 influence of schemas during retrieval/test. One way to examine top-down attentional
26 effects of goals is to monitor eye movements during goal-directed map study.

27 Goals may also influence memory *without* influencing eye movements during study. In
28 this case, schema development may only structure the coding of spatial information into
29 long-term memory, and not shape the visual learning experience itself. For instance, a route
30 goal may instantiate a schema to organize information into long-term memory in a manner
31 that facilitates knowledge of those routes, regardless of attentional processes during
32 learning. The resulting memory forms may facilitate performance on goal-congruent tasks,
33 such as knowing paths through the environment, but impair performance on goal-
34 incongruent tasks such as knowing relative landmark positions. In fact, much work has
35 shown that tasks inconsistent with a developed schema induce performance decrements
36 relative to consistent ones (Bower, Black, & Turner, 1979; Lampinen, Copeland, &
37 Neuschatz, 2001; Pezdek, Whetstone, Reynolds, Askari, & Dougherty, 1989; Pichert &
38 Anderson, 1977). In the present case, learning a map with a route goal would eventuate in
39 memory schemas affording higher performance on tasks congruent with this perspective
40 (e.g. finding routes) whereas inconsistent ones (e.g. judging canonical relationships
41 between landmarks) would suffer. That is, the activation of existing schemas at test should
42 facilitate subsequent task performance. Eye monitoring allows us to examine whether
43 schema development alone (without online modulation of visual attention) might explain
44 goal-congruent memory effects.

45 To this end, we used a goal manipulation paradigm that has produced memory
46 differences during both map study and navigation: Survey *versus* route goal instantiation
47 (Taylor et al., 1999; van Asselen et al., 2006). The survey goal encourages participants to
48 learn the overall layout of the environment, whereas the route goal emphasizes learning the
49 routes through the environment. In light of earlier work (Rossano & Hodgson, 1994;
50 Rossano & Morrison, 1996) we expect that individuals studying maps will focus visual
51 attention first towards peripheral information, and then central information. Goal
52 instantiation is expected to focus visual attention (i.e. Hopfinger et al., 2000) towards
53 particular elements of the environment such that the survey goal produces a focus on

buildings and street configurations, and the route goal a focus on individual streets and street names. Finally, we expect to find memory congruent with the goal perspective when testing for the flexible application of spatial memories (i.e. Taylor et al., 1999). That is, those who study a map with a survey goal are expected to perform better on survey- *versus* route-perspective memory tasks, whereas those with a route goal are expected to perform better on route- than survey-perspective tasks.

METHOD

Participants

Twenty-four college students (9 male, $M_{\text{age}} = 19.79$ years, $SD_{\text{age}} = 2.02$) participated for monetary compensation.

Materials

Maps

Two 2D maps were developed as adaptations of St. Olaf's and Grinnell College campus maps.¹ Each map depicted 14 landmarks, 6 street names, a compass rose (north-up) and were 1280 (width) by 1024 (height) pixels in size with 40 000 pixels/inch² resolution. The two maps were similar in spatial density for landmarks (St. Olaf's = 3402.40 pixels/inch²; Grinnell = 3397.89 pixels/inch²) and streets (St. Olaf's = 3828.13 pixels/inch²; Grinnell = 3771.67 pixels/inch²).

Eye tracker

We used an iViewX (SensoMotoric Instruments; Needham, MA) remote eyetracking device mounted on top of a 17" computer monitor (at 1280 × 1024 resolution). Gaze position was tracked using an infrared image of the left eye pupil and corneal reflections, sampled at 60 Hz; resolution was approximately 0.5° visual angle.

Tests

Participants completed two tests: Map drawing and statement verification. The former involved producing sketch maps on blank paper. The latter was paper-and-pencil based and involved answering 12 true/false statements for each environment. Six of these statements assessed knowledge from the survey perspective (e.g. 'the administration building is south-east of Cleves Hall'), and six from a route perspective (e.g. 'Standing with Moy Hall to your left, you reach physical education by walking straight ahead and turning right'). Statements were produced by randomly selecting 12 landmark pairs (e.g. administration, Cleves Hall) while maintaining unique pairings and minimizing repeated landmarks. Distances were measured between landmarks in each pair, and two sets of landmark pairs with equal average distances were created: One to be used in survey statements, and one for route statements. Survey statements used either the correct (3, TRUE) or incorrect (3, FALSE) coordinate term and anchor landmarks (i.e. the first-mention landmark) were randomly chosen for each pair with the exception that no single landmark appeared more than once in this position. Route statements began with an egocentric orienting clause

¹Maps are available from first author.

relative to the randomly chosen anchor landmark (e.g. standing with Moy Hall to your left), and then described the shortest route to the paired landmark; half of these statements were true and half false, and false statements had a reversed orientation term (e.g. Standing with Moy Hall to your right. . .). Statements were presented in random order on the test page, and accuracy was measured.

Procedure

Each participant was randomly assigned to one of the three goal groups (survey, route and none), and studied the two maps in counterbalanced order; each map was studied for 5 minute (with eye tracking), followed by a 10-minute testing phase.

Eye tracker calibration

Calibration was done using SensoMotoric Instruments' WinCal software, and repeated until the error between two fixations at any point was less than 1° , or average error for all points fell below 0.5° . All participants had an approximate viewing distance of 80 cm.

Map study

Each participant's assigned goal was written on the computer monitor (i.e. Taylor et al., 1999). The survey goal instructed participants: 'Try your best to learn the overall layout of the environment, such as knowing where buildings are relative to one another in canonical (north, south, east, west) coordinates'. The route goal instructed participants: 'Try your best to learn the routes around the environment, such as knowing how to get from one place to another and the things you would pass along the way'. The group without a perspective goal was instructed: 'Try your best to learn everything you can about the environment'. Maps were presented in the centre of the computer monitor; the study session lasted 5 minute.

Testing

The map drawing and statement verification tests, administered in counterbalanced order, followed each map study phase. Participants had up to 10 minute to draw their map. True/false statements were paper-and-pencil and self-paced. Participants were instructed to respond as quickly as possible without compromising accuracy.

RESULTS

Scoring and analysis

Eye movement

Eye movement was assessed in 1-minute time intervals. We used iViewAna (v.1.01.29) analysis software to assess the number and duration (minimum 100 millisecond) of eye fixations upon elements within 10 stimulus regions of interest (ROIs; five for each environment). ROI (see Figure 1) were made to represent: (1) Peripheral *versus* central map regions (each with equal occupied area), (2) buildings, (3) streets (name segments omitted), (4) street names and (5) the compass rose. We used peripheral-central difference scores to assess relatively global patterns of eye movement; these data are presented as the

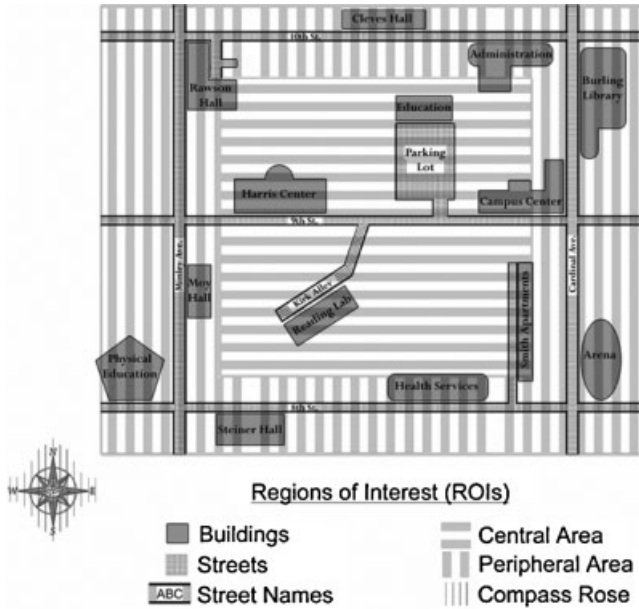


Figure 1. Adapted map of Grinnell College campus, with the six analysed regions of interest (ROIs) depicted: Buildings, streets, street names, peripheral and central areas and compass rose

total number of fixations per minute, proportion fixation duration (relative to full 1 minute time segment), and average fixation duration (fixation duration (millisecond)/number of fixations). For each of the other four ROIs listed above (buildings, streets, street names, compass rose), data are presented as average fixation duration only.

Five 3 (between-participants, goal perspective: Survey, route, none) \times 5 (within-participants, study minute: 1, 2, 3, 4, 5) \times 2 (within-participants, block: Block 1, block 2) mixed models ANOVAs confirmed that eye movements did not significantly change over the course of the two blocks for any of our ROIs ($ps > .05$). All subsequent ANOVAs combine data from the two blocks. One ANOVA was conducted for each of the ROIs, using a 3 (between-participants, goal perspective: Survey, route, none) \times 5 (within-participants, study minute: 1, 2, 3, 4, 5) mixed models design. Follow-up comparisons used the Bonferroni correction.

Map drawing

Maps were scored by two raters blind to the experimental manipulation. Each map was scored for landmark and street name recall, relative landmark and street positioning and quadrant accuracy (see Brunyé & Taylor, 2008a,b; Taylor & Tversky, 1992). Inter-rater reliability (using the intra-class correlation coefficient; Shrout & Fleiss, 1979) was high for landmark recall ($r = .98$), street name recall ($r = .96$), relative landmark positioning ($r = .92$), street positioning ($r = .94$) and quadrant accuracy ($r = .95$); after reviewing inter-rater discrepancies, we chose the first rater's scores as a more accurate representation of performance. One-way ANOVAs (between, goal perspective: Survey, route, none) examined performance on each of the five dependent measures. With the exception of those with a route goal recalling more street names than those in the other two goal groups ($F(2, 23) = 9.17$, $p < .01$, $\eta^2 = .23$), all analyses yielded null results and thus will not be considered further.

Statement verification

Verification accuracy was assessed within each of the two statement perspectives (survey and route), and data are presented as proportion accuracy. One mixed models ANOVA using a 3 (between, goal perspective: survey, route, none) \times 2 (statement perspective: Survey, route) design examined verification accuracy.

Linear regressions

A total of 4 follow-up linear regressions were conducted using eye movement data in the buildings, streets, street names and compass ROIs to predict memory effects at test. These regressions allow us to assess the extent to which eye movement differences during learning (*via* average fixation durations upon ROIs) may account for variability seen at test (*via* survey-route difference scores).

Eye movement results

Peripheral versus central

The number of fixations, proportion time spent fixated in each area, and average fixation duration are presented as peripheral minus central (i.e. lower numbers reflect relative central bias, higher numbers reflect peripheral bias). Overall, peripheral-central difference scores were lower during early minutes relative to later minutes; that is, participants tended to allocate attention towards central details during the first few minutes, and then towards peripheral details during later study, against earlier assumptions derived from memory results (Rossano & Hodgson, 1994; Rossano & Morrison, 1996).

Number of fixations

There was a main effect of study minute ($F(4, 84) = 13.72, p < .01, \eta^2 = .33$). Fixations showed a central bias in minutes 1–3 ($M = -22.21, SE = 2.89; M = -16.04, SE = 3.05$; and $M = -9.04, SE = 3.25$, respectively), and peripheral bias in minutes 4–5 ($M = 5.71, SE = 3.19$; and $M = 2.21, SE = 3.22$, respectively). Follow-up comparisons (4 comparisons, adjusted α of .0125) revealed that minute 1 showed a greater central bias relative to minutes 3 ($t(23) = 3.25, p < .01$), 4 ($t(23) = 6.45, p < .01$) and 5 ($t(23) = 6.11, p < .01$). This pattern did not interact with goal group ($p > .05$).

Proportion fixation duration

There was a main effect of study minute ($F(4, 84) = 14.02, p < .01, \eta^2 = .30$). The proportion of time that participants were fixated in central areas tended to be primarily in minute 1 ($M = -.11, SE = .02$), with no particular focus in minutes 2–3 ($M = .01, SE = .02$; and $M = .06, SE = .03$, respectively) and a focus on peripheral areas in minutes 4–5 ($M = .06, SE = .03$; and $M = .15, SE = .04$, respectively). Follow-up comparisons (4 comparisons, adjusted α of .0125) revealed that minute 1 showed a greater degree of central bias relative to minutes 2 ($t(23) = 3.13, p < .01$), 3 ($t(23) = 4.79, p < .01$), 4 ($t(23) = 5.24, p < .01$) and 5 ($t(23) = 5.55, p < .01$). This pattern did not interact with goal group ($p > .05$).

Average fixation duration

Average fixation duration in peripheral *versus* central areas did not vary by minute or goal group ($ps > .05$).

The following data are presented as average fixation duration only, as a representative measure; number of fixations and proportion fixation time revealed similar patterns.

Buildings

The overall average fixation duration was 720.79 millisecond ($SE = 37.99$). There was an effect of study minute ($F(4,84) = 5.35, p < .05, \eta^2 = .10$), qualified by a study minute by goal group interaction ($F(8,84) = 2.46, p < .05, \eta^2 = .09$). In minute 1, the survey goal group had longer average fixation durations ($M = 832.5, SE = 55.9$) relative to both the route goal ($M = 316.1, SE = 73.4$) group ($t(14) = 5.59, p < .01$), and the no goal ($M = 489.7, SE = 96.1$) group ($t(14) = 3.08, p < .01$). In minute 2, the survey goal group tended to have longer average fixations ($M = 885.7, SE = 129.6$), but did not differ statistically from the route ($M = 585.8, SE = 130.8$) or no goal ($M = 602.3, SE = 91.4$) groups; minutes 3–5 also showed no differences ($ps > .05$).

Streets

The overall average fixation duration was 483.89 millisecond ($SE = 34.65$). There was no main effect of study minute, but there was a study minute by goal group interaction ($F(8,84) = 3.32, p < .01, \eta^2 = .15$). In minute 1, the route goal group had longer average fixation durations ($M = 767.9, SE = 42.6$) relative to both the survey goal ($M = 500.4, SE = 67.5$) group ($t(14) = 3.35, p < .01$), and the no goal ($M = 315.5, SE = 71.5$) group ($t(14) = 5.43, p < .01$). In minute 2, the route goal group had longer average fixation durations ($M = 641.8, SE = 32.9$) relative to the no goal ($M = 256.2, SE = 48.8$) group ($t(14) = 6.6, p < .01$), but not the survey ($M = 430.1, SE = 79.5$) goal group ($t(14) = 2.46, p > .025^2$). No other study minute showed any group differences.

Street names

The overall average fixation duration was 773.08 millisecond ($SE = 54.82$). There was a main effect of goal group ($F(2,21) = 4.34, p < .05, \eta^2 = .12$). Overall, the route goal group had longer average fixation durations ($M = 976.5, SE = 149.1$) relative to the no goal ($M = 581.2, SE = 169.1$) group ($t(14) = 2.91, p < .01$), but not the survey goal ($M = 761.5, SE = 160.1$) group ($t = 2.35$). This effect did not interact with study minute.

Compass

The average fixation duration was 213.75 millisecond ($SE = 37.31$). There was an effect of study minute ($F(4,84) = 15.74, p < .01, \eta^2 = .26$), qualified by a study minute by goal group interaction ($F(8,84) = 5.88, p < .01, \eta^2 = .20$). In minute 1, the survey goal group had longer average fixation durations ($M = 1256.3, SE = 280.5$) relative to both the route goal ($M = 318.8, SE = 121.7$) group ($t(14) = 3.07, p < .01$) and the no goal ($M = 356.3, SE = 169.9$) group ($t(14) = 2.74, p < .025^2$); note that 87% of compass fixations within minute 1 were recorded during the first 10 second of study. No other minute showed group differences ($ps > .05$).

Memory task results

Statement verification

The statement verification task allowed us to compare knowledge for the overall layout of the environment from a survey (allocentric) perspective and knowledge for routes

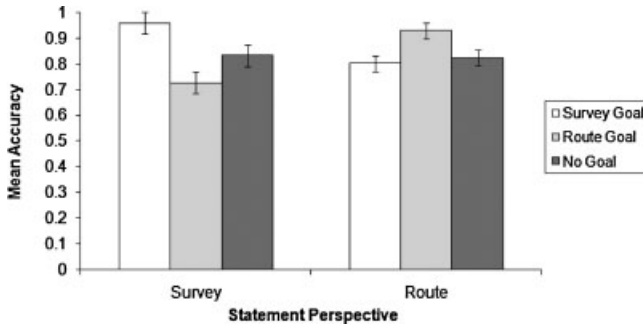


Figure 2. Mean accuracy and standard error on the statement verification task, separated by statement type (survey, route), for each of the three goal groups

(egocentric) through the environment, and how these might vary as a function of goal group.

Overall, performance on the statement verification task was high ($M = .85$, $SE = .02$). As depicted in Figure 2, goal group interacted with statement perspective (survey or route) ($F(2,21) = 12.98$, $p < .01$, $\eta^2 = .34$). Following map study with a survey goal, participants responded more accurately to survey statements relative to route statements ($t(7) = 3.64$, $p < .01$); conversely, with a route goal, participants responded more accurately on route relative to survey statements ($t(7) = 3.02$, $p < .025$).² With no goal, survey and route statement performance did not differ ($t(7) = .29$, $p > .05$).

Using eye movements to predict memory differences

Average fixation duration data from the primary ROIs of interest (buildings, streets, street names and compass rose) were used to predict survey minus route accuracy difference scores on the statement verification task. Each of the four regressions was done using minute 1 data only, as eye movement effects were most pronounced in this epoch relative to minutes 2–5. Note that with a survey-route difference score, positive scores denote higher performance on survey than route memory tasks, and negative scores denote higher performance on route than survey memory tasks. Overall, regressions suggest that longer average fixation on buildings and the compass rose led to higher difference scores ($\beta < .01$, $t(30) = 2.57$, $p < .05$ and $\beta < .01$, $t(30) = 2.27$, $p < .05$, respectively), whereas longer average fixation on streets and street names led to lower difference scores ($\beta < .01$, $t(30) = 1.85$, $p = .08$ and $\beta < .01$, $t(30) = 2.94$, $p < .01$, respectively).

DISCUSSION

Eye movement during map study

Overall, participants allocated visual attention from central to peripheral areas, supporting work suggesting that map study progresses from attending to central local features of an environment to relatively global coordinated features of the environment (e.g. Golledge &

²Bonferroni-corrected α of .025.

Spector, 1978). Once learned, however, map drawing performance showed no central or peripheral bias within resulting memory representations. Although other work (e.g. Rossano & Hodgson, 1994; Rossano & Morrison, 1996) demonstrated focused learning of peripheral map details relative to central ones during the first few minutes of learning, we propose that these earlier findings may have been due to higher spatial densities in central map areas. In contrast, the present maps were equated for spatial density across central and peripheral regions, eliminating any early attentional bias towards low densities. With this control, we found that participants generally progressed in the opposite manner. The possibility remains, of course, that had a map drawing task been completed early during study (e.g. following minute 1) we may have found a central focus, as suggested by high early central-peripheral difference scores.

During the first 2 minute of study individuals with a survey goal had longer fixations towards buildings and the compass rose, whereas those with a route goal had longer fixations on streets and street names. That is, a perspective goal can have an online effect on visual attention by focusing it towards particular map elements, but only early in study. This effect is likely due to having clearly explicated goals rather than general instructions to learn every map detail, and the early development of a memory schema that guides eye movement during learning. Some recent work using eye movements to investigate goals during the viewing of advertisements has found similar results (Rayner, Miller, & Rotello, *in press*). It appears to be the case that the relatively distributed eye movement in the no-goal group yielded moderate perspective-flexibility at test; that is, participants were equally able to solve problems within the goal, and the alternate, perspectives.

Perspective goals have online influences on visual attention towards particularly relevant environment elements, likely through the fast development of schemas congruent with explicated goals. For a survey goal eye movements are focused towards elements critical to gathering information about the overall layout of the environment: Buildings, and compass coordinates. The route goal, in contrast, biases attention towards the streets and street names that will comprise all routes through the environment. These early attentional foci, however, tend to diminish over the course of study, suggesting that goal-directed influences on attention may help build the framework in early study to which later study is then related. These results are consistent with some of the extant literature (LaBerge, 1995; Maruff et al., 1999; Pichert & Anderson, 1977), extend it to map study, and uniquely provide insights into the time course of top-down influences on attention during spatial information gathering. It does not appear to be the case, at least with map study, that the effects of perspective goals can be explained solely by schema activation during retrieval. If that were the case, results would demonstrate no reliable differences in eye movement during study; in contrast, the present results demonstrate that perspective goals actively control the allocation of visual attention.

Goal direction and map memory

Another objective of the present experiment was to investigate the influence of goals on the mental representations resulting from studying maps. In general, our results support earlier work (Taylor et al., 1999; van Asselen et al., 2006) showing that perspective goals influence the representation of spatial information.

Statement verification revealed an interaction between goal group and statement perspective. Those who studied with a route goal performed better on egocentric perspective statements whereas those with a survey goal performed better on allocentric

perspective statements. This contrasts with the no-goal group, which showed no performance differences towards either perspective statement and exhibited a moderate degree of perspective flexibility—that is, they could switch perspectives without compromising accuracy. The largest influences on perspective flexibility, however, occurred when goal-directed participants were tasked to solve problems in the same or the alternate perspective. As mentioned above, participants in the no-goal group performed equally well across both testing perspectives. Participants in the survey and route goal groups, however, showed increased performance in the congruent relative to the incongruent testing perspective. That is, performance was improved when goal and test perspectives matched, but not necessarily hindered when they did not. Goal instantiation clearly produced perspective-specific testing advantages that were seemingly independent of the initial learning format. Whereas maps present an allocentric perspective, a route perspective goal can bias spatial memories towards a first-person perspective. These results provide support for a growing body of evidence demonstrating the malleability of spatial memory, and a multitude of variables that affect the flexibility of these memory forms towards perspective-switching (Brunyé et al., in press; Brunyé & Taylor, 2008a, 2008b; Chabanne, Péruch, Denis, & Thinus-Blanc, 2004; De Beni, Pazzaglia, Gyselinck, & Meneghetti, 2005; Denis, 2008; Lee & Tversky, 2005; Noordzij & Postma, 2005; Noordzij, Zuidhoek, & Postma, 2006; Péruch, Chabanne, Nese, Thinus-Blanc, & Denis, 2006; Shelton & McNamara, 2004). Further, these results should be considered within the framework of schema activation at retrieval: Testing circumstances that provide the cues to activate existing schemas in long-term memory can predict performance on those tasks (Brewer, 2000; Brewer & Nakamura, 1984). Survey perspective statements activate relevant concepts (i.e. canonical relative locations of landmarks) and are thus facilitated by survey goals, and *vice versa* for route perspective statements.

Goal-directed attention and schemas

The present results provide evidence that perspective goals during spatial learning manifest themselves at both the attentional and representational levels. Goals have powerful online influences in that they guide attention towards relevant elements of an environment, especially in the early stages of information gathering. These seemingly subtle alterations in eye movement may have rather predictable effects on resulting memory representations. It is likely that this is accomplished by establishing schematic anchors that guide early visual attention during learning (i.e. Bransford & Johnson, 1972; Tse et al., 2007). The first few minutes of information gathering are thus involved in quickly creating a goal-congruent organization in memory, as suggested by the eye movement data. The resulting organizational schema then guides (and constrains) the remaining study time and building of a goal-congruent memory representation. The fact that eye movements over ROIs had reliable predictive value for later memory performance supports this contention: The greater the online modulation of visual attention towards goal-congruent information, the more subsequent retrieval was constrained by the resulting memory representations.

Applied implications

People's everyday experiences are constantly shaped by the influences of internally and externally motivated goals, intentions and motivations. The present work demonstrates that such contextual factors can lead to large memory differences, at least partially driven by

attention during learning. These findings have implications for spatial interface design and student learning.

Interfaces such as found on hand-held and in-vehicle navigation devices may benefit from designs that incorporate knowledge of where users focus attention. Indeed it may be the case that many contemporary interfaces present information too broadly or narrowly in consideration of a user's goals. The most common goal when using navigation devices, of course, is finding routes through novel environments, demanding the gathering and application of both route and survey knowledge towards ultimate success (e.g. Pazzaglia & De Beni, 2001). Matching information to varying user goals can reduce cognitive load, freeing higher level resources for problem-solving and reducing navigation errors (Kaplan, Kaplan, & Deardorff, 1974; Sweller, 1988). For instance, principles of cartographic generalization (i.e. reducing level of spatial detail; Hobbs, 1985) can be applied to areas irrelevant to an identified route; in fact, some work demonstrates that generalizing information incongruent with user goals results in improved usability, utility and memory for presented information (Agrawala & Stolte, 2001; Brunyé et al., 2007; Tomko & Winter, 2006). Of course, future work must determine the appropriate balance between presenting too sparse information that might result in ambiguities and cognitive costs (e.g. Mani & Johnson-Laird, 1982; Schneider & Taylor, 1999), and too dense information that might result in longer search times, reduced memory and poor subsequent transfer to complex problems (Florence & Geiselman, 1986; Mayer, 2001). The present work provides insights into the information types that are attended to as a function of varied perspective goals, and thus provides design recommendations for adaptive display technologies.

The present results have further implications for student learning and transfer of knowledge to novel problem sets. Research in training and education has consistently demonstrated that goals during learning may improve one element of memory while potentially impairing another (e.g. Geddes & Stevenson, 1997; Miller, Lehman, & Koedinger, 1999; Sweller & Levine, 1982; Sweller, Mawer, & Ward, 1982^{Q3}; Vollmeyer, Burns, & Holyoak, 1996). Whether studying textbooks, graphs and diagrams or maps, the greatest degree of memory flexibility may result from having either multiple goals or no particular goal at all. Given the ultimate motivation for educational practice to facilitate the development of flexible memory forms towards transfer success (i.e. Bransford, Brown, & Cocking, 1999), the amount of information revealed about subsequent test formats and learning objectives serves to constrain the learning experience and ultimately harms the flexible transfer of memories to novel problems (e.g. Vollmeyer & Burns, 2002). The present work suggests that these same results can be found with memory for spatial information; learning about novel environments in a manner that facilitates subsequent transfer appears best served by non-specific goals.

Limitations

The transient nature of eye movement differences, in that they appear to diminish after minutes 1 and 2, points at potential methodological considerations for future work. The eye movement results suggest that the effects of goal manipulation, at least at the level of visual attention, only manifest themselves during early study minutes. It is thus possible that the study time was excessively long and may have led to ceiling effects on some of our dependent measures. However, much work in our own and others' laboratories often uses map study durations from 5 to 20 minute in an effort to ensure adequate time to develop comprehensive memories of the presented environment. Indeed the present work did not

find ceiling effects in map drawing (overall accuracy $M = .79$) or statement verification (overall accuracy $M = .85$) data, suggesting that our 5-minute study period did not produce over-learning, *per se* (error data provided in the Results Section). We believe that our results provide new evidence on the time course of goal influences on guiding visual attention. It appears to be the case that these influences are quite short-lived; indeed it could be the case that early visual attention may be guided by a developing schema, and subsequent information gathering serves to further develop the comprehensiveness of these memories. Ultimately, however, test performance is still largely modulated by the nature of these goals, suggesting that the structure of the schema is maintained even after eye movement biases have diminished.

Future work will directly assess the time course of goal-directed visual attention alterations and memory formation during map study by using the present paradigm with relatively limited study time (i.e. 1, 2, 3, 4 minute). We expect that the schemas guiding knowledge acquisition have short-lived influences on visual attention but that extended study times are needed to prevent floor effects on our dependent tasks, and do not diminish the influence of goals on shaping resulting memories.

Conclusions

Given the short duration of visual attention biases during learning, and the relatively lasting effect on memory, we believe that our eye tracking results can be best explained by early schema instantiation and an active top-down control of visual attention during learning. This control serves to anchor the gathering of goal-relevant information; this pattern is complemented by activation of these schemas at test, resulting in goal-perspective specificity. The present results also illustrate that perspective dependence in memory is a result of both attentional processes during learning and the form of eventuating spatial memories.

Thus, when studying a map to find a route to the dining hall, one may limit the acquisition and storage of information necessary to know where this destination is relative to the overall campus layout; the same applies when studying to learn the layout and then later attempting to locate routes. Without a particular perspective goal, however, a relatively global schema can be developed, retrieved and flexibly applied across both problem sets. So what is a freshman to do? Either study in a way that facilitates perspective flexibility in memory, or keep a map (or knowledgeable roommate) handy at all times.

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