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Extended Experience Benefits Spatial Mental Model Development with Route but not
Survey Descriptions

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Abstract

Spatial descriptions symbolically represent environmental information through language and are written in two primary perspectives: survey, analogous to viewing a map, and route, analogous to navigation. Readers of survey or route descriptions form abstracted perspective-flexible representations of the described environment, or *spatial mental models*. The present two experiments investigated the maintenance of perspective in spatial mental models as a function of description perspective and experience (operationalized through repetition), and as reflected in self-paced reading times. Experiment 1 involved studying survey and route descriptions either once or three times, then completing map drawing and true/false statement verification. Results demonstrated that spatial mental models are readily formed with survey descriptions, but require relatively more experience with route descriptions; further, some limited evidence suggests perspective-dependence in spatial mental models, even following extended experience. Experiment 2 measured self-paced reading during three successive description presentations. Average reading times over the three presentations reduced more for survey relative to route descriptions, and there was no evidence for perspective-specificity in resulting spatial mental models. This supports Experiment 1 findings demonstrating the relatively time-consuming nature of acquiring spatial mental models from route, but not survey descriptions. Results are discussed with regard to developmental, discourse processing, and spatial mental model theory.

Extended Experience Benefits Spatial Mental Model Development with Route but not Survey Descriptions

Spatial descriptions convey geographical information through language, generally describing map-like configuration details or the best routes between landmarks. When asking a passer-by for directions you may receive information from a bird's-eye view, analogous to the perspective taken while viewing a map, or from a first-person view, analogous to the perspective taken during navigation. These perspectives, along with mixes of them, are the primary means of conveying environment information through language (Golledge, 1992; Siegel & White, 1975). The present experiments investigate the acquisition and maintenance of spatial perspectives in memory as a function of description perspective (route or survey) and repetition.

Spatial Descriptions

Survey descriptions, like maps, convey spatial information in an aerial (allocentric) perspective, using an extrinsic reference frame (i.e., relative to other spatial information) and cardinal directions (*north, south, east, and west*). In contrast, route descriptions convey spatial information from a first-person (egocentric) perspective, using an intrinsic reference frame (i.e., relative to the viewer) that guides readers on an imaginary tour, conveying information about landmarks, distances, and turns (Levelt, 1982; Taylor & Tversky, 1992a, 1992b). Considering these differences, one might expect correspondingly different mental representations following study. However, most work has demonstrated that with both route and survey descriptions individuals tend to develop abstracted and comprehensive *spatial mental models* of the described environments (Ferguson & Hegarty, 1994; McNamara, Hardy, & Hirtle, 1989; Noordzij & Postma,

2005; Taylor & Tversky, 1992a). These models are abstracted in that they do not appear to completely maintain described perspectives, and they are comprehensive in that they support map drawing and inferencing. This general finding extends earlier work suggesting multiple representations of memory for text (e.g., Bransford & Franks, 1971; Johnson-Laird, 1983; van Dijk & Kintsch, 1983) to the domain of spatial descriptions. Two primary indicators can be used as evidence for spatial mental models: first, the ability to go beyond the information provided in the text by generating inferences regarding novel spatial relationships, and second, the ability to make these inferences with a high degree of facility in both the learning perspective and the perspective not initially learned. The latter characteristic requires either perspective-free or perspective-flexible memory representations.

Conclusions regarding the degree of perspective flexibility of representations following alternative input formats have been mixed. Several studies have found source and memory perspective *dependence* in mental representations derived from maps and navigation (Evans & Pezdek, 1980; Leiser, Tzelgov, & Henik, 1987; Perrig & Kintsch, 1985; Sholl, 1987; Thorndyke & Hayes-Roth, 1982). Others have found results suggesting perspective *independence* or flexibility (Ferguson & Hegarty, 1994; McNamara, Hardy, & Hirtle, 1989; Taylor & Tversky, 1992a). Still other work suggests that spatial memory dependence upon source perspectives varies as a function of goals (Taylor, Naylor, & Chechile, 1999), experience (Golledge & Spector, 1978; Thorndyke & Hayes-Roth, 1982), test type (Shelton & McNamara, 2004), and instructions (Noordzij, van der Lubbe, & Postma, 2005, 2006; Zwaan & van Oostendorp, 1993). Noordzij and colleagues (2006), for instance, report converging evidence that reader expectations have

predictable influences on spatial mental model development; only when participants are told the nature of later tests do they show imagery and spatial mental model development during learning (assessed via EEG), and at test.

Taylor and Tversky (1992a) found that after reading survey or route descriptions participants could accurately draw maps of, and verify inference questions about the studied space. In fact, description study served these tasks as well as map study. In contrast, recent work using the same descriptions has demonstrated that participants appear to develop mental representations that are bound to the initial input perspective (Shelton & McNamara, 2004). When participants were tasked with scene recognition from various orientations there was a clear bias towards the first experienced path segment orientation of a route description, or the north-is-up characteristic of a survey description. This finding was replicated using video walkthroughs of the environments.

Clearly recent results are divergent with regard to the perspective-dependence and independence of spatial mental models. Much of this variation in findings, however, may in part be attributable to representational formats (e.g., Shelton & McNamara, 2004), study instructions (e.g., Noordzij et al., 2005, 2006), test types (e.g., Noordzij & Postma, 2005; Taylor & Tversky, 1992a), and individual differences (e.g., Denis, in press). An additional factor that may be particularly important towards the development of perspective-independent spatial mental models is experience or extent of learning (i.e., Bosco, Sardone, Scalisi, & Longoni, 1996). Indeed the possibility remains that people only develop spatial mental models when given sufficient experience with an environment; Taylor and Tversky (1992a) allowed up to three readings of a description per environment. The present work examines this specific issue by manipulating the

amount of description exposure (through repetition) on spatial mental model development.

Experience and Spatial Representation

A number of studies have found that increased environment experience leads to more detailed and accurate spatial mental models (Appleyard, 1970; Golledge & Spector, 1978; Kuipers, Tecuci, & Stankeiwicz, 2001; Ladd, 1970; Lee & Tversky, 2005; Sholl, 1987; Thorndyke & Hayes-Roth, 1982). Tolman (1948) was perhaps the first to demonstrate that, through sufficient experience, animals can form what he termed *cognitive maps*, holistic mental representations of environments that can be recruited to solve novel spatial tasks. Appleyard (1970) and Ladd (1970) later suggested that these mental models could only be formed after extensive experience with landmarks and the routes between them. Golledge and Spector (1978) supported this notion by demonstrating that individuals' mental representations of heavily traveled environments were more integrated and configural than those for less-traveled areas. Furthermore, Thorndyke and Hayes-Roth (1982) demonstrated that increased navigation experience eventuates in configural knowledge formation, without exposure to physical maps. This finding is supported by later work (Sholl, 1987) demonstrating the availability of mental representations without a preferred perspective with extensive environmental experience. Finally, computational modeling of wayfinding in complex environments also predicts a positive relationship between the number of times an individual follows a path, and the development of a boundary-rich allocentric mental representation (Kuipers et al., 2001). Taken together, this work supports Siegel and White's (1975) theory of spatial knowledge development, which posits a progression from representing landmarks, the

routes between them, and at the highest level integration into a spatial mental model. It is important to note that while much of this work assumes sequential mental model development it remains in question whether this progression may actually be more simultaneous in nature (e.g., Ishikawa & Montello, 2006; McDonald & Pellegrino, 1993; Ruddle, Payne, & Jones, 1997). Further, some work has found no evidence for inference generation advantages due to increased first-person experience, but some evidence for advantages following increased survey experience (e.g., Bosco et al., 1996).

Conflicting research examining spatial mental model development from map study and navigation has led us to question whether the perspective differences between survey and route descriptions may induce similar representational effects in readers. In fact, some recent work has suggested a high degree of visuospatial involvement during route relative to both survey (Brunyé & Taylor, in revision; Deyzac, Logie & Denis, 2006) and non-spatial procedural (De Beni et al., 2005; Pazzaglia, De Beni, & Meneghetti, 2007) description learning. Further, Noordzij and colleagues have consistently noted higher performance in sighted individuals (on distance estimation and scale model tasks) following the study of survey relative to route descriptions (Noordzij & Postma, 2005; Noordzij, Zuidhoek, & Postma, 2006). Based on this work, we hypothesize that the development of spatial mental models that can be applied to complex tasks, such as inferencing, perspective-switching, and map drawing, will be relatively difficult with route versus survey descriptions.

As such, our first experiment evaluates the time course of spatial mental model development from survey and route texts. Route description learning is expected to progress from representing landmarks, their interrelationships, to eventually developing a

spatial mental model that is abstracted from relationships explicitly described by the text (i.e., Siegel & White, 1975; Taylor & Tversky, 1992a). This hypothesis rests on the notion that there may be large processing similarities between route descriptions and navigation. Survey descriptions, in contrast to route descriptions and similarly to maps, directly detail landmark interrelationships and should therefore not necessitate this progression. These processing differences predict poorer performance on tasks requiring mental model application, such as inferencing and perspective taking, following limited experience with a route relative to a survey description. However, increased experience with route descriptions should diminish these performance differences. In fact, when participants study a route description several times, they make inferences at levels matching those who learned survey descriptions several times (Taylor & Tversky, 1992a). Further, this manipulation provides some insights into the potential time course of the transition from perspective-specific to perspective-independent spatial mental models.

Experiment 1

Our first experiment tests the influence of exposure (operationalized as 1 versus 3 study cycles) on spatial description learning. We modeled our materials and dependent measures after those used by Taylor and Tversky (1992a).

Method

Participants

A total of 48 Tufts University undergraduates participated for partial course credit, 24 learned each description once, and 24 learned each description thrice.

Materials

Spatial Descriptions. Two pairs of texts were chosen from Taylor and Tversky (1992a), the convention center and town, each describing an environment from two perspectives: survey and route (see Appendices A and B). The survey descriptions were organized hierarchically, breadth-first, while the route descriptions were linear and guided participants on a tour, making the fewest possible turns while mentioning every landmark along a continuous path. The survey descriptions used canonical terms (*north*, *south*, *east*, and *west*), while the route descriptions used egocentric terms (e.g., *right*, *front*). Both descriptions for each environment provided all relevant spatial information without indeterminacies, were equally coherent according to pilot judgments (Taylor & Tversky, 1992a), and had similar text length.

Tests. There were two memory tasks, map drawing and statement verification. For map drawing, participants drew a map of the just learned environment as accurately and with as much detail as possible on a blank sheet of paper. The true/false statements (see Appendix C) assessed knowledge directly (verbatim) and indirectly (inference and paraphrase) imparted by the text. Verbatim locative knowledge was tested from both survey and route perspectives. The verification task included eight verbatim locative statements, four survey and four route, for each environment. Note that verbatim locative statements in the unstudied perspective (i.e., across-perspective) necessarily function as inference statements. Other statements assessed verbatim and paraphrased nonlocative knowledge (four of each type), for each environment. Finally, statements assessed inferencing from both survey and route perspectives (six survey and six route statements). In all cases, correct inference statement verification required a representation

of the situation described by the text, rather than a representation of the text itself.

Overall, there were 22 true (78.5% of items) and six false (21.5% of items) statements for each environment.

Procedure

Learning. Each participant studied descriptions of the convention center and town from route or survey perspectives in a counterbalanced manner. Descriptions were presented on a computer screen one sentence at a time (14-pt Times New Roman font), removing the immediately preceding sentence before the next, at presentation rates established through a self-paced pilot study ($n = 8$). Average presentation time per sentence was 6.14 seconds (upper limit 9.86sec, lower limit 2.51sec, $SD = 1.62$ sec). Half of the participants learned each environment once, and half thrice. Because recent work (e.g., Noordzij et al., 2005, 2006) has demonstrated large influences of instructions and expectations on spatial mental model development, and further due to our blocked design, participants were instructed that they would be “*tested for their memory of the environment, including solving complex inference problems and reproducing a map from memory.*” These instructions came immediately prior to learning the first description.

Testing. Following each description participants completed the associated memory tasks in counterbalanced order. Participants had up to 10 minutes to draw their map. The true/false statements were self-paced and presented in random order one at a time; participants verified statements as quickly and accurately as possible by pressing keys labeled *true* (C) or *false* (M). Accuracy and response times were recorded.

Results

Scoring

Map Drawing. Maps were scored for landmark recall, relative landmark locations, and quadrant accuracy. Landmark recall compared the number of landmark names written on the maps relative to the total number learned (12). Relative landmark location assessed correspondence with 26 comparisons derived from survey (e.g., Is Maple St. south of the White Mountains?) and route (e.g., Is Maple St. on the left as you approach the White Mountains on Mountain Road?) descriptions. Whereas most drawn landmarks were labeled, it was not a requirement towards inclusion in this scoring procedure; landmarks depicted in generally the correct location and shape were included towards relative landmark location judgments. Quadrant accuracy was assessed by dividing each environment into quadrants along predetermined north/south and east/west axes, and comparing the number of landmarks drawn in each quadrant relative to the number supposed to appear in each quadrant. The four proportions were summed into a composite index of quadrant accuracy.

Test Statements. The accuracy and response times were averaged for each statement type within the two description perspectives.

Analysis

Three 2 (between, study cycle: 1 cycle, 3 cycles) X 2 (within, description perspective: route, survey) mixed repeated measures ANOVAs assessed map drawing performance. Three 2 (study cycle: 1 cycle, 3 cycles) X 2 (description perspective: route, survey) X 2 (statement type) mixed repeated measures ANOVAs examined accuracy from the statement verification task; three additional tests of this type examined log

(Log10; correcting positively-skewed distribution) transformed correct response time data. All planned comparisons used t -tests with the Bonferroni correction for multiple comparisons.

To examine test order effects we conducted a single mixed models ANOVA for each of our dependent measures using an additional factor: 2(between, order: map then statement verification, statement verification then map); none of these analyses showed any significant effects of test order (all p 's > .05). Thus, all subsequent analyses collapse across test order.

Map Drawing

The three map scoring procedures allowed for separate analyses of verbal landmark recall (declarative knowledge), relative landmark placement (local configural knowledge), and relative region placement (global configural knowledge). Each scoring procedure revealed specific memory advantages as a function of study cycle and description perspective (see Table 1).

Landmark Recall. Analysis of landmark recall yielded an effect of study cycle [$F(1, 46) = 11.220, MSe = .037, p < .01$]; participants recalled more landmarks after 3 cycles relative to 1 cycle, following both route and survey description learning.

Relative Landmark Locations. Relative landmark location accuracy yielded an effect of study cycle [$F(1, 46) = 12.053, MSe = .041, p < .01$]; participants located landmarks more accurately after 3 cycles relative to 1 cycle. An effect of description perspective [$F(1, 46) = 7.826, MSe = .041, p < .01$], revealed more accurate relative landmark placement after survey relative to route descriptions. Further, the data showed a study cycle by description perspective interaction [$F(1, 46) = 4.896, MSe = .041, p < .05$].

This interaction showed that the memory advantage for multiple study cycles was limited to route description reading as shown through independent samples t-tests using the Bonferroni correction (2 tests, critical alpha .025). Participants more accurately placed landmarks after 3 cycles relative to 1 cycle for route [$t(46) = 3.846, p < .01$], but not for survey descriptions [$t(46) = .946, p > .05$].

Quadrant Accuracy. As found with relative landmark accuracy, quadrant accuracy advantages for multiple study cycles is limited to route description reading. An effect of study cycle [$F(1, 46) = 14.343, MSe = .018, p < .01$], demonstrated higher accuracy after 3 cycles relative to 1 cycle. An effect of description perspective [$F(1, 46) = 7.309, MSe = .025, p < .05$] revealed higher accuracy following survey relative to route descriptions. Further, a study cycle by description perspective interaction [$F(1, 46) = 4.173, MSe = .025, p < .05$] indicated higher accuracy after 3 cycles relative to 1 cycle for route [$t(46) = 3.246, p < .01$], but not for survey descriptions [$t(46) = .198, p > .05$].

Statement Verification Accuracy

The statement verification task allowed us to examine both declarative memory (via locative verbatim within-perspective study and statement combinations; non-locative verbatim statements; paraphrased nonlocative statements), and inferencing and perspective switching from spatial mental models (via locative verbatim across-perspective study and statement combinations; locative inference statements). Overall, memory advantages of extended study time were found for the declarative memory measures following both route and survey description learning, and for the inferencing measures following route, but not survey, learning.

Testing for Response Bias. To test for response bias we conducted chi-square tests for dichotomous (true/false) variables, within the two description perspectives and two read cycles, using group averages organized in line with our statement verification ANOVAs. None of these tests revealed responses biased in the “true” direction ($\chi^2_{\max} = 3.14$, all p 's > .05; see Table 2).

Declarative Memory Measures. The present analyses compare memory for locative (verbatim within-perspective) and non-locative (verbatim, paraphrased) elements of the text. As depicted in Figure 1a, an effect of study cycle revealed higher accuracy after 3 relative to 1 cycle [$F(1, 46) = 4.27$, $MSe = .02$, $p < .05$]; this effect held for both description perspectives and for locative and non-locative statements. There were no other significant effects for these statement types (all p 's > .05).

Inference Measures. The present analyses compare memory for within-perspective (within-perspective inference) and across-perspective (across-perspective inference, across-perspective verbatim locative) application of spatial mental models. As depicted in Figure 1b, an effect of study cycle revealed higher accuracy after 3 relative to 1 cycle [$F(1, 46) = 11.115$, $MSe = .036$, $p < .01$]. Further, a study cycle by description perspective interaction showed a greater influence of the study cycle manipulation following route, relative to survey, descriptions [$F(1, 46) = 4.56$, $MSe = .031$, $p < .05$]. Specifically, participants responded more accurately after 3 cycles relative to 1 cycle following route description learning, for both within-perspective [$t(46) = 2.56$, $p < .01$] and across-perspective statements [$t(46) = 3.42$, $p < .01$]. These differences were not present following survey description learning (p 's > .05).

Statement Verification Response Time.

Analysis of statement verification response times allowed us to consider the relative difficulty of our tasks as a function of study cycles and learning perspective.

Declarative Memory Measures. As depicted in Figure 2a, there was a marginal effect of study cycle, suggesting faster response times after 3 cycles relative to 1 cycle [$F(1, 46) = 2.84, MSe = .03, p < .10$]. There were no other significant effects for these statement types (all p 's $> .05$).

Inference Measures. As depicted in Figure 2b, an effect of study cycle revealed higher accuracy after 3 relative to 1 cycle [$F(1, 46) = 14.373, MSe = .024, p < .01$]. Further, a study cycle by description perspective interaction showed a greater influence of the study cycle manipulation following route, relative to survey, descriptions [$F(1, 46) = 4.15, MSe = .019, p < .05$]. Specifically, participants responded more accurately after 3 cycles relative to 1 cycle following route description learning, for both within-perspective [$t(46) = 2.32, p < .025$] and across-perspective statements [$t(46) = 2.69, p < .01$]. These differences were not present following survey description learning (p 's $> .05$). Finally, there was a main effect of statement type [$F(1, 46) = 38.98, MSe = .012, p < .01$], whereby within-perspective inference questions were responded to faster than across-perspective inference questions. There were no other significant effects for these statement types (all p 's $> .05$).

Discussion

As previous work has suggested, increased experience with environments solidifies spatial mental model formation. Experiment 1 extended these findings to repetition of spatial descriptions. First, we found evidence that increased exposure (as

operationalized in study cycles) influenced spatial memory representations, with improved map drawing and inferencing speed and accuracy as a function of increased exposure. Second, we found higher accuracy and lower response times on inference verification following survey relative to route learning, when study time was restricted to one cycle. Importantly this effect diminished with exposure. This same interaction was found on relative location and quadrant accuracy in map drawing. Finally, we found that overall, inferencing performance was faster when there was no perspective switch from study to test. This finding demonstrates increased effort in generating an inference when that inference also requires a perspective switch.

Taken together, these results suggest that the ability to build spatial mental models from descriptions and apply them to the present tasks is contingent upon sufficient exposure, especially for route descriptions; that is, as with navigation, route description reading can serve map drawing and inferencing tasks, but only after extensive experience. Importantly, this contrasts with survey description reading which appears to serve these tasks relatively well after limited exposure. They further illustrate the added processing cost when inference generation also require a perspective switch, suggesting that even after three read cycles participants are maintaining some perspective characteristics of the descriptions. The implications of this latter finding will be further explored in the General Discussion.

Experiment 2

Our second experiment used self-paced reading to examine changes in reading times as a function of experience and description perspective. We address the question of whether and difficulties in developing spatial mental models during route description

reading will manifest themselves in participant reading times. Participants read each description three times in a self-paced manner. Taking into account Experiment 1 results, we made two main predictions. First, if constructing spatial mental models from route descriptions demands extensive experience, but survey descriptions do not, reading times should decrease across presentations of survey descriptions at a steeper rate than route descriptions. This hypothesis is based on the notion that increased reading times during discourse comprehension reflect increased difficulty integrating information into a developing situation model (i.e., Graesser, Swamer, & Hu, 1997; Haberlandt & Graesser, 1985).

Method

Participants

Sixteen Tufts University undergraduates participated for partial course credit.

Materials

All materials matched those used in Experiment 1.

Procedure

All procedures, with the exception of a change to self-paced reading and the elimination of the 1 study cycle, matched those of Experiment 1. Participants read descriptions three times in a self-paced manner, one sentence at a time (successive sentences replaced prior sentences), pressing the space bar to advance. Reading times per sentence were recorded. Following learning, they completed the two memory tasks. This procedure repeated for the second description.

Results

Scoring

Map drawing and statement verification scoring matched Experiment 1.

Reading Times. Two sentence types were analyzed, spatial and descriptive.

Spatial sentences described relative landmark locations or movement and orientations within an environment, and descriptive sentences detailed the landmarks. Reading times were divided by the number of syllables per sentence and averaged for each sentence type. A total of 23 outliers ($M \pm 2.5SD$; comprising 1.8% of all data) were removed from analyses.

Spatial Reading Times

Average reading times to spatial sentences revealed decreasing reading times as a function of increased study cycles; this effect, however, interacted with description perspective. Participants read both route and survey descriptions with similar speed on the first cycle, and subsequent cycles showed larger reading time reductions for survey relative to route descriptions. A main effect of presentation (1st, 2nd, or 3rd presentation) [$F(2, 30) = 111.923, MSe = 1010, p < .01$] revealed faster reading times for presentation 3 relative to presentation 1 [$t(15) = 19.435, p < .01$], and 2 [$t(15) = 6.499, p < .01$], see Figure 3a. Further, presentation 2 reading times were also faster than those for presentation 1 [$t(15) = 7.278, p < .01$]. An effect of perspective [$F(1, 15) = 4.944, MSe = 3462, p < .05$], revealed slower reading times for route relative to survey descriptions. A presentation by perspective interaction [$F(2, 30) = 14.976, MSe = 766.3, p < .01$], revealed that reading times became faster over the three presentations for survey descriptions at a steeper rate than for route descriptions. Specifically, survey and route

reading times did not differ within presentation 1 [$t(15) = 1.159, p > .05$], but differed in both presentations 2 [$t(15) = 2.525, p < .025$], and 3 [$t(15) = 3.924, p < .01$], with higher reading times for route relative to survey in both cases.

Descriptive Reading Times

In contrast to spatial sentence reading times, descriptive sentence reading times did not show an interaction between study cycle and description perspective. An effect of presentation [$F(2, 30) = 123.917, MSe = 1068, p < .01$] revealed faster reading times for presentation 3 relative to presentation 1 [$t(15) = 13.610, p < .01$], see Figure 3b. Further, presentation 2 reading times were faster than those for presentation 1 [$t(15) = 10.071, p < .01$]. Presentation did not interact with perspective. Note that descriptive reading times were faster than spatial reading times for both perspectives and within each presentation (all $p < .01$).

Memory Tasks

As in Experiment 1, we conducted a single mixed model ANOVA for each of our dependent measures using the additional factor of test order; none of these analyses showed any significant effects of test order (all p 's $> .05$). Thus, all subsequent analyses collapse across test order.

Memory task results replicated those from the 3 study cycle group in Experiment 1, see Tables 3 and 4 for data from the map drawing and statement verification tasks, respectively.

Map Drawing

There was no effect of description perspective for any of the map drawing measures (all p 's $> .05$; see Table 3).

Statement Verification Accuracy and Response Time (see Table 4)

Testing for Response Bias. As in Experiment 1, none of these tests revealed observed responses biased in the “true” direction ($\chi^2_{\max} = 3.22$, all p 's > .05; see Table 2).

There was no effect of description perspective or statement type on any of the declarative or inference measures (all p 's > .05).

Discussion

Experiment 2 demonstrated differential reductions in average reading times across study cycles as a function of description perspective. The negative slope over the three study cycles associated with survey descriptions was larger than that of route descriptions. This pattern was specific to spatial (versus descriptive) sentences. Memory task performance replicated that of the 3 study cycle group in Experiment 1. These results showed that participants could make inferences from either perspective, regardless of the learned perspective, but that inferencing was more difficult than retrieving information directly. Overall, these results suggest that route, relative to survey description reading, is difficult to the extent that it requires greater reading times to acquire comprehensive spatial mental models. We also note that unlike Experiment 1, there was no evidence for perspective-specificity when comparing within- versus across-perspective response times; the self-paced description reading may have provided individuals with ample opportunity to develop perspective-flexible models. Finally, we have demonstrated that self-paced reading is an effective design for allowing relatively naturalistic reading and examining the time course of spatial description reading.

General Discussion

Taken together, the present results illustrate that theoretical and computational accounts of spatial knowledge progression (i.e., Kuipers et al., 2001; Siegel & White, 1975; Thorndyke & Hayes-Roth, 1982) can be partially applied to spatial descriptions, complementing earlier work with maps and navigation. It appears that with route descriptions, similar to results found with navigation (e.g., Golledge & Spector, 1978; Thorndyke & Hayes-Roth, 1982), people require extensive environment experience to form spatial mental models. In contrast, with survey descriptions, similar to results found with maps (e.g., Taylor & Tversky, 1992a), the same degree of environment exposure does not seem necessary. These results suggest that survey descriptions are more directly translated into abstracted spatial mental models relative to route descriptions; these models are suitable for both configural tasks such as map drawing, and inference-making. This does not appear to be an effect of transfer-appropriate mechanisms; the present tasks demanded the application of configural memories (map drawing), egocentric memories (route statement verification), and spatial mental models (route and survey inference statement verification). After reading three times, each of these tasks was done equally well after both route and survey description reading. With only one reading of route descriptions participants were less able to perform both inferencing (within and across perspectives) and map drawing. It appears that spatial description readers may develop abstracted mental models of described environments, but clearly this may be partially an effect of reading experience and description perspective. These results support work demonstrating spatial mental model development following spatial description reading (e.g., De Beni et al., 2005; Denis, in press; Deyzac et al., 2006; Taylor & Tversky,

1992a), and other work suggesting relative difficulty developing these models with route relative to survey descriptions (e.g., Lee & Tversky, 2005; Noordzij & Postma, 2005; Noordzij, Zuidhoek, & Postma, 2006).

These results can be attributed to at least four mechanisms. First, while survey descriptions are presented hierarchically (breadth then depth), route descriptions are presented serially and may demand greater online information maintenance within working memory during reading, and updating relative to a principle reference vector (e.g., Shelton & McNamara, 2004). This maintenance may detract from cognitive resources necessary for higher-order integration and consolidation (i.e., Sweller, 1988). Relatedly, while survey descriptions directly convey configural information, that same information must be inferred from route descriptions. Spatial inferences may be formed during learning (online) and at retrieval (i.e., Graesser, Singer, & Trabasso, 1994), and presumably require a high degree of cognitive resources (i.e., Estevez & Calvo, 2000; Linderholm, 2002; Rapp, Klug, & Taylor, 2006). Third, route descriptions may promote active egocentric imagery, such as imagining ones' self walking (or driving) through the unknown environment, presenting additional cognitive load at the expense of higher-level abstraction, at least with limited experience (i.e., De Beni et al., 2005; Deyzac et al., 2006). Finally, in addition to spatial information, route descriptions inherently convey temporal-sequential information (e.g., *after* turning onto Maple St), perhaps necessitating increased cognitive load and detracting from visuospatial resources (i.e., Zwaan & Radvansky, 1998).

Seminal work looking at the progression of spatial knowledge development during navigation suggested that individuals represent landmarks, then landmark

interrelationships, then develop a mental model of the environment (Siegel & White, 1975). More recent work has demonstrated that the time course of mental model development may in fact be less sequential and more simultaneous in nature (e.g., Ishikawa & Montello, 2006; McDonald & Pellegrino, 1993; Ruddle et al., 1997); the present results support this work in several ways. Following only one study cycle of a route description participants were able to answer within- and across- perspective inference statements at a rate above chance (50%); thus, while accuracy was relatively low and responses were delayed, participants could still form limited inferences about the environment, from both route and survey perspectives. Taken together these results suggest that even after only one study cycle route description readers were able to *begin* developing flexible spatial mental models. These early models do not appear to be biased towards the route perspective, but also do not provide a high degree of service to inference generation. This work provides some support for the notion that developing mental models of environments may be best-characterized as a non-sequential process (i.e., Ishikawa & Montello, 2006; McDonald & Pellegrino, 1993; Ruddle et al., 1997). Even with limited experience with an environment the developing models are not inextricably bound to the learning format, suggesting that model development begins earlier rather than later, even with route descriptions.

The present design also allowed us to examine the influence of perspective switching during test. Experiment 2 results supported the notion that spatial mental models are perspective-flexible to the extent that accuracy or response times show no differences between when a perspective switch is required versus when it is not. Participants were able to inference from both route and survey perspectives with similar

accuracy and response times, perhaps due to the self-paced design allowing for extended reading times. Experiment 1 response time results showed that even with three reads participants are maintaining some perspective characteristics of the studied descriptions. This result is congruent with Shelton and McNamara's (2004) finding using the same descriptions: scene recognition shows biases towards the initial orientation of either given perspective. Spatial mental models may in fact preserve perspective characteristics in some situations, but Experiment 2 suggests that with over-learning, and other work suggests that with extended study-test lag time (i.e., Kintsch, Welsch, Schmalhofer, & Zimny, 1990), these effects may diminish. Taken together the present findings add to a growing body of evidence demonstrating that the development of spatial mental models is quite contingent upon multiple characteristics of the learning and testing circumstances.

It is our view that survey description readers develop spatial mental models even with limited reading experience, and that these models can be successfully applied to inferencing and map drawing. Even early on, these models do not appear to be tied to the learning perspective, as reflected in accuracy and response times to across-perspective inferences. Readers of route descriptions, however, only develop functionally comparable spatial mental models after sufficient exposure to the environment, in this case operationalized as three study cycles. Following three cycles the eventuating models following both route and survey description reading appear to be functionally equivalent; this is not to say, however, that these are equivalent in form, *or* that spatial mental models formed from survey descriptions do not also change with experience. Rather, our dependent measures demonstrate similar inferencing and map drawing performance after

three reads of survey and route descriptions; that is, only with additional reading can route description readers reach the performance of a survey description reader. This result may reflect a relatively static spatial mental model following only one survey description read; in contrast, it could possibly reflect an inability for our measures to differentiate between early and later mental models formed from survey descriptions. This could also reflect a ceiling effect following a single read of a survey description that precludes substantial accuracy increases following three reads; note, however, that the overall high response times also do not show substantial improvements following three relative to one read of a survey description. We feel that our dependent measures – drawing maps and inferencing about an environment – both have a high degree of ecological validity; for instance, forming inferences and taking an allocentric perspective both appear to be involved in complex wayfinding tasks (Hartley, Maguire, Spiers, & Burgess, 2003; Kato & Takeuchi, 2003; McNamara & Shelton, 2003; Montello, 2005; Prestopnik & Roskos-Ewoldsen, 2000; Rapp, 2003). We encourage the development and application of additional dependent measures (e.g., metric distance estimation; Noordzij & Postma, 2005; scene recognition; Shelton & McNamara, 2004) to provide a basis for a more precise determination of how mental models progress during survey description reading.

In considering our results we have drawn analogies between studying maps and reading survey descriptions, and navigating an environment and reading route descriptions. Taking this view allows for a rather parsimonious account of why spatial mental model development varies as a function of input perspective, but also introduces a few conceptual issues. First, there are obvious differences between the cognitive processes involved while studying a map versus reading a survey description; both,

however, allow a participant to derive information from an allocentric perspective (inherent to studying a map, or explicated in a spatial description), and directly convey configural information with limited inferencing about environmental layout. Second, there are large experiential differences between navigating an environment and studying a route description; both, however, restrict information acquisition to a serial process, allow participants to derive information from an egocentric perspective, and provide an indirect mechanism for gathering information about landmark interrelationships. The present work demonstrates that while most studies have compared maps with navigation as both input mechanisms and contributors to different mental representations, similar conclusions may be drawn from examining these issues with spatial descriptions.

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Table 1. *Experiment 1 Means and Standard Deviations for the Three Map Scoring Procedures, by Study Perspective and Study Cycle Group*

Measure and Group	Study Perspective			
	Survey		Route	
	M	SD	M	SD
<i>Landmark Recall</i>				
1 Study cycle	.774	.209	.753	.213
3 Study cycles	.903	.144	.889	.180
<i>Relative Landmark Locations</i>				
1 Study cycle	.903	.210	.698	.267
3 Study cycles	.955	.169	.931	.129
<i>Quadrant Accuracy</i>				
1 Study cycle	.941	.120	.792	.245
3 Study cycles	.982	.075	.961	.069

Table 2. *Experiment 1 and 2 chi-square values testing for response bias towards the “true” direction on the statement verification task. Values are presented by measure (locative and non-locative declarative; within- and across-perspective inference), by description perspective, and by study cycle group. $\chi^2_{crit, \alpha=.05} = 3.84$ for all conditions.*

Statement Type and Group	Study Perspective	
	Survey χ^2_{avg}	Route χ^2_{avg}
Exp 1: One Read Cycle Group		
<i>Declarative Measures</i>		
Locative	2.55	2.57
Non-locative	2.31	2.45
<i>Inference Measures</i>		
Within-perspective	3.14	3.14
Across-perspective	2.92	3.04
Exp 1: Three Read Cycle Group		
<i>Declarative Measures</i>		
Locative	2.52	3.06
Non-locative	2.36	2.64
<i>Inference Measures</i>		
Within-perspective	3.04	3.04
Across-perspective	3.00	2.99
Exp 2: One Read Cycle Group		
<i>Declarative Measures</i>		
Locative	3.02	2.29
Non-locative	2.64	2.16
<i>Inference Measures</i>		
Within-perspective	2.84	2.97
Across-perspective	3.12	2.82
Exp 2: Three Read Cycle Group		
<i>Declarative Measures</i>		
Locative	2.96	3.22
Non-locative	2.62	2.54
<i>Inference Measures</i>		
Within-perspective	2.78	2.98
Across-perspective	2.62	2.86

Table 3. *Experiment 2 Means and Standard Deviations for the Three Map Scoring Procedures, by Study Perspective*

Scoring Procedure	Study Perspective			
	Survey		Route	
	M	SD	M	SD
Landmark Recall	.895	.144	.911	.103
Relative Landmark Locations	.951	.078	.949	.081
Quadrant Accuracy	.964	.051	.945	.101

Note: No main effects of study perspective found in three one-way repeated measures ANOVAs.

Table 4. *Experiment 2 Accuracy and Response Time Means and Standard Deviations for the Statement Verification Task*

Statement Type	Study Perspective			
	Survey		Route	
	M	SD	M	SD
Accuracy				
<i>Declarative Measures</i>				
Locative	.968	.085	.906	.180
Non-locative	.951	.053	.937	.064
<i>Inference Measures</i>				
Within-perspective	.844	.166	.865	.174
Across-perspective	.854	.097	.790	.133
Response Times (sec.)				
<i>Declarative Measures</i>				
Locative	5.27	1.64	5.11	2.66
Non-locative	3.68	1.21	4.46	1.04
<i>Inference Measures</i>				
Within-perspective	7.23	2.16	7.52	2.85
Across-perspective	7.26	1.79	7.59	1.68

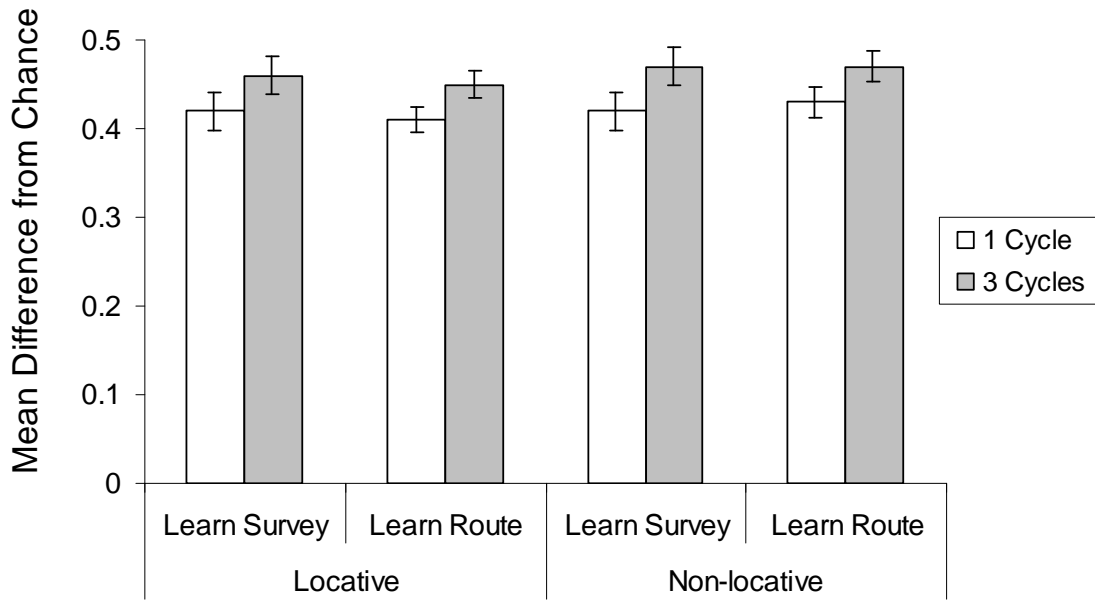
Figure Captions

Figure 1a-b. Experiment 1 mean percent correct accuracy levels represented as difference from chance (.5), for the two groups (1 study cycle, 3 study cycles), two description perspectives (survey, route), and two general classes of statement verification items: (a) locative and non-locative items that probe for declarative memory, (b) within- and across-perspective inference statements that probe for spatial mental model availability.

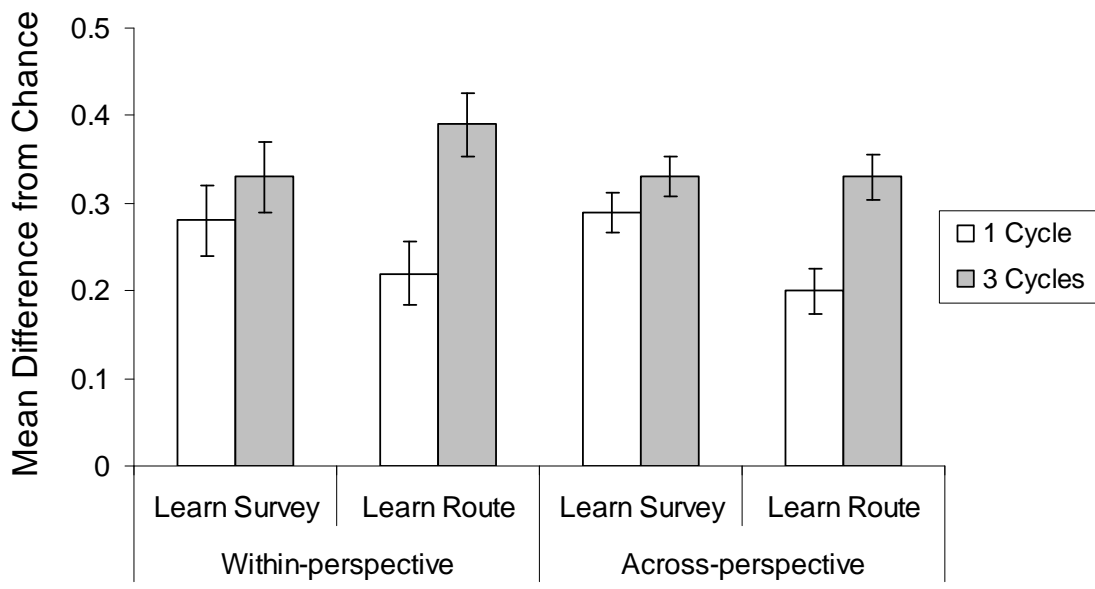
Figure 2a-b. Experiment 1 mean response time to correct statement verifications for the two groups (1 study cycle, 3 study cycles), two description perspectives (survey, route), and two general classes of statement verification items: (a) locative and non-locative items that probe for declarative memory, (b) within- and across-perspective inference statements that probe for spatial mental model availability.

Figure 3a-b. Experiment 2 mean reading times in milliseconds per syllable for the three presentations (1, 2, 3) and two description perspectives (survey, route), for (a) spatial sentences and (b) descriptive sentences.

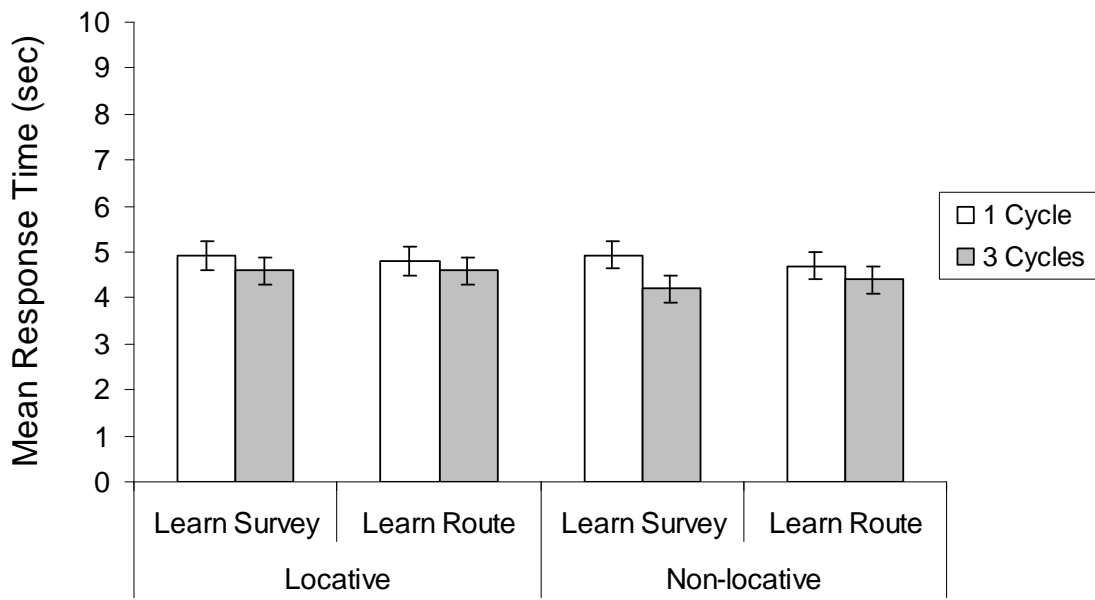
1a



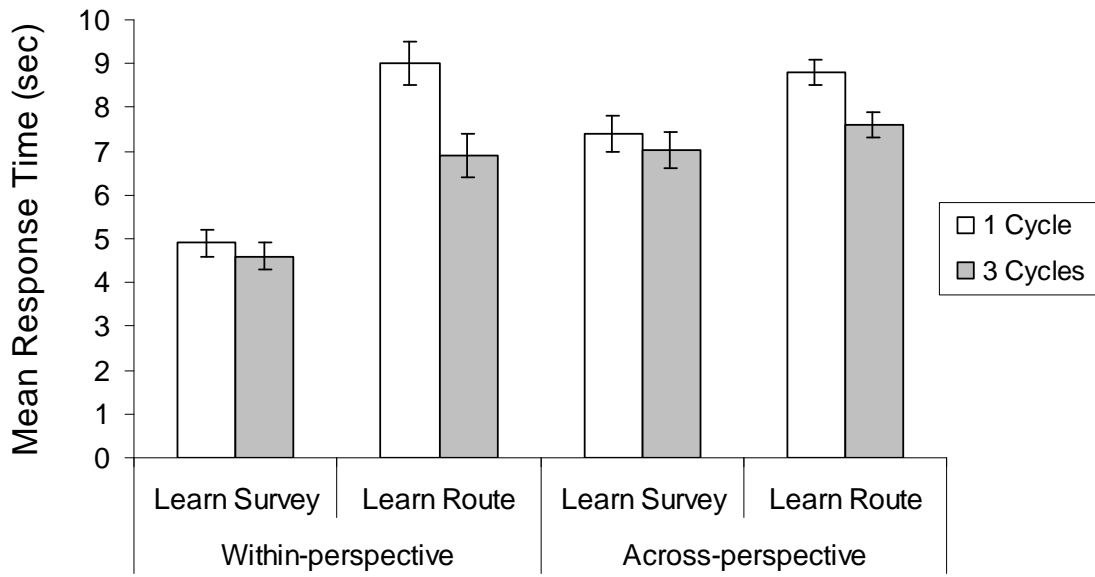
1b

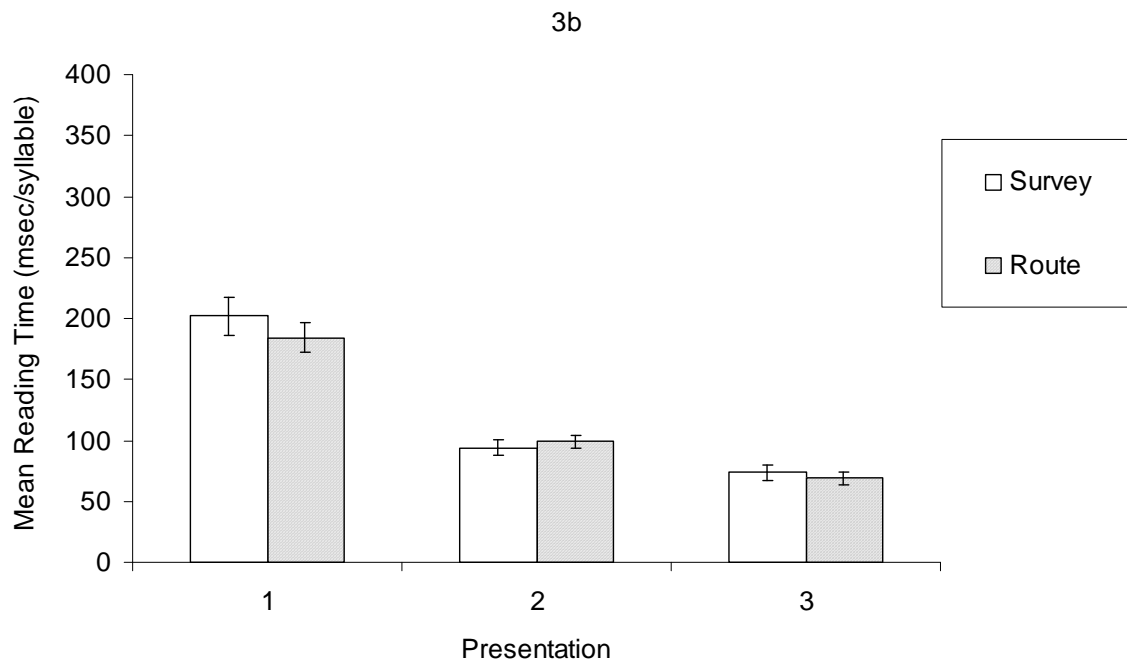
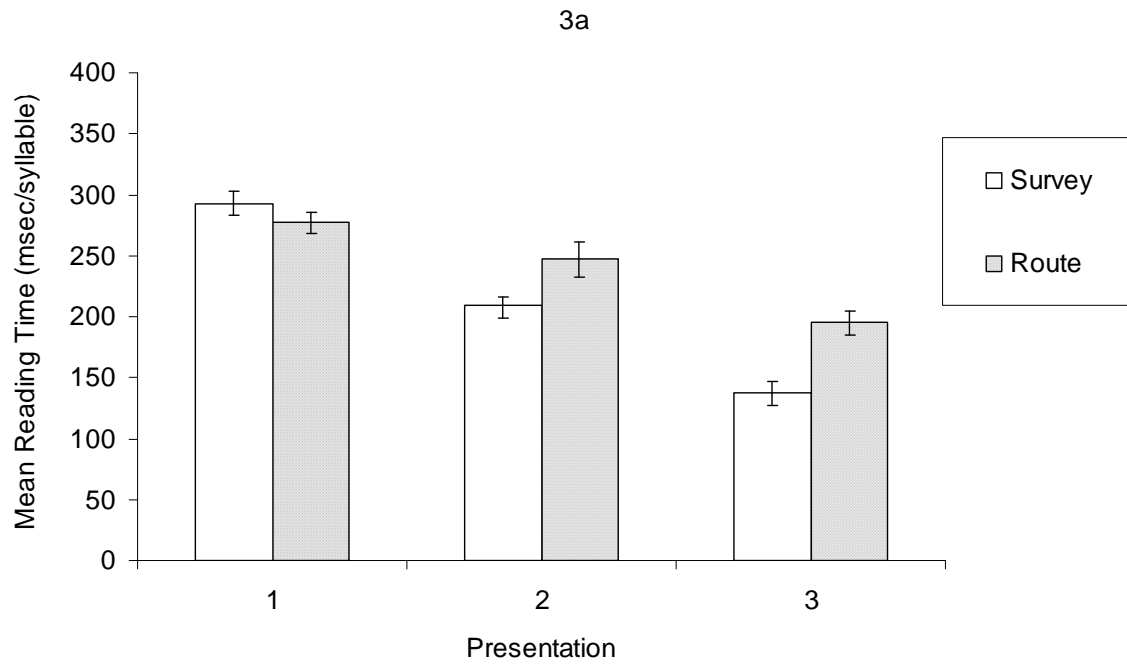


2a



2b





Appendix A

Survey Description: Convention Center

Several companies that manufacture electronics have decided to get together for a convention to show their wares. A large convention center was chosen because its large rectangular floor plan can be easily changed to accommodate the needs of various conventions. Temporary wall dividers are used to separate the displays and to form a single entrance to each display. The displays have been grouped according to three categories--Visual Equipment, Personal Computers, and Audio Equipment. The rectangular center section of the building is divided into four displays for the visual equipment. In the northwest corner of the center section, with the entrance facing north, are the Televisions. Like many television displays, the sets are lined up along the walls, all tuned to the same station. In the northeast corner of the center section, with the entrance facing north, are the VCR's. In the southwest corner of the center section, with the entrance facing south, are the 35mm Cameras. In the southeast corner of the center section, with the entrance facing south, are the Movie Cameras. The Movie Cameras are set up to film people as they walk by the display. The remainder of the displays are along the outer, rectangular wall of the Convention Center. The east wall has only one display, the Personal Computers. This display is in the northeast corner and extends for about half of the east wall. There are software samples available for potential customers to test the various computers. Along the north wall are the two Audio Equipment displays--the Stereo Components and the CD Players. Along the north wall, directly west of the Personal Computers, are the Stereo Components. The Stereo Components display includes such items as receivers, turntables, speakers, and tape decks. Directly west of the Stereo Components are the CD Players. In addition to the displays, there are four permanent features of the Convention Center located along the west and south walls--the Cafeteria, the Restrooms, the Office, and the Bulletin Board. Just west of the CD Players, beginning in the northwest corner of the Convention Center and extending for about half of the west wall, is the Cafeteria. The Cafeteria is privately run by a family that leases the space on a permanent basis from the Convention Center. Directly south of the Cafeteria, on the west wall, are the Restrooms. Directly south of the Restrooms, extending from the southwest corner for about a third of the south wall, is the Office. East of the Office, covering about half of the south wall, is the Bulletin Board. The Bulletin Board is used in every convention for the business cards of the participating companies. East of the Bulletin Board, on the east side of the building near the southeast corner, is the entrance.

Route Description: Convention Center

Several companies that manufacture electronics have decided to get together for a convention to show their wares. A large convention center was chosen because its large, rectangular floor plan can be easily changed to accommodate the needs of various conventions. Temporary wall dividers are used to separate the displays and to form a single entrance to each display. The displays have been grouped according to three categories--Visual Equipment, Personal Computers, and Audio Equipment. You go to the east side of the building near the southeast corner where you find the entrance. As you walk into the building, you see, on your left, a Bulletin Board. The Bulletin Board is used in every convention for the business cards of the participating companies. Continuing straight ahead from the entrance, where the Bulletin Board is on your left, you reach, on your right, the Movie Cameras. The Movie Cameras are set up to film people as they walk by the display. Walking past the Movie Cameras on your right, you see, again on your right, the 35mm Cameras. On your left, stretching into the corner of the building, is the Office. From the Office, you are forced to turn right and you see, to your immediate left, the Restrooms. You continue forward from the Restrooms until you see, on your left stretching into the corner of the building, the Cafeteria. The Cafeteria is privately run by a family that leases the space on a permanent basis from the Convention Center. From the Cafeteria, you walk forward, until you are forced to turn right and you see, to your immediate left, the CD Players. On your right are the Televisions. Like many television displays, the sets are lined up along the walls, all tuned to the same station. You walk past the Televisions, on your right, and continue forward until you see, again on your right, the VCR's. On your left are the Stereo Components. This display includes such items as receivers, turntables, speakers, and tape decks. From the Stereo Components you walk forward until you are forced to turn right and you see, to your immediate left, the Personal Computers. There are software samples available for potential customers to test the various computers. From the Personal Computers, you walk until you reach, on your left, the corridor leading to the entrance of the building.

Appendix B

Survey Description: Town

One of the largest town fairs and pumpkin festivals in the United States is held each year in the town of Etna. Etna is a typical small New England town. The lay-out of the town has not changed much since it was founded in the 1700's. Etna and its surrounding areas are bordered by four major landmarks: the White Mountains, the White River, the River Highway, and Mountain Rd. The northern border is made up of the White Mountain Range. Running north-south along the western border of this region is the White River. The southern border is made up of the River Highway. Along the eastern border, connecting the River Highway to the mountains, is Mountain Rd. Most of Etna lies west of Mountain Rd. just north of its intersection with the River Highway. Etna is built around four streets that surround the Town Park. On the eastern edge of the park, there is a white Gazebo. The Gazebo is used to house the town band during afternoon concerts. Along the eastern edge of the Town Park runs Mountain Rd. The other three streets in Etna are each only a block long. Along the southern border of the park runs Maple St. Maple St. is lined with large maple trees. These maples, when they come alive with color in the fall are an attraction for many tourists. Across the street from the park, on separate sides, lie three of the town's main buildings--the Town Hall, the Store, and the School. Across the street from the east side of the park is the Town Hall. The Town Hall is the oldest structure in the town and one of the buildings around which the town was built. Across the street from the north side of the park is the Store. People often gather at the Store to find out the latest town news. Across the street from the west side of the park is the School. The little red, one-roomed schoolhouse is the original school built when the town was founded. At the northwest corner of River Highway and Mountain Rd. is the Gas Station. One of the mechanics from the Gas Station sits in front of the station office and waves to all the cars that drive past.

Route Description: Town

One of the largest town fairs and pumpkin festivals in the United States is held each year in the town of Etna. Etna is a typical small New England town. The lay-out of the town has not changed much since it was founded in the 1700's. To reach Etna, drive east along the River Highway to where the highway crosses the White River. Continuing on the River Highway, for another half mile past the river you come to, on your left, Mountain Rd. You have reached the town of Etna. As you turn left onto Mountain Rd. from the River Highway, you see, on your immediate left, the Gas Station. One of the mechanics from the Gas Station sits in front of the station office and waves to all the cars that drive past. Straight ahead, you can see the road disappearing into the distant White Mountains. You drive on Mountain Rd. a block past the Gas Station, and come to, on your left, Maple St. Turning left onto Maple St., you see that the street is lined with large maple trees. These maples, when they come alive with color in the fall, are an attraction for many tourists. After turning left onto Maple St. from Mountain Rd., you see, on your right, the Town Park--a central feature of Etna. You travel a block on Maple St. and are forced to make a right turn. On your left, about a half a block after you turn off of Maple St., is the School. The little red, one-roomed schoolhouse is the original school built when the town was founded. Continuing along this street for another half a block, you are again forced to make a right turn. You turn and drive a half a block where you see, on your left, the Store. People often gather at the Store to find out the latest town news. This road continues for another half a block where it dead-ends into Mountain Rd. After you make a right turn onto Mountain Rd., you drive about a half a block to where you see, on your left, the Town Hall. The Town Hall is the oldest structure in the town and one of the buildings around which the town was built. From your position with the Town Hall on your left, you see, on your right, a white Gazebo near the edge of the park. The Gazebo is used to house the town band during afternoon concerts. You return to where Mountain Rd dead-ends into the River Highway. You turn left from Mountain Rd. and leave the town of Etna by taking the River Highway.

Appendix C

Town Environment

Survey Verbatim Locative

1. The northern border is made up of the White Mountain Range. 14
2. Along the eastern edge of the Town Park runs Mountain Rd. 14
3. On the eastern edge of the Town Park, there is a white Gazebo. 16
4. At the northwest corner of River Highway and Mountain Rd. is the Gas Station. 20

Route Verbatim Locative

1. As you turn left onto Mountain Rd. from River Highway, you see, on your immediate left, the Gas Station. 27
2. You drive on Mountain Rd. a block past the Gas Station, and come to, on your left, Maple St. 23
3. After turning left onto Maple St. from Mountain Rd., you see, on your right, the Town Park--a central feature of Etna. 36
4. From your position with the Town Hall on your left, you see, on your right, a white Gazebo near the edge of the park. 28

Verbatim Non-Locative

1. Etna is a typical small New England town. 12
2. The Town Hall is the oldest structure in the town and one of the buildings around which the town was built. 25
3. One of the largest town fairs and pumpkin festivals in the United States is held each year in the town of Etna. 29
4. People often gather at the Store to find out the latest town news. 17

Paraphrased Non-Locative

1. An attraction for many tourists, when they come alive with color in the fall, are the maples. 24
2. Built when the town was founded, the original school is the little red, one-roomed schoolhouse. 22
3. Waving to all the cars that drive past the front of the Gas Station is one of the station mechanics. 25
4. The town band uses the Gazebo during their afternoon concerts. 27

Survey Inference

1. The closest building to the White River is the School. 13
2. The Gas Station is east of the river and south of Maple St. 16
3. Directly across the Mountain Rd. from the Gazebo is the Town Hall. 18
4. The School is on a road that runs east-west. 10
5. On the west side of Mountain Rd. is the Town Hall. 12
6. Directly across the park from the School is the Gas Station. 15

Route Inference

1. From your position with the Town Hall on your left, the White Mountains are behind you. 20
2. Driving toward Mountain Rd. on Maple St., the School is behind you. 17
3. Driving from the Town Hall to the Gas Station, you pass Maple St on your right. 19
4. Driving toward the White Mountains on Mountain Rd., the Gas Station and the Town Hall will both be on your right. 26
5. Coming from the White Mountains on Mountain Rd., you turn left to reach the Store. 18
6. Driving toward Mountain Rd. from the Store, you see, on your left, the gazebo. 19

Convention Center Environment

Survey Verbatim Locative

1. Along the north wall, directly west of the Personal Computers are the Stereo Components.
2. Directly south of the Cafeteria, on the west wall, are the Restrooms.
3. In the northwest corner of the center section, with the entrance facing north, are the Televisions.
4. East of the Bulletin Board, on the east side of the building near the southeast corner, is the entrance.

Route Verbatim Locative

1. As you walk into the building, you see, on your left, a Bulletin Board.
2. You walk past the Televisions, on your right, and continue forward until you see, again on your right, the VCR's.
3. Walking past the Movie Cameras on your right, you see, again on your right, the 35mm Cameras.
4. Continuing straight ahead from the entrance, where the Bulletin Board is on your left, you reach, on your right, the Movie Cameras.

Verbatim Non-Locative

1. Several companies that manufacture electronics have decided to get together for a convention to show their wares.
2. The Cafeteria is privately run by a family that leases the space on a permanent basis from the Convention Center.
3. Like many Television Displays, the sets are lined up along the walls, all tuned to the same station.
4. Temporary wall dividers are used to separate the displays and to form a single entrance to each display.

Paraphrased Non-Locative

1. Some of the items in the Stereo Components Display include receivers, tape decks, and turntables.
2. The Movie Cameras are set up so that they film the passers-by.
3. Companies who are participating in the convention use the Bulletin Board to display their business cards.
4. Software samples are available so that customers can test the Personal Computers.

Survey Inference

1. The VCR's are north of the Movie Cameras and east of the Televisions.
2. Directly east of the Cafeteria are the CD Players.
3. The Cafeteria is northwest of the entrance and north of the Restrooms.
4. South of the 35mm Cameras are the Televisions.
5. Directly south of the Office are the Restrooms.
6. The Personal Computers are west of the Cafeteria and south of the entrance.

Route Inference

1. Looking into the Movie Camera Display, the Bulletin Board is behind you.
2. Walking from the Personal Computers to the Televisions, you pass, on your right, the Stereo Components.
3. Looking into the VCR display, the Cafeteria is to your right.
4. Walking from the Stereo Components to the CD's, you pass, on your right, the 35mm Cameras.
5. Walking from the Restrooms to the entrance, you pass, on your right, the CD Players.
6. Looking into the Cafeteria, the Office is to your left.