Available online at www.sciencedirect.com
ScienceDirect
ELSEVIER
Cognition xxx (2008) xxx–xxx
COGNITION
www.elsevier.com/locate/COGNIT

Representational flexibility and specificity following spatial descriptions of real-world environments

Tad T. Brunyé [a,*], David N. Rapp [b], Holly A. Taylor [c]

[a] *U.S. Army NSRDEC, Attn AMSRD-NSC-WS-P, Consumer Research & Cognitive Science, Kansas St., Natick, MA 01760, USA*
Q3 [b] *School of Education and Social Policy & Department of Psychology, Northwestern University*
[c] *Department of Psychology, Tufts University*

Received 17 September 2007; revised 4 March 2008; accepted 11 March 2008

Abstract

Current theories are mixed with regard to the nature of mental representations following spatial description reading. Whereas some findings argue that individuals' representations are invariant following text-based, map-based, or first-person experience, other studies have suggested that representations can also exhibit considerable flexibility. In the current project we investigated the influences of spatial description perspectives and depictions on the nature of mental representations. In Experiment 1, participants exhibited more flexibility following survey, compared to route, spatial descriptions. With extended study time, though, flexibility following route descriptions increased. In Experiment 2, complementary maps further enhanced flexibility for route-based descriptions. Interestingly, increased exposure to these maps actually reduced flexibility following survey descriptions. These results demonstrate that the nature of our spatial mental representations depends upon a variety of factors; delineating these factors is critical for resolving debates concerning the malleable and invariant characteristics of spatial memory.

Keywords: Spatial cognition; Mental models; Memory; Maps

---

[*] Corresponding author. Tel.: +1 617 306 6262.
E-mail address: tbrunye@alumni.tufts.edu (T.T. Brunyé).

0010-0277/$ - see front matter © 2008 Published by Elsevier B.V.
doi:10.1016/j.cognition.2008.03.005

Please cite this article in press as: Brunyé, T. T. et al., Representational flexibility and specificity ..., *Cognition* (2008), doi:10.1016/j.cognition.2008.03.005

1. Introduction

We learn about environments in a variety of ways; we can explore environments on foot, listen to verbal descriptions of places and spaces, study maps, and even build expectations for locations we have never seen. Our acquisition of knowledge about environments, and our resulting exploratory behavior within them, is thus informed by many different sources. Indeed, these diverse information sources can provide very different spatial perspectives for the environments they represent. For example, maps typically provide an overhead, survey view of features in an environment; in contrast verbal descriptions may provide first-person, route-based information about landmarks and paths, or relatively external bird's-eye information about environmental layout (Levelt, 1982; Linde & Labov, 1975; Taylor & Tversky, 1992b). Some sources even combine these perspectives: consider automobile GPS units that display map coordinates accompanied by verbal warnings for turns, or video games that allow players to navigate maze-like environments with the aid of an overhead map as a reference device.

What are the cognitive and behavioral consequences of the varied perspectives provided by these diverse sources? Previous research has tended to focus on the types of mental representations that individuals build as a function of singular perspectives offered by spatial experiences, such as following map-only or verbal-only experiences (Hirtle & Jonides, 1985; Kosslyn, Ball, & Reiser, 1978; Lee & Tversky, 2005; Noordzij & Postma, 2005; Shelton & McNamara, 2001, 2004; Tversky, 1991, 1992, 1993, 2000; Tversky, Kim & Cohen, 199~~1~~). This work has also examined, to some degree, how individuals apply those representations towards navigating (Ishikawa & Montello, 2006; Loomis, Klatzky, Golledge, & Philbeck, 1999; Montello, 1998, 2005; Wehner, 1999), and how those representations are further updated by information acquired during navigation. Findings suggest that the perspectives engendered by particular presentation formats lead to substantial differences in the mental representations people form of their environments, and their resulting navigation of those places. Thus, individuals might build representations that maintain a survey or route-based perspective, as a direct function of survey or route-based experience (Shelton & McNamara, 2004; Thorndyke & Hayes-Roth, 1982).

Precisely because different information sources can provide different spatial perspectives, a critical issue in spatial cognition involves the degree to which individuals can easily switch perspectives when thinking about and interacting in environments. Switching perspectives is, in many cases, essential in real-world environments. For instance, when we experience a construction detour or realize the map we are using is inaccurate or outdated, it may actually become *necessary* to switch perspectives. One commonplace switch involves thinking about locations from a ground-level representation of a route to a global, aerial representation of the environment layout (e.g., Hartley, Maguire, Spiers, & Burgess, 2003; Kato & Takeuchi, 2003; Prestopnik & Roskos-Ewoldsen, 2000). This type of perspective switch can assist in considering novel paths through an environment to fulfill navigation goals. The converse of this switch, of course, also occurs; maps, to a large degree, are only sufficient to the extent that an individual can transform the aerial view to a ground-level representation that

Please cite this article in press as: Brunyé, T. T. et al., Representational flexibility and specificity ..., *Cognition* (2008), doi:10.1016/j.cognition.2008.03.005

might guide actions through the environment. These cases suggest that perspective switching is a routine and necessary mechanism for successful locomotion.

The nature of this perspective switching, though, has engendered some controversy in the spatial cognition literature. This controversy focuses on whether mental representations of environments are encoded in a format that maintains the perspective of the original experience (e.g., route or survey), or whether these representations are to some degree perspective-flexible. While there is little debate whether individuals *can* switch perspectives to solve spatial problems, generate spatial inferences, and consider spatial arrays from multiple viewpoints (Chabanne, Péruch, Denis, & Thinus-Blanc, 2004; Ferguson & Hegarty, 1994; Shelton & McNamara, 2004; Taylor, Naylor, & Chechile, 1999; Taylor & Tversky, 1992a), there is less agreement about the nature of the underlying representations involved in such switching. A growing body of recent work has attempted to resolve this issue (e.g., Avraamides, Loomis, Klatzky, & Golledge, 2004; Brunyé & Taylor, 2008a, 2008b; De Beni, Pazzaglia, Gyselinck, & Meneghetti, 2005; Ishikawa & Montello, 2006; Klatzky, Lippa, Loomis, & Golledge, 2003; Levinson, 2003; Noordzij, Van der Lubbe, & Postma, 2005, 2006; Pazzaglia, De Beni, & Meneghetti, 2007; Péruch, Chabanne, Nese, Thinus-Blanc, & Denis, 2006; van Asselen, Fritschy, & Postma, 2006).

At least three models of spatial memory have emerged from this work. First, some evidence supports the notion that spatial representations are relatively perspective-free, or flexible, in that they need not be set by or maintain the perspective provided by the learning experience (e.g., Denis, 2008; Lee & Tversky, 2001; Taylor & Tversky, 1992a). For instance, Noordzij and Postma (2005) had participants learn survey or route descriptions and then perform recognition/priming and Euclidian distance estimation tasks. After both description perspectives, participants completed these tasks with a high degree of fluidity, suggesting that the representations derived from either description type contain information abstracted from the learned perspective. These representations were flexible to the extent that they could be applied quickly and accurately towards multiple tasks.

Alternatively, some evidence suggests that spatial representations are experientially grounded, such that memory maintains the perspectives offered by the experience (Lee & Tversky, 2005; Péruch et al., 2006; Schneider & Taylor, 1999). Shelton and McNamara (2004) had participants learn verbal or video versions of route and survey descriptions and then complete tasks assessing their memory for those descriptions. Performance on scene recognition and relative direction judgments showed decrements (i.e., poorer recognition and increased response latencies, respectively) when participants had to switch perspectives. Such results suggest that mental representations formed from route and survey descriptions (verbal or video) show biases towards initially learned perspectives. In line with this perspective-driven view, there is strong evidence outside of the spatial language literature that people develop what appear to be strictly egocentric (i.e., route perspective) memories through direct experiences with real-world environments. First, people develop viewpoint-dependent representations of object arrays that lead to predictably poor performance when original and subsequent imagined viewing angles mismatch (i.e., alignment effects; Diwadkar & McNamara, 1997; Shelton & McNamara,

Please cite this article in press as: Brunyé, T. T. et al., Representational flexibility and specificity ..., *Cognition* (2008), doi:10.1016/j.cognition.2008.03.005

1997, 2004). Second, disorientation following egocentric experiences reliably impairs pointing performance, which is thought to reflect the absence of stored global allocentric representations (Wang & Spelke, 2000). Third, movement within an environment appears to update egocentric representations that are both viewpoint dependent and self-motion dependent, but does not result in the development of relatively holistic representations (Simons & Wang, 1998; Wang & Simons, 1999). The findings from these projects suggest that the mental representations developed as a function of firsthand navigation, verbal descriptions, or visual depictions, are directly derived from, and aligned with, the nature of those initial experiences.

Still others argue that only spatial memories that code for both perspectives can fully account for the extant literature (for a recent review see Burgess, 2006). Several findings support this stance. First, alignment effects (as described above) also occur when the intrinsic structure of an object array is aligned or misaligned with a global structure, suggesting that people use and store allocentric configural information (i.e., walls of a room, or position of a lake relative to a building; McNamara, Rump, & Werner, 2003; Mou & McNamara, 2002). Second, neuroimaging work demonstrates separable functions and topography of egocentric and allocentric memory systems (Ekstrom et al., 2003; Maguire et al., 1998). As a result, recent two-system models posit parallel dual-perspective representations in long-term memory (Mou, McNamara, Valiquette, & Rump, 2004; Waller & Hodgson, 2006), much in contrast to earlier egocentric models (Wang & Spelke, 2002). Thus, two-system models suggest that flexible spatial memories code for both egocentric and allocentric memories.

In both the linguistic and non-linguistic spatial literature, attempts have been made to reconcile discrepant views by suggesting that the nature of spatial representations is not, in an invariant way, perspective-flexible or perspective-specific. Variables such as learning goals (Rossano & Reardon, 1999; Taylor et al., 1999; van Asselen et al., 2006), task instructions (Noordzij et al., 2005, 2006), experience with an environment (Bosco, Sardone, Scalisi, & Longoni, 1996; Brunyé & Taylor, 2008a) and individual differences (Denis, 2008; Gyselinck, De Beni, Pazzaglia, Meneghetti, & Mondoloni, 2007; Hegarty & Waller, 2005; Ishikawa & Montello, 2006; Noordzij et al., 2006; Prestopnik & Roskos-Ewoldsen, 2000) play important roles in determining the nature of spatial memories.

For instance, while response time costs are associated with perspective switching from newly learned environments, these costs appear to diminish with extended study (Brunyé & Taylor, 2008a; Thorndyke & Hayes-Roth, 1982). Relatively early in the learning process or with limited exposure, individuals typically exhibit perspective-specificity in memory, while over time, these representations appear less specific. Additionally, with longer delays between study and test, memory consolidation processes appear to lead to increasingly abstracted representations (i.e., Kintsch, Welsch, Schmalhofer, & Zimny, 1990), which are particularly amenable to perspective switching (e.g., Tversky, 1991).

Spatial experiences can provide multiple perspectives, and the information sources in these experiences influence the spatial representations individuals build (Lee & Tversky, 2001). The resulting representations can be perspective-invariant in that they easily afford perspective-switching, such as using egocentric terms to describe

Please cite this article in press as: Brunyé, T. T. et al., Representational flexibility and specificity ..., *Cognition* (2008), doi:10.1016/j.cognition.2008.03.005

a route after viewing a survey-based map. However, these representations can also be perspective-specific in that describing a route in egocentric terms may be difficult when the environment has only been experienced from a survey perspective. Yet we know that individuals are rarely exposed to a single perspective with an environment (e.g., exploring a new environment with a map in hand; strolling a shopping mall and checking a 'you-are-here' map; relying on travel directions from on-line sources that provide both maps and turn-by-turn sequences; playing multiplayer games that provide a variety of on-screen mapping tools, etc.) (Levine, Marchon, & Hanley, 1984; Lloyd, 2000; Lynch, 1960; Taylor, 2005; Tversky, 1992). Thus, the extent to which individuals develop flexible or inflexible spatial representations is likely contingent upon the variety of information sources they experience. Additionally, because most environments are not experienced in some invariant, single-perspective format, it is worth examining the ways in which multiple sources might influence spatial representations. While previous work has argued, to some degree, that combinations of linguistic and perceptual sources might provide a rich memory base for retrieval and perspective-switching (e.g., the conjoint retention hypothesis; Kulhavy, Stock, & Caterino, 1994; Kulhavy, Stock, Verdi, Rittschof, & Savenye, 1993), the ways in which these combinatorial sources are experienced could guide the nature of any underlying spatial representations. An important issue, then, is whether particular spatial content and task combinations mediate the degree to which individuals can freely switch perspectives. Work on this issue should provide insight into the conditions under which learners build perspective-specific or perspective-flexible representations as a function of spatial experiences.

The current study examined this issue by assessing the potential benefits and costs associated with perspective switching as a function of text descriptions of environments, potentially coupled with map depictions. The order that individuals experience these types of information sources might contribute to the ease with which they can efficiently switch perspectives between route and survey information. For our experiments, participants read path descriptions through neighborhoods based on the cities Pittsburgh, PA and Detroit, MI, written from either a survey or route perspective. In Experiment 1, these descriptions were presented on their own, while in Experiment 2 these descriptions were accompanied by maps highlighting the described path. After viewing these materials, participants completed verification trials for statements describing the path between two locations. These trials included statements that either matched the studied perspective or mismatched that perspective (and thus required a perspective switch). With these materials, we examined the flexibility of spatial representations by assessing the degree to which multiple information sources might facilitate perspective-switching for real-world environments. Flexibility would be evidenced if participants exhibited little difficulty or processing decrements in mismatching cases; processing difficulty, in contrast, would suggest relative specificity with respect to participants' representations.

We based our performance predictions on previous work examining non-combinatorial source influences on spatial representations, as well from the growing body of research on other factors (e.g., task goals) contributing to these representations. First, we predicted that participants would develop perspective-specific memories

Please cite this article in press as: Brunyé, T. T. et al., Representational flexibility and specificity ..., *Cognition* (2008), doi:10.1016/j.cognition.2008.03.005

after studying the materials for shorter periods of time, particularly following route descriptions (Brunyé & Taylor, 2008a), but that exposure to maps might reduce these perspective-specific effects. In map conditions, multiple information sources might help learners build richer representational connections between locations that foster perspective switching (Kulhavy et al., 1993). Further, we expected that any multi-format benefits would be more likely to occur when map exposure occurred prior to, rather than following, text descriptions. Maps might provide a preliminary information source that participants can maintain in working memory during reading, and use to guide the organization of subsequent propositional information (Kulhavy et al., 1993, 1994; Larkin & Simon, 1987). This is supported by research indicating that map-like overviews of environments benefit spatial knowledge acquisition mainly when they precede, rather than follow, spatial descriptions (Verdi, Johnson, Stock, Kulhavy, & Ahern, 1997; Verdi & Kulhavy, 2002). In a similar vein, individuals tend to include both written and gestured overviews before producing (written or aurally) more detailed spatial information (Melinger & Levelt, 2004; Taylor & Tversky, 1992b).

To summarize, our hypotheses with respect to these issues were based on three important sets of findings. First, map exposures should provide a useful organizing tool for integrating subsequent text information, while texts may provide less of an organizational scaffold for subsequent maps. Second, individuals who have limited experience with descriptions develop spatial memories that are biased towards the learned perspective (e.g., Brunyé & Taylor, 2008a; Taylor & Tversky, 1992a). Third, the extent of exposure to alternate perspectives may speed the progression from perspective-specific to perspective-flexible model development (Navon, 1977), such that extended study experiences might foster perspective-flexible representations. In two experiments we tested the validity of these hypotheses, and the flexibility of representations that might develop as a function of differing spatial information sources.

2. Experiment 1

Our first experiment examined the perspective specificity of representations following self-paced exposure to spatial descriptions. Participants read a survey or route description once, then assessed the validity of statements either congruent or incongruent with the learned perspective; see Table 1 for sample descriptions and statements. We were also interested in the degree to which the amount of time participants allocated to reading the descriptions would relate to specificity. Recall that perspective-specific representations are associated with restricted experience; thus, we expected study times to relate to the types of representations built, and interact with learning perspective. Finally, we expected that in line with recent work, any obtained perspective-specific effects would be especially pronounced following route descriptions, which are proposed to induce relatively high processing loads during reading (Brunyé & Taylor, 2008a, 2008b; Noordzij & Postma, 2005; Noordzij et al., 2006). High processing loads during route description reading are thought to arise due to the recruitment of multiple working memory resources towards

Please cite this article in press as: Brunyé, T. T. et al., Representational flexibility and specificity ..., *Cognition* (2008), doi:10.1016/j.cognition.2008.03.005

Table 1
Sample descriptions and statement verification trials of the route "Moore Field Playground to Johns Park," in the survey and route perspectives

Survey description
From Moore Field Playground, Pioneer Avenue runs south. Portions of Pioneer Avenue have been blocked off due to repair. Capital Avenue heads east from Pioneer Avenue. It is a small street without any traffic lights or stop signs. Highway 51 West heads south before quickly ending. This is the end of the interstate highway. Jacobs Street continues south from the highway. This part of Jacobs Street directly merges with the highway on-ramps. Whited Street then runs west. Johns Park is located on the northeast side of Whited Street. There is a pond where people can feed ducks slices of bread and crackers
Corresponding statement verification trials
Item 1, filler: Construction on Pioneer Avenue has been completed. (FALSE)
Item 2, congruent: Go north on Pioneer Avenue. (FALSE)
Item 3, congruent: Head east on Capital Avenue. (TRUE)
Item 4, congruent: Follow south on Highway 51 West. (TRUE)
Item 5: congruent: Drive north on Jacobs Street. (FALSE)
Item 6: congruent/incongruent: Go west on Whited Street/Go right on Whited Street. (TRUE)
Item 7, filler: People feed the ducks in Johns Park crackers and bread. (TRUE)
Route description
Turn left from Moore Field Playground to Pioneer Avenue heading south. Portions of Pioneer Avenue have been blocked off due to repair. Head left on Capital Avenue driving from Pioneer Avenue. It is a small street without any traffic lights or stop signs. Merge right onto Highway 51 West before it quickly ends. This is the end of the interstate highway. Continue onto Jacobs Street from the highway. This part of Jacobs Street directly merges with the highway on-ramps. Turn right directly onto Whited Street. Johns Park is on the right side of Whited Street. There is a pond where people can feed ducks slices of bread and crackers.
Corresponding statement verification trials
Item 1, filler: Construction on Pioneer Avenue has been completed. (FALSE)
Item 2, congruent: Go right on Pioneer Avenue. (FALSE)
Item 3, congruent: Head left on Capital Avenue. (TRUE)
Item 4, congruent: Follow right on Highway 51 West. (TRUE)
Item 5: congruent: Drive left on Jacobs Street. (FALSE)
Item 6: congruent/incongruent: Go right on Whited Street/Go west on Whited Street. (TRUE)
Item 7, filler: People feed the ducks in Johns Park crackers and bread. (TRUE)

processing the sequential nature of the text, the inferences required to represent landmark interrelationships, and spatial mental imagery.

2.1. Method

2.1.1. Participants

Twenty Tufts University undergraduates participated for partial course credit.

2.1.2. Materials

2.1.2.1. Spatial descriptions. Spatial descriptions were constructed loosely based on two neighborhoods, one in Pittsburgh, PA and the other in Detroit, MI (the same

Please cite this article in press as: Brunyé, T. T. et al., Representational flexibility and specificity ..., *Cognition* (2008), doi:10.1016/j.cognition.2008.03.005

neighborhood maps were used by Schneider & Taylor, 1999). Ten pairs of texts, written from a survey and route perspective, were developed for each environment. These texts described a path between two of 12 landmarks on a map. Each text contained nine sentences, six of which focused on a spatial description and three focused on a general description unrelated to spatial associations. The six spatial sentences described a path between two landmarks using, as indicated, either a survey or route perspective. The survey texts described relative locations using canonical terms from a static, external perspective (e.g., Nobles Lane heads *north* where *it* intersects with Whited Street. Carrick High School is on the *east* side of Nobles Lane, at the intersection of Nobles and Highway 51 East.). Route texts described the same path locations relative to the dynamic position of an individual within the environment (e.g., [from Whited St…] Turn *left* onto Nobles Lane. Carrick High School is on the *right* side of Nobles Lane, as *you* reach the intersection of Nobles and Highway 51 East.). The general description sentences provided descriptive details about the neighborhood (e.g., Whited Street was named in honor of Mayor Whited), and were always presented as sentences 2, 5, and 7. Descriptions were equated for length across landmark pairs and perspectives, and described only one idea each (e.g., either one fact or one step in a path). Within each neighborhood, major street names (e.g., Highway 51 on the Pittsburgh map) appeared in several descriptions; this repetition was equated for each neighborhood and across survey and route versions of each description.

2.1.2.2. Test statements. Seven statements were developed for each of the 10 pairs of spatial descriptions, resulting in seventy test statements. Two of these seven (sentences 1 and 7) always tested for the descriptive, non-spatial information (e.g., There is an annual Thanksgiving parade in Pittsburgh), with one item always true and one always false. Four statements (sentences 2–5) tested for spatial information from the studied perspective, either consistently survey (e.g., Go north on Nobles Lane) or consistently route (e.g., Go left on Nobles Lane). The perspective-switch statement (sentence 6) was the primary item of interest, as it tested for spatial information from either the studied or unstudied perspective. Of the five spatial sentences, either two or three were true, randomly interspersed across descriptions.

2.1.3. Design and procedure

In a repeated-measures design, each participant learned a series of 20 descriptions, half of which were survey and half route, and completed verification tasks immediately following each description. Reading times were measured for each description, and accuracy and response times were recorded during the verification task.

2.1.3.1. Learning and testing. Each participant first completed a brief practice session that included two descriptions (one route, one survey). Each participant then received a total of 20 descriptions, 10 describing a path between two landmarks in the "Pittsburgh" neighborhood and 10 between two landmarks in the "Detroit" neighborhood. Descriptions were blocked by neighborhood and presented such that each participant read one neighborhood in a route perspective and the other in survey perspective (in counterbalanced order across participants). Each set of

Please cite this article in press as: Brunyé, T. T. et al., Representational flexibility and specificity ..., *Cognition* (2008), doi:10.1016/j.cognition.2008.03.005

descriptions was presented in random order within blocks, in a single paragraph in the center of the screen; participants read each description at their own pace and pressed the spacebar when ready to begin the verification task for that description. In this experiment, participants did not view maps. Participants were told that they would learn several (ten) paths through one neighborhood, and then several paths through a different neighborhood.

After reading each practice and experimental description participants completed seven verification statements (two filler non-spatial items, five spatial items in the studied perspective). Statements were presented one at a time in the center of the screen. Participants were asked to indicate whether the information in each statement was true or false with respect to the immediately preceding description by pressing either C (labeled “yes”) or M (labeled “no”). Using a Latin square, texts were counterbalanced to ensure that of the 20 descriptions an individual read, half contained sentence 6 in the learned perspective (e.g., Go left on Nobles Lane, after a route description) and half in the unlearned perspective (e.g., Go north on Nobles Lane); further, half of each of these were presented as true, and half false (e.g., Go right on Nobles Lane, which was false). After completing the seven test statements, participants advanced to the next description. This procedure continued for the full set of materials.

2.2. Results

2.2.1. Analyses

The present experiment asked participants to learn survey and route descriptions, and then measured their accuracy and response times to statements that were congruent or incongruent with the learned perspective. First, we assessed description reading times as a function of study perspective using a paired-samples t-test comparing average reading times. Second, we assessed memory performance as a function of survey and route learning; we conducted two paired-samples t-tests on descriptive (sentences 1 and 7) and congruent (sentences 2–5) statement verification items, testing for differences between survey and route learning – one test for accuracy and one for response times. We then conducted two repeated-measures ANOVAs on congruent/incongruent (sentence 6) statement verification items, one for accuracy and one for response times (correct items only). Finally, we were interested in the extent to which reading times might predict perspective flexibility on statement verification; we used simple regression with average reading times as predictors and statement verification accuracy and response times as dependent measures.

2.2.2. Reading times

One participant’s route reading time data were identified as upper threshold outliers ($M \pm 2.5SD$; $M = 114.87$ s, $SD = 22.54$ s), and these data were removed from all subsequent analyses. Overall, participants spent significantly more time (in seconds) reading route descriptions ($M = 51.69$, $SD = 17.19$) than survey descriptions ($M = 44.43$, $SD = 17.67$) [$t(18) = 4.16$, $p < .01$, $d = .42$].

Please cite this article in press as: Brunyé, T. T. et al., Representational flexibility and specificity ..., *Cognition* (2008), doi:10.1016/j.cognition.2008.03.005

2.2.3. Verification accuracy

Paired-samples *t*-tests revealed no significant difference in accuracy between survey ($M = .72$, $SD = .18$) and route ($M = .79$, $SD = .14$) descriptions for non-spatial statements (i.e., statements 1 and 7; $t(19) = 1.77$, $p > .05$), nor any difference between survey ($M = .64$, $SD = .09$) and route ($M = .69$, $SD = .11$) descriptions for perspective–congruent test statements (i.e., statements 2–5; $t(19) = 1.76$, $p > .05$). Sentence 6, though, presents a case in which the test statement either matched or mismatched the perspective provided by statements 2–5 (and the studied description), and thus provides a test of spatial representation flexibility. A repeated-measures ANOVA on this test statement demonstrated a main effect of test perspective, with survey statements ($M = .68$, $SD = .14$) resulting in greater accuracy relative to route statements ($M = .59$, $SD = .15$) [$F(1,19) = 5.45$, $p < .05$, $MSE = .035$, $\eta^2 = .04$] (see Fig. 1a). This effect was qualified by a study by test perspective interaction [$F(1,19) = 5.38$, $p < .05$, $MSE = .012$, $\eta^2 = .11$]; follow-up paired-samples *t*-tests using the Bonferroni correction (two tests, α .025) revealed a difference between

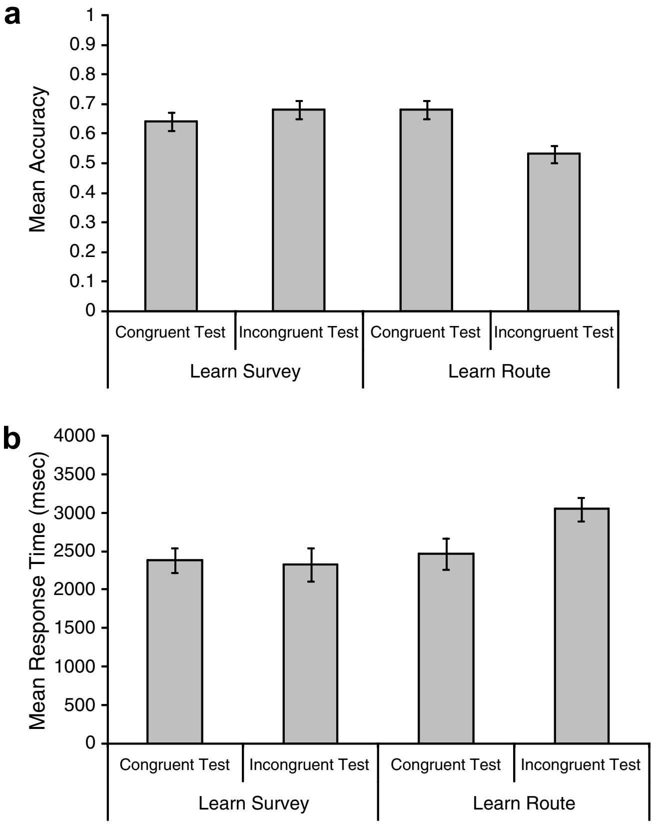

Fig. 1. Experiment 1: mean statement verification accuracy (a) and response times (b) following survey and route learning, for congruent– and incongruent–perspective test statements.

Please cite this article in press as: Brunyé, T. T. et al., Representational flexibility and specificity ..., *Cognition* (2008), doi:10.1016/j.cognition.2008.03.005

congruent and incongruent perspective statements following route [$t(19) = 3.26$, $p < .01$, $d = .42$], but not survey [$t(19) = .80$, $p > .05$, $d = .28$] descriptions. These results provide evidence for perspective-specificity following route descriptions, but relative flexibility following survey descriptions.

2.2.4. Verification times

Overall, response time patterns mirrored those found with accuracy. As expected, a paired-samples *t*-tests revealed no difference in verification times (in ms) between survey ($M = 3174.53$, $SD = 926.21$) and route ($M = 3087.60$, $SD = 865.55$) descriptions for non-spatial test statements (i.e., statements 1 and 7; $t(19) = .549$, $p > .05$), nor any difference between survey ($M = 2943.77$, $SD = 942.52$) and route ($M = 2994.02$, $SD = 734.17$) for perspective–congruent test statements (i.e., statements 2–5; $t(19) = .340$, $p > .05$). For sentence 6, a repeated-measures ANOVA demonstrated an effect of learning perspective, with longer verification times following route ($M = 2706.07$, $SD = 879.43$) relative to survey ($M = 2351.50$, $SD = 854.23$) descriptions [$F(1, 19) = 5.61$, $p < .05$, $MSE = 448577$, $\eta^2 = .13$] (see Fig. 1b). Further, there was a main effect of test perspective, with survey perspective statements ($M = 2713.98$, $SD = 832.17$) resulting in longer response times than route statements ($M = 2343.59$, $SD = 861.27$) [$F(1, 19) = 13.86$, $p < .01$, $MSE = 198018$, $\eta^2 = .06$]. This effect was qualified by a learning by testing perspective interaction [$F(1, 19) = 4.42$, $p < .05$, $MSE = 434455$, $\eta^2 = .10$]. Follow-up paired-samples *t*-tests using the Bonferroni correction (two tests, α .025) revealed a difference between congruent and incongruent perspective statements following route [$t(19) = 5.21$, $p < .01$, $d = .34$], but not survey [$t(19) = .28$, $p > .05$], descriptions. That is, similar to the accuracy results, there was evidence for perspective-specificity following route descriptions, but perspective-flexibility following survey descriptions.

2.2.5. Predicting statement verification performance via reading times

Four simple linear regressions were conducted to predict accuracy and response time performance on congruent- and incongruent-perspective test statements (statement 6) following route and survey description learning, as a function of description reading times. There was strong evidence that increases in route description reading times predicted higher performance on survey statement verification, for accuracy [$\beta = .004$, $t(18) = 6.16$, $p < .01$] and response times [$\beta = -.03$, $t(18) = 2.11$, $p < .05$]. Reading times during route description reading did not, however, predict accuracy [$\beta = .001$, $t(18) = .569$, $p > .05$] or response time [$\beta = .01$, $t(18) = .123$, $p > .05$] performance on route statement verification. Finally, survey description reading times did not predict accuracy or response time performance on survey [accuracy: $\beta = .0002$, $t(18) = .162$, $p > .05$; RT: $\beta = .005$, $t(18) = .528$, $p > .05$] or route [accuracy: $\beta = .0007$, $t(18) = .481$, $p > .05$; RT: $\beta = .002$, $t(18) = .298$, $p > .05$] statement verification.

2.3. Discussion

The present results demonstrate both reading time and judgment differences as a function of learned perspectives. First, participants spent more time reading

Please cite this article in press as: Brunyé, T. T. et al., Representational flexibility and specificity ..., *Cognition* (2008), doi:10.1016/j.cognition.2008.03.005

route compared to survey descriptions. This is congruent with recent work showing extended slowdowns with route versus survey descriptions, and further suggests that the cognitive mechanisms involved during route descriptions likely induce a high cognitive load. This load appears to be related to active 3D mental imagery (Brunyé & Taylor, 2008b; Farmer, Berman, & Fletcher, 1986; Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001), updating orientations relative to a principle reference vector (Shelton & McNamara, 2004), and inferring landmark interrelationships (Brunyé & Taylor, 2008b; Canas et al., 2003; Noordzij & Postma, 2005; Noordzij et al., 2006; Pazzaglia et al., 2007). All of these processes are especially relevant for reading route descriptions.

Second, participants developed perspective-flexible representations following survey descriptions, but less flexible representations following route descriptions. This was the case even though participants took longer to read route descriptions. These findings add to a growing body of literature suggesting that with limited experience (Brunyé & Taylor, 2008a) and more sensitive dependent tasks (Noordzij & Postma, 2005; Shelton & McNamara, 2004), spatial memories are, to a large degree, tied to the perspectives experienced during reading. This is in contrast to work contending that spatial mental models are spontaneously abstracted from these perspectives (e.g., Ferguson & Hegarty, 1994; Lee & Tversky, 2001; Taylor & Tversky, 1992a). It is important to note the asymmetric results related to this notion: the representations that result from survey-based experiences appeared to be abstracted beyond the original perspective, while those formed from route descriptions appeared tied to an initially experienced orientation. Some work suggests that this is likely established as early as the first path segment of a route (i.e., Shelton & McNamara, 2004), but that these ties may diminish with over-learning (Appleyard, 1970; Brunyé & Taylor, 2008a; Golledge & Spector, 1978; Kuipers, 1978; Ladd, 1970; Lee & Tversky, 2005; Sholl, 1987; Thorndyke & Hayes-Roth, 1982), increased study-test lags (Kintsch et al., 1990), and goal instantiation (Taylor et al., 1999; van Asselen et al., 2006).

Finally, our design allowed us to examine the possibility that reading times during study may predict later performance on statement verification. Perspective-specificity following route learning was associated with exposure to those descriptions: participants who spent longer reading route descriptions showed a degree of perspective-flexibility; note, however that performance was still quite low relative to that following survey description reading. This regression highlights the potential importance of the amount of experience on the type of representations individuals might construct for spatial descriptions, replicating recent findings that perspective-flexibility increases with repeated exposure to route descriptions (Brunyé & Taylor, 2008a).

3. Experiment 2

While the previous findings are informative with respect to the conditions that might foster perspective-flexible representations, experiences with spatial directions are hardly limited to linguistic descriptions. Individuals often consult maps while exploring environments or reading and listening to directions. Our second experiment tested the potential influence of a single, self-paced map exposure depicting the path detailed in the spatial descriptions. Participants viewed the maps either before or after reading a spatial description of a path.

There are two primary motivations and hypotheses for this work. First, from a theoretical stance, it is unclear whether the perspective-specificity noted with route descriptions might be reduced by providing a survey perspective prior to or following route learning, and whether the duration of map study may affect the impact of that map on comprehension. Map viewing prior to learning can instantiate a map-like schema or provide organizing principles for incoming description information (Kulhavy et al., 1993, 1994; Larkin & Simon, 1987; Navon, 1977; Verdi & Kulhavy, 2002; Verdi et al., 1997). This is expected to be the case with route, but not survey descriptions, as the latter may already provide the requisite organizing information to guide description reading. More familiarity with the maps, as assessed by viewing time, was also expected to predict the extent of their benefit – in particular, the degree to which they reduce perspective-specific representations.

Second, from an applied stance, the potential benefits of viewing route maps coupled with linguistic descriptions, as are commonly used in on-line mapping tools (e.g., mapquest, google maps, yahoo maps, etc.) and in-vehicle navigation systems, are relatively unknown. If map viewing fosters perspective-flexibility, then a case can be made for the cognitive benefits of multi-format spatial information displays, as suggested by work in multimedia learning (Brunyé, Taylor, Rapp, & Spiro, 2006; Mayer, 2005).

3.1. Method

3.1.1. Participants and design

Forty Tufts University undergraduates participated for partial course credit. As in Experiment 1, we manipulated description perspective (survey, route); the present experiment additionally manipulated, between-participants, whether a route map was viewed immediately prior to or after description reading.

3.1.2. Materials

With the exception of the maps, all materials were identical to those in Experiment 1. Route maps were developed for each of the Experiment 1 descriptions, highlighting (in yellow) the described path between two landmarks (see Fig. 2a and b). Canonical axes were depicted by a compass rose situated in the lower right corner of the image. Each map was 600 × 600 pixels in size, depicting 15 landmarks and 16 street names.

3.1.3. Procedure

With the exception of map study, all procedures matched those used in Experiment 1. Half of the participants received a map prior to the description (map-prior), and half following the description (map-after). Map study was self-paced in both cases; participants viewed each map in the center of the screen, and then proceeded to either the corresponding description (map-prior) or the verification task (map-after) by pressing the space bar.

Please cite this article in press as: Brunyé, T. T. et al., Representational flexibility and specificity ..., *Cognition* (2008), doi:10.1016/j.cognition.2008.03.005

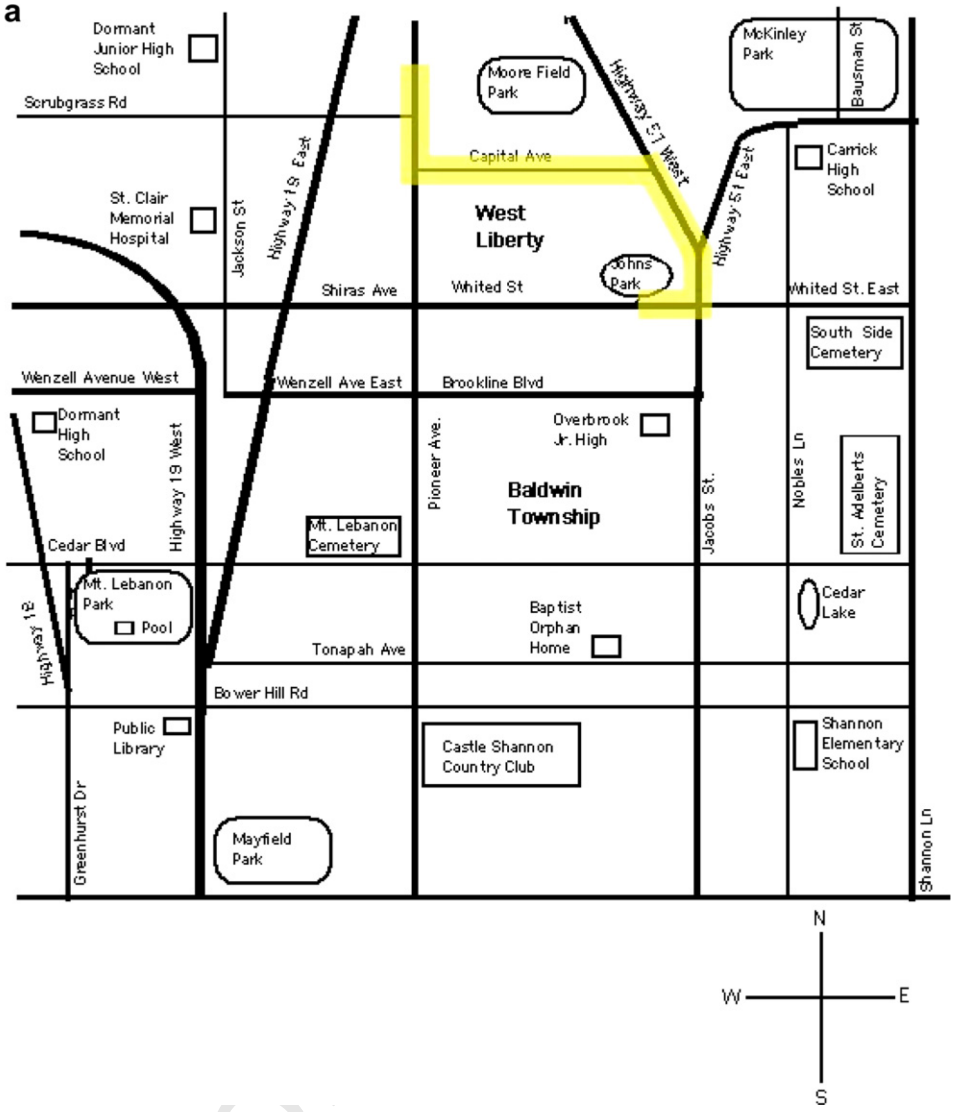

Fig. 2. Studied maps, adapted from the cities of Pittsburgh (a) and Detroit (b). Fig. 1a depicts a highlighted route corresponding to the sample text provided in Table 1.

3.2. Results

The present analyses were similar to those in Experiment 1, with the addition of a mixed models (2 within: route, survey × 2 between: map-prior, map-after) ANOVA on map study times, and assessments of the role map presentations played.

Please cite this article in press as: Brunyé, T. T. et al., Representational flexibility and specificity ..., *Cognition* (2008), doi:10.1016/j.cognition.2008.03.005

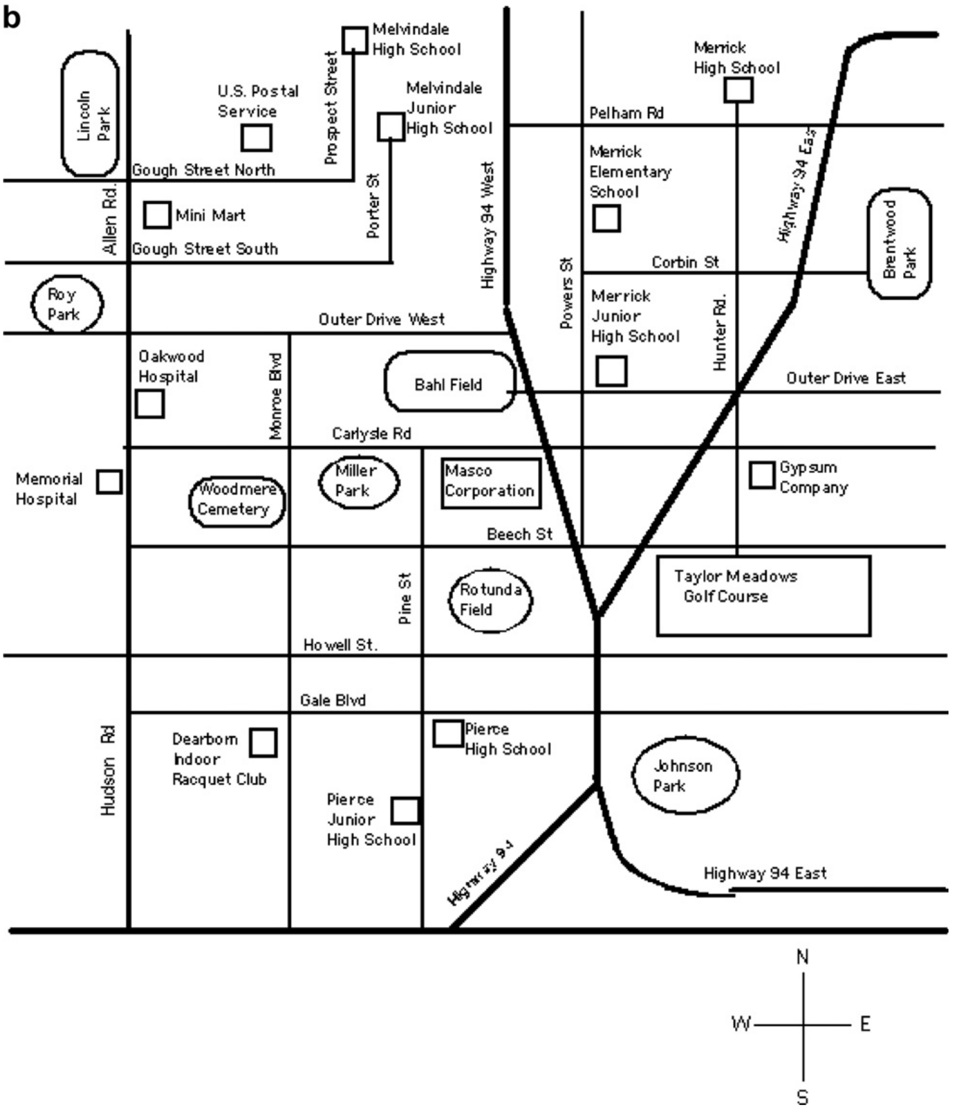

Fig 2. (*continued*)

3.2.1. Map study times

A mixed models ANOVA revealed that participants spent comparable amounts of time studying the map in map-prior ($M = 18.67$, $SD = 6.61$) and map-after conditions ($M = 20.57$, $SD = 8.98$) [$F(1,38) = .577$, $p > .10$]; this was qualified, however, by an interaction with description perspective [$F(1,38) = 6.35$, $p < .05$, $\eta^2 = .05$]. Within the map-after group, participants spent more time studying the map when it followed a route description ($M = 22.92$, $SD = 8.69$) than a survey description

Please cite this article in press as: Brunyé, T. T. et al., Representational flexibility and specificity ..., *Cognition* (2008), doi:10.1016/j.cognition.2008.03.005

($M = 18.22$, $SD = 10.29$) [$t(19) = 3.33$, $p < .01$, $d = .49$]. As would be expected, a similar difference was not observed in the map prior group (see Fig. 3; route: $M = 18.73$, $SD = 7.42$; survey: $M = 18.62$, $SD = 6.75$) [$t(19) = 1.03$, $p > .05$].

3.2.2. Reading times

Participants in the map-after group spent more time (in seconds) reading route descriptions ($M = 52.74$, $SD = 18.67$) than survey descriptions ($M = 46.71$, $SD = 22.05$) [$t(19) = 2.92$, $p < .01$, $d = .30$]. The map-prior group showed similar reading times for route ($M = 47.71$, $SD = 15.20$) and survey ($M = 46.35$, $SD = 10.63$) descriptions [$t(19) = .445$, $p > .05$].

3.2.3. Verification accuracy

See Table 2 for verification task results. A mixed models ANOVA (2 within: route, survey × 2 between: map-prior, map-after) did not reveal any effects for descriptive, non-spatial test statements (i.e., statements 1 and 7; all p's $> .05$), nor any effects for perspective–congruent test statements (i.e., statements 2–5, all p's $> .05$). For test statement 6, which either matched or mismatched the perspective provided by the preceding statements, we found a significant two-way interaction between description perspective and test congruency in the map-prior group [$F(1,19) = 9.46$, $p < .01$, $MSE = .035$, $\eta^2 = .14$; see Fig. 4]; there was evidence for perspective specificity following survey descriptions, but not route descriptions. This interaction did not appear, however, in the map-after group [$F(1,19) = .01$, $p > .10$, $MSE = .062$]; evidence was obtained for perspective flexibility following both survey and route learning.

3.2.4. Verification times

A mixed models ANOVA (2 within: route, survey × 2 between: map-prior, map-after) did not reveal any effects for descriptive, non-spatial test statements (i.e., statements 1 and 7; all p's $> .05$), nor any effects for perspective–congruent test

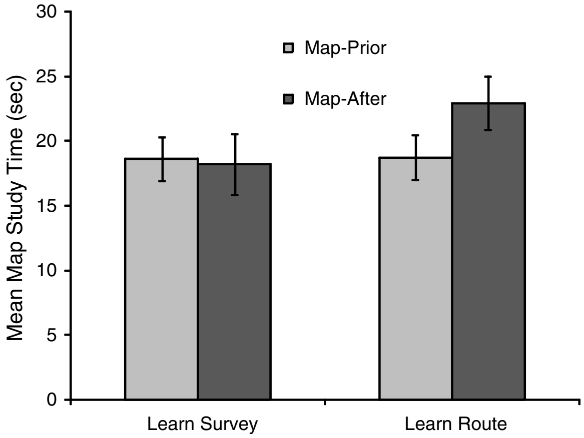

Fig. 3. Experiment 2: mean map study times as a function of description perspective (survey, route) and map placement (map-prior, map-after).

Please cite this article in press as: Brunyé, T. T. et al., Representational flexibility and specificity ..., *Cognition* (2008), doi:10.1016/j.cognition.2008.03.005

Table 2
Experiment 2: accuracy and response time means and standard deviations on the statement verification task, for the two study perspectives, two map placements, and three statement types

Statement type	Study perspective			
	Survey		Route	
	M	*SD*	*M*	*SD*
Accuracy				
Map-prior				
Descriptive non-spatial (items 1 and 7)	.76	.18	.72	.15
Congruent spatial (items 2–5)	.77	.15	.73	.14
Congruent spatial (item 6)	.74	.23	.76	.18
Incongruent spatial (item 6)	.67	.21	.79	.21
Map-after				
Descriptive non-spatial (items 1 and 7)	.77	.19	.76	.17
Congruent spatial (items 2–5)	.75	.15	.72	.10
Congruent spatial (item 6)	.78	.23	.80	.22
Incongruent spatial (item 6)	.80	.19	.77	.19
Response times (ms)				
Map-prior				
Descriptive non-spatial (items 1 and 7)	3186.3	906.6	3087.1	1077.8
Congruent spatial (items 2–5)	2866.2	831.2	3128.9	972.2
Congruent spatial (item 6)	3052.3	1426.3	2724.6	1338.7
Incongruent spatial (item 6)	2168.8	681.7	2637.5	1207.8
Map-after				
Descriptive non-spatial (items 1 and 7)	3294.7	1048.9	3136.3	929.9
Congruent spatial (items 2–5)	2943.4	906.6	3108.6	1323.9
Congruent spatial (item 6)	2503.2	903.1	2411.2	839.1
Incongruent spatial (item 6)	2574.5	1582.4	2873.8	2455.9

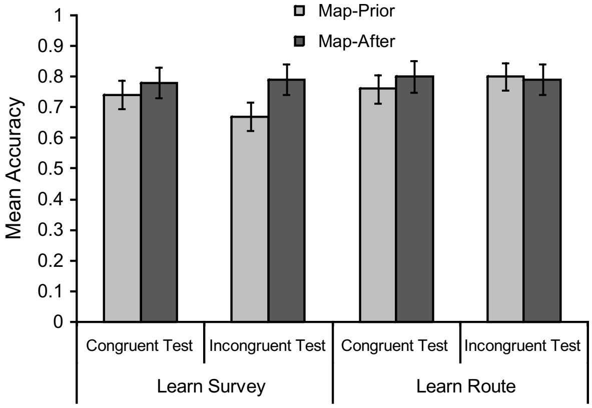

Fig. 4. Experiment 2: mean statement verification task accuracy as a function of description perspective (survey, route), statement congruency (congruent, incongruent), and map placement (map-prior, map-after).

Please cite this article in press as: Brunyé, T. T. et al., Representational flexibility and specificity ..., *Cognition* (2008), doi:10.1016/j.cognition.2008.03.005

statements (i.e., statements 2–5; all p's > .05). Unlike the accuracy results, no effect was obtained for statement 6 (all p's > .05).

3.2.5. Predicting statement verification performance via map study times and reading times

Four simple linear regressions were conducted to predict accuracy and response time performance on congruent- and incongruent-perspective statements following route and survey description learning, as a function of map study times. In the map-after group, there was little evidence that longer map viewing times affected test performance. The only potential effect was observed following survey learning: longer map viewing times predicted lower performance for route statement verifications [accuracy: $\beta = .01$, $t(19) = 3.56$, $p < .01$; RT: $\beta = .092$, $t(18) = 3.88$, $p < .01$]. In this case, longer map viewing times following survey learning may have reinforced the survey perspective, reducing performance on statements requiring a perspective switch. For the map-prior group, there was no evidence that map viewing times influenced statement verification performance (all p's > .05).

Additional simple linear regressions were conducted to predict statement verification performance (accuracy, RT) as a function of description reading times. In the map-after group, increases in route description reading times predicted higher performance on survey statement verification, for response times [$\beta = -.05$, $t(18) = 2.14$, $p < .05$], but not accuracy [$\beta = .004$, $t(18) = 1.85$, $p > .05$]. No other regression yielded significant predictive value of description reading times towards statement verification performance (all p's > .05).

3.3. Discussion

This second experiment assessed the effect of map viewing on the flexibility of spatial representations formed from survey and route descriptions. Participants viewed maps either immediately prior to or following description reading. As in Experiment 1, participants overall spent more time reading route relative to survey descriptions, but only if they viewed the map after these descriptions, not before. This finding provides some evidence that slower reading times for route descriptions may be due to difficulty building up a map-like model of the described environment (see also Brunyé & Taylor, 2008a; Chabanne et al., 2004; Ishikawa & Montello, 2006; Noordzij & Postma, 2005). Similar slowdowns were not observed when participants had access to the map prior to descriptions, and thus a potential schema for the incoming information. Map study times provided additional support for this finding. In map-prior conditions, participants spent similar amounts of time studying the maps; in map-after conditions, participants spent more time studying the maps after route relative to survey descriptions. It is worth noting that overall map study times were rather low, which may have been due to the task instructions. Because participants were aware they would be tested on text descriptions of paths, rather than map details, the current project might have led participants to spend less time on the maps that they might in other conditions or for other experiences. Regardless, this possibility does not obviate the critical results – the combination of reading and map study

Please cite this article in press as: Brunyé, T. T. et al., Representational flexibility and specificity ..., *Cognition* (2008), doi:10.1016/j.cognition.2008.03.005

times indicate that route descriptions are a difficult format for developing perspective-flexible representations (Brunyé & Taylor, 2008a; Lee & Tversky, 2005). In fact, this suggests that the perspective mismatch between route descriptions and survey maps may take time to integrate into an abstract representation.

With respect to verification accuracy, early map study provided benefits for route learning, but also appears to have reinforced the survey perspective during survey learning, resulting in less perspective flexibility. Overall, later map study appears more effective at developing perspective-flexible memories, to be used at test, for both description types.

Predicting accuracy and response time performance via map study times allowed us to assess the influence of map study duration on subsequent test performance. Whereas survey description study alone may induce perspective-flexibility, extended map study following survey learning can reinforce the survey perspective in memory. This result presents an interesting distinction between survey and route descriptions; in Experiment 1, increased exposure to route descriptions was associated with greater perspective flexibility, while the results of Experiment 2 demonstrate that increased exposure to survey perspectives can be associated with greater perspective specificity. This refines previous notions contending that extended time, in general, may enhance perspective flexibility.

4. General discussion

One goal for attempting to encode spatial information is to build a representation that will prove useful for successfully navigating and understanding environments. We might use those representations to make inferences beyond that spatial information, such as alternate paths to a destination or the approximate distances between locations. If our mental representations are perspective-flexible, this would facilitate the activities necessary for reorganizing or reconstructing what we know to easily generate inferences. However, if our mental representations are perspective-specific, such activity would require substantial cognitive effort to conduct the necessary transformations and computations (i.e., Brunyé & Taylor, 2008b). Early work in spatial cognition considered mental representations as invariant, such that they were always perspective-specific or flexible, leading to continued debate over the nature of our underlying spatial memories. More contemporary work, however, has considered the possibility that the nature of our spatial representations is a function of the ways in which we acquire spatial information, the content of those experiences, and our goals for using that information.

In our study we examined the contributions of text descriptions, map depictions, and study time on spatial representations. Specifically, we looked at how survey and route descriptions experienced in isolation, or coupled with complementary map information, might influence performance on a verification task. This task tested memory for the specific steps necessary to complete a route, providing a measure of both accuracy and speed. Importantly, this test allowed us to examine whether studied perspectives made it more or less difficult to evaluate the steps in a descrip-

Please cite this article in press as: Brunyé, T. T. et al., Representational flexibility and specificity ..., *Cognition* (2008), doi:10.1016/j.cognition.2008.03.005

tion that either matched or mismatched those perspectives. Our results demonstrate that with limited exposure, route descriptions, much like navigation, lead to perspective-specificity in memory, supporting early and recent work with maps, descriptions, and navigation (e.g., Brunyé & Taylor, 2008a; Chabanne et al., 2004; Golledge & Spector, 1978; Thorndyke & Hayes-Roth, 1982). Route descriptions also require more time to study than survey descriptions, suggesting they are more complex and induce a higher working memory load; route descriptions thus present a relatively difficult format for developing spatial mental models (e.g., Brunyé & Taylor, 2008a; Lee & Tversky, 2005; Noordzij & Postma, 2005; Noordzij, Zuidhoek, & Postma, 2006). In contrast, survey descriptions are relatively amenable to developing spatial mental models that support perspective-flexibility, even following limited study time.

Our results show that while route descriptions tend to engender perspective-specific representations, when coupled with extended study, they can indeed promote perspective-flexible representations (i.e., spatial mental models; Taylor & Tversky, 1992a; Tversky, 1991). Why do route descriptions present such initial difficulty? Consider that while survey descriptions can provide an explicit indication of multiple relationships between several landmarks and paths, route descriptions are limited with respect to the number and types of relationships they can indicate at any one time. In line with this notion, the inferences required to develop map-like knowledge from route descriptions likely demand a high degree of cognitive resources (i.e., Brunyé & Taylor, 2008b; De Beni et al., 2005; Gyselinck et al., 2007; Pazzaglia et al., 2007). Additionally, route descriptions promote a high degree of mental imagery relative to a constantly changing position of the implied self. The necessary updating of these spatial orientations and views likely demands considerable visuospatial resources (i.e., Brunyé & Taylor, 2008b; De Beni et al., 2005; Deyzac, Logie, & Denis, 2006). The use of these resources to update a route perspective may detract from the resources necessary to integrate multiple locations into a flexible model.

Given the cognitive costs of route instructions, why are they so commonly used for navigation? Some work shows that route descriptions tend to use landmarks as visual cues at critical decision points, and knowledge of landmark characteristics from the ground perspective might be particularly important for successfully guiding locomotion through novel environments (Denis, Pazzaglia, Cornoldi, & Bertolo, 1999; Tom & Denis, 2003). In this case, it would seem fitting to use landmark-rich route descriptions. However, we also must emphasize the potential differences between using route descriptions to actively guide locomotion (i.e., Giudice, Bakdash, & Legge, 2007; Loomis, Golledge, & Klatzky, 1998; Tom & Denis, 2003), versus using them for study purposes. Indeed route descriptions might incur cognitive cost towards developing flexible mental representations and this could be at least partially a result of attempts at imagining movement through an environment (i.e., embodiment during spatial description reading; Avraamides, 2003; De Vega & Rodrigo, 2001). In contrast, route descriptions might be exceedingly useful when any potential costs can be off-loaded onto a piece of paper or navigation device during actual movement. Thus, individuals might rely on route descriptions despite any inherent problems in that they prove direct and effective when there are external

Please cite this article in press as: Brunyé, T. T. et al., Representational flexibility and specificity ..., *Cognition* (2008), doi:10.1016/j.cognition.2008.03.005

resources that can be recruited to complete tasks. Future work should assess possible distinctions between the utility of memory representations for laboratory-based memory tasks versus relatively naturalistic navigation, and the possible role of real and imagined movement in both.

Beyond mere perspective-based linguistic descriptions, the current project also demonstrated that a single exposure to a map can influence the nature of individuals' representations. Map viewing prior to description study was expected to promote schema instantiation (e.g., Kulhavy et al., 1993, 1994), and perspective-flexibility in memory when studying route descriptions (e.g., Navon, 1977). Interestingly, map study appeared to be a useful tool to address the challenges of studying a route description, and one that was actively utilized by participants. Route description reading appears to be facilitated by prior and later map viewing, both in terms of reading efficiency and memory flexibility. In contrast, combining maps and survey descriptions reinforces the learned perspective and makes the representation less amenable to perspective switching. This result emphasizes that survey descriptions alone may be relatively amenable to the development of perspective-flexible spatial mental models, but coupling maps with these descriptions can lead to the development of perspective-specific representations that are limited in terms of flexibility at test. That is, the survey perspective is not always a format readily suited to flexibility, based on the nature of a spatial learning experience.

To what might we attribute the observed benefits (relative to Experiment 1) that resulted from maps coupled with route descriptions? These results might be explained by at least two common cognitive mechanisms. First, transfer-appropriate processing (e.g., Morris, Bransford, & Franks, 1978) and recency (e.g., Atkinson & Shiffrin, 1968) effects predict higher performance with overlapping study and test characteristics, and short lags between these two phases. The information provided by maps and route descriptions may have indeed led to such flexibility at test. When maps accompany survey descriptions, in contrast, the mental representations are only transfer-appropriate towards congruent-perspective tests. Second, any difficulty incurred by the challenge of reading route descriptions may have been resolved by map viewing. Effortful disambiguation has been found to increase the development of comprehensive memories, especially for demanding learning materials (Auble, Franks, & Soraci, 1979; Wills, Estow, Soraci, & Garcia, 2006; Wills, Soraci, Chechile, & Taylor, 2000); this appears to be the case with both route and survey descriptions. One or both of these mechanisms may have produced the memory advantages seen when map study accompanied route description learning.

Ideally, presentations of descriptions and depictions should conform to organizations that facilitate perspective flexibility in memory. With route descriptions, maps appear to provide a schema to either guide the integration of later routes or integrate earlier routes; with survey descriptions the up-front schema provided by a map appears to guide acquisition to the extent that resulting memories maintain a survey perspective. From a theoretical perspective, flexible memory forms are likely abstractions from the provided information, multi-dimensional renderings that are accessible from several perspectives and orientations (Bryant

Please cite this article in press as: Brunyé, T. T. et al., Representational flexibility and specificity ..., *Cognition* (2008), doi:10.1016/j.cognition.2008.03.005

& Tversky, 1999; Tversky, 1993, 2000). Two-system spatial memory models posit both egocentric and allocentric perspectives existing in parallel (see Burgess, 2006), which could foster much of the perspective-flexibility demonstrated in the present experiments; in Experiment 1 this was accomplished with extended study times, perhaps allowing route description readers ample opportunity to develop accompanying allocentric models of the environments. In Experiment 2 this was accomplished when egocentric perspectives (route description reading) were coupled with map viewing, allowing for the representation of both perspectives in memory. The present results extend our understanding of some of the conditions that foster perspective-flexible representations. Consider that evidence has suggested continued study can enhance the likelihood individuals will move from specific to flexible representations. The findings in the current project demonstrate that continued experience actually exerts differential effects as a function of *what* is studied. While extended experience with information from a route perspective indeed promotes representational flexibility, continued experience with information from a survey perspective actually promotes representational rigidity. Future work will investigate whether navigation experience following route description reading may yield similar rigidity.

It is clear that spatial memory cannot, in some invariant way, be described as perspective-specific or perspective-flexible. Changes in learning formats, the amount of exposure we receive to some spatial information, and the quality and detail (e.g., Brunyé, Taylor, & Worboys, 2007) of spatial information sources can all influence our ability to quickly and accurately imagine spatial environments from novel perspectives (e.g., Rapp, Culpepper, Kirkby, & Morin, 2007). In the current project, we begin to investigate how spatial experiences, when combined in particular ways, differentially impact the types of representations that individuals build from what they read and see. Future work should continue to investigate these issues, coupling presentation order and content with other critical influences on general comprehension, including task goals, instructions, familiarity, and of course, individual differences among comprehenders. Understanding the degree to which each of these factors influences the nature of our spatial representations adds to existing accounts that investigate the malleable nature of spatial memory. To the extent that any such malleability reflects true perspective flexibility, these factors may prove useful in documenting the methods and processes responsible for our navigation successes and failures.

5. Uncited reference

Q1 Tversky et al. (1999).

References

Appleyard, D. (1970). Styles and methods of structuring a city. *Environment and Behavior, 2*, 100–118.

Please cite this article in press as: Brunyé, T. T. et al., Representational flexibility and specificity ..., *Cognition* (2008), doi:10.1016/j.cognition.2008.03.005

Atkinson, R. C., & Shiffrin, R. M. (1968). Human memory: A proposed system and its control processes. In K. W. Spence & J. T. Spence (Eds.), *The psychology of learning and motivation* (8th ed.). London: Academic Press.

Auble, P. M., Franks, J. J., & Soraci, S. A. Jr., (1979). Effort toward comprehension: Elaboration or "aha"? *Memory & Cognition, 7*, 426–434.

Avraamides, M. N. (2003). Spatial updating of environments described in texts. *Cognitive Psychology, 47*(4), 402–431.

Avraamides, M. N., Loomis, J. M., Klatzky, R. L., & Golledge, R. G. (2004). Functional equivalence of spatial representations derived from vision and language: Evidence from allocentric judgments. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 30*(4), 804–814.

Bosco, A., Sardone, L., Scalisi, T. G., & Longoni, A. M. (1996). Spatial models derived from verbal descriptions of fictitious environments: The influence of study time and the individual differences in visuo-spatial ability. *Psychologische Beiträge, 38*, 451–466.

Brunyé, T. T., & Taylor, H. A. (2008a). Extended experience benefits spatial mental model development with route but not survey descriptions. *Acta Psychologica, 127*, 340–354.

Brunyé, T. T., & Taylor, H. A. (2008b). Working memory mechanisms in developing spatial mental models from survey and route descriptions. *Journal of Memory and Language, 58*, 701–729.

Brunyé, T. T., Taylor, H. A., Rapp, D. N., & Spiro, A. B. (2006). Procedural learning: The role of working memory in multimedia learning experiences. *Applied Cognitive Psychology, 20*, 917–940.

Brunyé, T. T., Taylor, H. A., & Worboys, M. (2007). Levels of detail in descriptions and depictions of geographic space. *Spatial Cognition and Computation, 7*(3), 227–266.

Bryant, D. J., & Tversky, B. (1999). Mental representations of spatial relations from diagrams and models. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 25*, 137–156.

Burgess, N. (2006). Spatial memory: How egocentric and allocentric combine. *Trends in Cognitive Sciences, 10*, 551–557.

Canas, J. J., Salmeron, L., Antoli, A., Fajardo, I., Chisalita, C., & Escudero, J. T. (2003). Differential roles for visuospatial and verbal working memory in the construction of mental models of physical systems. *International Journal of Cognitive Technology, 8*, 45–53.

Chabanne, V., Péruch, P., Denis, M., & Thinus-Blanc, C. (2004). Mental scanning of images constructed from visual experience of verbal descriptions: The impact of survey versus route perspective. *Imagination, Cognition and Personality, 23*, 163–171.

De Beni, R., Pazzaglia, F., Gyselinck, V., & Meneghetti, C. (2005). Visuospatial working memory and mental representation of spatial descriptions. *European Journal of Cognitive Psychology, 17*, 77–95.

De Vega, M., & Rodrigo, M. J. (2001). Updating spatial layouts mediated by pointing and labeling under physical and imaginary rotation. *European Journal of Cognitive Psychology, 13*, 369–393.

Denis, M. (2008). Assessing the symbolic distance effect in mental images constructed from verbal descriptions: A study of individual differences in the mental comparison of distances. *Acta Psychologica, 127*, 197–210.

Denis, M., Pazzaglia, F., Cornoldi, C., & Bertolo, L. (1999). Spatial discourse and navigation: An analysis of route directions in the City of Venice. *Applied Cognitive Science, 13*(2), 145–174.

Deyzac, E., Logie, R. H., & Denis, M. (2006). Visuospatial working memory and the processing of spatial descriptions. *British Journal of Psychology, 97*, 217–243.

Diwadkar, V. A., & McNamara, T. P. (1997). Viewpoint dependence in scene recognition. *Psychological Science, 8*, 302–307.

Ekstrom, A. D., Kahana, M. J., Caplan, J. B., Fields, T. A., Isham, E. A., Newman, E. L., et al. (2003). Cellular networks underlying human spatial navigation. *Nature, 425*, 184–187.

Farmer, E. W., Berman, J. V., & Fletcher, Y. L. (1986). Evidence for a visuo-spatial scratchpad in working memory. *Quarterly Journal of Experimental Psychology, 38*, 675–688.

Ferguson, E. L., & Hegarty, M. (1994). Properties of cognitive maps constructed from text. *Memory & Cognition, 22*, 455–473.

Giudice, N. A., Bakdash, J. Z., & Legge, G. E. (2007). Wayfinding with words: Spatial learning and navigation using dynamically-updated verbal descriptions. *Psychological Research, 71*(3), 347–358.

Golledge, R., & Spector, A. N. (1978). Comprehending the urban environment: Theory and practice. *Geographical Analysis, 10*, 403–426.

Gyselinck, V., De Beni, R., Pazzaglia, F., Meneghetti, C., & Mondoloni, A. (2007). Working memory components and imagery instructions in the elaboration of a spatial mental model. *Psychological Research, 71*(3), 373–382.

Hartley, T., Maguire, E. A., Spiers, H. J., & Burgess, N. (2003). The well-worn route and the path less traveled: Distinct neural bases of route following and wayfinding in humans. *Neuron, 37*, 877–888.

Hegarty, M., & Waller, D. A. (2005). Individual differences in spatial ability. In P. Shah & A. Miyake (Eds.), *The Cambridge handbook of visuospatial thinking* (pp. 121–169). New York: Cambridge University Press.

Hirtle, S. C., & Jonides, J. (1985). Evidence of hierarchies in cognitive maps. *Memory & Cognition, 13*, 208–217.

Ishikawa, T., & Montello, D. R. (2006). Spatial knowledge acquisition from direct experience in the environment: Individual differences in the development of metric knowledge and the integration of separately learned places. *Cognitive Psychology, 52*, 93–129.

Kato, Y., & Takeuchi, Y. (2003). Individual differences in wayfinding strategies. *Journal of Environmental Psychology, 23*, 171–188.

Kintsch, W., Welsch, D., Schmalhofer, F., & Zimny, S. (1990). Sentence memory: A theoretical analysis. *Journal of Memory and Language, 29*, 133–159.

Klatzky, R. L., Lippa, Y., Loomis, J. M., & Golledge, R. G. (2003). Encoding, learning, and spatial updating of multiple object locations specified by 3-d sound, spatial language, and vision. *Experimental Brain Research, 149*(1), 48–61.

Kosslyn, S. M., Ball, T. M., & Reiser, B. J. (1978). Visual images preserve metric spatial information: Evidence from studies of image scanning. *Journal of Experimental Psychology: Human Perception and Performance, 4*, 1–20.

Kuipers, B. J. (1978). Modeling spatial knowledge. *Cognitive Science, 2*, 129–153.

Kulhavy, R. W., Stock, W. A., & Caterino, L. C. (1994). Reference maps as a framework for remembering text. In Schnotz & Kulhavy (Eds.), *Comprehension of graphics* (pp. 153–162). Holland: Elsevier Science.

Kulhavy, R. W., Stock, W. A., Verdi, M. P., Rittschof, K. A., & Savenye, W. (1993). Why maps improve memory for text: The influence of structural information on working memory operations. *European Journal of Cognitive Psychology, 5*, 375–392.

Ladd, F. (1970). Black youths view their environment: Neighborhood maps. *Environment and Behavior, 2*, 74–99.

Larkin, J. H., & Simon, H. A. (1987). Why a diagram is (sometimes) worth ten thousand words. *Cognitive Science, 11*, 65–99.

Lee, P., & Tversky, B. (2001). Costs of switching perspectives in route and survey descriptions. In J. Moore & K. Stenning (Eds.), *Proceedings of the 23th Annual Conference of the Cognitive Science Society* (pp. 574–579). Mahwah, NJ: Lawrence Erlbaum Associates.

Lee, P. U., & Tversky, B. (2005). Interplay between visual and spatial: The effect of landmark descriptions on comprehension of route/survey spatial descriptions. *Spatial Cognition and Computation, 5*, 163–185.

Levelt, W. J. M. (1982). Linearization in describing spatial networks. In S. Peters & E. Saarinen (Eds.), *Processes, beliefs, and questions. Essays on formal semantics of natural language and natural language processing* (pp. 199–220). Dordrecht: Reidel.

Levine, M., Marchon, I., & Hanley, G. L. (1984). The placement and misplacement of you-are-here maps. *Environment and Behavior, 16*, 139–157.

Levinson, S. C. (2003). *Space in language and cognition: Explorations in cognitive diversity*. Cambridge: Cambridge University Press.

Linde, C., & Labov, W. (1975). Spatial structures as a site for the study of language and thought. *Language, 51*, 924–939.

Lloyd, R. (2000). Understandng and learning maps. In R. Kitchin & S. Freundschuh (Eds.), *Cognitive mapping: Past, present, and future* (pp. 88–107). London, UK: Routledge.

Loomis, J. M., Golledge, R. G., & Klatzky, R. L. (1998). Navigation system for the blind: Auditory display modes and guidance. *Presence: Teleoperators and Virtual Environments, 7*, 193–203.

Loomis, J. M., Klatzky, R. L., Golledge, R. G., & Philbeck, J. W. (1999). Human navigation by path integration. In R. G. Golledge (Ed.), *Wayfinding behavior: Cognitive mapping and other spatial processes* (pp. 125–151). Baltimore, MD: Johns Hopkins Press.

Lynch, K. (1960). *The image of the city*. Cambridge, MA: MIT Press.

Maguire, E. A., Burgess, N., Donnett, J. G., Frackowiak, R. S. J., Frith, C. D., & O'Keefe, J. (1998). Knowing where, and getting there: A human navigation network. *Science, 280*, 921–924.

Mayer, R. E. (2005). *The Cambridge handbook of multimedia learning*. New York, NY: Cambridge University Press.

McNamara, T. P., Rump, B., & Werner, S. (2003). Egocentric and geocentric frames of reference in memory of large-scale space. *Psychonomic Bulletin & Review, 10*, 589–595.

Melinger, A., & Levelt, W. (2004). Gesture and the communicative intention of the speaker. *Gesture, 4*, 119–141.

Miyake, A., Friedman, N. P., Rettinger, D. A., Shah, P., & Hegarty, M. (2001). Visuospatial working memory, central executive functioning, and psychometric visuospatial abilities: How are they related? *Journal of Experimental Psychology: General, 130*, 621–640.

Montello, D. R. (1998). A new framework for understanding the acquisition of spatial knowledge in large-scale environments. In M. J. Egenhofer & R. G. Golledge (Eds.), *Spatial and temporal reasoning in geographic information systems* (pp. 143–154). New York: Oxford University Press.

Montello, D. R. (2005). Navigation. In P. Shah & A. Miyake (Eds.). *The Cambridge handbook of visuospatial thinking* (Vol. 18, pp. 257–294). New York: Cambridge University Press.

Morris, C. D., Bransford, J. D., & Franks, J. J. (1978). Levels of processing versus transfer appropriate processing. *Journal of Verbal Learning and Verbal Behavior, 16*, 519–533.

Mou, W., & McNamara, T. P. (2002). Intrinsic frames of reference in spatial memory. *Journal of Experimental Psychology: Learning, Memory and Cognition, 28*, 162–170.

Mou, W., McNamara, T. P., Valiquette, C. M., & Rump, B. (2004). Allocentric and egocentric updating of spatial memories. *Journal of Experimental Psychology: Learning, Memory and Cognition, 30*, 142–157.

Navon, D. (1977). Forest before trees: The precedence of global features in visual perception. *Cognitive Psychology, 9*, 353–383.

Noordzij, M. L., & Postma, A. (2005). Categorical and metric distance information in mental representations derived from route and survey descriptions. *Psychological Research, 69*, 221–232.

Noordzij, M. L., Van der Lubbe, R. H. J., & Postma, A. (2005). Strategic and automatic components in the processing of linguistic spatial relations. *Acta Psychologica, 119*, 1–20.

Noordzij, M. L., Van der Lubbe, R. H. J., & Postma, A. (2006). Electrophysiological support for strategic processing of spatial sentences. *Psychophysiology, 43*, 277–286.

Noordzij, M. L., Zuidhoek, S., & Postma, A. (2006). The influence of visual experience on the ability to form spatial mental models based on route and survey descriptions. *Cognition, 100*, 321–342.

Pazzaglia, F., De Beni, R., & Meneghetti, C. (2007). The effects of verbal and spatial interference in the encoding and retrieval of spatial and non-spatial texts. *Psychological Research, 71*, 484–494.

Péruch, P., Chabanne, V., Nese, M.-P., Thinus-Blanc, C., & Denis, N. (2006). Comparing distances in mental images constructed from visual experience or verbal descriptions: The impact of survey versus route perspective. *Quarterly Journal of Experimental Psychology, 59*, 1950–1967.

Prestopnik, J. L., & Roskos-Ewoldsen, B. (2000). The relations among wayfinding strategy use, sense of direction, sex, familiarity, and wayfinding ability. *Journal of Environmental Psychology, 20*, 177–191.

Rapp, D. N., Culpepper, S. A., Kirkby, K., & Morin, P. (2007). Fostering students' comprehension of topographic maps. *Journal of Geoscience Education, 55*, 5–16.

Rossano, M. J., & Reardon, W. P. (1999). Goal specificity and the acquisition of survey knowledge. *Environment and Behavior, 31*, 395–412.

Schneider, L. F., & Taylor, H. A. (1999). How do you get there from here? Mental representations of route descriptions. *Applied Cognitive Psychology, 13*, 415–441.

Shelton, A. L., & McNamara, T. P. (1997). Multiple views of spatial memory. *Psychonomic Bulletin & Review, 4*, 102–106.

Shelton, A. L., & McNamara, T. P. (2001). Visual memories from nonvisual experiences. *Psychological Science, 12*, 343–347.

Please cite this article in press as: Brunyé, T. T. et al., Representational flexibility and specificity ..., *Cognition* (2008), doi:10.1016/j.cognition.2008.03.005

Shelton, A. L., & McNamara, T. P. (2004). Orientation and perspective dependence in route and survey learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 30*(1), 158–170.

Sholl, M. J. (1987). Cognitive maps as orienting schemata. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 13*, 615–628.

Simons, D. J., & Wang, R. F. (1998). Perceiving real-world viewpoint changes. *Psychological Science, 9*, 315–320.

Taylor, H. A. (2005). Mapping the understanding of understanding maps. In P. Shah & A. Miyake (Eds.), *The Cambridge handbook of visuospatial thinking* (pp. 295–333). New York: Cambridge University Press.

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

Taylor, H. A., & Tversky, B. (1992a). Spatial mental models derived from survey and route descriptions. *Journal of Memory and Language, 31*, 261–292.

Taylor, H. A., & Tversky, B. (1992b). Descriptions and depictions of environments. *Memory & Cognition, 20*, 483–496.

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

Tom, A., & Denis, M. (2003). Referring to landmark or street information in route directions: What difference does it make? In W. Kuhn, M. F. Worboys, & S. Timpf (Eds.), *Spatial information theory: Foundations of geographic information science* (pp. 384–397). Berlin: Springer.

Tversky, B. (1991). Spatial mental models. In G. H. Bower (Ed.). *The psychology of learning and motivation: Advances in research and theory* (Vol. 27, pp. 109–145). NY: Academic Press.

Tversky, B. (1992). Distortions in cognitive maps. *Geoforum, 23*, 131–138.

Tversky, B. (1993). Cognitive maps, cognitive collages, and spatial mental models. In A. U. Frank & I. Campari (Eds.), *COSIT'93, lecture notes in computer science 716*. Berlin: Springer.

Tversky, B. (2000). Remembering spaces. In E. Tulving & F. I. M. Craik (Eds.), *Handbook of memory* (pp. 363–378). New York: Oxford University Press.

Tversky, B., Kim, J., & Cohen, A. (1999). Mental models of spatial relations and transformations from language. *Advances in Psychology, 128*, 239–258.

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

Verdi, M. P., Johnson, J. T., Stock, W. A., Kulhavy, R. W., & Ahern, P. (1997). Organized spatial display and texts: Effects of presentation order and display type on learning outcomes. *Journal of Experimental Education, 64*, 303–317.

Verdi, M. P., & Kulhavy, R. W. (2002). Learning with maps and texts: An overview. *Educational Psychology Review, 14*, 27–46.

Waller, D., & Hodgson, E. (2006). Transient and enduring spatial representations under disorientation and self-rotation. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 32*, 867–882.

Wang, R. F., & Simons, D. J. (1999). Active and passive scene recognition across views. *Cognition, 70*, 191–210.

Wang, R. F., & Spelke, E. (2000). Updating egocentric representations in human navigation. *Cognition, 77*, 215–250.

Wang, R. F., & Spelke, E. S. (2002). Human spatial representation: Insights from animals. *Trends in Cognitive Sciences, 6*, 376–382.

Wehner, R. (1999). Large-scale navigation: The insect case. In C. Freksa & D. M. Mark (Eds.), *Spatial information theory: Cognitive and computational foundations of geographic information science* (pp. 1–20). Berlin: Springer.

Wills, T. W., Estow, S., Soraci, S. A., & Garcia, J. (2006). The aha effect in groups and other dynamic learning contexts. *The Journal of General Psychology, 133*, 221–236.

Wills, T. W., Soraci, S. A., Chechile, R. A., & Taylor, H. A. (2000). "Aha" effects in the generation of pictures. *Memory & Cognition, 28*, 939–948.

Please cite this article in press as: Brunyé, T. T. et al., Representational flexibility and specificity ..., *Cognition* (2008), doi:10.1016/j.cognition.2008.03.005