In press at Cognition

Body-Specific Representations of Spatial Location

Tad T. Brunyé [2,1]

Aaron Gardony [2,1]

Caroline R. Mahoney [2,1]

Holly A. Taylor [1]

[1] Tufts University, Department of Psychology, Medford, MA

[2] U.S. Army NSRDEC, Cognitive Science, Natick, MA

Contact Author
Tad T. Brunyé, Ph.D.
Tufts University
Department of Psychology
490 Boston Ave
Medford, MA 02155
Telephone: 617-306-6262

In press at Cognition

Abstract

The *body specificity hypothesis* (Casasanto, 2009) posits that the way in which people interact with the world affects their mental representation of information. For instance, right- versus left-handedness affects the mental representation of affective valence, with right-handers categorically associating good with rightward areas and bad with leftward areas, and left-handers doing the opposite. In two experiments we test whether this hypothesis can: extend to spatial memory, be measured in a continuous manner, be predicted by extent of handedness, and how the application of such a heuristic might vary as a function of informational specificity. Experiment 1 demonstrates systematic and continuous spatial location memory biases as a function of associated affective information; right-handed individuals misremembered positively- and negatively-valenced locations as further right and left, respectively, relative to their original locations. Left-handed individuals did the opposite, and in general those with stronger right- or left-handedness showed greater spatial memory biases. Experiment 2 tested whether participants would show similar effects when studying a map with high visual specificity (i.e., zoomed in); they did not. Overall we support the hypothesis that handedness affects the coding of affective information, and better specify the scope and nature of body-specific effects on spatial memory.

Keywords: Spatial cognition, embodied cognition, emotion

Body-Specific Representations of Spatial Location

Successfully thinking about space is essential to daily functioning, allowing us to figure out where we are, where goal locations are and how to get there. Much of the cognitive science literature examining spatial thinking is largely concerned with the form and function of spatial memory representations and how they are affected by various factors. One important insight from this research is the finding that spatial memories cannot be suitably characterized as simple invariant isomorphic representations of experienced or studied space. Rather, spatial mental representations are flexible, malleable and quite vulnerable to several factors characterizing their acquisition and use. These include the geographic structure of the environment, availability of non-spatial information, level and type of experience, manner of retrieval, goals and emotional state during encoding, and individual differences in spatial aptitude and preferences (e.g., Brunyé, Mahoney, Augustyn, & Taylor, 2009; Brunyé & Taylor, 2008a,b, 2009; Gyselinck, Meneghetti, De Beni, & Pazzaglia, 2009; Hegarty, Montello, Richardson, Ishikawa, & Lovelace, 2006; Maddox, Rapp, Brion, & Taylor, 2008; McNamara, Halpin, & Hardy, 1992; Meneghetti, Gyselinck, Pazzaglia, & De Beni, 2009; Taylor, Naylor, & Chechile, 1999; Waller, 2000). <u>For instance, differing user goals (e.g., learning about the layout versus learning how to get around) when learning a new environment biases not only where people look on a map, but also how they structure their mental representations to suit such goals (Brunyé & Taylor, 2009; Taylor et al., 1999).</u> Fully characterizing the range of variables impacting the form and function of spatial memory is critical for predicting wayfinding behavior, and informing comprehensive theories of spatial understanding. To this end, the present research discovers three factors that influence the nature of spatial memories resulting from map study: informational valence, participant handedness, and spatial granularity.

Spatial Mental Representations

There is a popular view (or misconception; i.e., B. Tversky, 1993, 2005) that spatial memory is comprised of mental images of environmental structure, commonly referred to as *cognitive maps*. In this view (i.e., Jeffery & Burgess, 2006; Tolman, 1948), mental representations of space take on a two-dimensional format akin to a cartographer's map, and these mental images can be inspected in order to solve spatial problems. It is easy to imagine ways in which map-like mental images could provide a convenient mechanism for extracting useful information, such as landmark locations and the paths and Euclidean distances that define their interrelationships. The cognitive map metaphor, however, is limited in its ability to account for the wide range of human spatial behavior. For instance, people form hierarchies in spatial memory that reliably distort both distance and direction judgments; these hierarchies can be formed using geographic (e.g., number of cities; Thorndyke, 1981; political borders; Stevens & Coupe, 1978) and topographic (e.g., rivers, mountain ranges; Canter & Tagg, 1975) information to impose conceptual structure on an environment (for reviews, see McNamara, 1986; B. Tversky, 1991). In addition to spatial features, several non-spatial characteristics can also distort map memory. These include functional (e.g., building purpose; Hirtle & Jonides, 1985), semantic (Hirtle & Mascolo, 1986), and demographic (e.g., race; Maddox et al., 2008) information associated with spatial locations and regions. Several decades of research have thus demonstrated numerous systematic distortions in spatial memory (cf., McNamara, 1986; Thorndyke, 1981; B. Tversky, 1981, 2005), providing clear evidence that spatial mental representations take on a form dissimilar to simple isomorphic mental images of conventional maps. Indeed B. Tversky (2005) has proposed that *cognitive collage* is perhaps a more suitable

In press at Cognition

metaphor than cognitive map, given that spatial mental representations appear to be "fragmented, schematized, inconsistent, incomplete, and multimodal" (p. 12).

Characterizing the full range of factors affecting spatial memory is critical in developing comprehensive theories of spatial understanding. However, many contemporary theoretical advances in spatial cognition give limited recognition to the effects of individual differences and contextual factors on the development of flexible spatial memories (e.g., McNamara, Sluzenski, & Rump, 2008; Shelton & McNamara, 2001; B. Tversky, 2005, 2009). One understudied topic is the extent to which affectively valenced information associated with spatial locations might influence people's ability to accurately memorize map-based information. Whether learning about tragic events on the nightly news or experiencing them first-hand as a civilian or military emergency first responder, associating affectively valenced information to particular locations is exceedingly common. In general, these events can be negative, neutral, or positive in valence. Though little research has investigated whether and how spatial memory might vary as a function of affectively valenced information, some recent research examining the *body specificity hypothesis* provides strong theoretical motivation for investigating such a possibility.

Affective Valence and the Body Specificity Hypothesis

Some early research demonstrated that the right and left sides of the body are consistently mapped to positive and negative valence, respectively (Davidson, 1992; Natale, Gur, & Gur, 1983). Current theories are mixed with regard to potential explanations for such a pattern; first is the argument that this mental metaphor reflects linguistic experience (Boroditsky, 2000; Gentner, Bowdle, Wolff, & Boronat, 2001; Meier & Robinson, 2004), and second is the argument that the mental metaphor reflects bodily experience (Lakoff & Johnson, 1999; Piaget, 1969). Some recent research has effectively tested between these two competing theoretical accounts by examining how participant handedness might influence the representation of valenced information (Casasanto, 2009; Casasanto & Jasmin, 2010; Willems, Hagoort, & Casasanto, 2010). Under the theory that bodily experiences drive mental metaphors, Casasanto (2009) hypothesized that perceptuomotor fluency imparted by right- or left-handedness would affect whether participants associate good or bad with right or left body axes. In general, the hypothesis stressed that if mental metaphors associating valenced information with spatial axes are a result of bodily experience, then those who interact with the world in different ways would form different associations (through correlational learning; i.e., Hebb, 1949).

In five experiments, Casasanto found support for what he calls the *body specificity hypothesis*. For instance, when participants were tasked to draw (Experiment 1) or assign (Experiment 3) cartoon animals into areas reflecting whether they were good or bad, participants showed a strong tendency to place good animals in an upper box relative to bad animals. Critically, right- and left-handers also tended (approximately 70% of the time) to place good animals in right or left boxes, respectively. That is, participants placed good stimuli in an area corresponding to their dominant hand (right or left), and bad stimuli in the opposing area. Participants showed similar patterns when judging alien creatures (Experiment 4), products and job applicants (Experiment 5) that were placed to the right or left; the creature, product or applicant featured on the side of their dominant hand was consistently associated with relatively positive attributes. These results were found regardless of whether the person physically used their dominant hand to make a response. It appears that participants associated positive valence with the side of their body that they could use more fluently. This general finding corresponds to a number of other studies suggesting that the manner in which individuals interact with the world

In press at Cognition

biases perception and decision making (e.g., Beilock & Holt, 2007; Casasanto & Jasmin, 2010; Oppenheimer, 2008; Reber, Winkielman, & Schwarz, 1998; Van den Bergh, Vrana, & Eelen, 1990; Willems et al., 2010).

The Current Studies

The present research sought to extend earlier findings in four primary ways. First, the extant literature demonstrating body-specific effects focuses primarily on judgment and decision making, and does not consider potential effects of body-specific heuristics on human memory. Indeed it could be the case that whereas body-specific effects might be found during online processes such as perception and motor movement, they may not result in body-specific traces in long-term memory (for a review of such distinctions, see Hastie & Park, 1986). However, memory in general, and spatial memory in particular, traditionally proves quite vulnerable to effects of biases and heuristics (i.e., Halpern & Kelly, 1993; B. Tversky, 1981). If the heuristics underlying body-specific effects are due to general processing mechanisms one might expect support for the body-specificity hypothesis within the domain of spatial memory. To test the scope of body-specific effects, we examined whether human spatial memory would prove vulnerable to interactive effects of handedness and valence.

Second, we examined whether the mapping between spatial location and informational valence could be represented in a continuous manner. In prior work (Casasanto, 2009), the author used the proportion of judgments in categorical space to draw inferences about people's mental representations of space and valence. Memory for spatial locations is a prime candidate for examining the nature of the association between location and informational valence, given work demonstrating that continuous metric spatial information characterizes spatial memories for

In press at Cognition

both maps (Denis & Zimmer, 1992; Kosslyn, Ball, & Reiser, 1978; McNamara, 1986; Thorndyke & Hayes-Roth, 1982) and spatial descriptions (Noordzij & Postma, 2005). Given this work, we expect that memory for spatial locations will be biased in a continuous manner characterized by shifts in metric space. This hypothesis is also based on a study examining the spatial representation of affectively valenced information (Crawford, Margolies, Drake, & Murphy, 2006), in which the authors found that participants misremembered the spatial locations of positive information as higher relative to negative information. They did not find any effects of valence on the horizontal dimension, likely due to small participant samples of unspecified handedness. A specific prediction of the *body specificity hypothesis* is that handedness and informational valence will modulate how people organize information, though no studies to date have specifically examined whether this applies to non-categorical spatial judgments.

Our third goal was to better-specify the contribution of handedness to the mental representation of affective valence. In all previous studies examining right- versus left-handedness and the representation of valence (Casasanto, 2009; Casasanto & Jasmin, 2010; Willems et al., 2010), handedness was treated solely as a dichotomous variable. However, contemporary theories of handedness consider it a continuous factor that is often associated with differential degrees of effect on measures of spatial and verbal processes (e.g., Annett, 1972; Bishop, 1990; Brenneman, Decker, Meyers, & Johnson, 2008; Dean & Reynolds, 1997; Dean & Woodcock, 2003; Grace, 1987). If body-specific effects are driven by left versus right motoric fluency (i.e., Casasanto, 2009), then the extent of polarized fluency should predict the magnitude of such effects; the extant literature has not examined this possibility. In the present studies we measure handedness on a continuous scale (Oldfield, 1971) and perform our analyses with handedness as both a dichotomous and continuous variable. If right- versus left-handedness is a

In press at Cognition

reliable contributor to the differential spatial representation of affective valence, then extent of handedness should predict any effects. Such a result would provide strong evidence that body-specific effects are related to an individual's fluency imparting action upon the world with a particular side of their body, and minimize the possibility of between-group mediating factors.

Our fourth goal was to assess whether body-specific effects would manifest in conditions of high certainty due to visual specificity. To increase the practical relevance of our research we chose to use Google^{TM} Maps of an actual U.S. city (Buffalo, NY); our first experiment used a zoom level of 1000 linear ft/inch, and our second experiment 250ft/inch. Our intention was to test the conditions under which the application of body-specific heuristics might be more or less likely to emerge. To operationalize this, we varied our stimulus maps between different zoom levels. In general, people introduce heuristics under conditions of uncertainty (Kahneman, Slovic, & A. Tversky, 1982). The reduction of granularity at low zoom levels abstracts from metric details (Wolter, Freska, & Latecki, 2008) and might increase the use of heuristics that shape spatial memory. In general, the use of heuristics such as good-right and bad-left might only be introduced when augmenting a relatively impoverished spatial information source (i.e., Lederman, Klatzky, Collins, & Wardell, 1987). In general, lower zoom levels provide lower visual specificity, an inability to specify precise locations, and relatively categorical (e.g., to the west of center, below the main highway) location memory (Brunyé, Taylor & Worboys, 2007; Shimron, 1978; McNamara, Hardy, & Hirtle, 1989; Rossano & Hodgson, 1994; Schneider & Taylor, 1999). In contrast, higher zoom levels introduce finer degrees of granularity and visual specificity (e.g., a building of a particular shape, size and color) that can be used to accurately recall spatial locations. It could be the case that any spatial memory biases introduced by valence and handedness could be restricted to cases of low visual specificity.

In press at Cognition

Experiment 1

Spatial memory for real-world and large-scale environmental features has generally received little attention in the literature examining embodied influences on human performance (e.g., Brunyé, Mahoney & Taylor, 2010; Coventry & Garrod, 2005; for a review, see Taylor & Brunyé, in press). Given that humans behave in an inherently spatial world, and use spatial perception and memory to navigate during real-world tasks, understanding the full range of influences on spatial memory may prove valuable towards more general understandings of human spatial behavior. The body-specificity hypothesis presents a unique framework for examining body-specific influences on spatial memory.

Our first experiment examined the effects of handedness and informational valence on the ability to accurately recall spatial locations. To this end, we had groups of right- and left-handed participants learn about map locations that were associated with positive, neutral, or negative events. They were then tasked with cued recall during which they selected a point on the map where a given event took place; we measured the distance and direction between the originally learned and the selected location as a function of event valence and participant handedness. This experiment used a low zoom level (1000 linear ft/inch) and hypothesized that both right- and left-handed individuals would bias positively-valenced information upward (on the screen/map space) relative to negatively-valenced information.

We also expected that whereas right-handed individuals would bias positive information to the right of negative information, left-handed individuals would do the opposite. Such a result would support the *body specificity hypothesis* (Casasanto, 2009), and extend this work to the continuous metric representation of spatial locations.

Method

Participants. 72 Tufts University undergraduates participated for monetary compensation. Thirty-six participants self-reported as right-handed, and 36 as left-handed. We used the Edinburgh Inventory (Oldfield, 1971) to measure extent of handedness, which produces scores ranging from -100 (strongly left-handed) to +100 (strongly right-handed). With this scale, the right-handed group reported mean handedness of 73.47, and the left-handed group -41.67.

Materials.

Maps. We used the Google^{TM} Maps utility to produce a map image of a densely populated area of Buffalo, NY, USA. The map measured 900 x 900 pixels and used a zoom level of 1000 linear ft/inch. A total of 96 versions of the map were created, each with one location depicted with a small (17 pixel diameter) yellow dot (see Figure 1a). In designating the map locations, we pseudo-randomly distributed twenty-four locations within each of four invisible concentric squares. Restrictions on random placement included a minimum 15 pixel separation between locations, and between locations and the concentric square edge.

1a *1b*

Figure 1. Sample map stimuli used in Experiment 1 (1a) and Experiment 2 (1b), with zoomed out and zoomed in environments, respectively.

Event Descriptions. We created 32 event descriptions (see Table 1) modeled after brief 2-3 sentence news headlines and stories, 8 of which were positively valenced (e.g., *At the following location, a family wins a trip to Disney World. The family entered and won a local contest, which will pay all expenses for the family's first trip to Disney World!*), 8 negatively valenced (e.g., *At the following location, a family is killed in a tragic car accident. Due to rainy weather and poor visibility the father lost control of the car, slamming into a tree at 65mph.*), and 16 neutral (e.g., *At the following location, Tylenol outsells Advil. Drugstore announces that sales of Tylenol are higher than Advil for the third consecutive month.*). To ensure differences in valence between our three event conditions (positive, negative, neutral), we conducted a pilot study that involved nine participants reading and rating each description on a scale ranging from 1(sad) to 5(happy) with 3 being neutral (i.e., Bradley & Lang, 1994). A repeated-measures ANOVA demonstrated that ratings differed significantly as a function of event condition, $F(2, 16) = 98.26$, $p < .01$, with the highest ratings in the positive condition (*M* = 4.02, *SD* = .14), then the neutral condition (*M* = 3.23, *SD* = .05), and the lowest ratings in the negative condition (*M* = 1.58, *SD* = .13) (all pairwise *p's* < .01).

Table 1. *Example event description stimuli for positive, negative and neutral event types (all preceded by "At the following location,").*

Positive:

A family wins a trip to Disney World. The family entered and won a local contest, which will pay all expenses for the family's first trip to Disney World!

Six kittens are rescued from a tree. Little is known as to how they got so high, but all six kittens were saved and returned to their thankful owner.

Oldest man in the world celebrates 112th birthday! A healthy and happy Joe Smith, celebrated with family and friends, he has 23 smiling grandchildren and 5 great grand children.

Negative:

A family is killed in a tragic car accident. Due to rainy weather and poor visibility the father lost control of the car, slamming into a tree at 65mph.

Child attacked by grizzly bear. Kyle Klein age 7 was playing in his back yard when he was attacked by a bear, and is now in critical condition at local hospital.

Tour bus crashes killing 75. A large greyhound bus holding 75 tourists for a tour of the city, lost control and crashed killing all passengers aboard.

Neutral:

Tylenol outsells Advil. Drugstore announces that sales of Tylenol are higher than Advil for the third consecutive month.

New bus stop added. A new bus stop was added to the West D line, this was added to close the gap between stop 8a and stop 7d.

At the following location, middle school track meet rescheduled. Due to inclement weather the track meet will be scheduled for a different day.

Comprehension Questions. For each event description we designed a single inference question. The intention was to ensure that participants were reading for comprehension; that is, rather than simply processing the landmark identity (e.g., drugstore) and associating it with a presented location, we wanted to ensure that participants were comprehending event valence. Inference questions required participants to go beyond the information directly conveyed by the event description, such as (corresponding to the negative event detailed above), *Was the tree damaged by the car?* Overall, accuracy on these inference questions was high (*M* = .90, *SD* = .04), suggesting that participants were reading for comprehension.

Procedure.

In a brief practice session, each participant was exposed to a series of 4 locations and associated events, using methods identical to the experimental blocks. For the experimental blocks, they learned a total of 32 locations and associated events embedded within a sequence of 8 learning and testing blocks containing 4 trials each. Within a block, a participant learned four events (one positive, one negative, and two neutral), each randomly paired with a single map location (one from each map quadrant). The event description was presented for 8 seconds (corresponding to approximately 250msec/word; Rayner, 1998) immediately preceding the presentation of the map with a marked location (presented for 3 seconds). Location and event pairs were presented in random order within a block. Immediately following the presentation of the four location and event pairs, the participant was tested on their memory for the locations. During the testing phase, the participant was cued with one of the four event descriptions and then shown a map without any indicated location, and instructed to click on the map (using a standard mouse with their dominant hand) to indicate where they remember the event taking place. Participants were given as much time as they needed to identify a map location, and the four tested description-location pairs were presented in random order. Finally, participants were presented with four comprehension questions, in random order, corresponding to the four learned events; for each question, participants responded by clicking a 'yes' or 'no' box below the question.

This learning and testing sequence repeated itself across 8 blocks with a brief arithmetic filler task placed between successive blocks. Three experimental scripts were developed using the SuperLab software, each containing 32 description-location pairs; each script used a different randomly-selected set of 32 locations (8 from each concentric square, from the pool of 96), to maximize the sampling of locations across the entire map. We also partially counterbalanced the order of block presentation by randomly sampling three orders from a balanced 8-order Latin Square (Byers, 1996), and applying them to the three scripts, respectively.

Results

Data Scoring.

When a participant clicked a map location, the experimental software automatically recorded click location in (x,y) coordinate space. For each of the 32 trials per participant, we calculated the difference in the x and y pixel dimensions relative to the actual learned location. In this way, vertical memory bias is reflected as positive (upward) or negative (downward) movement in the y dimension; similarly, horizontal memory bias is reflected as positive (rightward) or negative (leftward) movement in the x dimension. Due to large variation in participant responses, trials were removed if x or y variation exceeded 200 pixels from an actual location (approximately 2SD above and below the x and y variation means). This process resulted in the removal of 106 trials (4% of all data), with similar removal rates for positive (27), negative (23) and neutral (56/2=28) trials.

Given that neutral event descriptions did not carry affective valence and were thus an effective control condition, for each participant we calculated residual bias by subtracting averaged x and y variation during neutral trials from averaged x and y variation for valenced trials. In this way, x and y directional bias is calculated relative to a neutral control condition, which accounts for any predisposed individual biases towards particular map regions or directions. All analyses use residual bias data. Effect sizes are calculated using eta-squared (η^2)

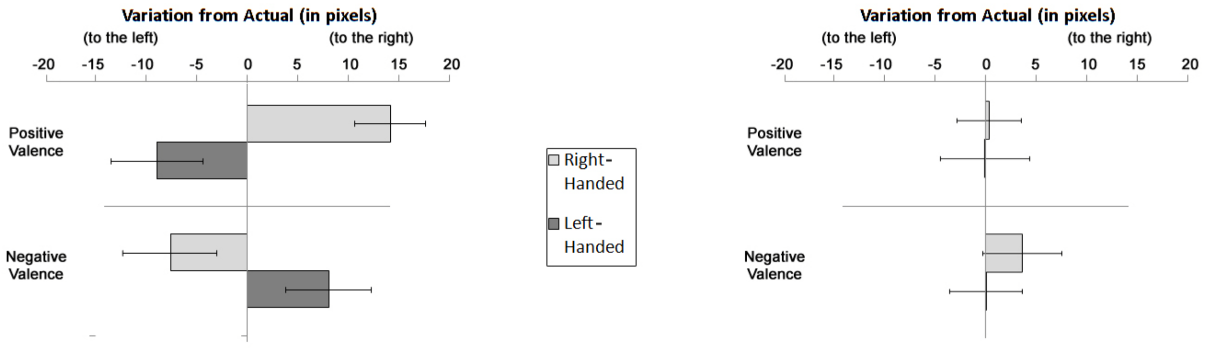
and Cohen's d (*d*). There were no main or interactive effects of which concentric square contained a landmark (all *F*'s < 1), and all subsequent analyses thus collapsed across this factor.

Effects of Handedness and Informational Valence

Data are detailed in Table 2. To evaluate the effects of handedness and informational valence on memory for spatial locations, we first conducted a 2(Handedness: right, left) x 2(Valence: positive, negative) x 2(Dimension: x, y) mixed ANOVA with Handedness as the only between-participants factor. There was a main effect of Valence, $F(1, 70) = 10.39$, $p < .01$, $\eta^2 = .04$, but no main effects of Handedness or Dimension ($p = .63$, $p = .56$, respectively). This effect was qualified by a three-way interaction between Handedness, Valence and Dimension, $F(1, 70) = 8.55$, $p < .01$, $\eta^2 = .04$. As detailed in Table 2, variation along the y (vertical) dimension did not vary as a function of Handedness, though positive information was biased upward and negative information somewhat downward. This was evidenced by a main effect of Valence, $F(1, 70) = 13.74$, $p < .01$, $\eta^2 = .16$, but no effect of Handedness or interaction between these two factors (*F's* < 1). Both right-handed, $t(35) = 2.44$, $p = .02$, $d = .41$, and left-handed, $t(35) = 2.85$, $p < .01$, $d = .47$, participants showed vertically higher placement of locations linked with positive relative to negative information.

More importantly, as seen in Figure 2a, variation along the x (horizontal) dimension varied as a function of both Handedness and Valence. To specifically test this effect, we conducted a 2 x 2 interaction contrast within the x dimension, with Handedness and Valence as factors. This analysis revealed an interaction, $F(1, 70) = 19.67$, $p < .01$, $\eta^2 = .22$. Two paired t-tests with a Bonferroni-corrected alpha ($\alpha = .025$) revealed that both right- and left-handed participants showed differential directional bias for positive versus negative information, $t(35) =$

3.94, $p < .01$, $d = .66$, and $t(35) = 2.51$, $p = .017$, $d = .42$, respectively, though they did so in an opposite manner. An alternative analysis method used independent-samples t-tests, testing right- versus left-handed groups, one within positive and one within negative; this analysis revealed a between-groups difference within positive, $t(70) = 4.02$, $p < .01$, $d = .95$, and negative, $t(70) = 2.50$, $p = .015$, $d = .59$, valence. Overall, the majority (25) of the 36 right-handed participants showed a positive bias to the right (i.e., x variation greater than 0), and 20 showed a negative bias to the left (i.e., x variation less than 0). Further, 20 of the 36 left-handed participants showed a positive bias to the left, and 19 showed a negative bias to the right.



2a 2b

Figure 2. Experiment 1 (2a) and 2 (2b) mean and standard error of X axis residual variation from actual learned location as a function of informational valence and participant handedness.

Our second set of analyses was focused on the extent to which our effects of Valence could be attributed to the magnitude of participant handedness. We conducted four simple linear regressions, asking whether extent of right- and left-Handedness (range from -100 to +100) could predict the extent to which positive and negative information was biased to the left or right. For right-handed participants, we found that higher degrees of right-handedness predicted the extent to which positive information was biased to the right, $\beta = .38$, $t(35) = 2.07$, $p < .05$, and the extent to which negative information was biased to the left, $\beta = .51$, $t(35) = 2.10$, $p < .05$. For left-handed participants, we found that higher degrees of left-handedness predicted the extent to which positive information was biased to the left, $\beta = .48$, $t(35) = 4.14$, $p < .01$, but not the extent to which negative information was biased to the right, $\beta = .11$, $t(35) = .82$, $p > .05$.

Table 2. *Experiment 1 and 2 mean and standard error X and Y residual variation (neutral is raw variation) for each of the three valence conditions (Negative, Neutral, Positive), and two handedness groups (Right-handed, Left-handed).*

	X Axis Variation		Y Axis Variation	
Experiment 1	*M*	*SE*	*M*	*SE*
Negative Valence				
Left-handed	8.1	4.2	-5.2	6.2
Right-handed	-7.6	4.6	-5.0	5.7
Neutral Valence				
Left-handed	-3.1	2.4	-2.1	2.4
Right-handed	-6.9	1.8	-9.4	2.2
Positive Valence				
Left-handed	-8.9	4.5	12.1	4.9
Right-handed	14.2	3.5	12.2	6.2
Experiment 2	*M*	*SE*	*M*	*SE*
Negative Valence				
Left-handed	0.2	4.2	1.6	4.3
Right-handed	4.4	4.6	6.3	4.5
Neutral Valence				
Left-handed	1.2	2.2	-0.2	2.2
Right-handed	-0.4	1.5	-1.5	1.9
Positive Valence				
Left-handed	-.02	5.3	4.2	4.3
Right-handed	.48	3.8	-1.7	3.3

Experiment 1 Discussion

Our first experiment found evidence that affective valence biases the mental representation of spatial location, and that this relationship is contingent upon participant

In press at Cognition

handedness. Whereas both right- and left-handed individuals biased landmark locations associated with positive information upward and negative information downward (i.e., Crawford et al., 2006), handedness showed differential effects on the horizontal representation of valenced information. Right-handed individuals biased spatial locations to the right of their actual location when they were associated with positive information, and to the left when associated with negative information; left-handed individuals did the opposite. Further, we found some evidence that the extent of right- or left-handedness predicts the magnitude of these effects. Those with the strongest degree of handedness to the right or left showed the largest horizontal biases as a function of informational valence, with one exception: stronger left-handedness did not predict greater negative information biases to the right. This result complements the overall low tendency for left-handed participants to bias negative information to the right in the non-regression analyses (see Table 2). Note that our right-handed participants were more strongly right-handed than our left-handed participants were left-handed, as suggested by mean EHI scores of 73.47 and -41.67, respectively. As such, our left-handed participants may show overall weaker body-specific effects given an overall weaker extent of lateralized motoric fluency.

Together, Experiment 1 results provide strong support for the *body specificity hypothesis*, which posits that the manner in which we interact with the world shapes mental representations. We provide the first evidence that biases can be identified in a spatial memory task involving the memorization of events and spatial locations along continuous spatial axes, and are influenced by the extent of participant handedness.

In press at Cognition

Experiment 2

Our second experiment was designed to test a condition under which the application of body-specific heuristics might be less likely to emerge. To this end, we zoomed-in (4x) on the same Buffalo, NY environment to a scale 250 linear ft/inch (see Figure 1b). The level of visual detail offered by this increased zoom level is expected to affect whether valence and handedness influence memory for spatial locations. Research investigating the application of heuristics demonstrates that under conditions of uncertainty (Kahneman et al., 1982) and low spatial detail (Lederman et al., 1987) people are more likely to introduce heuristics towards performing a variety of memory and problem solving tasks. We expect that with an increased zoom and thus higher granularity and visual specificity, participants would be less likely to introduce body-specific biases into their memory for spatial locations.

Method

Participants. 72 Tufts University undergraduates participated for monetary compensation, none of which had participated in Experiment 1. Thirty-six participants self-reported as right-handed, and 36 as left-handed. Again using the Edinburgh Inventory (Oldfield, 1971), the right-handed group reported mean handedness of 71.57, and the left-handed group -61.22.

Materials & Procedure

We used the same map of Buffalo, NY, USA, zoomed to a level of 250 linear ft/inch, with a common central point to the map used in Experiment 1. Higher zoom levels alter the visual specificity of the map, which is most commonly defined by an *indistinguishability relation* (Hobbs, 1985), which assesses the extent to which two map elements are visually distinguishable. Because high resolution is preserved at high zoom levels while using contemporary mapping technologies (e.g., Google^{TM} Maps), the indistinguishability relation is directly and positively related to zoom level. In this manner, indistinguishable landmarks at low zoom levels become distinguishable at higher zoom levels (Keet, 2007), particularly at pronounced relative zoom levels (i.e., 4x, as presently used). All other materials and procedures were identical to those used in Experiment 1.

Results

Data Scoring.

Data scoring procedures were identical to those used in Experiment 1. Outlier removal resulted in the removal of only 76 trials (3% of all data). Comprehension question accuracy was again very high (92.1%).

Effects of Handedness and Informational Valence

As in Experiment 1, to evaluate the effects of handedness and informational valence on memory for spatial locations, we conducted a 2(Handedness: right, left) x 2(Valence: positive, negative) x 2(Dimension: x, y) mixed ANOVA with Handedness as the only between-participants factor. In contrast to Experiment 1, this analysis did not reveal any significant main effects or interactions (all p's > .05). In general, variation along the x (horizontal) and y (vertical) dimensions did not vary as a function of Handedness or Valence (see Figure 2b). In fact, though individual participants showed wide variation in their locational estimates, condition means generally approached zero (overall M = 1.92, Range -1.72 to 6.28; as detailed in Table 2).

Testing for Differences Across Experiments

To specifically test for a difference between the results of Experiments 1 and 2, we performed an omnibus ANOVA with the addition of the two experiments as a between-participants factor with 2 levels (Map Detail: zoomed out, zoomed in). The 2(Handedness: right, left) x 2(Valence: positive, negative) x 2(Dimension: x, y) x 2(Map Detail: zoomed in, zoomed out) mixed ANOVA revealed a significant four-way interaction, $F(1, 140) = 6.67$, $p = .01$, $\eta^2 = .01$. Specifically, the four-way interaction demonstrates that the three-way interaction found in Experiment 1 ($p < .01$) and the nonsignificant three-way interaction term found in Experiment 2 ($p = .56$), were indeed different from one another.

Experiment 2 Discussion

Our second experiment tested a condition under which we expected body-specific heuristics less likely to manifest: with stimuli of high visual detail. Results supported this hypothesis, demonstrating no three-way interaction between Handedness, Valence, and Dimension. In fact, participants showed very low overall error in their locational estimates. This result converges well with literature demonstrating that people tend to apply heuristics towards memory and problem solving tasks only when the task introduces conditions of uncertainty (Kahneman et al., 1982; Lederman et al., 1987). The level of detail offered by the increased zoom made participants less likely to introduce bias into their memory for spatial locations.

As in Experiment 1, we again found no evidence that neutral valence information was biased along the horizontal or vertical axes for left- or right-handers. Evidence for body-specific effects only arose when information was exceedingly positive or negative. We note, however, that neutral scenario valence may be differently perceived when comprehended independently of the negative or positive scenarios. That is, without the context of relatively positive or negative information, spatial memory for neutral locations may be biased in correspondence with participant handedness and perceived valence. Future research might examine such a possibility.

General Discussion

Embodied influences on spatial memory have received relatively little attention, but carry potentially large implications for explaining and predicting human spatial performance. The present research identified three new factors that predictably bias human spatial memory: the handedness of the individual, the valence of associated information, and the granularity of a spatial display. In 2009, Casasanto proposed the *body-specificity hypothesis*, which predicts that the direction in which spatial representations are biased varies as a function of both participant handedness and the valence of learned information. We provided a test of this hypothesis within the context of learning spatial locations and valenced events. Our results demonstrate spatial memory biases on a continuous metric scale using practically relevant stimuli. We support prior work demonstrating upward biases for positive and downward biases for negative information (Crawford et al., 2006), regardless of handedness. We extend more recent work by demonstrating that right-handed individuals show spatial memory biases for positive information to the right of the learned location, and negative information to the left of the learned location; left-handed individuals show the opposite pattern. Critically, we also demonstrate that, in line with theoretical conceptualizations of the role of handedness in cognition (Annett, 1972; Bishop, 1990; Brenneman et al., 2008; Dean & Reynolds, 1997; Dean & Woodcock, 2003; Grace, 1987), strength of handedness is a powerful predictor of memory effects. This finding extends the *body-specificity hypothesis* in an important way: though individuals can be bifurcated into right- versus left-handed, stronger support for the role of bodily experience in shaping mental

In press at Cognition

representations can be found by examining the strength of handedness. We propose that the extent to which individuals show dominant use of either the right or left hand in interacting with the world with perceptuomotor fluency may predict the extent to which handedness will affect the mental representation of valenced events. This is in line with recent conceptualizations of embodied cognition, which posit that the manner in which we experience and interact with the world strongly shape the way we think about and manipulate memories of the world (Barsalou, 2005, 2008).

The spatial granularity of map stimuli further influenced the extent to which handedness and informational valence influenced spatial memory. In Experiment 1, with a map of low spatial specificity due to a low zoom level, participants applied heuristics that shaped location memory; when maps had a higher degree of spatial specificity due to a four-fold increase in zoom level, this result disappeared. This pattern supports research demonstrating that lower spatial granularity leads to an inability for people to isolate and remember precise locations, and the introduction of relatively categorical representations of space (Brunyé et al., 2007; Shimron, 1978; McNamara et al., 1989; Rossano & Hodgson, 1994; Schneider & Taylor, 1999). This is in contrast to higher zoom levels, higher spatial specificity, and subsequently more accurate spatial memory that is not as vulnerable to the influence of heuristics. This finding suggests that only under conditions of uncertainty will participant handedness and information valence reliably bias human spatial memory to the extent that it affects locational estimates. It also underscores the importance of understanding the precise circumstances under which substantial biases will be introduced, and thus the circumstances under which adaptive interfaces hold promise in applied contexts. Indeed when individuals study maps with low spatial granularity they appear to be most vulnerable to memory biases, and thus, within this context, interface alterations such as spatial cueing and automated zooming may hold their greatest promise. This possibility presents an exciting opportunity for future research to differentiate the conditions under which such interfaces hold promise for enhancing human performance (e.g., Haas, Nelson, Repperger, Bolia, & Zacharias, 2001; Wickens, Vincow, & Yeh, 2005). Future research may also attempt to better disentangle the possible effects of visual specificity versus memorization ease. Specifically, the lower density spatial information presented in Experiment 2 may be relatively easy to memorize in addition to its higher visual specificity. These issues are difficult to disentangle given they tend to be highly correlated, though one possible technique is to increase the retention interval to test how handedness might influence spatial memory biases over time. Another technique is to use dependent measures that may prove more sensitive in detecting the application of heuristics under conditions of relative certainty, such as event-related potentials or movement tracking.

The present results further speak to the origins of mental metaphors that bias human behavior. Theories are mixed with regard to whether linguistic or bodily experiences produce mental metaphors that link space and valence (Boroditsky, 2000; Casasanto, 2009; Gentner et al., 2001; Lakoff & Johnson, 1999; Meier & Robinson, 2004). Controversy has arisen at least partially because both linguistic and bodily experiences predict similar findings on the vertical dimension (i.e., good is up, bad is down). Casasanto's (2009) *body-specificity hypothesis* allows for direct testing of whether linguistic or bodily experience underlies the mapping of valence to horizontal space by differentiating right- and left-handers. Though we did not directly test between linguistic versus bodily influences, it is difficult to account for the present results by proposing effects of linguistic convention alone. Indeed participants showed opposite associations depending on their right- versus left-handedness. Thus, the abstract concept of valence appears to be embodied in that its mapping to left or right space depends on the manner in which individuals use their bodies to interact with the world. Of course, this raises the question of what factors contribute to the valence-specific vertical variation found in this and other experiments. It could be the case that both linguistic and bodily experiences interact to bias memory, though in certain circumstances one influence may more strongly shape mental representation than the other. Future experiments should attempt to dissociate the relative influences of these two factors.

Memorizing spatial locations and the events that took place there is an exceedingly common task, and many daily events can carry high degrees of emotional valence. Contrary to earlier theoretical positions positing isomorphic mental representations of viewed or experienced environments, spatial mental representations are shaped by a variety of variables internal to individuals (e.g., goals, affective states, spatial abilities, preferences) and contextually driven (e.g., racial characteristics of area, geographic structure). The altered shape of these spatial mental representations biases behavior in somewhat predictable ways (e.g., McNamara, 1986; B. Tversky, 1991). The present research uniquely demonstrates that individual differences in handedness and the informational valence associated with map-based locations can further bias human spatial memory. Future research will specifically examine whether such memory biases translate into altered performance during route planning and navigation tasks.

References

Annett, M. (1972). The distribution of manual asymmetry. *British Journal of Psychology, 63*(3), 343-358.

Barsalou, L. W. (2005). Situated conceptualization. In H. Cohen & C. Lefebvre (Eds.), *Handbook of categorization in cognitive science* (pp. 619-650). St. Louis: Elsevier.

Barsalou, L. W. (2008). Grounded cognition. *Annual Review of Psychology, 59*, 617-645. doi:10.1146/annurev.psych.59.103006.093639

Beilock, S. L., & Holt, L. E. (2007). Embodied preference judgments: Can likeability be driven by the motor system? *Psychological Science, 18*(1), 51-57. doi:10.1111/j.1467-9280.2007.01848.x

Bishop, D. V. (1990). Handedness, clumsiness and developmental language disorders. *Neuropsychologia*, *28*(7), 681-690. doi:10.1016/0028-3932(90)90123-6

Boroditsky, L. (2000). Metaphoric structuring: Understanding time through spatial metaphors. *Cognition*, *75*(1), 1-28. doi:10.1016/S0010-0277(99)00073-6

Bradley, M. M., & Lang, P. J. (1994). Measuring emotion: The self-assessment manikin and the semantic differential. *Journal of Behavior Therapy and Experimental Psychiatry, 25*(1), 49-59. doi:10.1016/0005-7916(94)90063-9

Brenneman, M. H., Decker, S., Meyers, J., & Johnson, K. (2008). Does a continuous measure of handedness predict reading processes and reading-related skills across the lifespan? *Laterality: Asymmetries of Body, Brain and Cognition*, *13*(6), 481-503. doi:10.1080/13576500802164133

Brunyé, T. T., Mahoney, C. R., Augustyn, J. S., & Taylor, H. A. (2009). Emotional state and local versus global spatial memory. *Acta Psychologica, 130*(2), 138-146. doi:10.1016/j.actpsy.2008.11.002

Brunyé, T. T., Mahoney, C. R., & Taylor, H. A. (2010). Moving through imagined space: Mentally simulating locomotion during spatial description reading. *Acta Psychologica, 134*, 110-124.

Brunyé, T. T., & Taylor, H. A. (2008a). Extended experience benefits spatial mental model development with route but not survey descriptions. *Acta Psychologica, 127*(2), 340-354. doi:10.1016/j.actpsy.2007.07.002

Brunyé, T. T., & Taylor, H. A. (2008b). Working memory in developing and applying mental models from spatial descriptions. *Journal of Memory and Language, 58*(3), 701-729. doi:10.1016/j.jml.2007.08.003

Brunyé, T. T., & Taylor, H. A. (2009). When goals constrain: Eye movements and memory for goal-oriented map study. *Applied Cognitive Psychology, 23*(6), 772-787. doi:10.1002/acp.1508

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. doi:10.1080/13875860701515472

Byers, J. A. (1996). Random selection algorithms for spatial and temporal sampling. *Computers in Biology and Medicine, 26*, 41-52.

Canter, D., & Tagg, S. K. (1975). Distance estimation in cities. *Environment and Behavior, 7*(1), 59-80. doi:10.1177/001391657500700102

Casasanto, D. (2009). Embodiment of abstract concepts: Good and bad in right- and left-handers. *Journal of Experimental Psychology: General, 138*(3), 351-367. doi:10.1037/a0015854

Casasanto, D., & Jasmin, K. (2010). Good and bad in the hands of politicians: Spontaneous gestures during positive and negative speech. *PLoS ONE, 5*(7), e11805. doi:10.1371/journal.pone.0011805

Coventry, K. R., & Garrod, S. C. (2005). Spatial prepositions and the functional geometric framework. Towards a classification of extra-geometric influences. In L. A. Carlson & E. van der Zee (Eds.), *Functional features in language and space: Insights from perception, categorization and development*, pp. 149-162. Oxford University Press.

Crawford, L. E., Margolies, S. M., Drake, J. T., & Murphy, M. E. (2006). Affect biases memory of location: Evidence for the spatial representation of affect. *Cognition & Emotion, 20*(8), 1153. doi:10.1080/02699930500347794

Davidson, R. J. (1992). Anterior cerebral asymmetry and the nature of emotion. *Brain and Cognition, 20,* 125–151. doi:10.1016/0278-2626(92)90065-T

Dean, R. S., & Reynolds, C. R. (1997). Cognitive processing and self-report of lateral preference. *Neuropsychology Review.Special Issue: Assessment of Laterality, 7*(3), 127-142. doi:10.1023/B:NERV.0000005948.00009.ed

Dean, R. S., Woodcock, R. W., & Riverside Publishing Company. (2003). *Dean-woodcock neuropsychological battery*. Itasca, IL: Riverside Publishing Company.

Denis, M., & Zimmer, H. D. (1992). Analog properties of cognitive maps constructed from verbal descriptions. *Psychological Research/Psychologische Forschung, 54*(4), 286-298. doi:10.1007/BF01358266

Gentner, D., Bowdle, B. F., Wolff, P., & Boronat, C. (2001). Metaphor is like analogy. In D. Gentner, K. J. Holyoak & B. N. Kokinov (Eds.), *The analogical mind: Perspectives from cognitive science (pp*. 199-253). Cambridge, MA, US: The MIT Press.

Grace, W. C. (1987). Strength of handedness as an indicant of delinquents' behavior. *Journal of Clinical Psychology, 43*(1), 151-155. doi:10.1002/1097-4679(198701)43:1<151::AID-JCLP2270430126>3.0.CO;2-T

Gyselinck, V., Meneghetti, C., De Beni, R., & Pazzaglia, F. (2009). The role of working memory in spatial text processing: What benefit of imagery strategy and visuospatial abilities? *Learning and Individual Differences, 19*(1), 12-20. doi:10.1016/j.lindif.2008.08.002

Haas, M. W., Nelson, W. T., Repperger, D., Bolia, R., & Zacharias, G. (2001). Applying adaptive control and display characteristics to future air force crew stations. *International Journal of Aviation Psychology, 11*(2), 223-235. doi:10.1207/S15327108IJAP1102_06

Halpern, A. R., & Kelly, M. H. (1993). Memory biases in left versus right implied motion. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19,* 471-484.

Hastie, R., & Park, B. (1986). The relationship between memory and judgment depends on whether the judgment task is memory-based or on-line. *Psychological Review, 3*, 258-268.

Hebb, D. O. (1949). *The organization of behavior; a neuropsychological theory*. New York: Wiley.

Hegarty, M., Montello, D. R., Richardson, A. E., Ishikawa, T., & Lovelace, K. (2006). Spatial abilities at different scales: Individual differences in aptitude-test performance and spatial-layout learning. *Intelligence, 34*(2), 151-176. doi:10.1016/j.intell.2005.09.005

Hirtle, S. C., & Jonides, J. (1985). Evidence of hierarchies in cognitive maps. *Memory & Cognition, 13*(3), 208-217.

Hirtle, S. C., & Mascolo, M. F. (1986). Effect of semantic clustering on the memory of spatial locations. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 12*(2), 182-189. doi:10.1037/0278-7393.12.2.182

Hobbs, J. R. (1985). Granularity. *Proceedings of the International Joint Conference on Artificial Intelligence, 432-435.*

Jeffery, K. J., & Burgess, N. (2006). A metric for the cognitive map: Found at last? *Trends in Cognitive Sciences, 10*(1), 1-3. doi:10.1016/j.tics.2005.11.002

Kahneman, D., Slovic, P., & Tversky, A. (1982). *Judgment under uncertainty : Heuristics and biases*. Cambridge; New York: Cambridge University Press.

Keet, C. M. (2007). Granulation with indistinguishability, equivalence, or similarity. *Proceedings of the IEEE International Conference on Granular Computing, 11.*

In press at Cognition

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), 47-60. doi:10.1037/0096-1523.4.1.47

Lakoff, G., & Johnson, M. (1980). The metaphorical structure of the human conceptual system. *Cognitive Science: A Multidisciplinary Journal, 4*(2), 195-208. doi:10.1207/s15516709cog0402_4

Lakoff, G., & Johnson, M. (1999). *Philosophy in the flesh : The embodied mind and its challenge to western thought*. New York: Basic Books.

Lederman, S. J., Klatzky, R. L., Collins, A., & Wardell, J. (1987). Exploring environments by hand or foot: Time-based heuristics for encoding distance in movement space. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 13*(4), 606-614. doi:10.1037/0278-7393.13.4.606

Maddox, K. B., Rapp, D. N., Brion, S., & Taylor, H. A. (2008). Social influences on spatial memory. *Memory & Cognition, 36*(3), 479-494. doi:10.3758/MC.36.3.479

McNamara, T. P. (1986). Mental representations of spatial relations. *Cognitive Psychology, 18*(1), 87-121. doi:10.1016/0010-0285(86)90016-2

McNamara, T. P., Halpin, J. A., & Hardy, J. K. (1992). Spatial and temporal contributions to the structure of spatial memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 18*(3), 555-564. doi:10.1037/0278-7393.18.3.555

McNamara, T. P., Hardy, J. K., & Hirtle, S. C. (1989). Subjective hierarchies in spatial memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15*(2), 211-227. doi:10.1037/0278-7393.15.2.211

McNamara, T. P., Sluzenski, J., & Rump, B. (2008). Human spatial memory and navigation. In H. L. Roediger, III (Ed.), *Cognitive psychology of memory*. Volume 2 in J. Byrne (Editor-in-chief), *Learning and memory: A comprehensive reference* (pp. 157-178). Oxford: Elsevier.

Meier, B. P., & Robinson, M. D. (2004). Why the sunny side is up: Associations between affect and vertical position. *Psychological Science, 15*(4), 243-247. doi:10.1111/j.0956-7976.2004.00659.x

Meneghetti, C., Gyselinck, V., Pazzaglia, F., & De Beni, R. (2009). Individual differences in spatial text processing: High spatial ability can compensate for spatial working memory interference. *Learning and Individual Differences, 19*(4), 577-589. doi:10.1016/j.lindif.2009.07.007

Natale, M., Gur, R. E., & Gur, R. C. (1983). Hemispheric asymmetries in processing emotional expressions. *Neuropsychologia, 21*(5), 555-565. doi:10.1016/0028-3932(83)90011-8

Noordzij, M. L., & Postma, A. (2005). Categorical and metric distance information in mental representations derived from route and survey descriptions. *Psychological Research, 69*(3), 221-232. doi:10.1007/s00426-004-0172-y

Oldfield, R. C. (1971). The assessment and analysis of handedness: The edinburgh inventory. *Neuropsychologia, 9*(1), 97-113. doi:10.1016/0028-3932(71)90067-4

Oppenheimer, D. M. (2008). The secret life of fluency. *Trends in Cognitive Sciences, 12*(6), 237-241. doi:10.1016/j.tics.2008.02.014

Piaget, J. (1969). *The child's conception of time*. New York: Ballantine Books.

Rayner, K. (1998). Eye movements in reading and information processing: 20 years of research. *Psychological Bulletin, 124*(3), 372-422. doi:10.1037/0033-2909.124.3.372

Reber, R., Winkielman, P., & Schwarz, N. (1998). Effects of perceptual fluency on affective judgments. *Psychological Science, 9*(1), 45-48. doi:10.1111/1467-9280.00008

Rossano, M. J., & Hodgson, S. L. (1994). The process of learning from small-scale maps. *Applied Cognitive Psychology, 8*(6), 565-582. doi:10.1002/acp.2350080604

Schneider, L. F., & Taylor, H. A. (1999). How do you get there from here? mental representations of route descriptions. *Applied Cognitive Psychology, 13*(5), 415-441.

Shelton, A. L., & McNamara, T. P. (2001). Systems of spatial reference in human memory. *Cognitive Psychology, 43,* 274-310.

Shimron, J. (1978). Learning positional information from maps. *Cartography and Geographic Information Science, 5*, 9-19.

Stevens, A., & Coupe, P. (1978). Distortions in judged spatial relations. *Cognitive Psychology, 10*(4), 422-437. doi:10.1016/0010-0285(78)90006-3

Taylor, H. A., & Brunyé, T. T. (in press). I go right, north and over: Processing spatial language. In D. Waller (Ed.), *Spatial Language.*

In press at Cognition

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

Thorndyke, P. W. (1981). Distance estimation from cognitive maps. *Cognitive Psychology, 13*(4), 526-550. doi:10.1016/0010-0285(81)90019-0

Thorndyke, P. W., & Hayes-Roth, B. (1982). Differences in spatial knowledge acquired from maps and navigation. *Cognitive Psychology, 14*(4), 560-589. doi:10.1016/0010-0285(82)90019-6

Tolman, E. C. (1948). Cognitive maps in rats and men. *Psychological Review, 55*(4), 189-208.

Tversky, B. (1981). Distortions in memory for maps. *Cognitive Psychology, 13*(3), 407-433. doi:10.1016/0010-0285(81)90016-5

Tversky, B. (1991). Spatial mental models. In G. H. Bower (Ed.), *The psychology of learning and motivation: Advances in research and theory (pp*. 109-145). San Diego, CA, US: Academic Press.

Tversky, B. (1993). Cognitive maps, cognitive collages, and spatial mental models. In A. U. Frank, & I. Campari (Eds.), *Spatial information theory A theoretical basis for GIS (pp*. 14-24). Berlin: Springer-Verlag. doi:10.1007/3-540-57207-4_2

Tversky, B. (2005). Functional significance of visuospatial representations. In P. Shah, & A. Miyake (Eds.), *The cambridge handbook of visuospatial thinking* (pp. 1-34). New York, NY, US: Cambridge University Press. doi:10.1017/CBO9780511610448.002

Tversky, B. (2009). Spatial cognition: Embodied and situated. In P. Robbins and M. Aydede (Editors). *The Cambridge Handbook of Situated Cognition*. (pp. 201-217). Cambridge: Cambridge University Press.

Van den Bergh, O., Vrana, S., & Eelen, P. (1990). Letters from the heart: Affective categorization of letter combinations in typists and nontypists. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 16*(6), 1153-1161. doi:10.1037/0278-7393.16.6.1153

Waller, D. (2000). Individual differences in spatial learning from computer-simulated environments. *Journal of Experimental Psychology: Applied, 6*(4), 307-321. doi:10.1037/1076-898X.6.4.307

Wickens, C. D., Vincow, M., & Yeh, M. (2005). Design applications of visual spatial thinking: The importance of frame of reference. In P. Shah, & A. Miyake (Eds.), *The cambridge handbook of visuospatial thinking (pp*. 383-425). New York, NY, US: Cambridge University Press. doi:10.1017/CBO9780511610448.011

Willems, R. M., Hagoort, P., & Casasanto, D. (2010). Body-specific representations of action verbs: Neural evidence from right- and left-handers. *Psychological Science, 21*(1), 67-74. doi:10.1177/0956797609354072

Wolter, D., Freksa, C., & Latecki, L. (2008). Towards a generalization of self-localization. In M. Jefferies, & W. Yeap (Eds.), *Robotics and cognitive approaches to spatial mapping* (pp. 105-134) Springer Berlin / Heidelberg. doi:10.1007/978-3-540-75388-9_7

In press at Cognition

Table 1. *Example event description stimuli for positive, negative and neutral event types (all preceded by "At the following location,").*

Positive:

A family wins a trip to Disney World. The family entered and won a local contest, which will pay all expenses for the family's first trip to Disney World!

Six kittens are rescued from a tree. Little is known as to how they got so high, but all six kittens were saved and returned to their thankful owner.

Oldest man in the world celebrates 112th birthday! A healthy and happy Joe Smith, celebrated with family and friends, he has 23 smiling grandchildren and 5 great grand children.

Negative:

A family is killed in a tragic car accident. Due to rainy weather and poor visibility the father lost control of the car, slamming into a tree at 65mph.

Child attacked by grizzly bear. Kyle Klein age 7 was playing in his back yard when he was attacked by a bear, and is now in critical condition at local hospital.

Tour bus crashes killing 75. A large greyhound bus holding 75 tourists for a tour of the city, lost control and crashed killing all passengers aboard.

Neutral:

Tylenol outsells Advil. Drugstore announces that sales of Tylenol are higher than Advil for the third consecutive month.

New bus stop added. A new bus stop was added to the West D line, this was added to close the gap between stop 8a and stop 7d.

At the following location, middle school track meet rescheduled. Due to inclement weather the track meet will be scheduled for a different day.

In press at Cognition

Table 2. *Experiment 1 and 2 mean and standard error X and Y residual variation (neutral is raw variation) for each of the three valence conditions (Negative, Neutral, Positive), and two handedness groups (Right-handed, Left-handed).*

	X Axis Variation		Y Axis Variation	
Experiment 1	*M*	*SE*	*M*	*SE*
Negative Valence				
Left-handed	8.1	4.2	-5.2	6.2
Right-handed	-7.6	4.6	-5.0	5.7
Neutral Valence				
Left-handed	-3.1	2.4	-2.1	2.4
Right-handed	-6.9	1.8	-9.4	2.2
Positive Valence				
Left-handed	-8.9	4.5	12.1	4.9
Right-handed	14.2	3.5	12.2	6.2
Experiment 2	*M*	*SE*	*M*	*SE*
Negative Valence				
Left-handed	0.2	4.2	1.6	4.3
Right-handed	4.4	4.6	6.3	4.5
Neutral Valence				
Left-handed	1.2	2.2	-0.2	2.2
Right-handed	-0.4	1.5	-1.5	1.9
Positive Valence				
Left-handed	-.02	5.3	4.2	4.3
Right-handed	.48	3.8	-1.7	3.3

In press at Cognition

Figure Captions

Figure 1. Sample map stimuli used in Experiment 1 (1a) and Experiment 2 (1b), with zoomed out and zoomed in environments, respectively.

Figure 2. Experiment 1 (2a) and 2 (2b) mean and standard error of X axis residual variation from actual learned location as a function of informational valence and participant handedness.

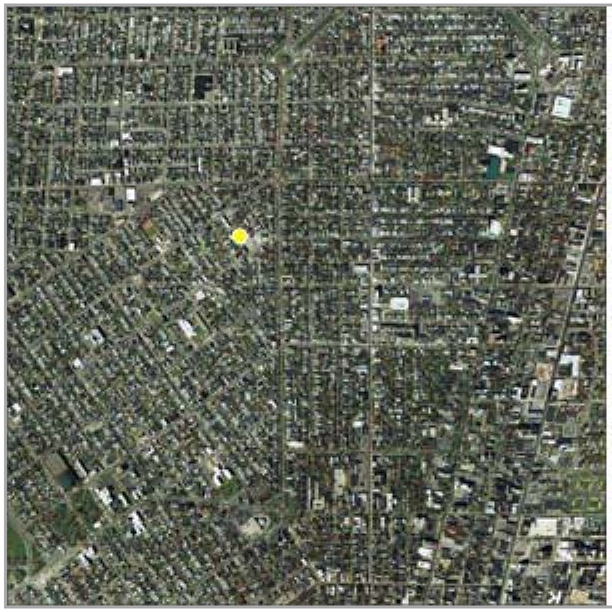


Figure 1a

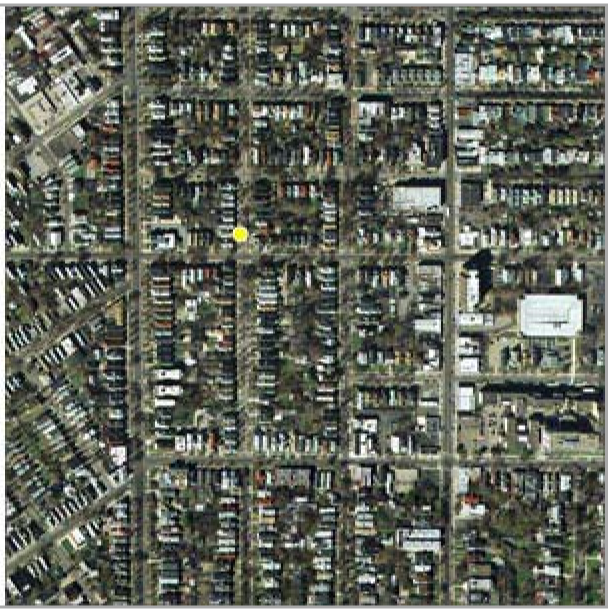


Figure 1b

In press at Cognition

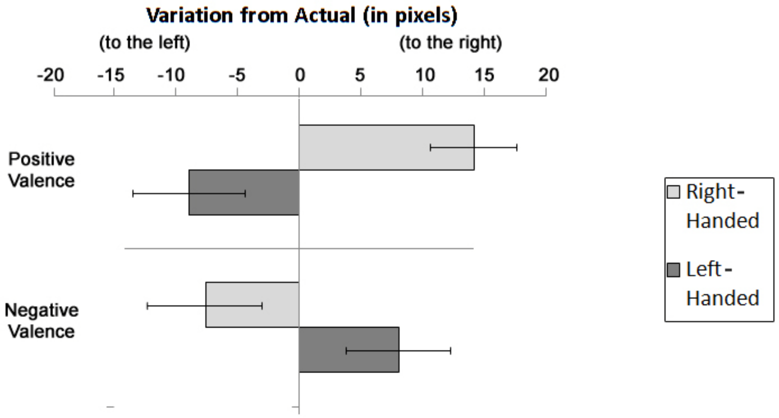


Figure 2a

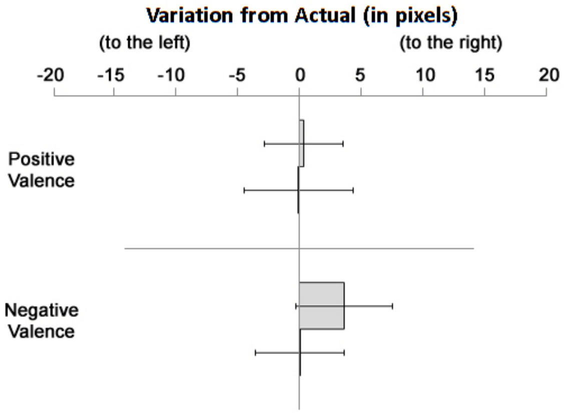


Figure 2b