

**Aaron Gardony**  
**Tad T. Brunyé\***  
**Caroline R. Mahoney**

Department of Psychology  
Tufts University  
Medford, MA  
and  
Cognitive Science  
U.S. Army NSRDEC  
Natick, MA

**Holly A. Taylor**

Department of Psychology  
Tufts University  
Medford, MA

# Affective States Influence Spatial Cue Utilization during Navigation

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## Abstract

Humans navigate complex environments effectively by identifying and monitoring environmental spatial cues (i.e., landmarks). Previous research has shown that affective states modulate cue utilization, attentional focus, and memory. Like other human behaviors, navigation is performed within an affective context and thus may fall under its influence. The present study examines the influence of affective state on cue utilization in novel virtual environments. Employing a within-participants factorial design, we manipulated participants' affect, crossing valence (happy, sad) and arousal (high, low), with available cue type (global cues: present, absent; and local cues: present, absent) within a desktop virtual environment. Results indicated that low relative to high arousal states promote global cue utilization during navigation through novel environments; there were no effects of affective valence. Arousal effects decreased with environmental familiarity, indicating its influence on cue utilization during the initial learning of novel environments. The results are discussed with regard to theories of affect, spatial cognition, and navigation.

## I Introduction

Navigation in real-world environments is an exceedingly common yet highly complicated task. While recent technological developments (e.g., portable GPS) have simplified moving from point A to point B, we still strongly rely on local and global environmental cues to navigate the world around us (Burgess, 2006; Etienne, 1992; Ishikawa, Fujiwara, Imai, & Okabe, 2008). These information sources also play a large role in our long and short term mental representations of environments. We remember the local pharmacy not as (latitude 42.397189°N, longitude -71.122806°E), but as “on the south side of town” or “in the square, next to the fitness center” and we are capable of reorienting when lost because “that tree looks awfully familiar.”

Mental representations of environments can be flexible and integrate information from a variety of perspectives (Brunyé & Taylor, 2008; Taylor & Tversky, 1992; Tversky, 2005), though the ultimate nature of these representations is strongly contingent upon which aspects of the environment are attended to during encoding (i.e., Brunyé & Taylor, 2009; Devlin & Bernstein, 1995; Sandstrom, Kaufman, & Huettel, 1998; Shelton & Gabrieli, 2004). Spatial cue salience, novelty, and importance interact to shape our real-time mental representations of environments. Internal factors such as affective state may also

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\*Correspondence to thaddeus.brunye@us.army.mil.

influence which cues are utilized toward guiding navigation. In his seminal paper, Easterbrook (1959) hypothesized that emotional arousal has a narrowing effect on cue utilization. As arousal increases, one focuses on an increasingly narrow range of cues; attention is centered and peripheral information ignored. Depending on situational factors (e.g., environmental spatial cues) this narrowing of attention may be either detrimental or beneficial, though no work to date has specifically examined affective state influences on navigation and spatial memory. To this end, the present research examines the extent to which the affective states characterizing navigation experiences influence the range of spatial cues relied upon for effective navigation. This work is motivated by and integrates two disparate research areas. First is research demonstrating how affective state influences the range of perceptual cues individuals use in a variety of circumstances. Second is research demonstrating that humans use both local and global cues to effectively navigate virtual environments. These research areas are reviewed below.

### **1.1 Affective State and Perceptual Narrowing**

Affective state can be divided into two orthogonal components that each fall along bipolar continua: arousal (high versus low) and valence (positive versus negative) (Lang, Bradley, & Cuthbert, 2008; Revelle & Loftus, 1992; Tellegen, 1985). Arousal refers to the intensity of affective experience, ranging from calm to excited; valence refers to the direction of affective experience, ranging from unpleasant to pleasant (Lane, Chua, & Dolan, 1999). Numerous studies have supported and built upon Easterbrook's original finding that arousal narrows cue utilization (see Levine & Edelman, 2009, for a review). Arousal-induced perceptual narrowing has been further demonstrated in attention and long- and short-term memory, and numerous theories have resulted from this research. One group of studies, conducted by Elizabeth Loftus and colleagues, reveals narrowed perception in eyewitness testimony and crime recollection. Loftus, Loftus, and Messo (1987) found that participants remembered fewer details of a store robbery

image, such as environmental surroundings and the assailant's appearance, when the assailant held a gun compared to a personal check. The arousing effect of the weapon's presence in the scene led participants to focus their gaze on the gun, neglecting to encode peripheral scene details. Loftus referred to this phenomenon as weapon focus. Since Loftus's seminal work on weapon focus, many studies have demonstrated arousal-induced narrowing of attention and poor recall in eyewitness accounts (see Christianson, 1992, for a review). Many of these results have been extended to working memory (Mather et al., 2006), long-term memory (Cahill & McGaugh, 1995), and autobiographical memories (Talarico, Berntsen, & Rubin, 2009). The relationship between affective arousal and memory, however, is debated. In reviewing numerous papers examining this link, some of which found contradictory findings to those of Loftus and Easterbrook, Levine and Edelman (2009) ultimately concluded that arousal enhances attention to and memory for information that is relevant to current goals. This conclusion is in line with previous research that suggests arousal increases the likelihood of a dominant response within a given context (Berlyne, 1967).

A recent explanation for affective arousal effects on perceptual narrowing is that arousal impairs memory for information that is typically perceptually suppressed but does not impair memory for other salient information in the foreground (Mather, Gorlick, & Nesmith, 2009). Taken together, this research suggests that arousal does not directly affect the process of information retrieval but rather narrows attention during encoding, ultimately leading to the secondary effect of better recall for central versus peripheral information. Research on arousal's cognitive effects has also revealed that arousal modulates attentional focus through systematically biasing attention toward local information. Derryberry and Reed (1998) found that trait anxiety led to faster processing of local versus global targets. The researchers concluded that participants' focused attention resulted from their preference for local perceptual information.

Other studies concerning the valence component of the affective state uncovered similar perceptual biases. In addition to high arousal, some work suggests that nega-

tive affect (e.g., sadness) leads to greater reliance on local processing (Basso, Schefft, Ris, & Dember, 1996; Gasper & Clore, 2002). In contrast, positive valence (e.g., happiness) can lead to greater reliance on global processing, such as seeing more connections (Isen & Daubman, 1984) and focusing on global rather than local elements of a visual scene (Gasper & Clore, 2002). Some recent work, however, has challenged the view that valence influences global versus local cue reliance. For instance, when valence and arousal were specifically examined in a crossed ( $2 \times 2$ ) design, the authors only found evidence for arousal (but not valence) altering cue utilization (Corson & Verrier, 2007). The mixed data with regard to the relative influence of arousal and valence in altering global versus local focus warrants additional research. Thus, to further elucidate the effects of both arousal and affective state (i.e., positive versus negative mood), the present study crossed high and low arousal with positive and negative affect to reveal their independent and interactive influences on cue utilization during a virtual navigation task.

## 1.2 Consequences for Navigation

As with all human behavior, navigation is performed within an affective context. Affect serves as a backdrop to daily actions and decisions and affects cognition in a variety of ways (Storbeck & Clore, 2007). It is possible, as the present research suggests, that affect can influence which landmarks we utilize while navigating. Broadly defined, landmarks fall into two categories: local and global. Local landmarks are proximal environmental cues that aid in orientation and route navigation and often serve as beacons along a path. Local cues provide accurate positional information of the current location, subgoal locations (e.g., turns), and ultimate goal location; but are also perceived as less reliable than global cues (given their often transient nature; Cheng & Spetch, 1998). Local cues are often used in describing environments and spoken directions often refer to local landmarks, for example, “turn left at the *stop sign*” (Denis, Michon, & Tom, 2007; Michon & Denis, 2001; Raubal & Winter, 2002). Global landmarks are distal cues that primarily serve as orienting tools, provide

directional information, and define one’s global reference frame (Lynch, 1960). Canonical directions (NSEW), the position of the sun, and distant buildings or mountain ranges are all examples of global landmarks. Animals and humans utilize both cue types and no universal preference appears to exist. For example, studies of animals’ spatial cue preference have gathered mixed results. When presented with both cue types simultaneously and in isolation, rats (Redhead, Roberts, Good, & Pearce, 1997), desert ants (Collett, Collett, Bisch, & Wehner, 1998), bees (Dyer, 1991), and black-capped chickadees (Duff, Brownlie, Sherry, & Sangster, 1998) preferentially rely on local cues, whereas Columbian ground squirrels (Vlasak, 2006) and stickleback fish (Huntingford & Wright, 1989) prefer global cues. These studies demonstrate that many animals are capable of utilizing both cue types but often tend to prefer one over the other.

In general, humans can rely on both cue types during navigation and for creating and maintaining spatial mental models of environments (Steck & Mallot, 2000). Like animals, we can flexibly switch between which spatial cues we utilize depending on what information is most readily available, stable, and reliable (Hamilton, Johnson, Redhead, & Verney, 2009). Some research suggests that utilization of spatial cues is modulated by an existing hierarchy in spatial representations. In other words, humans differentially rely upon local versus global spatial cues as a function of environmental circumstances. Biegler and Morris (1996) proposed that local cues are considered more accurate while global cues are considered more reliable. If a large discrepancy exists between the available cue types, navigators preferentially rely on global cues. If, however, the discrepancy is miniscule, local cues are preferred for their accurate positional information (Foo, Warren, Duchon, & Tarr, 2005). In a recent study (Ruddle, Volkova, Mohler, & Bülthoff, 2011), when participants were tasked to navigate out-and-back routes, they showed reduced errors (e.g., missed or incorrect turns) with local relative to global cues. Thus, there is some evidence that humans rely strongly upon local cues when navigating small-scale environments. As previous research has demonstrated, affective state can influence the preferential allocation of

attention to visual cues and bias both information processing and memory. We investigate the possibility that affective states may promote the utilization of specific landmark types during navigation.

### 1.3 The Present Study

The increased computing power of modern PCs has allowed virtual environment (VE) research to flourish. VEs provide a realistic analogue to real-world navigation, provide accurate measures of navigational efficiency and behavior, and allow for tight experimental control of environments and navigation (Loomis, Blasovich, & Beall, 1999; Péruch & Gaunet, 1998). Real-world environments are exceptionally detailed and dynamic, containing multitudes of local and global landmarks. VE research allows for navigation in simplistic environments with modifiable and carefully controlled cues and scenery.

We created a virtual version of an adapted Morris water maze (Morris, 1981) and manipulated spatial cue type and participants' affective state (between high and low arousal and positive and negative valence) and measured performance over a series of navigation trials. The virtual adapted Morris water maze involves identifying and returning to an identified (but invisible) target platform location over a series of successive trials (typically 10). On the first trial, the participant searches the environment for the invisible platform; upon finding it, the platform becomes visible and the trial ends. On subsequent trials, the participant attempts to relocate the target platform as quickly as possible, using any available cues to guide their way. In this manner, the maze challenges spatial working memory and spatial learning mechanisms by requiring navigators to constantly update their current position relative to any visible landmarks, and learn the vectors defining platform location (i.e., Vorhees & Williams, 2006). Virtual mazes are a powerful tool for investigating human navigation behavior under controlled circumstances (e.g., Astur, Ortiz, & Sutherland, 1998; Jacobs, Laurance, & Thomas, 1997; Jacobs, Thomas, Laurance, & Nadel, 1998; Sandstrom et al., 1998). Based on the premise that high arousal narrows perception and promotes local processing and a domi-

nant response, and low arousal broadens perception and promotes global processing, we predict that global cues will benefit navigation (as measured via path and time efficiency, and heading error) most in low versus high arousal states, and local cues will benefit navigation most in high versus low arousal states. In line with recent research demonstrating the powerful effect of arousal, but not emotional valence, on information processing in general (e.g., Corson & Verrier, 2007; Vogt, De Houwer, Koster, Van Damme, & Crombez, 2008), we predict little effect of valence on cue utilization.

## 2 Method

### 2.1 Participants and Design

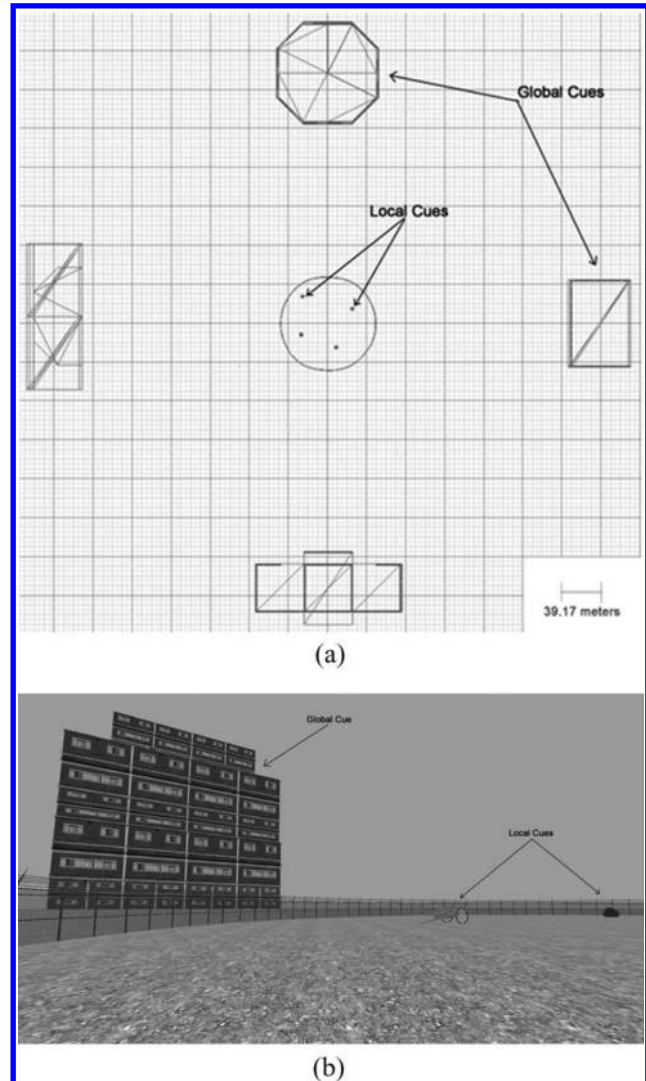
Forty-eight male Tufts University undergraduates (age  $M = 19.33$ ) participated for monetary compensation. Sample size was determined using Cohen's (1977) method. We selected males exclusively to avoid gender differences in cue utilization during VE navigation (i.e., Astur et al., 1998; Chai & Jacobs, 2010). The study used a 2(Valence: happy, sad)  $\times$  2(Arousal: high, low)  $\times$  2(Global Cues: present, absent)  $\times$  2(Local Cues: present, absent) within-participants factorial design. To minimize potential order effects, we completely counterbalanced the order of affective states across days and participants ( $4! = 24$  total affective state orders). The order of cue condition was also completely counterbalanced across participants ( $4! = 24$  total cue condition orders), with a single participant receiving the same order on each of the four days.

### 2.2 Materials

**2.2.1 Mood Induction.** We used a mood induction technique involving the presentation of affective images and mood-congruent music. Four groups of 100 affective images were selected from the international affective picture system (IAPS; Lang et al., 2008), crossing high and low arousal with positive and negative valence. We also adopted controlled musical stimuli (Husain, Thompson, & Schellenberg, 2002) matching the four affective conditions; these stimuli were composed of a Mozart sonata in MIDI format with altered

tempo (fast, slow) and mode (major, minor). These four musical stimuli reliably (i.e., Husain et al., 2002) elicit high and low arousal (fast versus slow tempo, respectively) and positive and negative affect (major and minor mode, respectively).

**2.2.2 Virtual Environments.** We designed a virtual maze similar to the Morris water maze task using a video game editor (Unreal Engine 2 by Epic Games, Raleigh, NC). Each environment contained an open outdoor area with a solid blue sky devoid of global spatial cues (e.g., clouds, sun), surrounded by a large circular border fence. The circular area measured approximately 4960 Unreal Units (UUs) in diameter (94.5 m); UUs are a standardized distance metric for use with the Unreal engine (16 UUs = approximately 1 linear ft or 0.3048 m). Each environment contained an invisible circular target area measuring 512 UUs (9.75 m) in diameter. In total, we created 80 environments crossing target platform location (20) with cue type (4). The 20 possible target platform locations were divided into four groups of five and arranged within each quadrant. The four cue types were composed of global cues, local cues, global and local cues, or no cues. Global cues consisted of four distant and distinct multistory buildings placed at each of the cardinal directions (approximately 9000 UUs or 171.5 m from the border fence) outside of the boundaries of the navigable environment; two global landmarks could be viewed at once within the simulated FOV. Local cues were composed of four items (e.g., rock, bush, wagon, haystack), one placed in a random (across participants) position within each quadrant; multiple local landmarks could be viewed at once within the simulated FOV. There were 48 possible starting locations for participant navigation, each containing four possible starting orientations, corresponding to canonical NSEW. Avatar height was 88 UUs (1.67 m) and avatar movement speed was fixed at 480 UUs/s (circumnavigation took approximately 32 s, navigating the diameter took approximately 10 s); other movement types inherent in the software, including jumping, strafing, crouching, and weapon use, were disabled. Participants navigated the virtual environment task on a 20 in widescreen LCD monitor at 1440 × 900 resolution with



**Figure 1.** (a) A scale overhead depiction of the environment. (b) A screenshot from within the virtual environment depicting global and local cues.

a simulated field of view (FOV) of 90° from a viewing distance of approximately 2 ft using a standard keyboard (W forward) and mouse (to control orientation). The software automatically sampled avatar coordinate position and roll, pitch, and yaw at 100 ms intervals. Figure 1(a) depicts a scale version of the environment, and Figure 1(b) depicts a view of global and local cues from within the environment.

**2.2.3 Manipulation Checks.** To evaluate the effectiveness of our mood induction, we assessed affect-

tive state using the Profile of Mood States (POMS) questionnaire (McNair, Lorr, & Droppleman, 1971), which includes 65 affective adjectives rated on a 5-point Likert scale. We also used the brief mood introspection scale (BMIS; Mayer & Gaschke, 1988), which involves rating a series of 16 affective adjectives using a 5-point Likert scale.

**2.2.4 Questionnaires.** To assess video game experience, we used a common video game questionnaire (Basak, Boot, Voss, & Kramer, 2008) that contains a series of eight questions probing for frequency, proficiency, and type of video gaming experience. Overall, participants reported moderate video gaming proficiency ( $M = 1.4$  on scale from 1–4) and frequency of use ( $M = 2.1$  hr/wk).

## 2.3 Procedure

**2.3.1 Overall Procedure.** After providing informed consent and completing the video game questionnaire, participants completed a 10-min training session during which they familiarized themselves with the controls of the virtual environment and the tasks administered via SuperLab software (i.e., the POMS and BMIS). During each subsequent test session, participants first reported their affective state with the POMS. They then watched IAPS pictures while listening to affective-congruent music through closed-ear headphones. Once the slideshow ended, the music continued and participants completed a BMIS questionnaire and began the first set of navigation trials. After each of the four sets of navigation trials (one for each of the four cue types), participants completed the BMIS. Following completion of the fourth set and the last BMIS, the music was terminated and participants completed a post-navigation POMS. Participants finished four test sessions (one for each affect condition) separated by at least 24 hr.

**2.3.2 Mood Induction.** The affective state was manipulated in two phases. Participants first watched a slideshow consisting of 100 preselected IAPS images while listening to affect-congruent music. Each image was presented for 2,500 ms with a 500 ms interstimulus

interval. To help maintain the induced affective state, music continued to play throughout the four sets of navigation trials. Participants listened to the music on stereo headphones and the volume was kept constant between sessions and participants.

**2.3.3 Navigation.** Participants navigated four virtual environments, one for each of the four cue conditions (global only, local only, global + local, none). Within each cue condition, participants were instructed to find an invisible target platform as quickly as possible during each of 11 successive navigation trials. The target platform location was randomly chosen for each of the four cue conditions (within participants, without replacement), and held constant within each set of 11 successive navigation trials. For each navigation trial, a participant began at a randomly-determined location (of 48) and orientation (of four), sampling from 192 potential location and orientation combinations without replacement. The target platform became visible if the participant stepped within its circular diameter or after 1 min passed without success. After finding the platform, a 10 s intertrial interval restricted participants to the platform area (allowing reorientation) before beginning the next trial; this interval was designed to provide participants with an opportunity to orient themselves with regard to their surroundings (see also Chai & Jacobs, 2010; Hamilton, Driscoll, & Sutherland, 2002; Morris, 1981; Sutherland & Dyck, 1984). Participants completed 10 such trials, navigating to a platform that became visible when discovered. The 11th trial was a probe trial during which no feedback was given if the participant reached the platform (i.e., the platform did not become visible; see also Astur et al., 1998; Chai & Jacobs, 2010; Hamilton et al., 2009; Morris, 1981; Sutherland & Dyck, 1984). The probe trial lasted 1 min after which the program loaded the next cue condition and set of navigation trials.

**2.3.4 Manipulation Checks.** Participants reported their affective state using the POMS immediately prior to mood induction and at test session end. To measure the ongoing maintenance of affective states during the four sets of navigation trials, participants also

**Table 1.** Mean (and SE) Subscale Scores from the POMS and BMIS, for Each of the Four Affective States; For the BMIS, We Report Subscale Scores Averaged Across All Time Points

	Time point 1		Time point 2	
	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>
POMS				
<i>Vigor subscale</i>				
High arousal, positive valence	8.9	0.5	10.8	0.6
High arousal, negative valence	9.3	0.6	10.9	0.7
Low arousal, positive valence	9.3	0.5	9.4	0.6
Low arousal, negative valence	8.6	0.6	9.5	0.6
<i>Depression subscale</i>				
High arousal, positive valence	15.3	0.8	12.3	0.9
High arousal, negative valence	14.7	0.8	14.7	0.9
Low arousal, positive valence	14.4	0.9	12.5	0.8
Low arousal, negative valence	13.7	0.7	14.0	1.0
Mean of all time points				
	<i>M</i>	<i>SE</i>		
BMIS				
<i>Arousal subscale</i>				
High arousal, positive valence	25.9	.57		
High arousal, negative valence	26.5	.59		
Low arousal, positive valence	25.1	.48		
Low arousal, negative valence	25.5	.52		
<i>Pleasantness subscale</i>				
High arousal, positive valence	46.1	.99		
High arousal, negative valence	42.5	1.1		
Low arousal, positive valence	46.7	1.1		
Low arousal, negative valence	43.1	1.0		

completed the BMIS at five points: immediately prior to and after each of the four sets of navigation trials.

### 3 Results

#### 3.1 Manipulation Checks

To assess the effectiveness of our affect induction, we administered the POMS at the beginning and end of each test session, and the BMIS before and after each set of navigation trials.

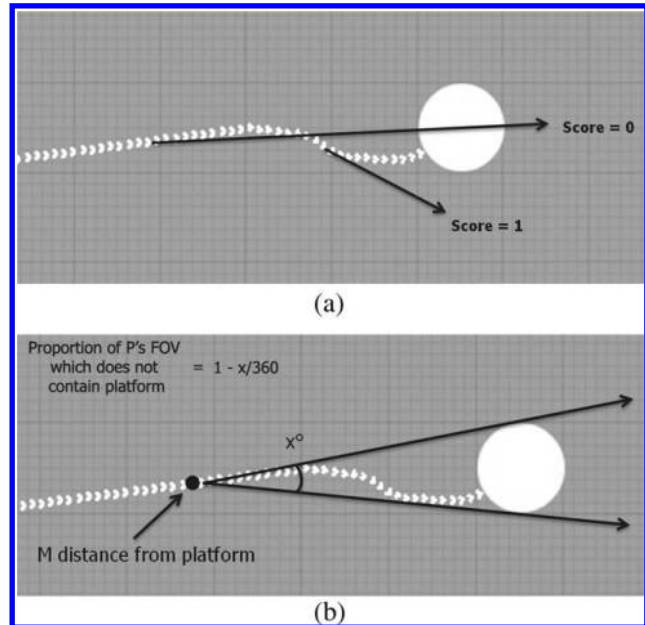
**3.1.1 POMS.** The POMS was scored using standard scoring procedures (McNair et al., 1971) that divide questionnaire responses into six subscales, two of which are currently of interest: *vigor*, which measures affective arousal, and *depression*, which measures affective valence. To test the effectiveness and persistence of our affect induction, we submitted subscale scores (see Table 1) to separate repeated-measures ANOVAs with Arousal (2: high, low) and Valence (2: positive, negative) as independent variables. At time point 1, prior to affect induc-

tion, as expected, there were no effects of Arousal or Valence, and no interactions when examining vigor or depression subscale scores (all  $p > .05$ ). At time point 2, however, analysis of vigor scores revealed an effect of Arousal,  $F(1, 47) = 4.89, p < .05, \eta^2 = .05$ , but not Valence,  $F(1, 47) = .09, p > .05, \eta^2 < .01$  (interaction,  $p > .05$ ). Further, analysis of depression scores at time point 2 revealed an effect of Valence,  $F(1, 47) = 4.68, p < .05, \eta^2 = .18$ , but not Arousal,  $F(1, 47) = .36, p > .05, \eta^2 < .01$ . Recall that POMS time point 2 follows the completion of all four sets of navigation trials; given that the affective states generally persisted through the entire test sessions, these results demonstrate both the specificity and longevity of our arousal and valence manipulations.

**3.1.2 BMIS.** The BMIS was scored using standard scoring procedures (Mayer & Gaschke, 1988) that divide questionnaire responses into *arousal* (high/low) and *pleasantness* (happy/unhappy) subscales. To test the effectiveness of our affect induction, we averaged BMIS responses across the five time points and submitted subscale data (see Table 1) to separate repeated-measures ANOVAs with Arousal (2: high, low) and Valence (2: positive, negative) as independent variables. Analyses revealed the effectiveness of our affect induction. Analysis of the arousal subscale revealed an effect of Arousal,  $F(1, 47) = 8.17, p < .01, \eta^2 = .12$ , but not Valence,  $F(1, 47) = 3.25, p > .05, \eta^2 = .02$  (interaction,  $p > .05$ ). Analysis of the pleasantness subscale revealed an effect of Valence,  $F(1, 47) = 27.35, p < .01, \eta^2 = .13$ , but not Arousal,  $F(1, 47) = .76, p > .05, \eta^2 < .01$  (interaction,  $p > .05$ ).

### 3.2 Navigation Performance

Three automated navigation performance measures were collected during each trial; path efficiency, time efficiency, and heading error. Path efficiency related the participant's actual path length (PLa) to the optimal path/vector length (PLo) between a starting location and platform edge (PLo/PLa); this measure has a maximum of 1 and a minimum infinitely approaching 0. Time efficiency related the participant's actual navigation duration



**Figure 2.** (a) A graphical depiction of the calculation of raw heading error. (b) The proportion of the participant's field of view that does not contain the platform. The small white arrows indicate the participant's heading direction at each point along a navigated path.

(NDa) to the optimal navigation duration (NDo); this measure (NDo/NDa) has a maximum of 1 and a minimum infinitely approaching 0. Finally, heading error related a participant's heading direction to the optimal heading direction at all points along the participant's path; this measure accounted for the random chance of facing the platform at each point along the path. More specifically, the heading error is calculated by first assigning a binary score to each sampled data point (sampled at 100 ms intervals) along the participant's path according to whether a vector-based line of sight protruding from the participant's facing direction fell within the platform radius (score = 0) or outside of the platform radius (score = 1) as depicted in Figure 2(a). This resulted in a raw heading error score which ranges from zero (always facing platform) to one (never facing platform). This score is insufficient as it does not consider the random probability of viewing the platform, which increases linearly with increased proximity to the platform. To account for this, the trial's mean distance from the platform is first calculated, then from this distance we calculate the proportion of the participant's field of

view that does not contain the platform, as depicted in Figure 2(b). This value is then subtracted from the average of the raw heading error scores for that trial. This corrected measure ranged from infinitely approaching 1 (never facing the platform) to infinitely approaching  $-1$  (always facing the platform).

Recall that participants completed a series of 10 navigation trials and then an 11th probe trial. On trial 1, participants are completely naive to platform location, and thus we did not expect effects of Arousal, Valence, or Cue Type. Subsequent navigation trials, however, provide the opportunity to demonstrate knowledge of platform location, and thus are expected to be affected by our manipulations, particularly for trial 2. To simplify analyses, we averaged our data into five trial groups; group 1 contained trial 1, group 2 contained trial 2, group 3 contained trials 3–5, group 4 contained trials 6–8, and group 5 contained trials 9, 10 and the first phase of the trial 11 probe (i.e., from start to first stepping on the invisible platform). In this way, group 1 contained data prior to identifying platform location (trial 1 alone), and group 2 contained the first trial (trial 2) wherein participants had the opportunity to demonstrate affective state influences on navigation performance. The latter three groups evenly divided the subsequent nine trials; within each of these three groups, trial-by-trial data were strikingly similar as demonstrated by no significant main or interactive effects of Trial Number (all  $p > .29$ ) in three separate 2(Arousal: high, low)  $\times$  2(Valence: positive, negative)  $\times$  2(Global Cues: present, absent)  $\times$  2(Local Cues: present, absent)  $\times$  3(Within-Group Trial Number: 1,2,3) ANOVAs.

### 3.3 Analyses

To examine our main questions of interest, data were subjected to 2(Arousal: high, low)  $\times$  2(Valence: positive, negative)  $\times$  2(Global Cues: present, absent)  $\times$  2(Local Cues: present, absent)  $\times$  5(Trial Group: 1, 2, 3, 4, 5) repeated-measures ANOVAs, one for each of the three navigation performance measures (path efficiency, time efficiency, heading error). In the case of significant interactions, further analyses specifically examined our hypotheses.

**Table 2.** Mean (and SE) Navigation Scores by Cue Type (Present vs. Absent)

	Present		Absent	
	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>
<i>Path efficiency</i>				
Global cues	0.67	.01	0.57	.01
Local cues	0.73	.01	0.50	.01
<i>Time efficiency</i>				
Global cues	0.51	.01	0.45	.01
Local cues	0.56	.01	0.39	.01
<i>Heading error</i>				
Global cues	−0.29	.01	−0.25	.01
Local cues	−0.38	.01	−0.16	.01

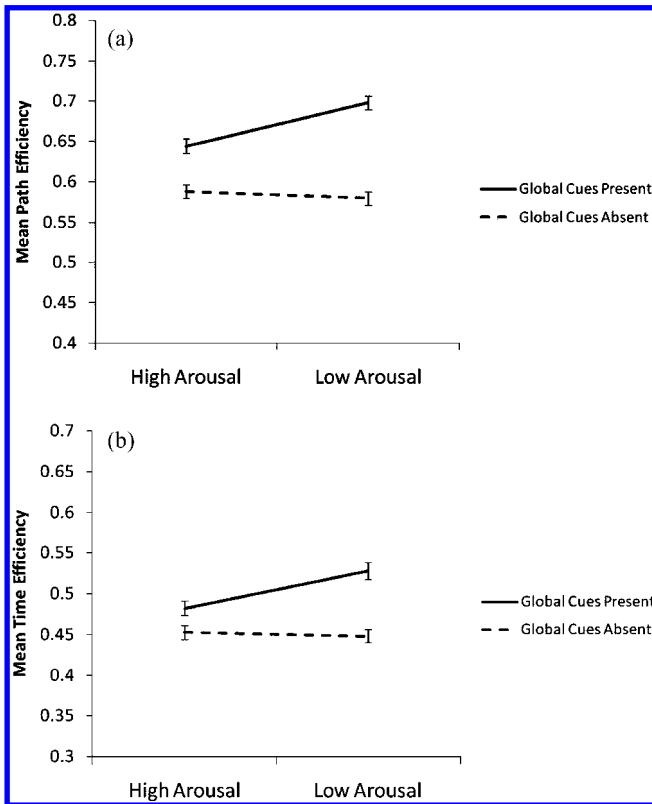
Data from the latter part of the probe trial (trial 11 after stepping on the invisible platform) were separately analyzed. Recall that during this final trial, the platform did not become visible once the participant entered its perimeter. The probe trial (beginning upon a participant's first entrance into the platform perimeter) thus provided the opportunity to evaluate participant perseveration around the invisible platform location as a function of Arousal, Valence, and the presence or absence of Global versus Local cues. We begin by detailing path and time efficiency and heading error during each of the five Trial Groups. We then provide analyses regarding probe trial performance.

**3.3.1 Path Efficiency.** The omnibus  $2 \times 2 \times 2 \times 2 \times 5$  ANOVA revealed a main effect of Global Cues,  $F(1, 47) = 184.34$ ,  $p < .01$ ,  $\eta^2 = .08$ , with overall higher path efficiency when global cues were present relative to absent. There was also a main effect of Local Cues,  $F(1, 47) = 909.51$ ,  $p < .01$ ,  $\eta^2 = .44$ , with overall higher path efficiency when local cues were present relative to absent. Means are presented in Table 2. There was also a main effect of Trial Group,  $F(4, 188) = 725.49$ ,  $p < .01$ ,  $\eta^2 = 1.08$ , with higher overall path efficiency in later trial groups. Means are presented in Table 3.

These effects were qualified by an interaction between Arousal and Global Cues,  $F(1, 47) = 6.09$ ,  $p < .05$ ,  $\eta^2 < .01$ , as depicted in Figure 3(a). To further examine

**Table 3.** Mean (and SE) Navigation Scores by Trial Group

	Trial Group									
	G1		G2		G3		G4		G5	
	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>
Path efficiency	0.25	.01	0.67	.01	0.72	.01	0.73	.01	0.71	.01
Time efficiency	0.21	.01	0.5	.01	0.5	.01	0.56	.01	0.55	.01
Heading error	-0.08	.01	-0.29	.01	-0.32	.01	-0.33	.01	-0.33	.01



**Figure 3.** (a) Mean path and (b) time efficiency as a function of arousal state (high, low) and the presence or absence of global cues. The error bars show SE.

this interaction, we performed two separate simple effects tests, one within the high and one within the low arousal condition, using a Bonferroni correction term ( $\alpha = .025$ ). Within both high and low arousal, the presence versus absence of global cues led to increased path efficiency, though the effect was substantially pronounced within the low arousal condition ( $F_{\text{low arousal}} = 147.8$ ,  $F_{\text{high arousal}} = 80.62$ ), as indicated by the interac-

tion. In general, those in a low arousal state were better able to take advantage of the presence of global cues, relative to those in a high arousal state.

Path efficiency with Local Cues was overall high and did not vary as a function of Arousal or Valence conditions ( $p > .10$ ). There was no three-way interaction between Valence, Global Cues, and Trial Group ( $p > .10$ ), or Valence, Local Cues, and Trial Group ( $p > .10$ ), and no four- or five-way interactions ( $p > .10$ ).

**3.3.2 Time Efficiency.** The omnibus  $2 \times 2 \times 2 \times 2 \times 5$  ANOVA revealed a main effect of Global Cues,  $F(1, 47) = 85.29$ ,  $p < .01$ ,  $\eta^2 < .01$ , with overall higher time efficiency when global cues were present relative to absent. There was also a main effect of Local Cues,  $F(1, 47) = 921.29$ ,  $p < .01$ ,  $\eta^2 = .07$ , with overall higher time efficiency when local cues were present relative to absent. Means are presented in Table 2. There was also a main effect of Trial Group,  $F(4, 188) = 607.1$ ,  $p < .01$ ,  $\eta^2 = .18$ , with higher overall time efficiency in later trial groups. Means are presented in Table 3.

These effects were qualified by an interaction between Arousal and Global Cues,  $F(1, 47) = 5.37$ ,  $p < .05$ ,  $\eta^2 < .01$ , as depicted in Figure 3(b). To further examine this interaction, we performed two separate simple effects tests, one within the high and one within the low arousal condition, using a Bonferroni correction term ( $\alpha = .025$ ). Within both high and low arousal, the presence versus absence of global cues led to increased time efficiency, though as indicated by the interaction, the effect was more pronounced in the low arousal condition ( $F_{\text{low arousal}} = 75.49$ ,  $F_{\text{high arousal}} = 41.73$ ), as indicated by the interaction. As with path efficiency, those in a low arousal state were better able to take advantage of the

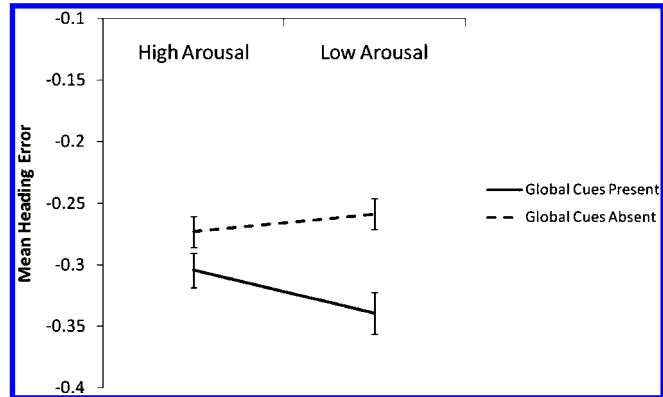
presence of global cues, relative to those in a high arousal state.

Time efficiency with Local Cues was overall high and did not vary as a function of Arousal or Valence conditions ( $p > .10$ ). There was no three-way interaction between Valence, Global Cues, and Trial Group ( $p > .10$ ), or Valence, Local Cues, and Trial Group ( $p > .10$ ), and no four- or five-way interactions ( $p > .10$ ).

**3.3.3 Heading Error.** The omnibus  $2 \times 2 \times 2 \times 2 \times 5$  ANOVA revealed a main effect of Global Cues,  $F(1, 47) = 70.4, p < .01, \eta^2 = .01$ , with overall lower heading error when global cues were present relative to absent. There was also a main effect of Local Cues,  $F(1, 47) = 1088.29, p < .01, \eta^2 = .26$ , with overall lower heading error when local cues were present relative to absent. Means are presented in Table 2. There was also a main effect of Trial Group,  $F(4, 188) = 420.82, p < .01, \eta^2 = .18$ , with a lower overall heading error in later trial groups. Means are presented in Table 3.

These effects were qualified by a marginal three-way interaction between Arousal, Global Cues, and Trials,  $F(4, 188) = 1.99, p < .10, \eta^2 = .18$ , suggesting that Arousal may differentially modulate the use of Global Cues within the five Trial Groups. To examine this possibility, we conducted five separate  $2(\text{Arousal: high, low}) \times 2(\text{Global Cues: present, absent})$  ANOVAs, one for each trial group. In Trial 1, the Arousal by Global Cues interaction was nonsignificant,  $F(1, 47) = .29, p > .05, \eta^2 < .01$ . In Trial Group 2, however, this interaction reached significance,  $F(1, 47) = 3.91, p < .05, \eta^2 < .01$ , as depicted in Figure 4. Within both high and low arousal, the presence versus absence of global cues led to increased time efficiency, though as indicated by the interaction, the effect was more pronounced in the low arousal condition ( $F_{\text{low arousal}} = 70.13, F_{\text{high arousal}} = 26.16$ ). As with path and time efficiency, those in a low arousal state were better able to take advantage of the presence of global cues, relative to those in a high arousal state. The Arousal by Global Cues interaction diminished, however, through Trial Groups 3–5 (all  $p > .10$ ).

**3.3.4 Probe Trial Performance.** Probe trial perseveration, as an index of confidence in platform loca-



**Figure 4.** Mean heading error as a function of arousal state (high, low) and the presence or absence of global cues. Note that lower (more negative) heading error scores indicate higher performance. The error bars show SE.

**Table 4.** Mean Distance from Platform Edge During Probe Trial by Cue Type (Present vs. Absent)

	Present		Absent	
	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>
Global cues	1342.59	22.85	1712.27	14.27
Local cues	1362.26	22.65	1692.6	16.13

tion, was measured in two ways. First, we measured the participants' mean distance (in UUs) from the platform edge during probe trial duration. An omnibus  $2(\text{Arousal: high, low}) \times 2(\text{Valence: positive, negative}) \times 2(\text{Global Cues: present, absent}) \times 2(\text{Local Cues: present, absent})$  ANOVA did not reveal significant interactions of Arousal or Valence with Cue Type, and no three-way interaction (all  $p > .05$ ). As would be expected, a main effect of Global Cues demonstrated higher mean distance (i.e., greater distance from the platform) when global cues were absent relative to when they were present,  $F(1, 47) = 497.51, p < .01, \eta^2 = .20$ . The same was found with Local Cues, with higher mean distance when local cues were absent relative to when they were present,  $F(1, 47) = 164.83, p < .01, \eta^2 = .16$ . Means are presented in Table 4.

Second, we measured the number of times the participant passed through the platform perimeter.

**Table 5.** Number of Passes Through Platform Perimeter During Probe Trial by Cue Type (Present vs. Absent)

	Present		Absent	
	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>
Global cues	4.67	.19	3.32	.12
Local cues	4.86	.23	3.13	.11

A  $2 \times 2 \times 2 \times 2$  ANOVA did not reveal any two- or three-way interactions (all  $p > .05$ ). As with the mean proximity measure, we found a main effect of Global Cues demonstrating lower number of platform passes when global cues were absent relative to when they were present,  $F(1, 47) = 81.09, p < .01, \eta^2 = .08$ . The same was found with Local Cues, with a lower number of platform passes when local cues were absent relative to when they were present,  $F(1, 47) = 62.24, p < .01, \eta^2 = .14$ . Means are presented in Table 5.

**3.3.5 Overall Cue Utilization.** Our final set of analyses specifically examined the relative utility of each cue type (local, global, global and local, none) in supporting navigation performance. To do so, we collapsed our time and path efficiency and heading error data across Valence, Arousal, and Trial Group, and specifically examined conditions wherein only local (local only), global (global only), both global and local (global and local), or no (none) landmarks were available. This analysis allowed us to specifically examine which cue type proved the most effective at supporting navigation in the present paradigm. For each dependent measure, we performed a repeated-measures ANOVA with four levels of the independent variable Cue Type (local only, global only, global and local, none), and then in the case of a significant effect we followed up by conducting all pairwise  $t$ -tests using a Bonferroni correction to reduce the likelihood of a type I error ( $\alpha/6 = .008$ ).

Path efficiency revealed a main effect of Cue Type,  $F(3, 141) = 380.99, p < .01, \eta^2 = .89$ . Paired  $t$ -tests revealed higher path efficiency with local cues relative to both global cues,  $t(47) = 10.23, p < .008, d = .43$ , and no cues,  $t(47) = 15.14, p < .008, d = .46$ . Global and local cues together led to higher path efficiency relative

to global cues alone,  $t(47) = 9.55, p < .008, d = 1.38$ , but not relative to local cues ( $p > .008$ ). Finally, no cues led to lower path efficiency relative to all other cue types (all  $p < .008$ ). Means are presented in Table 6.

Time efficiency revealed a main effect of Cue Type,  $F(3, 141) = 229.11, p < .01, \eta^2 = .83$ . Paired  $t$ -tests revealed higher time efficiency with local cues relative to both global cues ( $M = .46, SE < .01$ ),  $t(47) = 8.69, p < .008, d = 1.25$ , and no cues,  $t(47) = 26.85, p < .008, d = 3.87$ . Global and local cues together led to higher time efficiency relative to global cues alone,  $t(47) = 6.70, p < .008, d = .97$ , but not relative to local cues alone ( $p > .008$ ). Finally, no cues led to lower time efficiency relative to all other cue types (all  $p < .008$ ). Means are presented in Table 6.

Heading error revealed a main effect of Cue Type,  $F(3, 141) = 480.14, p < .01, \eta^2 = .91$ . Paired  $t$ -tests revealed lower error with local cues relative to both global cues ( $M = -.21, SE = .01$ ),  $t(47) = 16.99, p < .008, d = 2.45$ , and no cues,  $t(47) = 33.13, p < .008, d = 4.78$ . Global and local cues together led to lower error relative to global cues alone,  $t(47) = 16.98, p < .008, d = 2.45$ , but not relative to local cues alone ( $p > .008$ ). Finally, no cues led to higher error relative to all other cue types (all  $p < .008$ ). Means are presented in Table 6.

## 4 Discussion

The present study examined how affective state influences spatial cue utilization during a virtual navigation task. Path efficiency, time efficiency, and heading error data converged to support our hypothesis that affective state, specifically arousal, modulates navigators' reliance on spatial cues. The present data specifically implicate arousal states in driving global cue use; in all cases, participants took advantage of global cues, but a low relative to high arousal state made navigators particularly amenable to global cue utilization. These effects were most pronounced early on (trial 2 through trial group 3); that is, differences in navigation performance due to arousal decreased as participants continued through the 11 navigation trials. This suggests that arousal's influence on spatial cue utilization decreases as spatial mental representations solidify and become stored

**Table 6.** Mean (and SE) Navigation Scores by Cue Type (Overall Cue Utilization)

	Global		Local		Global and local		No cues	
	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>
Path efficiency	0.61	.01	0.74	.01	0.72	.01	0.39	.01
Time efficiency	0.46	.01	0.57	.01	0.55	.01	0.32	.01

in long-term memory. Therefore, arousal holds high significance during initial orientation and navigation in a novel environment.

#### 4.1 Landmark Hierarchy and Perceptual Narrowing

Research in cue utilization often refers to information as central or peripheral. Easterbrook's (1959) oft-cited conclusions discuss the perceptual narrowing effects of arousal with high arousal leading to greater focus on central information at the expense of peripheral information. In the present study, there was a reliable cost of high arousal states in participants' ability to use available global (peripheral) cues for navigation. To our knowledge, we provide the first evidence that affective state, in this case arousal, can modulate spatial cue reliability and affect navigation performance.

Recall that the present study equated both landmark availability and reliability; the virtual environments presented both global and local cues in equal numbers and with permanent environmental stability. As previous research has shown, both humans (Foo et al., 2005) and mice (Biegler & Morris, 1996) employ an organized hierarchy of spatial representations. Local landmarks provide accurate positional information while global landmarks are considered more reliable and stable. With landmark availability and stability equated, we demonstrate an overall preference for local cues, which appear to be perceived as central information for efficient navigation (see also Ruddle et al., 2011). This pattern, in which stable local cues are prioritized for guiding navigation through small-scale environments, merges the present study's findings with various theories regarding affective state influences on visual perception and mem-

ory. One theory posited by Mather et al. (2009) suggests that arousal impairs memory for information that is typically suppressed, such as background contextual information. They found that memory for a background pattern was reduced when an arousing image was located in the foreground. In the present study's virtual environments, with local and global cues equated in reliability, local cues were perceived as central information, pushing global cues out of the foreground. It is possible, therefore, that in some cases high arousal leads to a greater focus on local cues but also impairs memory for perceptually suppressed global cues. Levine and Edelman (2009) suggest that arousal leads to enhanced memory for information relevant to current goals. In the present study, local cues, with their accurate positional information, are most relevant to the goal of reaching the hidden platform. Perhaps the most parsimonious theory is that of Berlyne (1967) who suggests that arousal promotes a dominant response. If humans generally prefer local cues (Foo et al., 2005) and global and local landmarks are equated for availability and stability, then utilizing local cues is the dominant response and strategy for effective navigation.

Though it is clear that high arousal states reduced reliance on global cues, we found no direct evidence that high arousal states promote local cue utilization. This pattern, however, may be an indication of overall dependence on local cues for the present task. That is, local cues appear to provide the highest degree of granularity for serving navigation in the present task, and the lack of increased local cue reliance may indicate a ceiling effect. We also found no evidence that affective valence, that is, the positive versus negative aspect of emotion, affects spatial cue utilization in our paradigm. This result is in contrast to some work suggesting that negative

affect (e.g., sadness) can promote a local focus (Basso et al., 1996; Gasper & Clore, 2002), and positive affect (e.g., happiness) can promote a global focus (Gasper & Clore, 2002; Isen & Daubman, 1984). Our research converges with some recent evidence that challenges this view and suggests that earlier work confounds the effects of arousal and valence on cognitive performance (Corson & Verrier, 2007).

## 4.2 Implications

Navigation is always performed in an affective context and humans often must quickly learn novel environments. If arousal reliably modulates cue utilization then it can influence not only how spatial mental models of novel environments are formed but also the completeness of these models, given available cues. This can have deep ramifications for populations susceptible to acute bouts of arousal, such as military and civilian emergency first responders, who face heightened arousal states and require strong navigational ability on a daily basis. In novel environments with few or unreliable local landmarks, an aroused individual should pay special attention to global aspects of the environment to counter the inclination to rely less upon global cues. Such context-sensitive broadening of perspective can serve to bolster one's spatial mental model, creating a more comprehensive and detailed representation of an environment. If, however, there are sufficient reliable local cues available, people can utilize those cues effectively not only while navigating but also through giving directions, regardless of affective state. Such reliance on local landmarks would call for careful assessment of landmark reliability as arousal-induced preference for local landmarks rests on the assertion that those landmarks are stable.

Our findings further previous research that emphasizes the role arousal plays in influencing cognitive processes. In past affective state dependent research, arousal was often obscured and overshadowed by valence, a confound which often led to confusing and misinterpreted results (Revelle & Loftus, 1990). Disentangling the influences of arousal from valence in affective research is an important consideration, of which recent research has

taken note (Corson & Verrier, 2007; Vogt et al., 2008). Converging with earlier work (e.g., Storbeck & Clore, 2008), we emphasize arousal's task-related feedback and ability to reinforce current inclinations and processing strategies, and reduce reliance on peripheral information. In other words, arousal does not change what one thinks but rather encourages what one already thinks is correct. Future affect-based research must not only continue to consider arousal in its manipulations but also seek to uncover the underlying thoughts and inclinations that arousal reinforces.

## 4.3 Limitations

Some important limitations constrain the results of the present study. While desktop VE navigation serves as a respectable model of real navigation, it is not as close an analogy as more immersive methods. Such systems, which incorporate some combination of wide FOV head-mounted displays (HMDs), motion tracking, and treadmill locomotion, offer a better simulation of real-world navigation. These fully immersive systems can also provide proprioceptive and vestibular cues that give the user a better sense of being there (Ruddle, Payne, & Jones, 1999). The utility of HMD systems continues to be debated. Some recent research has shown that HMDs can be perceived as more intuitive and natural, and also lead to relatively real-world navigation behavior given that they allow for real physical rotations and translations (i.e., Chance, Gaunet, Beall, & Loomis, 1998; Ruddle & Lessels, 2009). In certain cases, however, there is some limited evidence that desktop VEs can lead to more accurate navigation and stronger spatial learning (Ruddle & Péruch, 2004; Sousa Santos et al., 2009).

The trial sequence of the present study was also highly predictable. The probe trial in each virtual environment was always presented on Trial 11. In some cases, this led to participants quickly realizing that the platform had disappeared and either ceasing movement or navigating aimlessly until the trial ended. Our counterbalancing scheme should minimize any discernable influence of this realization. This potential issue, however, can be remedied in future implementations of virtual Morris water maze tasks by randomizing the placement of the

probe trial within a set of ending trials in order to discourage trial counting or other similar strategies.

#### 4.4 Future Directions

While the present research reveals the significance of affective state on cue utilization during navigation and spatial working memory, it leaves open several questions that may be addressed in future studies. The virtual Morris water maze task employed in the present study allowed for strict control of available landmarks and incorporated sparse environments. This resulted in high reduction of confounds and high internal validity. However, the unrealistic environments and landmarks tended to reduce ecological validity. A future study, conducted in our lab, seeks to replicate the design of the present study in a more realistic urban environment. Using realistic cues such as the sun (global), distant buildings (global), and building signs (local), we can determine whether the present study's results are reproducible in more familiar and realistic environments.

Tracking eye movements during virtual environment navigation can also yield valuable and generalizable results. We gathered our conclusions based on navigation cue types (global vs. local) in isolation. Other studies, such as Steck and Mallot (2000), present both cue types only to later remove one type to examine the effects of such a change on navigation. Conversely, real-world environments contain numerous global and local cues that are used in forming complex spatial mental models. Presently, only a handful of studies have included eye-tracking measures in virtual environment navigation-based studies (Hamilton et al., 2009; Mueller, Jackson, & Skelton, 2008) and to date none has addressed affective state as a factor in cue utilization during navigation. Observing which aspects of the environments (i.e., landmarks) participants fixate on while navigating can offer greater insight into the influence of affective state on navigation and spatial working memory.

Lastly, manipulating landmark availability and reliability can reveal whether affective state influences the flexibility of spatial cue utilization. Our conclusions rest on the equal availability and reliability of global and local

landmarks in the present study's virtual environments. When equated, humans preferentially rely on local cues, though low arousal states can heighten reliance on global cues. Future research may consider manipulating both affective state and landmark reliability to assess potential interactive effects. Since local landmarks tend to be less reliable than global landmarks and landmark reliability is often difficult to assess accurately, findings from such research can further elucidate the importance of affective state on spatial cue utilization, yielding implications for navigation in high arousal states.

## 5 Conclusions

The present study demonstrates that heightened states of arousal reduce global cue utilization, that lower arousal states may promote global cue reliance, and that these effects are strongest during early environmental learning. Indeed, these effects are immediately evident as one begins navigating and encoding salient aspects of the environment and are thus assumed to affect aspects of visual perception and spatial working memory. The results of the present study hold special significance for populations exposed to extended levels of high arousal, for which efficient navigation and spatial working memory within novel environments is critical. Future research is needed in order to examine whether heightened arousal is linked to reliance on local cues or merely the dominant response and whether the present study's pattern of findings can be replicated in more realistic settings.

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