Effects of home environment structure on navigation preference and performance: A comparison in Veneto, Italy and Utah, USA

Erica M. Barhorst-Cates[1], Chiara Meneghetti[2], Yu Zhao[3], Francesca Pazzaglia[2], and Sarah H. Creem-Regehr[4]

[1]Moss Rehabilitation Research Institute, Elkins Park, PA, USA

[2]Department of General Psychology, University of Padua, Padua, Italy

[3]Department of Electrical Engineering and Computer Science, Vanderbilt University, Nashville, TN, USA

[4]Department of Psychology, University of Utah, Salt Lake City, UT, USA

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Abstract

Individuals differ in preferences to use route versus survey strategies or distal versus proximal cues for navigation. The current study aimed to examine the effects of environmental structure experience in environment representations. Two groups of participants from Salt Lake City (Utah, USA) and Padua (Veneto, Italy) completed a series of navigation tasks in familiar and novel virtual environments as well as navigation strategy questionnaires. The results showed that Padua participants – compared to Utah participants - had more accurate survey knowledge of locations in their city and country, were more accurate at using proximal cues to remember target locations, and were more likely to use navigation strategies that involved shortcuts. Utah participants did not use distal cues more accurately or use more survey-based strategies despite their higher reported sense of direction and cardinal knowledge compared to Padua participants. Overall the results support that environmental demands shape environment strategies and performance.

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1. Introduction

1.1. Environment structure, space and navigation preference

Individuals differ vastly in their preference and use of the following options for navigation directions: (a) Start on 100 South facing the Salt Lake City Temple. Head east toward the Wasatch mountains to 1400 East. Turn south. You have arrived at campus. (b) Start by facing the Basilica di Sant'Antonio. Turn left and walk to the first street on your right, then turn right and continue to the Cappella S. Massimo. Turn left and continue across the bridge to campus. These examples of directions in (a) Salt Lake City, Utah, USA and (b) Padua, Veneto, Italy exemplify several individual differences in navigation strategies, including the use of proximal (near) or distal (far) cues (Newcombe, 2018; Padilla, et al., 2017; Sandstrom, Kaufman, & Huettel, 1998) and the use of route (egocentric) or survey/orientation (world-based/allocentric) strategies (Lawton & Kallai, 2002; Pazzaglia & De Beni, 2001). While a large amount of prior research has aimed to identify and relate these individual differences, surprisingly little work has focused on the characteristics of a navigator's home environment as an explanation for why these individual differences occur. The aim of the current paper is to assess differences in navigation strategy and performance in both novel (virtual) and familiar environments for individuals from cities that differ drastically in structure, specifically regarding access to distal and proximal cues and street layout.

Questionnaires assessing navigation abilities and strategies show consistent individual differences, and these differences are also supported by objective behavioral measures. For instance, research demonstrates large individual differences in accuracy at using distal (stable far away landmarks, such as mountains) or proximal (nearby landmarks, such as a building or street sign) cues. This is shown with variations on the Morris Water Maze task (Daugherty et al., 2015; Mueller et al., 2008; Padilla et al., 2017; Woolley et al., 2010) in which individuals learn a target location in a virtual environment (VE) that contains only distal or only proximal cues, and then must return to the location from a novel position. Successful performance requires accurate encoding of the location relative to the available cues. These studies have shown that better navigators (e.g., males) tend to perform better than poor navigators at using distal cues in this task. Proximal cues, in contrast, can be used by skilled and poor navigators alike. However, it is unknown how one’s familiarity with distal or proximal cues due to experience in their home environment might affect their tendency to perform well with either cue in this task. In other words, it may be that people who live in a place with salient distal cues (such as mountains or lakes) are better at using them.

Another reliable and well-studied individual difference involves the types of spatial strategies people prefer to use when navigating (Lawton, 2001; Marchette, Bakker, & Shelton, 2011; Newcombe, 2018; Pazzaglia & De Beni, 2001; Pazzaglia & Meneghetti, 2017). Navigation can be performed using route-based strategies—those that are dependent on continual updating of one’s own position from an egocentric, or viewer-based, perspective along a route, making use of landmarks (i.e., turn right when you reach the second stop sign)—or survey-based strategies—those that rely on allocentric, or world-based, representations of the environment (i.e., navigating with cardinal directions). Notably, the use of distal cues and survey strategies are both considered more allocentric (world-based) and are more often used by better navigators (Chen, Chang, & Chang, 2009). Individuals who use survey-based strategies may benefit from distal cues in particular because the cues provide constant directional information (Chai & Jacobs, 2009). Survey strategies also allow an individual to form a global representation of spatial relationships in an environment with view-independent features (Meneghetti, Pazzaglia, & De Beni, 2011; Silverman et al., 2000), which could allow for computation of shortcuts. In tasks such as the Dual Solutions Paradigm (DSP), the tendency to take shortcuts serves as an indicator of one's use of survey strategies (Boone et al., 2019; Furman et al., 2014; Marchette et al., 2011; Weisberg & Newcombe, 2016). In the DSP, participants locate targets in a virtual maze by choosing to follow either a learned route ("response" learning) or by taking a novel shortcut ("place" learning). Individuals vary on a continuum of taking shortcuts versus following routes and both strategies can be successful; the number of targets found has not been linked to the strategy used (Marchette et al., 2011).

1.2. Environmental and Cultural Differences

Despite these large differences in the ways that individuals navigate, much of the prior research has not considered the navigation demands of specific environments and whether those strategies are always the optimal ones in every environment (Peer et al., 2021). Although allocentric strategies have been touted as more optimal than egocentric strategies and good navigators tend to use allocentric strategies, it is unclear whether allocentric strategies are always more advantageous in every situation. A clear understanding of individual differences and how they arise is necessary for both theoretical (e.g., how navigation abilities and strategies develop or change) and applied outcomes (e.g. how to design customizable navigation systems).

Although there are clear benefits of understanding these effects, we lack research assessing how *built-in access* to distal or proximal cues or the layout and structure of the potential routes in one's home environment may affect the development of preferences for one strategy or another. Evidence across animals and humans suggests that environment structure affects exploration behaviors in a way that may encourage development of different strategies. Rats in a grid “Manhattan”-style maze explore more and travel further away than rats in an irregular “Jerusalem”-style maze, who tend to remain near the initial landmarks and retrace paths (Yaski, Portugali, & Eilam, 2011), suggesting that grid layouts provide a predictable source of spatial information which facilitates exploration. People in the U.S. generally have greater spatial understanding of orthogonal spaces (Montello, 1991; Sadalla & Montello, 1989), suggesting a preference for gridlike environments and survey strategies for those with experience with this type of environment (Peer et al., 2021). However, this preference can be contingent on the type of environment a person is accustomed to. In the Midwestern/Western U.S., including Salt Lake City, property boundaries and street layouts were established using the U.S. Public Land Survey method, where space is divided into predictable portioned rectangles that are oriented in relation to the cardinal directions. This differs dramatically from cities in the Northeastern/Southern U.S., where property boundaries and subsequent street layouts were established using the irregularly structured “metes and bounds” system that involved natural barriers and/or settlers’ claims. In a direction-giving task to familiar locations, Lawton (2001) observed that individuals from gridlike cities were more likely to use cardinal directions (considered an allocentric strategy) compared to individuals from irregularly structured cities. This supports the assumption that home environment influences navigation strategies, and moreover that individuals from gridlike cities may be more likely to use allocentric navigation strategies.

Many cities in Europe also do not follow a predictable grid structure, which has led to the use of more route-based strategies. For instance, when providing directions to familiar locations, Dutch individuals rely more landmark and right-left descriptors (considered route strategies) compared to U.S. individuals, who rely more on cardinal directions and street names (Hund, Schmettow, & Noordzij, 2012). This difference in navigation strategy is also be influenced by cultural norms and expectations (e.g., in the U.S. grid layouts facilitate use of cardinal directions but do not do so in Europe; Davies & Pederson, 2001). As such, both environmental features and cultural norms may impact strategies for representing the spatial layout of the environment—even though some people may grow up and live in a gridlike environment, they may not use gridlike survey strategies to navigate because it is not culturally normal to do so (Davies & Pederson, 2001).

Clearly, an individual's home environment affects their navigation strategies, at least for giving directions to familiar locations, but it is unknown whether people from gridlike environments who use survey strategies excel in every navigation situation, like new environment learning. Several studies suggest that allocentric strategies and regular gridlike environments may not always facilitate the best navigation abilities. For instance, Denis et al. (1999) found that individuals who attempted to use survey strategies to navigate in the spatially complex city of Venice (where mainly proximal cues are viewable) performed more poorly on a navigation task than individuals who preferred landmark strategies. Similarly, recent unpublished data of individuals across 38 countries who played the virtual navigation game SeaHero Quest demonstrated that "Street Network Entropy", or environmental irregularity, enhanced spatial navigation abilities (Coutrot et al. 2020 preprint). These studies suggest that the "optimal" navigation strategy depends on the type of environment in which one is navigating, and moreover that the more complex and challenging the home environment, the greater the navigation abilities of those living there.

1.3. The Current Study

In the current study, we aimed to measure how home environment differences in street layout and access to distal vs. proximal cues relate to navigation behaviors in familiar and novel environments. We tested samples of age and education-matched individuals in Salt Lake City, (Utah, USA) and in Padua (Veneto, Italy), two environments that strongly differ in their street layout and access to distal cues. We included four tasks that each addressed different components of navigation: (1) use of proximal or distal cues in novel environments, (2) use of survey or route strategies in novel environments, (3) survey knowledge of locations in the familiar environment, and (4) self-reported ability and strategy preferences. We also included mental rotation as a control measure of (small-scale) spatial abilities, predicting that there would be no difference. This would provide evidence that the effects are due to environment differences, not spatial ability differences.

We formulated the following hypotheses for each task:

H1: Differences in proximal and distal cue use in novel (virtual) environments will be explained by the availability and experience of using those cues in the home environment. We predicted that Padua participants would exhibit behaviors consistent with how one might navigate in the city of Padua (relying on proximal cues) whereas Utah participants would exhibit behaviors consistent with how one might navigate in Salt Lake City (relying on the mountains as distal cues). In a Virtual Water Maze Task, we expected that, while overall performance would be worse across both groups with distal cues, Padua would outperform Utah with proximal cues and Utah would outperform Padua with distal cues.

H2: Differences in route-retracing versus shortcut strategies in novel (virtual) environments will be explained by differences in home environment structure. On the Dual

Solutions Paradigm, we predicted that Padua participants would show more route-retracing behaviors, consistent with navigation strategies commonly reported by Europeans (Hund et al., 2012) and that Utah participants would show more of a preference for shortcuts, consistent with the reported use of survey strategies in the Western U.S. in gridlike cities (Lawton, 2001).

H3: Differences in survey knowledge of familiar environments will be explained by differences in home environment structure. In a pointing task, we predicted that participants in Utah would show greater accuracy in pointing than Padua participants. Pointing is a commonly used measure in field and real-world navigation research (e.g., Davis & Cashdan, 2019; Berry & Bell, 2014; Wang & Brockmole, 2003; Montello et al., 1999) and is thought to reflect an individual's survey knowledge of the familiar environment (i.e., pointing to an unseen location reflects a "shortcut" beeline direction to that location from one's current location). We predicted that experience with the structure of the Utah home environment would be associated with better survey knowledge, leading to higher pointing accuracy.

We included a battery of self-report questionnaires to provide further support for the hypotheses, expecting to find converging evidence for differences in strategy preference in the two environments. We expected that Padua participants would report more route-based navigation strategies while Utah participants would report more survey-based strategies, consistent with previous cross-cultural work (e.g., Hund et al., 2012; Lawton, 2001; Davies & Pederson, 2001) and in line with the expected behavioral results.

Finally, in exploratory analyses, we took advantage of the novel within-subjects design of our battery of tasks to examine the relationships between self-reported abilities and strategy preferences, the relationship between navigation performance in novel and familiar environments, and the relationship between two virtual navigation tasks that have not previously been studied in conjunction.

2. Method

2.1. Participants

Prior research has been sufficiently powered to detect cultural differences in navigation strategy using from 24 (Davies & Pederson, 2001) to 50 (Hund et al., 2012) participants in each group. A power analysis using the effect size for pointing accuracy between groups in Davies and Pederson (2001) revealed that at least 36 participants (18 per group) were needed to obtain a power of 0.96 with an effect size of d=1.26. Prior research on the water maze has shown individual differences effects with 108 participants (54 per group; Padilla et al., 2017) and prior research on the DSP has shown individual differences effects with 20 participants per group (Boone et al., 2019). Considering this, we aimed for a conservative sample of at least 50 participants in each location. Participants were students at the University of Utah and University of Padua who were approximately matched for age and education. Our final sample included 56 Utah participants (33 female) and 56 Padua participants (35 female).

The average age of the Utah participants was 23 (range 18-46) and Padua participants was 23 (range 18–35). Participants at the University of Utah received partial course credit as compensation for completing the experiment and participants at the University of Padua were volunteers. Each participant provided written informed consent via methods that were approved by each university’s subsequent ethical review board. We aimed to recruit participants who had at least some familiarity with each city, in that they either lived in the city or commuted to the city for work or school. 45 participants reported that they were from Padua and 29 participants reported that they were from the Salt Lake valley. The average years of familiarity of the Salt Lake Valley was 8.71 (*SD*=7.64) for Utah participants was lower than that of Padua area 13.32 (*SD*=8.12) for Padua participants $F(1,110) = 9.60$, p=.002.

2.2. Testing Locations

Salt Lake City and Padua serve as ideal comparison environments due to their inherent differences in both street layout and distal cue access. The layout of Salt Lake City is a grid. The structure of the street names necessarily requires navigators to use an allocentric reference frame while navigating because they are organized in terms of cardinal directions (e.g., 100 North, 200 South, 1400 East), as shown in Figure 1. Padua, Italy, in contrast, does not afford a predictable and structured navigation experience, with the winding streets through tall buildings and lack of a systematic street name structure. These two cities also vary in their natural and built distal and proximal cues. In the Salt Lake valley, there are highly salient mountains on the East and West that are viewable from almost anywhere. The orthogonal and cardinal-direction-oriented structure of the streets especially facilitates the navigator's potential to use the mountains to orient (from any intersection, one could look up or down the street and have access to a distal cue). Padua, in contrast, does not have directly viewable mountains. Moreover the structure of the narrow, winding streets through tall buildings would prevent access to distal cues even if they were there. Finally, these cities also vary in cultural norms for navigation, which may also influence individual differences in navigation in novel environments as well as self-reported navigation strategies.

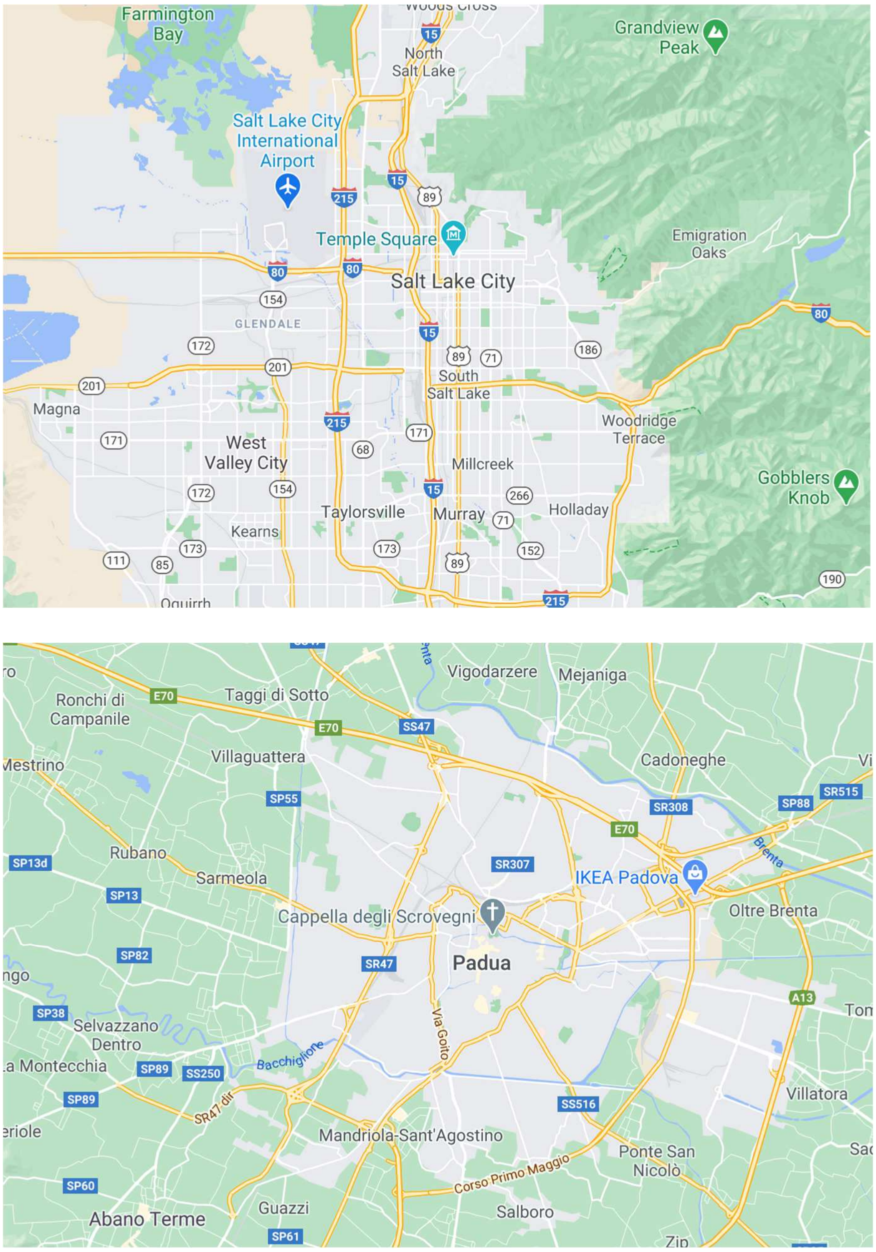
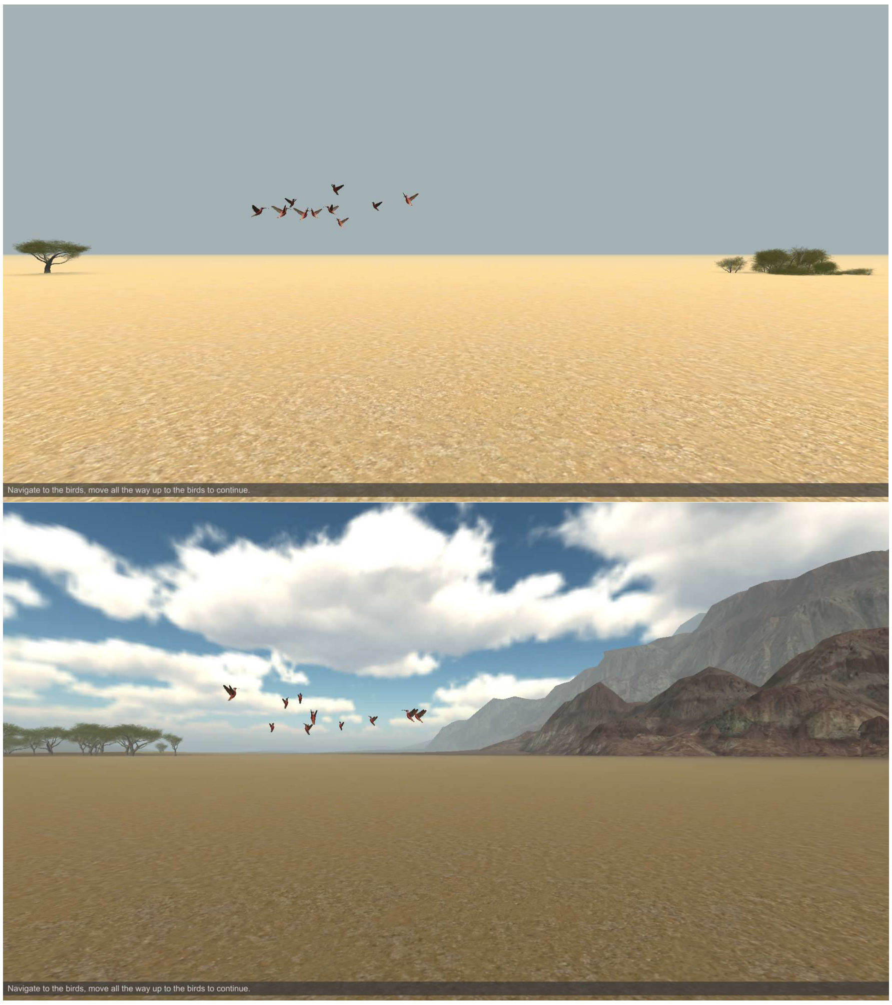


Figure 1. Maps of Salt Lake City (Utah, USA) and Padua (Veneto, Italy). Images taken from Google Maps.

2.3. Materials

Mental Rotation Test (MRT; short version; De Beni et al., 2014; adapted from Vandenberg & Kuse, 1978). Participants completed 10 items in 3 minutes and they received a point if both correct answers were selected.

Water Maze task (Padilla et al., 2017). In the task, participants used the keyboard to travel to a group of birds in a natural outdoor landscape and memorized the location, with the presence of either mountains and the sun (distal cues) or trees, bushes, and rocks (proximal cues), as shown in Figure 2. Then, in subsequent recall trials, participants were placed at random locations in the environment and asked to return to the remembered initial location of the birds, which became hidden from view. Once participants believed they were in the correct location, they indicated with a key response and the birds appeared to provide feedback. Then, after an opportunity to view the environment again, participants advanced to the next trial. The birds were always in the same location within each condition, but the starting location of participants varied trial to trial. Participants completed 6 trials in each condition (distal and proximal). The distal and proximal conditions were blocked within participants and order of conditions was counterbalanced across participants. We recorded distance error and response time for each trial.


Navigate to the birds, move all the way up to the birds to continue.

Navigate to the birds, move all the way up to the birds to continue.

Figure 2. Virtual water maze task modified from Padilla et al. (2017). On the top is the proximal condition and on the bottom is the distal condition.

Dual-Solutions Paradigm (Furman et al., 2014 with a slight difference in background rendering). The VEs were custom built and run through the videogame Portal, administered on a laptop computer. Following the procedures described by Furman et al. (2014), participants first watched 3 videos of a route through a maze environment that included 12 objects located in alcoves along the route, as shown in Figure 3. Each video lasted 60 seconds. Participants were told to memorize the route and the location of the objects. After watching the videos, participants were placed in the VE in a random location that changed on each trial. Then they were cued with the name of an object at the top of the screen and instructed to find the object as efficiently as possible. We instructed participants that the most efficient path to the object may differ from the video they watched, and that because of the time limit to find the object, they should focus on navigating both confidently and efficiently. Prior to the beginning of the time limit, participants' viewpoint was rotated automatically in a 360° circle in order to orient them to the starting position in the VE. Participants navigated using the WASD keys on the keyboard and had 39 seconds to reach the goal before the trial would time out.

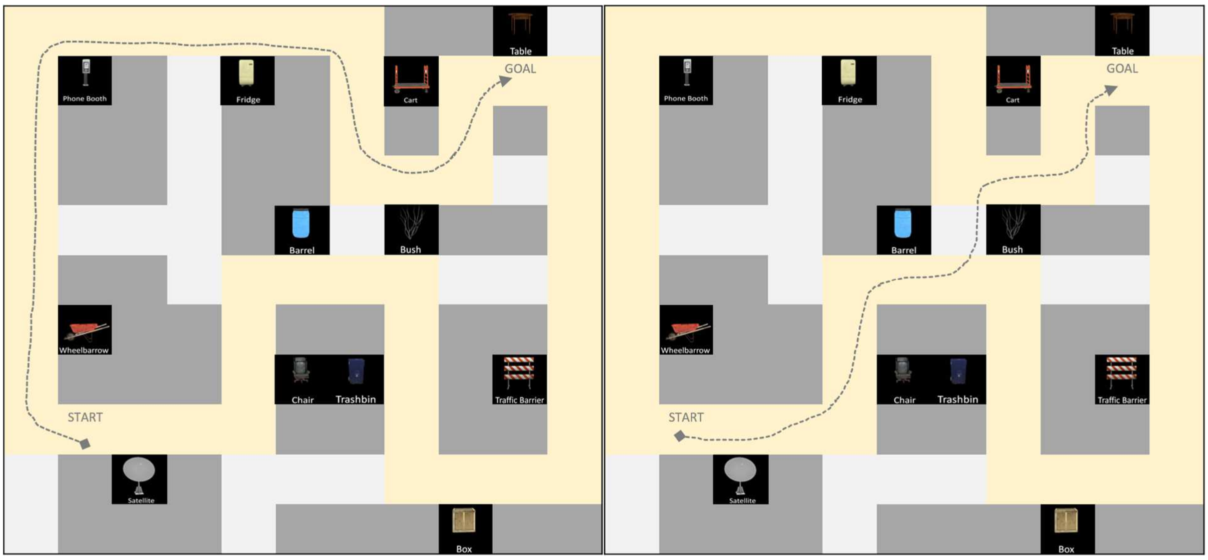


Figure 3. Overview map of Dual Solutions Paradigm. Gray squares represent the walls. Yellow squares represent the learned route. On the left is an example of following the familiar route to reach the target location (the Table). On the right is an example of taking a shortcut to the Table.

For each trial, the participant's position and orientation in the VE were collected every fourth of a second. We transformed the VE into an 11*11 grid and participant's position along the x-and y-axes was converted to steps along the grid. We first classified the trial into three types: "route fastest," "shortcut fastest" and "equal" by determining the shortest path to the goal. After categorizing the type of trial, we then measured success in each trial and the strategy each individual used through analyzing the trace of participants. A trial was considered successful if participants reached at a minimum the grid square next to the alcove of a goal object (Furman et al., 2014). We also conducted a follow-up analysis to allow a more liberal coding of correct responses by expanding the successful area to the 8 grid squares surrounding the object (see these results in the footnote). Successful trials were classified as "shortcut" or "familiar path" based on the percentage of the participant's route on either the familiar path or a shortcut. If the majority of a participant's route was neither, it was coded as "wandering". All participants completed trials where taking the learned route was the optimal strategy, trials where taking a novel shortcut was the optimal strategy, and trials where either option was optimal. As has been done in prior work using the DSP, we computed the "Solution Index" (SI) as the percentage of classifiable shortcut-available successful trials that were taken using a shortcut out of the total number of successful shortcut-available trials. A score of 0 on the SI would indicate always taking the learned route and a score of 1 would indicate always taking a shortcut.

There were in total 24 navigation trials in each environment (2 trials for each of the 12 objects) completed in a random order. Each participant learned and completed recall trials in only one of the two environments. Of the Padua participants, 34 completed Environment 2 and 21 completed Environment 1. Because of a technical error with Environment 2, all Utah participants completed Environment 1.

Pointing Task. In the pointing task, we used an iPhone compass held against the participant's back in order to get heading angle. Participants began by facing to where they believed north is and we measured that angle to assess for accuracy and knowledge of cardinal directions. We provided feedback and asked the participant to return to north between each place. Then we asked participants to turn to face 16 locations—4 within a 5 km radius, 4 within a 10 km radius (combined to form the "City" pointing trials), 4 within the state/region, and 4 within the country. The location used for the pointing task is reported in supplementary material (See Table S1). For each place, the participant first indicated if they were familiar with the location by indicating “yes, no, or so-so.” Then participants turned to face the location and their angle was recorded.

Questionnaires. We included a battery of questionnaires that assessed various self-reported measures of navigation ability, strategy, and exploration behaviors. We included the Lawton and Kallai (2002) International Wayfinding Strategy scale, a 17-item scale which measures route strategy tendencies (6 items) and survey or “orientation” strategy (11 items) tendencies ($\alpha = 0.67$). We also included the Lawton (1994) spatial anxiety scale, an 8-item scale which measures of how much anxiety is caused by navigation for an individual ($\alpha = 0.73$). We additionally included the 13-item Sense of Direction and Spatial Representation Scale (SDSR; Pazzaglia, Cornoldi, & De Beni, 2000), which measures Sense of Direction-Survey (6 items) preference, Cardinal Knowledge (3 items), and Landmark-Route (4 items) preference ($\alpha = .81$). Finally, we included the 10-item Attitudes toward Orienting Tasks (AtOT) scale (De Beni et al., 2014) which measures individual’s pleasure and displeasure with orientation and spatial exploration tasks ($\alpha = 0.76$).

2.4. Procedures

Participants were initially greeted by researchers and provided written informed consent. Instructions were presented in either Italian or English to Padua and Utah participants respectively.

With the exception of the pointing task, all tasks were completed in counterbalanced orders. For the Padua participants, the pointing task was conducted first for every participant, and for the Utah participants it was conducted last. This was done as a result of the procedural demands in each location. In Padua, we met participants outside the Psychology building and completed the task first before heading inside. In Salt Lake City, participants met researchers in a specific indoor room, so participants completed all indoor tasks first and then ended with the outdoor task. The Water Maze, DSP, and questionnaires were all administered on computers and the MRT was administered via paper and pencil. Finally, participants were debriefed, thanked, and dismissed. The experiment took approximately 1.75 hours for each participant.

3. Results

R (R Core Team, 2019) version 3.6.2 was used for statistical analyses. We wanted to first assure that any difference in navigation performance was not a function of a difference in small-scale spatial abilities. As expected, there was no difference in performance (p>.4) on Mental Rotation between Utah (M=3.84, SD=2.51, 95% CI [3.17, 4.51]) and Padua (M=3.48, SD=2.13, 95% CI [2.91, 4.05]) on MRT.

3.1. Water Maze

For our first hypothesis, we expected that participants' familiarity with cues given their home environment would explain differences in their reliance upon proximal and distal cue use when faced with navigating a novel environment, which we tested using the Virtual Water Maze. Due to technical, experimenter, or recording errors, only 47 out of 56 Utah participants completed the Water Maze. We computed the average distance error and average time to indicate the remembered location across the 6 trials. First, we compared performance between the distal and proximal tasks expecting to replicate prior findings that people are overall more accurate in the proximal compared to the distal condition (Padilla et al., 2017). As expected, a paired t-test showed that average distance errors in Proximal were significantly lower (*M*=14.27, *SD*=10.16) than average distance errors in Distal (*M*=35.80, *SD*=14.23), $t(102)=-17.29$, $d = 1.70$, $p<.001$, 95% CI [-24.0, -19.06] as shown in Figure 4. Response time in the Proximal condition (*M*=72.41, *SD*=26.39) did not differ from time to respond in the Distal condition (*M*=67.96, *SD*=30.89, $t(102)=1.82$, $p = .07$).

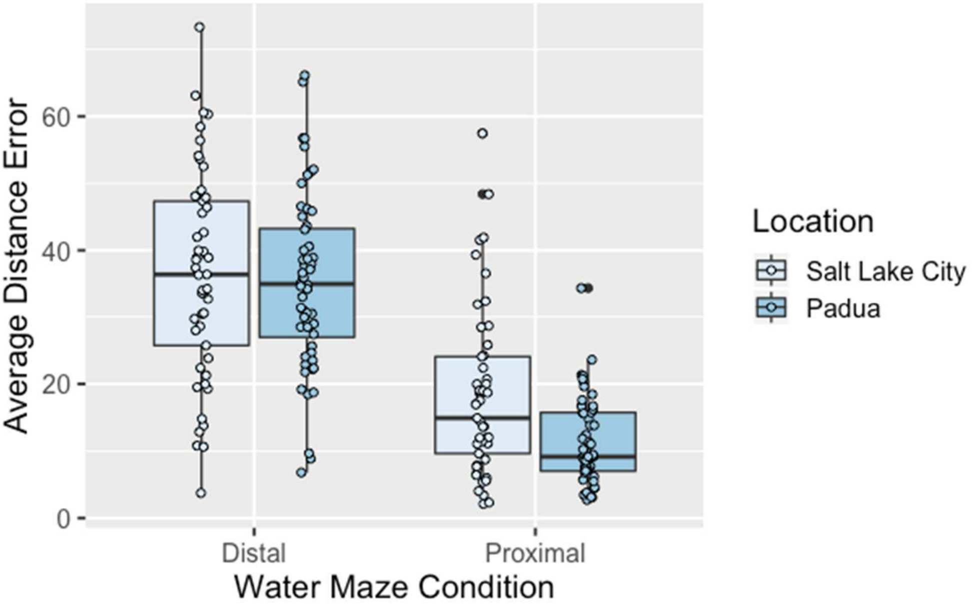


Figure 4. Boxplot of distance errors in the Distal and Proximal conditions of the Water Maze separated by location.

Next, we wanted to test differences in performance between Padua and Utah. We ran a multivariate Analysis of Variance (MANOVA) with location (Padua vs. Utah) as the predictor and Proximal average distance error and Distal average distance error as the outcome variables. There was an overall main effect of Location $F(2,100)=7.24$, $\eta_p^2 = .13$, $p=.001$. This effect, as shown by Figure 4 and by the means presented in Table 1, was driven by the proximal cue condition: there was a significant effect of Location $F(1,101)=12.08$, $\eta_p^2 = .11$, $p=.001$, $t= -7.06$, 95% CI [-10.83, -3.28] with Padua participants, as predicted, performing with lower distance errors than Utah participants. There was no significant effect of Location for distal cue accuracy (p=.7). These effects remained after controlling for years of familiarity, which did not significant predict distance accuracy in either proximal (p=0.4) or distal (p=0.8) conditions.

We also examined average response time using the same MANOVA. There was an overall main effect of Location $F(2,100)=3.52$, $\eta_p^2 = .07$, p=.03). Utah participants responded significantly more quickly than Padua participants in both the proximal $F(1,101)=6.71$, $\eta_p^2 = .06$, p=.01, t=13.94, 95% CI [4.02, 23.87] and distal $F(1,101)=4.39$, $\eta_p^2 = .04$, p=.04, t=11.12, 95% CI [-.83, 23.07] conditions. These effects remained after controlling for years of familiarity, which did not significantly predict timing performance in either proximal (p=0.9) or distal (p=0.1) conditions.

Table 1. Descriptive statistics for pointing and VE tasks.

		Location			
		Padua		Salt Lake City	
		M ± SD	*[95% CI]*	*M ± SD*	*[95% CI]*
Water Maze task	Proximal Time	78.4±26.1	[71.4, 85.4]	65.3±25.2	[57.8, 72.7]
	Proximal Distance	11.2±6.3	[9.6, 12.9]	17.9±12.5	[14.2, 21.6]
	Distal Time	73.7±34.0	[64.6, 82.8]	61.1±25.5	[53.6, 68.6]
	Distal Distance	35.2±13.0	[31.7, 38.7]	36.5±15.7	[31.9, 41.1]
Dual Solutions Paradigm	Accuracy	.42±.20	[.36, .47]	.49±.19	[.44, .54]
	Solution Index	0.57±.26	[.50, .64]	0.45±.24	[.39, .52]
	% Wandering	.40±.20	[.35, .45]	.49±.22	[.43, .55]
Pointing Error	City	16.1°±12.6	[12.8, 19.4]	32.6°±14.9	[28.3, 36.9]
	State/ Region	36.0°±28.7	[27.9, 44.0]	38.0°±18.8	[32.6, 43.5]
	Country	25.9°±16.4	[21.3, 30.5]	35.0°±17.8	[29.9, 40.2]

3.3. Dual Solutions Paradigm

In our second hypothesis, we expected that differences in route-retracing versus shortcut strategies in novel (virtual) environments would be explained by differences in home environment structure, which we tested using the Dual Solutions Paradigm. We used separate linear regressions to test for the effect of Location on overall accuracy, Solution Index, and amount of wandering. As Table 1 shows, overall accuracy was not significantly different (*B*=-.07, *p*=.08) between Utah and Padua participants, and was somewhat lower than previously reported accuracy (Furman et al., 2014; Boone et al., 2019)[1]. However, contrary to our expectations, the Padua participants had a significantly higher Solution Index (*B*=.11, *p*=.02) than Utah participants. As demonstrated in Figure 5, on the trials where the shortest path to the target was a novel shortcut rather than the learned route, the Padua participants were more likely than Utah participants to take the shortcut. Similarly, Utah participants also spent a significantly larger (*B*=-.08, *p*=.045) proportion of their "wandering" time on the familiar path compared to Padua participants. These effects remained even after controlling for years of familiarity, which was not predictive of any measure (*ps*>0.1).

Contrary to prior research that has shown no relationship between the Solution Index and success at finding targets (Marchette et al., 2011), a linear regression with SI predicting accuracy revealed a significant relationship in our data (*B*=-.25, *p*=.001). As the SI shifted more toward a preference for shortcuts, the proportion of targets found decreased. We then added location to the model and observed a persistent effect of SI (*B*=-.22, *p*=.002) but no effect of location (*B*=-.05, *p*=.2) on accuracy. This suggests that route-retracing may have been the more optimal strategy for these participants, regardless of location.

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[1] We also ran the same analysis with our more liberal coding scheme. A point was given as a correct response if participant was in any of the 8 surrounding squares in the grid. With this coding, the proportion accurate for Utah was 0.54 (*SD*=.18) and the proportion accurate for Padua was 0.49 (*SD*=.18). A linear regression revealed that these did not significant differ (*p*=.2). The SI for Utah was .43 (*SD*=.24) and for Padua was .51 (*SD*=.20). A linear regression revealed a trending effect of Location (*B*=.08, *p*=.06), again with Padua participants showing a higher preference for shortcuts than Utah participants.

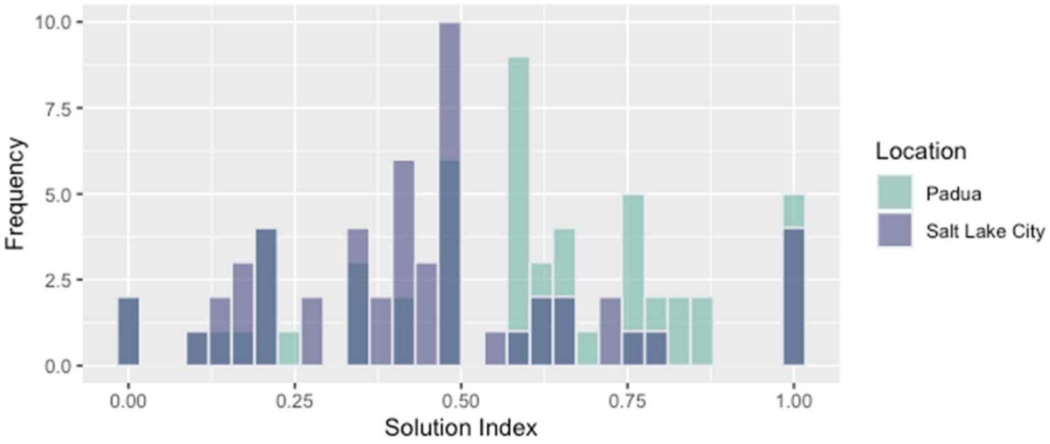

Figure 5. Histogram of Solution Indices broken down by location.

3.4. Pointing task

In our third hypothesis, we expected that differences in survey knowledge of familiar environments would be explained by differences in home environment structure, which we tested using a pointing task. We excluded 13 participants who had pointing errors greater than 90˚ from the following analysis (5 from Padua). We conducted a MANOVA with Location (Utah vs. Padua) predicting City, Region/State, and Country pointing error. Mean pointing error is presented in Table 1. The overall effect was significant F(3,95)=14.07, $\eta_p^2 = 0.31$, p<.001. As shown in Figure 6, contrary to our predictions, Padua participants had significantly lower errors than Utah participants in City pointing $F(1,97)=35.65$, $\eta_p^2 = .269$, $p<.001$, $t=-16.51$, 95% CI [-22.00, -11.02] and Country pointing $F(1,97) = 7.05$, $\eta_p^2 = .07$, $p=.009$, $t=-9.12$, 95% CI [-15.94, -2.31]. There was no difference between groups in Region/State pointing accuracy ($p=.7$). These effects remained even after controlling for years of familiarity, which was not a significant predictor of pointing accuracy at the City ($p=.1$), State/Region ($p=.9$), or Country level ($p=.9$).

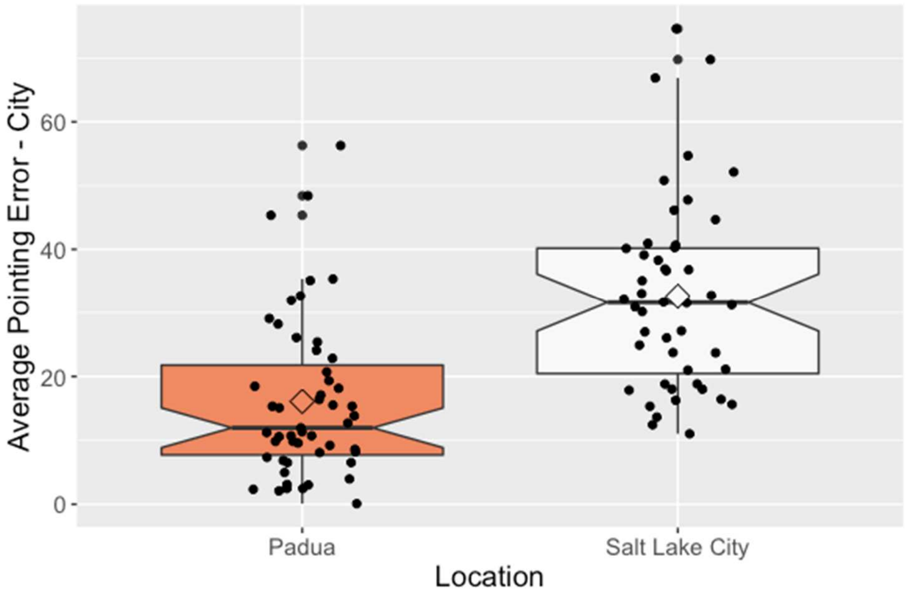

Figure 6. Boxplot of pointing error for locations at the City level. The line represents the median and the diamond represents the mean.

3.5. Questionnaires

We included a battery of questionnaires, expecting to find converging evidence in support of the expected behavioral differences, with Utah participants reporting more survey strategies, and Padua participants reporting more route strategies. We ran a MANOVA with Location as the factor and each subscale of the SDSR (sense of direction, cardinal knowledge, landmark-route), AtOT, Lawton Spatial Anxiety, Lawton Route, and Lawton Orientation as dependent variables. The overall effect of Location was significant F(7,104) = 19.14, η_p^2= 0.56, p<.001. Utah participants reported on the SDSR significantly higher sense of direction $F(1,110) = 19.28$, $\eta_p^2=.149$, $p<.001$, $t=-.62$, *95% CI* [-.9, -.3] and use of cardinal knowledge $F(1,110) = 29.95$, $\eta_p^2=.214$, $p<.001$, $t=-1.3$, 95% CI [-1.8, -.8]. compared to Padua participants, but there was no difference between groups on the landmark-route subscale ($p=0.7$), as shown in Table 2. Utah participants also reported significantly higher route tendencies on the Lawton Route subscale $F(1,110)=5.25$, $\eta_p^2=.046$, $p<.03$, $t=-.27$, 95% CI [-.5, -.04] compared to Padua participants. There were no significant differences on any other subscales ($ps>.1$).

Table 2. Means from navigation questionnaire

		Location			
		Padua		Salt Lake City	
		M±SD	*[95% CI]*	*M±SD*	*[95% CI]*
SDSR	Sense of Direction-survey preference	2.66±.65	[2.5, 2.8]	3.28±.83	[3.1, 3.5]
	Cardinal Knowledge	2.08±.95	[1.8, 2.3]	3.37±1.49	[3.0, 3,8]
	Landmark-Route preference	3.78±.47	[3.7, 3.9]	3.83±.67	[3.7, 4.0]
ATOT		4.35±.65	[4.2, 4.5]	4.13±.79	[3.9, 4.3]
SAS		2.32±.44	[2.2, 2.4]	2.40±.87	[2.2, 2.6]
IWSS	Orientation strategy	2.86±.42	[2.7, 3.1]	2.86±.73	[2.8, 3.0]
	Route strategy	3.49±.61	[3.3, 3.7]	3.76±.64	[3.6, 3.9]

Note. SDSR:Sense of Direction Spatial Representation Scale. AtOT:Attitudes toward Orienting Tasks. SAS: Spatial Anxiety Scale. IWSS: International Wayfinding Strategy Scale.

Finally, we performed a correlation with all measures and set an alpha level of 0.01 to adjust for multiple comparisons. We excluded participants with pointing errors greater than 90° from all correlations. Of particular interest, as shown in Figure 7, we observed that proportion correct on the DSP was significantly correlated with distance error in the Distal condition of the Water Maze task ($r=-.38$, $p<.001$). The greater the number of targets found in the DSP, the lower the distance error in the distal condition of the water maze.

We also observed several relationships between Water Maze task performance variables. We observed a significant relationship between Distal Distance Error and Proximal Distance Error ($r=.50$, $p<.001$), Proximal Time and Proximal Distance Error ($r=-.37$, $p<.001$), Distal Time and Proximal Distance Error ($r=-.28$, $p=.007$), Distal Time and Distal Distance Error ($r=-.51$, $p<.001$), and Distal Time and Proximal Time ($r=.62$, $p<.001$). These results show that the two conditions of the Water Maze task are highly related, and that error decreased with increasing time. Interestingly, we also observed that participants' error in pointing to locations within the country was significantly correlated with their performance on the proximal condition of the water maze (*r*=.37, *p*<.001). Larger pointing errors were related to larger distance errors.

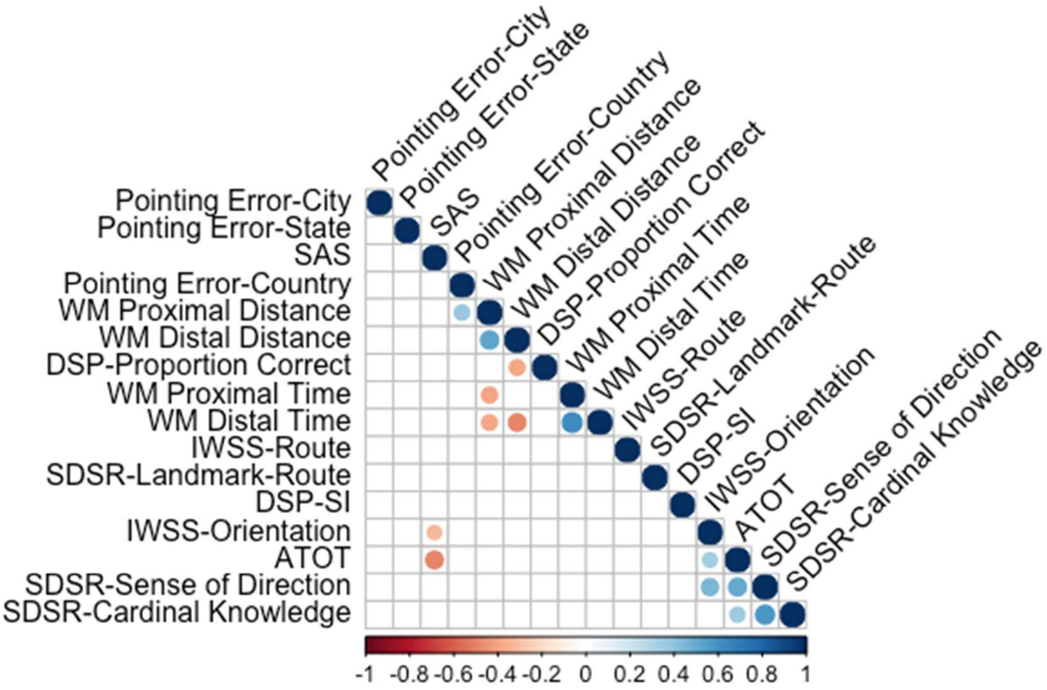

Figure 7. Correlation matrix. Significant correlations are indicated with circles at the p<.01 level. DSP: Dual Solutions Paradigm. SI: Solution Index. WM: Water Maze.

4. Discussion

Young adult participants in Salt Lake City (Utah, USA) and Padua (Veneto, Italy) completed a battery of navigation tasks aimed at characterizing strategy preference and performance as a function of different home environment structures. Participants were matched for age, education, and did not differ in small-scale spatial ability (mental rotation), but their home environment structure differed significantly. Our results partially supported our hypotheses. For H1, we did observe that Padua participants outperformed Utah participants on the Proximal condition of the Water Maze, but Utah participants did not excel on the Distal condition. For H2, counter to our expectations, Utah participants were less likely to take shortcuts in the Dual Solutions Task, suggesting *lower* use of survey strategies in Utah compared to Padua. For H3, Padua participants were surprisingly more accurate at pointing to familiar target locations, suggesting greater survey knowledge. Despite these behavioral effects demonstrating lower survey-knowledge use in Utah participants, Utah participants did self-report more survey-based strategies, consistent with our hypothesis.

As expected, Padua participants showed greater accuracy at using proximal cues compared to Utah participants. An environment with salient proximal landmark cues (such as Padua) may encourage use of those cues for navigation (Denis et al., 1999) even in novel environments. We replicated prior work showing that individuals overall perform better with proximal than distal cues (Padilla et al., 2017). Proximal cues may be easier to use because they provide more location specificity, and the Padua participants were particularly good at using them. We were surprised that Utah participants did not show the expected advantage over Padua at using distal cues, but we suspect that the extreme difficulty of the distal cue condition may have resulted in floor effects that did not allow us to detect individual differences. Indeed, other research shows that the proximal condition is more sensitive to individual differences (Padilla et al., 2017). It is possible that a combined distal and proximal condition may have shown a Utah advantage, but this needs to be explored in future research.

One of the most intriguing findings is that Padua participants tended to take more shortcuts on the Dual Solutions Paradigm, which ran counter to our predictions that Utah participants would be better at using survey strategies. While some of our participants used the learned route or a novel shortcut on every classifiable trial, the majority fell somewhere in the middle—sometimes using the route and sometimes using a shortcut (as has been seen in prior work; Furman et al., 2014; Boone et al., 2019). Padua participants were more likely to fall closer to the shortcut side of the continuum, while Utah participants tended to retrace routes. Contrary to prior work, however, we did observe a significant relationship between the Solution Index and success at finding trials (the tendency to take shortcuts related to higher success). This suggests that the shortcut strategy may have been more likely to be used by better navigators. This work provides an important extension of previous cross-cultural/environmental research that has examined navigation in the familiar environment (Lawton, 2001; Hund et al., 2012; Davies & Pederson, 2001) by extending the assessment of strategies into novel (virtual) environments. Additionally, to our knowledge, the relationship between the Water Maze and the Dual Solution Paradigm has not been tested, despite many calls for much needed comparisons of various virtual navigation tasks (e.g., Newcombe, 2018). We show a significant relationship between success on the Dual Solution Paradigm and accuracy on the Distal condition of the Water Maze task, with a higher number of targets found relating to less error in the water maze.

Performance on the pointing task also ran counter to our hypothesis, with Padua participants pointing more accurately than Utah participants to familiar locations. This advantage was observed despite the greater self-reported use of survey strategies in Utah participants on the questionnaire. Taken together these results suggest that gridlike environments with distal cues do not necessarily facilitate “better” survey-based strategies for the individuals who live there. In fact, Padua participants, who experience irregularly structured street layouts and proximal landmarks, tended to excel on tests of proximal landmark cue-use and survey knowledge. We suggest that the irregular environmental layout of Padua may create a “desirably difficult” (Bjork & Bjork, 2011) navigation challenge that encourages more flexible use of the cognitive map, allowing for the use of both egocentric and allocentric representations, including the computation of shortcuts. In contrast, the predictable, gridlike structure of Salt Lake City may encourage predictable behaviors (retracing a route) and view-independent representations may not be prompted because of the continuous availability/use of grid-structure (also facilitated by the street names). Therefore for navigational success in the local environment of the Utah participants, view-independent representations may not be required (but see Peer et al., 2021). Indeed, individuals who grew up in grid cities are more likely to have poor navigation abilities compared to individuals from more irregular cities (Coutrot et al. 2020 preprint). These results, combined with the results from our study, suggest a strong influence of home environment structure, with more entropic environments actually facilitating navigation ability. Although grid cities tend to facilitate the use of self-reported survey-based strategies (as seen in the current Utah questionnaire results and other studies; e.g., Lawton, 2001), these purportedly superior strategies do not necessarily generalize to better navigation in novel situations.

4.1. Limitations and Future Directions

This study had some limitations, including methodological ones. The average success rates on the Dual Solutions Paradigm were lower than those that have been reported previously (Furman et al., 2014; Boone et al., 2019). Methodological constraints in our experimental design resulted in a longer time period between encoding and test, which may have led to more forgetting. The Italian participants also had the disadvantage of needing to translate the English target name at the beginning of each trial (although a research assistant was continually present to vocalize the translation on each trial), which may have impaired performance.

We also recognize that it is difficult to identify exactly what differentiates the two populations, as we purposefully selected the locations because they varied in several of the hypothesized mechanisms (such as access to cues, street layout, and cultural norms). While we designed our battery of tasks to specifically address different component processes (and found evidence for particular effects), it is certain that a combination of factors, including environment structure, differentiates individuals in terms of their navigation strategies and abilities. This tightly linked combination of factors is both a limitation and a strength of the current study. While the goal in research is often to control as many factors as possible by selecting homogenous participants, applications such as navigational assistive devices should take into account the variable factors that contribute to a user's preferences, including potentially where they are from.

Future research could examine the effects of experience with traveling to other types of environments and methods of transportation (e.g., walking, driving, taking public transportation), especially considering cultural differences in frequency of travel and transportation methods. Future research should also further examine the effects of street network entropy (Coutrot et al., 2020) on navigation abilities. Some of our own preliminary data on the same battery of tasks in a small sample of lifelong residents of Venice suggests that greater entropy (Venice is famously even more spatially complex than Padua) increases the effects we observed here (see the Supplementary Materials for details). Interestingly, one's home environment may explain substantial variability in commonly used navigation paradigms and may explain effects beyond other “inherent” characteristics that have been previously studied such as age or gender. It is clear that future research should consider home environment as an additional variable to account for individual differences in navigation.

5. Conclusion

Taken together, our results suggest that there are multiple successful ways to navigate (Shelton et al., 2013) that are influenced by the structure of the home city environment. We demonstrate home environmental effects in the success at using proximal cues, as well as in navigation strategy preference and survey-based pointing accuracy. The individual differences effects that we observed between environments were in favor of Padua participants having better navigation abilities than Utah participants, which was not explained by differences in underlying small-scale spatial abilities. This suggests that more complex, irregular environments may facilitate better navigation abilities. These results emphasize the need for further analysis of what features and individual experiences within cities contribute to navigation advantages.

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Table S1. Locations for the pointing task.

	Within the city		Cities within the Veneto region	Cities in the Country
	5 km radius	10 km radius		
Padua	Stanga	Torre dell’Orologio	Verona	Roma
	Portello	Prato della Valle	Vicenza	Napoli
	Parco Europa	Basilica di Sant’Antonio	Venezia	Milano
	Fiera	Palazzo Bo	Treviso	Firenze
	Within the city		Cities within the Utah state	Cities in the Country
Utah	Kingsbury Hall	Hogle Zoo	Provo	Las Vegas
	Union Building	University of Utah Hospital	Park City	Seattle
	Stadium Trax Station	Sugarhouse Park	Logan	Houston
	Utah Museum of Fine Arts	Utah State Capitol Building	Wendover	Washington D.C.

Note. We combined the 5 and 10 km radius trials into a single “city” pointing variable.

Supplementary Materials

Venice Sample

The city of Venice is notorious for its high “Street Network Entropy,” or chaotic irregular street layout (Coutrot et al., preprint). Some studies have shown unique navigation preferences for residents of Venice with navigation performance being impaired when individuals use survey strategies (e.g., Denis et al., 1999). This suggests that Venice, perhaps even more than Padua, may encourage the use of distinctive navigation strategies. As an exploratory additional sample, we conducted the same battery of tasks on 9 lifelong residents of Venice ($M_{\text{age}} = 27.22$, range 26 to 30; 4 females). We expected that the greater environmental complexity and irregularity would reveal even stronger effects than those observed for individuals in Padua.

Although we did not conduct statistical comparisons due to the large difference in sample size, we compared Venice participants’ scores on each task to Padua participants’ scores calculating standardized z scores (Venice participant – Padua participants Mean/ Padua participants SD), as shown in Figure 8. This allowed us to determine qualitatively whether the Venice participants’ performance differed largely from the Padua participants’ and in what direction. Overall, Venice participants tended to have higher MRT scores, lower pointing errors in City, Region, and Country pointing tasks, and higher accuracy on the DSP compared to participants from Padua. Preference to take a shortcut on the DSP was similar to that preference for Padua participants. Venice participants also tended to take more time to complete the Water Maze task, especially in the Distal condition, and had lower distance errors in both Distal and Proximal conditions compared to participants from Padua. Although these data are from a small sample, the results suggest an interesting trend in favor of enhanced navigation abilities for individuals from a more complex environment. See the Supplementary Material table S2 of descriptive statistics from Venice participants.

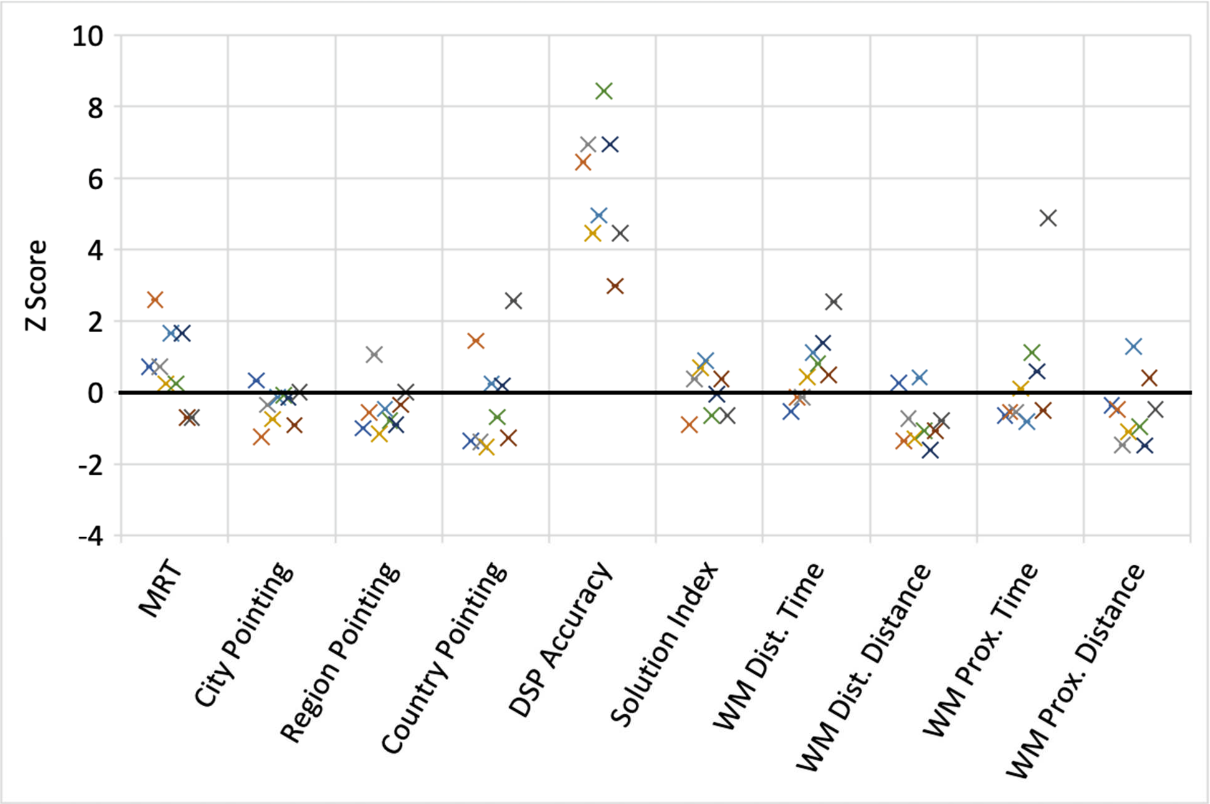

Figure 8. Standardized z-scores for Venice participants. Each participant is represented as an x. The black line at zero represents the average response for Padua participants. The tendency for Venice participants to perform better or worse than the Padua participants is reflected in the number of points that fall below or above the average Padua performance (above or below zero). WM stands for water maze, Dist. for distal, and Prox. for proximal.

Table S2. Descriptive results from Venice sample.

Task	*n*	*M*±SD	95% *CI*
Mental Rotation	9	5±2.35	[3.5, 6.5]
Pointing Error - City	9	11.52±6.36	[7.4, 15.7]
Pointing Error – Region	9	22.78±19.34	[10.1, 35.4]
Pointing Error – Country	9	22.66±23.54	[7.3, 38.0]

DSP Accuracy	8	0.48±.15	[.38, .58]
DSP Solution Index	8	0.57±.18	[.45, .69]
Water Maze Distal Time	9	96.16±31.8	[75.4, 116.9]
Water Maze Distal Distance Error	9	24.77±9.15	[18.8, 30.8]
Water Maze Proximal Time	9	88.89±46.93	[58.2, 119.6]
Water Maze Proximal Distance Error	9	7.99±5.65	[4.3, 11.7]

Note. One participant did not complete the DSP because of technical issues.