Neighborhoods, Directions and Distances: Segmentation Effects in a Real-World City

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Abstract

People often segment spaces into hierarchically structured subspaces. Judgments about inter-point distance and direction are more accurate within than between segments. However, especially in large-scale complex spaces, segmentation may be necessary for flexible navigation. In this study, we looked at spatial segmentation in a real-life city. We asked citizens of Istanbul, a transcontinental city spread over Europe and Asia with natural waterways that divide it into multiple neighborhoods, to indicate how they segment their city and to perform spatial judgments between well-known landmarks. We examined segmentation effects for divisions they endorsed, and for those others use but they do not report using. Additionally, we examined the impact of gender, age, time spent in the city, and frequency of using connecting routes and bridges. We replicated basic segmentation effects for the primary division, used by all, between the European and Asian sides. For the European side, which has a geographic boundary (The Golden Horn), segmentation impaired the accuracy of spatial representation of participants. For the Asian side, where there is a potential division that is more notional, we found different effects. Individual's age, sex, time spent in the city, and frequency of using connecting routes also influenced spatial judgments. These results suggest that (i) spatial segmentation effects exist in the real-world, (ii) segmentation in a city-scale environment is differently affected by physical and conceptual boundaries, and (iii) sex, age, and navigation experiences are associated with the cognitive representation of a city.

Keywords: spatial cognition; spatial memory; environmental segmentation

Introduction

Cognitive maps represent locations in a common allocentric format that allows recovery of distances and directions between locations and flexible planning of routes (Gallistel, 1989; O'Keefe & Nadel, 1978). However, representations of space are often segmented into multiple local representations, which are then organized hierarchically. The relations among segments might then be more graph-like, i.e., coarser, with more accurate knowledge of distance and direction within than between segments (Chrastil & Warren, 2014; Peer, Brunec, Newcombe & Epstein, 2021; Meilinger, 2008). Small scale environments and vista spaces (like rooms) might be more easily represented in a map-like representation than large-scale spaces (Peer et al., 2021; Wolbers & Wiener, 2014), but segmentation effects have been found at a variety of scales.

For vista space, McNamara (1986) used objects in a room segmented into four quadrants and found that direction judgments were distorted by relative segment directions and that distances were overestimated between segments and underestimated within segments. Kosslyn, Pick, and Fariello (1974) showed that both adults and children judged a distance between two objects as being longer when the two objects were separated by an opaque barrier than when there was no barrier between these two objects.

For large-scale virtual environments, Han and Becker (2014) tested participants as they played a taxi game in an environment consisting of two virtual neighborhoods. They found that when the virtual neighborhoods were separated, subjects have more pointing errors and longer reaction times for between-segment judgments, regardless of whether segmentation is by physical borders or conceptual characteristics. When physical and conceptual boundaries were eliminated, subjects made no more errors between the environments, suggesting a unified representation. Participants in Kim and Maguire's (2018) study learned locations of paintings in a virtual environment consisting of several rooms and floors. Responses were faster when judging objects within the same room compared to different rooms. Peer and Epstein (2021) tested people in a virtual town where people learned object locations in a square courtyard with a river running through it. The river created a physical boundary that did not obstruct visibility. They observed segmentation effects where distance comparisons task performance was higher for within-segment judgments than between-segment judgments.

For real-world spaces at environmental scale, Uttal, Friedman, Hand, and Warren (2010) found that conceptual

In J. Culbertson, A. Perfors, H. Rabagliati & V. Ramenzoni (Eds.), *Proceedings of the 44th Annual Conference of the Cognitive Science Society*.

segmentation of Northwestern University's campus (north, south, middle) affects distance estimations. Participants placed the location of different buildings on a blank map to recreate the campus. Distances between the three segments were estimated as larger than within, but only for subjects familiar with the campus. Hirtle and Jonides (1985) showed evidence for segmentation of space that affects distance estimations by using tree clustering of free recall order information. Subjects learned 32 landmarks in the central Ann Arbor, an environment with no strict boundaries. The inferred clustering was related to distance estimations, with shorter distance estimations within cluster and longer for between clusters.

For truly geographic scale, Stevens and Coupe (1978), and Okabayashi and Glynn (1984) tested participants' memory of map locations and found distortions of direction and position of US cities to conform with state boundaries. Canter and Tagg (1975) looked at distance estimations of participants in seven cities. They grouped cities as coastal cities with a large water boundary at one side or as river cities, with water running through it. In cities with a river, short distances were overestimated, and long ones underestimated. In coastal cities, all distances were overestimated. Griesbauer et al. (2021) studied London taxi drivers, who must undergo extensive training to learn how to navigate between thousands of places in the city. London cabbies were asked to indicate their perceived boundaries for London boroughs and areas. They found that prominent parks (e.g., Hyde Park) and River Thames, which divides London into 'north of the river' and 'south of the river', influenced a segmented mental representation of London.

The present study tackled two issues: individual variation in segmentation, and whether segments are based on physical or conceptual boundaries, in a real-world city. People do not always divide their city (or other areas) into the same neighborhoods. For instance, some people may be more influenced by parks, as were the London cabbies, and others more influenced by rivers or shopping areas. Previous studies have not systematically evaluated whether and how variable segmentation affects integration of a city. In addition, we evaluated influences of gender, age, and spatial experience in the city. Aging effects are observed in most navigation tasks (Wolbers & Hegarty, 2010). Male advantages are found in navigation by adulthood (Nazareth, Huang, Voyer, Newcombe, 2019) influenced by gender inequality (Coutrot et al., 2018).

In this study, we examined distance and direction judgments of citizens of Istanbul, which is a transcontinental city with salient spatial boundaries, notably the Bosphorus Strait that divides the city into 'European' and 'Asian' sides, and the Golden Horn waterway that further divides the European side into 'north of the horn' and 'south of the horn'. All residents use the Europe-Asia division, some but not all use the Golden Horn, some divide the Asian side by a non-physical "coastal non-coastal" demarcation.

Methods

Participants

A total of 191 participants completed the experiment (114 female, age range = 18 – 81). The study was approved by the Temple University ethical committee, and each participant provided informed consent. Convenience snowball sampling was used to recruit participants, a link to the survey was shared on social media pages of universities' student groups and personal contacts (i.e., friends and family), who then shared the link further with their social circles.

Design and Procedure

Istanbul is a city with very salient segmentation, a transcontinental city with a natural strait that connects two large bodies of water (Black Sea and Sea of Marmara) and separates the city into Asian and European sides. It also has another major waterway; The Golden Horn is an inlet of The Bosphorus. It is a large natural harbor and separates the European shore of Istanbul into two.

In a preliminary study, we contacted 48 Istanbul citizens and asked them to segment the city on a map. Participants drew boundaries of their segments on a map of Istanbul. We analyzed the boundary drawings by overlaying all drawings together to extract the most commonly occurring segments. The overlay of the map showed 100% agreement for the Bosphorus as a prominent boundary that segments the city. The Golden Horn also emerged as a boundary, at around 70%. Some participants further divided the Asian side into two subsections; the agreement for this division was around 40%. We decided on 4 different ways to segment the city of Istanbul (Figure 1) for the main study. We then picked a total of 12 well known landmarks, 3 from each subregion. Few of these landmarks were inland, a fact that depends on the history and geography of the region.

The study was set up with Qualtrics software. Total duration was around 35 minutes. Participants began with a questionnaire concerning gender and age, current residence in Istanbul and how long they have lived in the city. They were also asked which districts in Istanbul they have lived, studied, and worked in. We also asked them their frequency of using connecting routes and bridges between subsections to understand their navigation experience around the city and between the segments. Response options were less than once a month, several times a month, once a week, several times a week and every day.

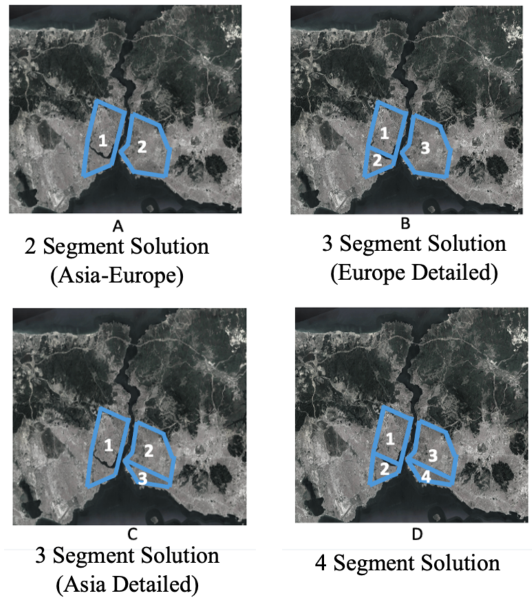

Figure 1: Four segmentation options.

Before presenting participants with the spatial tasks, we asked them to pick the segmentation of the 4 options closest to how they mentally segment the city. We then presented them with picture and names of 12 landmarks and asked them if they knew the landmark and if they ever visited its location. The layout of the landmarks is shown in Figure 2. Participants then were asked to estimate distance and directions between the landmarks in three spatial measures.

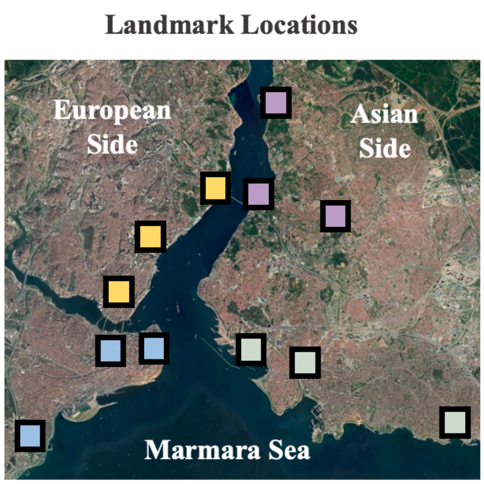

Figure 2: Locations of landmarks for each segment.

Distance Estimation Task. Participants completed 20 distance estimation trials. On each trial, participants saw the names of two landmarks on the screen. They used a slider to estimate the direct distance in km between the two landmarks (Figure 3). The two landmarks were from the same segment for within trials and different segment for between trials.

Distance Comparison Task. Participants completed 10 distance comparison trials. On each trial, participants saw a target landmark paired with two other landmarks and were asked to indicate which pair had shorter distance between them.

Judgement of Relative Direction (JRD) Task. Participants first solved two practice trials followed by feedback to get familiarized with the task. Then they completed 20 trials of an offsite JRD task. On each trial, participants were presented with the names of three landmarks next to a circular array. They were instructed to imagine that they were standing at the location of the first landmark (center landmark), facing toward the second landmark (facing landmark), and to indicate where on the array the third landmark (target landmark) would be (Figure 3). Participants were asked to show where the target landmark would be on the circular array. The first and second landmark were always from the same segment, while the target landmark was from the same segment for within trials, and from a different segment for between trials. For the pointing task, the absolute value of the angular difference between participants' answers and the correct angle was calculated for each trial and then averaged across within and between segment trials to yield between and within pointing error scores.

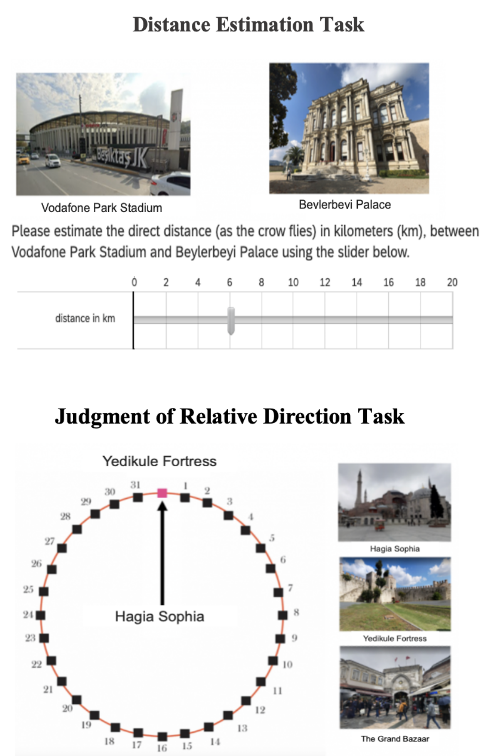

Figure 3: Distance and direction (JRD) estimation tasks.

Results

Table 1 shows which of the 4 segmentation patterns people selected.

Table 1: Segmentation preference of participants

Segmentation	n
2-Segment Solution (Asia vs Europe)	47
3-Segment Europe Detailed Solution	44
3-Segment Asia Detailed Solution	32
4-Segment Solution	68

Asia versus Europe Segmentation

Since it is the most prominent solution used by all residents, we first coded all participants' (N=191) spatial estimations according to the 2-segment solution, the strait separating the city into two large segments of European side and Asian side.

For the distance estimation task, we calculated participants' relative distance errors as the absolute difference between the actual and estimated distances divided by the actual distances. We separated distance trials based on whether the two landmarks were on the same segment (within) or on different segments (between). Dividing the trials in this manner resulted in 12 within trials and 8 between trials per participant. A paired-sample t test on within versus between trial types revealed that participants overestimated all distances (Figure 4). However, this error was more marked for comparisons across segments, $t= (189) = 9.89$, $p <0.001$, $r = 0.37$. Between segment distance errors were higher (M=0.98, SD=0.7) compared to within segment distance errors (M=0.51, SD=0.4).

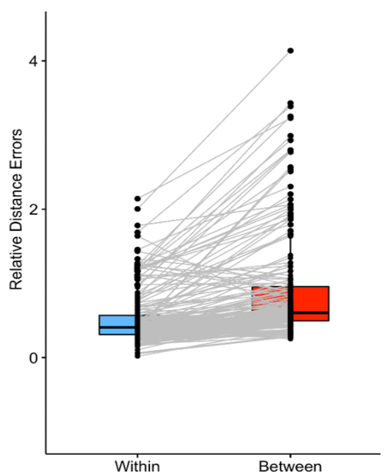

Figure 4: Within segment and between segment distance errors for 2-segment solution, N=191.

Similarly, when participants were asked to make distance comparisons between landmarks, they made more correct responses when all three landmarks were on the same side of the straight, compared to when the landmarks were from different segments. Average accuracy for within segment comparisons was 92% compared to between segment comparisons at 81% ($t = 9.44$, $p < 0.001$; r =0.55).

To examine differences in the pointing task, we calculated the absolute direction errors and corrected them to be under 180 degrees. We separated pointing trials based on whether the target landmark was on the same segment with the center and facing landmarks (within) or on different segments (between). Dividing the trials in this manner resulted in 12 within trials and 8 between trials per participant. Figure 5 shows the results of a paired-sample t test on within versus between trial types which revealed a significant difference, $t(189) = 19.25$, $p <0.001$, $r= 0.44$. Participants had larger pointing errors for between segment trials (M=68.77, SD=14.8) than within segment trials (M=53.54., SD=12.4).

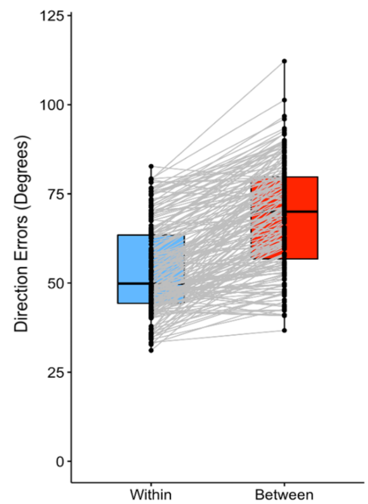

Figure 5: Within segment and between segment direction errors.

Segmentation of European Side

We examined if the Golden Horn waterway that divides European side into north and south resulted in segmentation effects by comparing distance and direction errors for subjects who segmented the European side to those who did not segment European side. We grouped participants as those who did and did not segment Europe. Participants who selected 3-Segment Europe Detailed Solution (n=44) and the 4-Segment Solution (n=68), divide Europe into two (N=112). Participants who selected 3-Segment Asia Detailed Solution (n=32) and the 2-Segment Solution (n=47), did not divide Europe into two (N=79). Participants' distance and direction errors examined in a mixed analysis of variance (ANOVA) with error type (between v within) as within-subject variable and segmentation status (segmented v did not segment) as between-subject variable.

Distance trials were separated based on whether the two landmarks were on the same segment (within) or on different segments (between). Dividing the trials in this manner resulted in 3 within trials and 3 between trials per participant. A mixed measures ANOVA on distance deviations (Figure 6) revealed a significant main effect of error type, F (1, 188) = 39.44, $p < 0.001$, $\eta_p^2 = 0.173$, and a significant interaction between error type and segmentation, F (1, 188) = 14.498, $p < 0.001$, $\eta_p^2 = 0.072$. Between segment distance errors of subjects who segmented (M=0.89, SD=0.85) were higher than between errors of those who did not segment Europe (M=0.71, SD=0.58). The main effect of segmentation status was nonsignificant, p > 0.05.

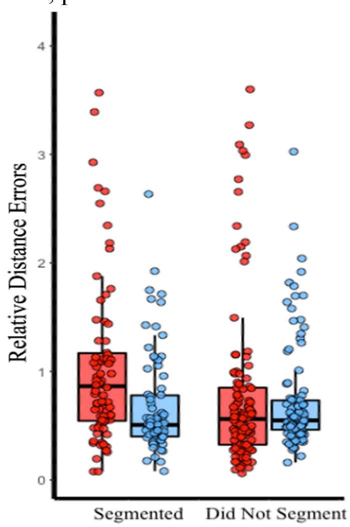

Figure 6: Within segment and between segment distance errors by participant's segmentation status of Europe, segmented (N=112) and did not segment (N=79).

For pointing errors (JRD) there were 3 within trials and 3 between trials per participant. A mixed measures ANOVA on direction deviations revealed a significant main effect of error type F (1, 188) = 65.106, $p < 0.001$, $\eta_p^2 = 0.25$. The main effect of segmentation was nonsignificant, $p > 0.05$. The interaction effect between error type and segmentation was not significant, $p > 0.05$.

Segmentation of Asian Side

When the Asian side is segmented, the division is not by water but by a less visible "coastal non-coastal" demarcation. We compared distance and direction errors for subjects who segmented the Asian side to those who did not segment Asian side. Participants who selected 3-Segment Asia Detailed Solution (n=32) and the 4-Segment Solution (n=68), divide Asia into two (N=100). Participants who selected 3-Segment Europe Detailed Solution (n=44) and the 2-Segment Solution (n=47), did not divide Asia into two (N=91).

Participants' distance and direction errors examined in a mixed analysis of variance (ANOVA) with error type (between v within) as within-subject variable and segmentation status (segmented v did not segment) as between-subject variable. There were 3 within trials and 3 between trials per participant. Results of ANOVA on distance deviations revealed a significant main effect error type F (1, 188) = 40.44, $p < 0.001$, $\eta_p^2 = 0.180$. The main effect of segmentation status was nonsignificant, $p > 0.05$. The interaction effect between error type and segmentation was not significant, $p > 0.05$.

The pointing errors for Asia segmentation had 3 within trials and 3 between trials per participant. A mixed measures ANOVA on direction deviations revealed a significant main effect of error type F (1, 188) = 58.923, $p < 0.001$, $\eta_p^2 = 0.20$. The main effect of segmentation was nonsignificant, $p > 0.05$. The interaction effect between error type and segmentation was not significant, $p > 0.05$.

Impact of Age, Gender and Experience in the City

Finally, we examined the impact of gender, age, time spent in the city, and travel frequency between connecting routes on distance and direction performance by running regression models. We conducted three step multiple regressions with the spatial measures as dependent variables. Gender was entered at step one, followed by age at step two. Variables related to experience in the city, frequency of travel and time spent in the city were entered at the step 3.

In the first model we looked at between distance errors as dependent variable. Gender explained 3.8 % of variance in overall distance errors, F (1, 189) = 8.422, p = 0.004. Age explained an additional 1.5 % of variance, F (1, 188) = 4.023, p = 0.045. Finally, city experience factors explained an additional 10.4 % of the variance in the model, and this change was significant, F (2,186) = 12.580, $p < 0.001$. There was a significant effect of gender (β = 0.145, p = 0.035) and age (β = -0.175, p = 0.01) for between distance errors, where males and younger subjects had lower between distance errors compared to females and older subjects. Travel (β = -0.223, p = 0.001) and time spent in the city (β = -0.221, p = 0.001) were also significant, where subjects who lived in the city longer and traveled more had lower between distance errors.

In the second model looking at within distance errors, we observed a similar pattern. Gender explained 3.3 % of variance in overall distance errors, F (1, 189) = 7.509, p = 0.007. Addition of age explained an additional 3.5 % of variance, F (1, 188) = 8.134, p = 0.005. Finally, addition of city experience factors explained an additional 5.2 % of the variance in the model, this change was significant, F (2,186) = 7.943, $p < 0.001$. There was a significant effect of gender, age and time spent in the city ($p < 0.05$). However, there was no significant effect of travel between connecting bridges and routes on within distance performance (β = -0.128, p = 0.065).

In the third model, we looked at between direction errors. Only gender and age were significant predictors of direction errors. Gender explained 11.7 % of variance in between direction errors, while addition of age explained an additional 24.6 % of variance, F (1, 188) = 73.348, $p < 0.001$. However, there was no significant effect of travel frequency and time spent in the city on the between direction errors, $p > 0.05$. Similarly on our fourth model looking at within direction errors, only gender and age were significant predictors of direction errors. Gender explained 4.7 % of variance in between direction errors, while addition of age explained an additional 20.3 % of variance, $F(1, 188) = 51.39$, $p < 0.001$. However, there was no significant effect of travel frequency and time spent in the city on the between direction errors, $p > 0.05$.

Discussion

The goal of this study was to understand how residents of a real-world city represent its spatial structure with physical and conceptual boundaries, and how segmentation of the environment into subspaces affects spatial judgments.

We observed an expected effect of Europe-Asia segmentation, finding that within segment distance and direction judgements were more accurate compared to between segment judgements. Next, we investigated whether a less salient geographical boundary that further divides the European side into two and a more conceptual boundary that divides the Asian side also triggered segmentation effects. For European and Asian segmentations, we separately compared participants' distance and direction errors as a function of whether they had themselves segmented the corresponding sides. For the European segmentation we found that both groups were less accurate in their between segment distance judgements. However, people who segmented the space into two had larger errors for between segment judgements. Their segmentation effects were more marked, and accuracy was impaired for between if enhanced for within. For the Asian segmentation, we found a main effect of error type for both distance and direction errors. However, the error was in the opposite direction of the usually observed segmentation effects. For direction judgments, we saw the expected pattern of higher errors between the segments compared to within segment. We did not observe an effect of segmentation choice for distance or direction.

Overall, we observed different patterns of spatial coding for segmentations created by waterways compared to more conceptual boundaries. Combined, these findings highlight the need for further investigation of the effects of different types of boundaries have on spatial coding. In addition, we found gender and age effects both for distance and direction errors, where men outperformed women and younger participants outperformed older participants. Subjects who spent more time in the city and those who more frequently travel had better spatial performance, probably due to increased exposure to the environment. With increased familiarity, some participants may start to build a more unified representation of their space. In sum, cognitive maps of a real-world city showed some expected effects but also underlined the need to differentiate types of segmentation (barriers to movement versus conceptual), and to examine individual differences in endorsement of segmentations.

Acknowledgments

This work was supported by the National Science Foundation (EHR 1660996).

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