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RESEARCH ARTICLE

# Exploring small city maps

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**Abstract** The exploration of city maps has exploded recently due to the wide availability, increasing use of, and reliance on small positioning and navigational devices for personal use. In this study, subjects explored small, 3-mile diameter circular maps exemplifying five different types of street networks common in the United States, in order to locate a hypothetical city hall. Chosen locations indicated that subjects are able to identify more accessible sites. Monitoring eye position revealed that women explored maps faster, using more widely dispersed but more narrowly focused gaze clusters than men. The type of street network influenced the time spent by the eyes in a locale and differentially affected the size of gaze clusters between women and men, underscoring the complex interactions of gender-specific strategies with street network types.

**Keywords** Spatial cognition · Map reading · Eye movements

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## Introduction

We explore the environment by moving our eyes and fixating them on the objects of interest. Yarbus (1967) exploited this fact by recording the *x*–*y* coordinates of eye positions and plotting them on the picture seen. Such plots directly revealed the objects of interest as those objects with high density of eye fixations. Moreover, the distribution of eye fixations within the boundaries of an object provides valuable information concerning features of interest of the object itself. For example, when exploring a face, most of the eye fixations are on the eyes, nose, and mouth, a fact that directly underscores their importance as crucial features of the face. This approach was applied to the exploration of maps with varying degrees of success (Steinke 1987) but has been revived recently in evaluating static and interactive visual displays (Fabrikant et al. 2008; Coltekin et al. 2009, 2010). The recording of eye position during the exploration of natural scenes by monkeys (Burman and Segraves 1994; Phillips and Segraves 2010) yielded valuable insights concerning the neural mechanisms guiding the eyes to the features of interest in various strategies of scene exploration. For example, neural activity in the frontal eye fields during eye fixation predicted the direction and goal of two upcoming saccades to targets embedded in natural scenes (Phillips and Segraves 2010). Monitoring eye position has also proved very useful in identifying the strategy for the route chosen in complex mazes (Crowe et al. 2000). Indeed, our paper extends those latter studies to human-made layouts and maps of cities. Unlike the mazes, which were randomly generated and restricted, the map stimuli used in this study are rich networks of straight or/and curved streets arranged in various designs by human beings over many years.

Small handheld navigational aid devices have been used increasingly during the past several years. The current wide availability of GPS for personal use (e.g., in iPhones) raises the question of how they are used by the subject, what strategies are followed, how a search can become more efficient and effective (i.e., take less time and be more accurate), and how these devices can support broad band spatial learning in addition to providing instructions for reaching specific destinations. In addition, the users vary widely in gender, age, race, or ethnic background. It would be important to know how maps, strategies for exploring maps and differences by gender, age, race, or other characteristics of subjects are interrelated. This is an emergent field in spatial cognition, which holds great promise for delineating the effects of these factors and their interaction. Our study represents an effort in that direction.

It is presently unknown how small-size city maps are explored by subjects, what strategies are applied, and how gender and types of street network may affect map exploration. In our study, we use a common landmark (city hall) as a desired point of interest. Our general hypothesis was that both city hall location and the visual exploration of the map depend on map parameters, and that they vary with gender.

## Methods

### Subjects

Twelve healthy human subjects participated in these experiments as paid volunteers. They ranged in age from 19 to 58 years. Six were women (age $36.8 \pm 5.8$ years, mean $\pm$ SEM) and six were men ($38.8 \pm 7.0$ years); the age did not differ significantly between the two genders ($P = 0.36$, $t$ test). The research protocol was approved by the relevant Institutional Review Boards, and informed consent was obtained from the subjects prior to the study, according to the Declaration of Helsinki.

### Stimuli

Stimuli were maps of 3-mile diameter urban areas, extracted from street center-line maps compiled by ESRI and representing several U.S. Metropolitan Statistical Areas (Atlanta, GA; Baltimore, MD; Chicago, IL; Los Angeles, CA; New York, NY; Pittsburgh, PA; St. Louis, MO; Tampa, FL; Washington, DC). Street center-line maps, as analyzed here, show no information other than the position of streets relative to one another, scaled length, alignment, sinuosity, and pattern of intersections of the street network; scaled street width, topography, urban development and land use, or any other kind of three-dimensional information do not feature. Thus, the choice of stimuli is geared toward studying how subjects respond to the spatial structure of the street network and particularly its shape, density, and connectivity. The sample was chosen to represent five ideal types of street networks (Southworth and Owens 1993; Peponis et al. 2007), namely regular grids, colliding grids, supergrids, curvilinear grids, and cul-de-sacs.

Regular grids consist of orthogonally intersecting patterns of streets; colliding grids arise from the intersection of multiple regular grids rotated with respect to one another, as was typical in many US cities at the turn of the twentieth century; supergrids consist of sparsely spaced orthogonally intersecting main arteries (often at 0.5-mile intervals) with irregular street patterns filling in the large blocks surrounded by the arteries (as is typical, for example, in Los Angeles); curvilinear grids arise from the intersection of curvilinear streets as was typical in many US suburbs developed between the end of the nineteenth century and the 1950s; and cul-de-sacs consist of hierarchically branching street networks encompassing many cul-de-sacs as is typical in many low-density US city suburbs since the 1960s.

Our stimuli were circular in shape to avoid potential anchoring effects of corners in a rectangular display. They were composed of black lines of uniform width, representing streets, on a white background. Four stimuli per street network type (all together 20 stimuli) were presented to each subject in a pseudorandom sequence.

The stimuli were chosen by a group of seven experts (two professors and five doctoral students of architecture and urban design at the School of Architecture, Georgia Institute of Technology); having understood and agreed on the above definitions of ideal types, each expert freely and independently explored the center-line maps of the 20 most populated Metropolitan Statistical Areas in the United States, looking for possible circular extracts of 3-mile diameter that match one of the ideal types as perfectly and consistently as possible. The examples identified by each expert were pooled into a single group. Any examples that did not satisfy the definition according to any of the experts were removed. The process continued until all experts reached agreement that each of the five ideal types was well represented by four particular examples. Thus, while the stimuli were extracted from particular cities, they are not intended to be the representative of the street network of those cities, or of average conditions in US metropolitan areas. Rather, they were chosen as appropriate illustrations of a typology that reflects distinctions that are common in the relevant literature. At the scale of 3 miles, the most frequent condition in US metropolitan areas would bring together several of the theoretical types in various hybrid forms. While the sample of stimuli represents the most distinctly different street network types that are found in US cities, it is not intended to represent the larger set of distinctly different types that are found around the world.

### Experimental paradigm

#### *Setup*

Subjects sat comfortably on a chair with chin and arm supported to stabilize the head and body. The subject's right forearm manipulating the mouse lay on a firm horizontal support. Stimuli were presented on a computer screen placed at eye level and at a distance of ~78 cm in front of the subject.

#### *Task*

A trial started by presenting an open circle at the center of a blank black computer screen; subjects were instructed to fixate their eyes on this circle and to position the mouse cursor inside. After 1.5 s, the stimulus appeared and subjects were asked to choose a hypothetical city hall location by clicking a mouse in the desired location. The subject was instructed not to trace a path. The experiment proceeded at the subject's pace.

### Data acquisition

The experiment was controlled by a program written in Visual basic (Microsoft Visual Basic 2005, version 8.0). Relevant data include (1) time of presentation of stimuli, (2) $x$–$y$ position of the mouse (sampled at 200 Hz), and (3) $x$–$y$ position of the eye (sampled at 200 Hz). The $x$–$y$ eye position was recorded using a video-based pupil/corneal reflection tracing system (model ETL-400, ISCAN, Inc., Burlington, MA).

### Data analysis

#### *Behavioral and gaze clusters*

During the exploration of city maps, subjects fixated their eyes on various locations, resulting in distinct $x$–$y$ eye position clusters. We used the Matlab $K$-means clustering analysis ("kmeans" and "silhouette" routines) to identify $x$–$y$ eye position clusters. The following parameters were used in the kmeans routine: distance = 'sqEuclidean' (squared Euclidean), start = 'uniform' (select $k$ points uniformly at random from the range of $x$), and maximum iterations = 1,000.

The following intrinsic cluster parameters were extracted for each trial: number of clusters, cluster radius (1 SD of the $x$- and $y$-eye position of a particular cluster), average intercluster distance (defined as the average Euclidean distance between the centers of all clusters), distance from the center of the map, and cluster time (time spent in a cluster). In addition, the following two measures were obtained from mouse press data: (1) decision time, defined as the moment from the start of the trial to the moment when the mouse started moving toward the chosen location, and (2) the coordinates of the position where the mouse was clicked locating the hypothetical city hall. To identify the map parameters that were important in determining where to place the hypothetical city hall, the mouse clicks were treated as centers of circular buffers. Their radius was constant for all responses and equal to the mean radius of all eye position clusters obtained for all 20 stimuli maps presented to all subjects. The option of an arbitrary radius for the buffer was rejected as having no advantages; the convention adopted is sensitive to the scale of the patches of concentrated interest suggested by subject's eye positions while also supporting comparisons across subjects and stimuli.

#### *Space syntax parameters*

The whole map and the part of it that was encircled by the region defined by city hall and gaze clusters (defined above) were analyzed and characterized by the following two kinds of measures. The first set comprises the number of street segments, the number of street intersections, the number of dead ends, the total length of streets, and the number of urban blocks. Their derivatives such as distance between intersections and street length per unit area were also calculated. These measures together with their derivatives provided an aggregate numerical profile of each map. Such profiling is a common practice in city planning, transportation, urban design, and public health literature (Jacobs 1993; Southworth and Owens 1993; Handy 1996; Cervero and Kockelman 1997; Matley et al. 2000; Handy et al. 2003; Frank et al. 2005; American Planning Association 2006; Parks and Schofer 2006; Kerr et al. 2007).

The second set of measures, metric reach, and directional reach, describe individual street segments (Peponis et al. 2008). Metric reach is a measure of the total street length available within a walking network distance; directional reach is a measure of the total street length available within a specified number of direction changes (zero direction change provides an estimate of the linear extents of streets and two direction changes provide an estimate of the extent of the network which can be reached in immersed navigation without great cognitive effort). Metric and directional reach are described in more detail below.

Metric reach measures the total street length accessible from the midpoint of each street segment within a network distance threshold. This measure expresses the idea of a "walking shed" defined in city planning and urban design literature (Hess 1997; Hess et al. 1999; Ewing and Cervero 2001). However, the idea is generalized and applied to all street segments, as a descriptor of network morphology, rather than to locations of special interest, such as schools or parks, as a descriptor of their catchment area. For the purpose of this study, metric reach was computed at 1/6 of a mile radius, to describe the relationship of each segment to its immediate surroundings.

Directional reach measures the total street length accessible from the midpoint of each street segment within a number of direction changes. The importance of direction changes as a map network property is implicitly recognized in the planning literature when the straight line distance between points is compared to the actually available shortest path distance (Hess 1997; Randall and Baetz 2001; Handy et al. 2003; Lee and Moudon 2006). It is also explicitly recognized in the literature on environmental psychology (Sadalla and Magel 1980; Moeser 1988; O'Neil 1991; Montello 1991; Bailenson et al. 1998, 2000; Jansen-Osman and Wiedenbauer 2004). In space syntax, direction changes are taken as a basis for measuring universal network distances (from all possible origins to all possible destinations) in order to model pedestrian movement in urban areas (Hillier et al. 1987, 1993; Peponis et al. 1989, 1997; Penn et al. 1998; Hillier and Iida 2005; Baran et al. 2008), to interpret the preferential presence of certain streets in cognitive maps drawn by subjects, or the structural congruence between cognitive maps and actual street networks (Kim and Penn 2003), or to model route choices in virtual urban environments (Conroy Dalton 2003). For the purposes of this study, directional reach was estimated for 0 and 2 direction changes, taking 30 degrees as the threshold for identifying a direction change—a threshold which has been found to provide descriptions of street networks that are well correlated with pedestrian movement and commercial land uses.

### *Statistical procedures*

Data were analyzed using standard statistical methods (Snedecor and Cochran 1989) and either the SPSS IBM statistical package (version 20) or the SAS JMP package (version 9). Data were transformed to normalize their distribution and stabilize the variance (Snedecor and Cochran 1989). Specifically, the following data were log-transformed: number of eye position clusters, distance of cluster from the center, cluster time, number of street segments per cluster area (street segment density), number of street intersections per cluster area (street intersection density), and number of dead ends per cluster area (dead end density).

## Results

The set of stimulus maps is shown in Fig. 1, arranged by type. The way in which maps appeared on the black screen is illustrated in Fig. 2, for a representative subset of stimuli.

### Decision time

Subjects decided on the city hall location after a decision time of 8.378 ± 0.374 s (mean ± SEM, $N = 228$ valid trials). Women took less time to decide than men (Fig. 3; 7.57 ± 0.47 s vs. 9.20 ± 0.58 s, $P = 0.028$, $t$ test); the type of city street network did not have a statistically significant effect. The first question to be examined is whether decision time was affected by stimulus map characteristics. Stimulus type did not affect decision time whether considering all subjects ($F_{4,223} = 1.23, P = 0.3$, partial $\eta^2 = 0.02$), or men ($F_{4,108} = 0.41, P = 0.8$, partial $\eta^2 = 0.015$) and women ($F_{4,110} = 1.18, P = 0.32$, partial $\eta^2 = 0.041$), separately. The effect of all common city planning measures on decision time was evaluated using a stepwise multiple linear regression where the decision time was the dependent variable and the following stimulus parameters were the independent variables: total street length in the stimulus, number of intersections in the stimulus, number of dead ends in the stimulus, number of intersections per street length, number of dead ends per street length, average distance between intersections, number of road segments in the stimulus, average length of road segments, average distance of road segment centroids from the center of the stimulus, average mean directional distance of each road segment from all others, average directional reach with zero direction changes, average directional reach with zero direction changes expressed as a proportion of total street length in the stimulus, average directional reach with two direction changes, and average mean metric reach at sixth of a mile radius. Of these variables, only the average directional reach with zero direction changes expressed as a proportion of total street length in the stimulus was statistically significantly and negatively associated with decision time ($t_{226} = 2.27, P = 0.024, r = -0.15$). Thus, subjects spent less time when dealing with stimuli whose streets are longer and less sinuous.

A different issue concerns the possible dependence of decision time on particular space syntax parameters of chosen city hall locations, that is, the position of mouse click. This was evaluated by performing a stepwise multiple linear regression where the decision time was the dependent variable and the following parameters of the circular mouse click buffer (see "Methods") were the independent variables: relative directional distances associated with the mouse click, relative directional reach with zero direction changes, relative directional reach with two direction changes, and relative metric reach at 1/6 mile radius. (These parameters were standardized relative to the stimulus by subtracting the mean value of the parameter for the whole stimulus and dividing by the standard deviation.) We found that only the relative directional reach with two

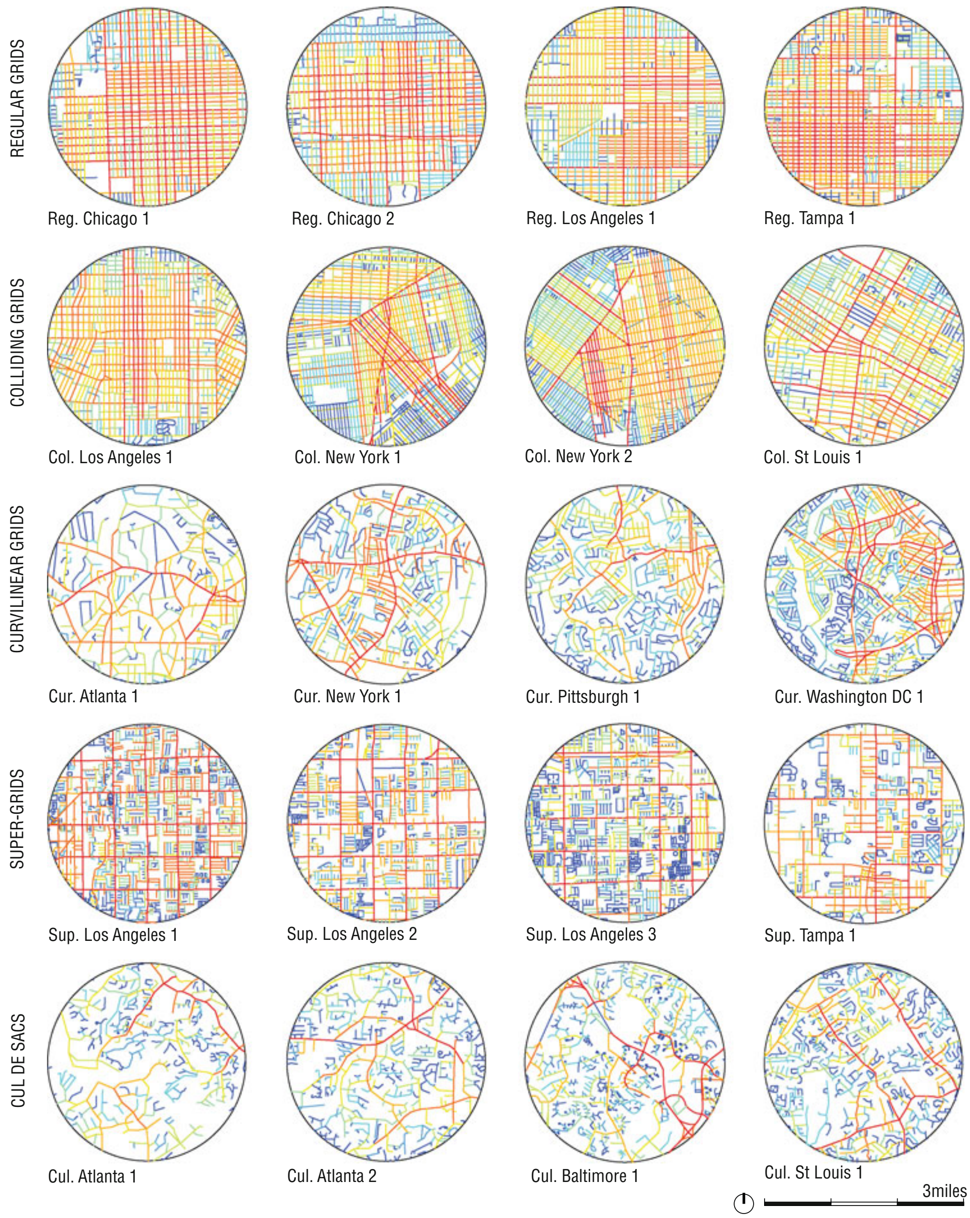


**Fig. 1** The set of stimulus maps used in the experiment. Maps are *colored* to represent an aspect of spatial structure. The spectrum from *red* to *blue* corresponds to the variation of street length that is accessible within two direction changes from the center of each street segment. *Coloring* is according to Jenks natural breaks with *red* corresponding to higher values and *blue* to lower. Each stimulus map is *colored* according to its own range of values

direction changes had a significant positive effect of the decision time $(t_{222} = 2.93, P = 0.004, r = 0.193)$. Thus, subjects who chose a syntactically more central location spent more time examining the stimuli.

## Space syntax analysis of chosen city hall locations

Chosen city hall locations were $0.567 \pm 0.02$ miles (mean $\pm$ SEM, $N = 228$ trials) away from the stimulus center (more than a third of the available radius), on average, without significant effects of gender or network type. Supposing the desirable city hall location to be prominent, the data indicate that subjects did not equate prominence with the geometric center of the stimulus, but looked at the street network, as was intended for the experiment (see "Discussion"). The question is what properties of the network are associated with their choices.

The street segments associated with mouse press buffers had longer linear extension (zero direction changes reach) $(F_{1,34299} = 589.0, P < 0.001, \eta^2 = 0017)$, more street length accessible within two direction changes (two direction changes reach) $(F_{1,34299} = 919.2, P < 0.001, \eta^2 = 0.026)$, and more street length accessible within a 6th of a mile (metric reach) $(F_{1,34299} = 98.8, P < 0.001, \eta^2 = 0.003)$, as compared to other street segments. (The analysis is based on standardized values in order to allow pooling the data from different stimuli.) Thus, in general, subjects placed city hall in more accessible locations, as was expected.

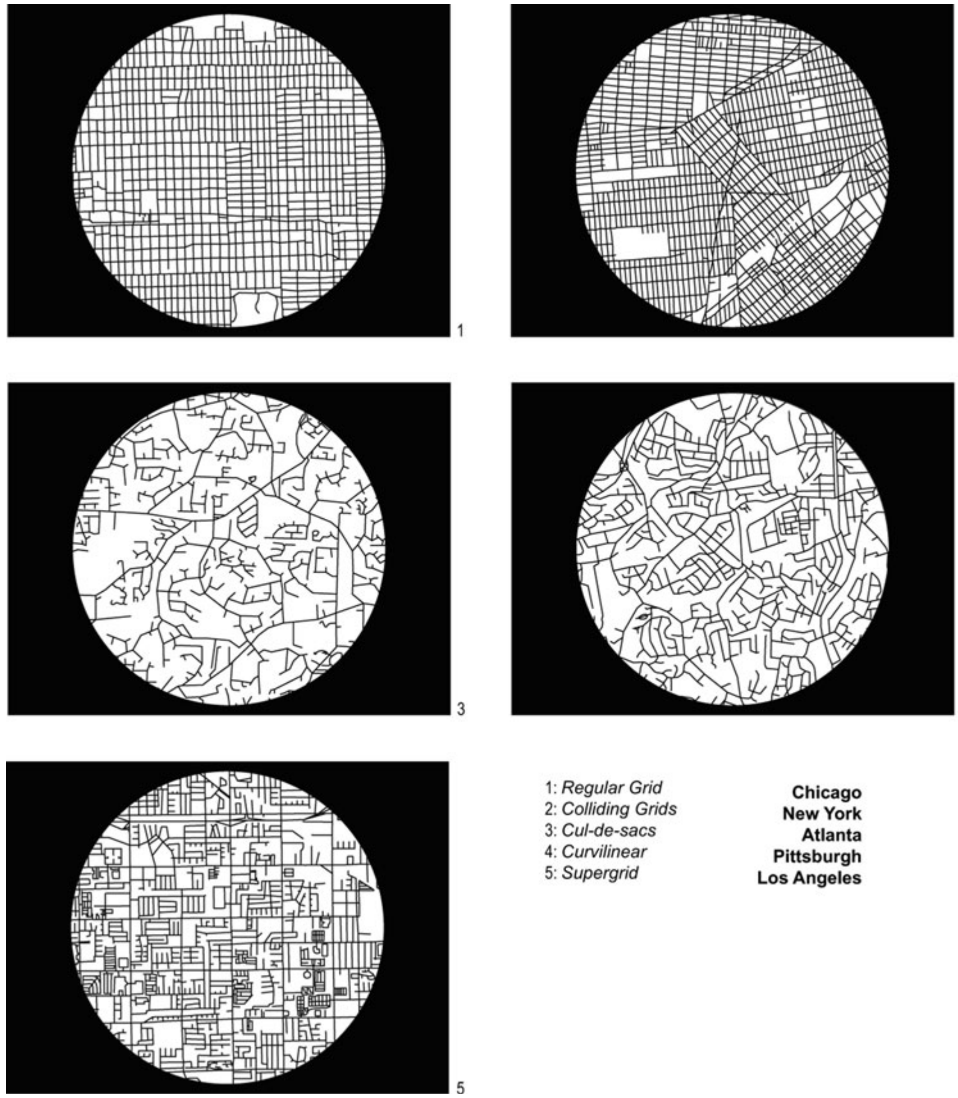


**Fig. 2** Examples of the five types of map street networks used as stimuli: regular grid, colliding grid, cul-de-sac, curvilinear grid, and supergrid

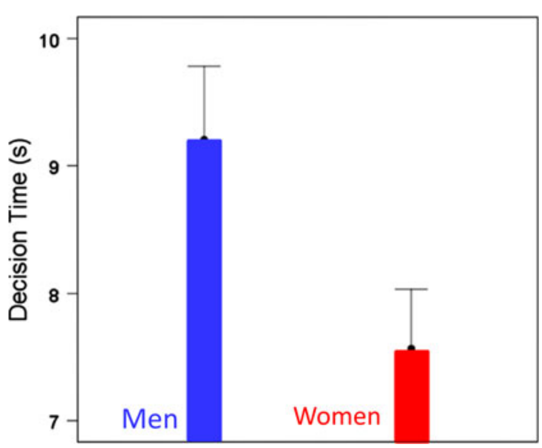


**Fig. 3** Average decision times (mean ± SEM) for men and women ($N = 113$ trials for men and 115 trials for women)

Men and women did not differ statistically significant as to the mean standardized values for the same space syntax variables describing their mouse press buffer.

Given the consistent decision and success of subjects to place city hall in objectively better connected and more accessible locations, the question as to how subjects explored the maps visually becomes even more interesting. Examples of eye positions are shown in Fig. 4. The analysis of the pattern of clustering of these positions led to the strongest and more interesting findings of the study.

## Gender differences in map exploration

Gender and spatial map attributes had independent, major, and systematic effects on various aspects of map exploration. We analyzed these relations using an ANCOVA where

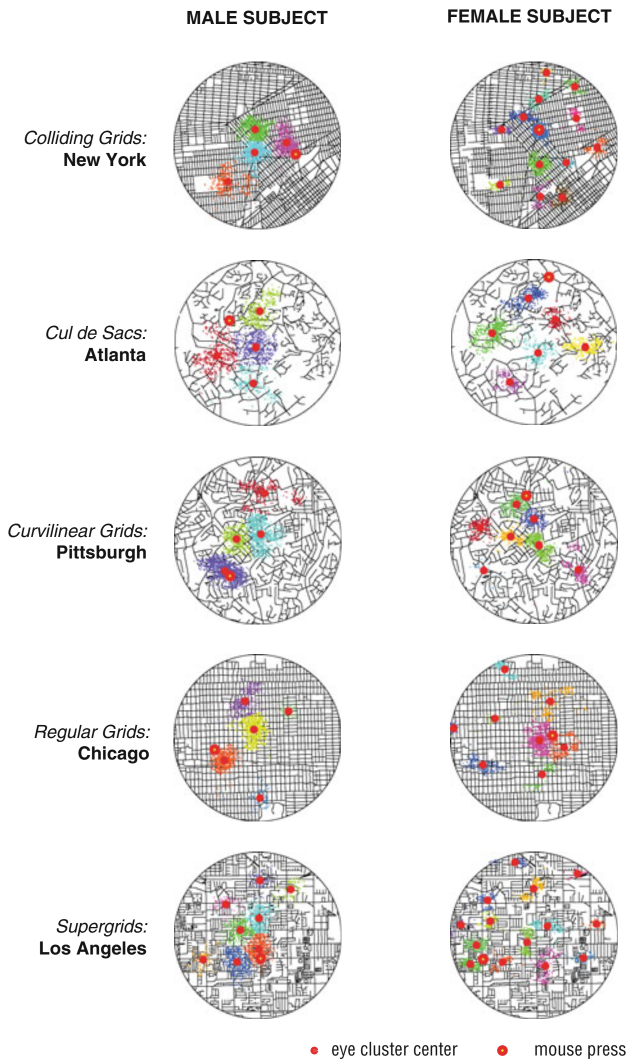


**Fig. 4** Visual exploration of city maps. Eye position clusters from a man (*left column*) and a woman (*right column*). *Different colors* denote separate clusters; *red circles* indicate cluster centers; *red and yellow larger circles* indicate the chosen city hall locations

the stimulus type and gender were fixed factors and age was a covariate. We found the following (Fig. 5). (a) The number of clusters decreased with age ($P = 0.002$) and was higher in women ($F_{1,221} = 7.97$, $P = 0.005$, partial $\eta^2 = 0.035$) but did not differ significantly among street network types; also, the Gender × Street Network interaction was not significant. (b) The cluster radius was smaller in women ($F_{1,1377} = 56.32$, $P < 10^{-12}$, partial $\eta^2 = 0.039$) and was significantly affected by street network type ($F_{4,1381} = 2.56$, $P = 0.028$, partial $\eta^2 = 0.008$), with the regular grids having the smallest average cluster size. In addition, there was a strong interaction between gender and street network type ($P < 10^{-4}$), in that women and men had practically identical cluster sizes for the regular (linear) grid, but men had larger cluster sizes for all of the other grids. (c) The average intercluster distance was higher in women ($F_{1,1377} = 70.2$, $P < 10^{-15}$, partial $\eta^2 = 0.049$) and was significantly affected by street network type ($F_{4,1377} = 3.91$, $P = 0.004$, partial $\eta^2 = 0.011$), with the regular grids having the smallest average intercluster distance. In addition, there was a significant interaction between gender and street network type ($F_{1,1377} = 2.74$, $P = 0.027$, partial $\eta^2 = 0.008$), in that men (in contrast to women) had much higher intercluster distances for the cul-de-sac grid (relative to the other grids). (d) Average time spent in each cluster (adjusted for cluster radius) did not differ significantly between genders but was significantly affected by the street network type ($F_{4,1376} = 4.22$, $P = 0.002$, partial $\eta^2 = 0.012$) with the curvilinear grid having the highest cluster time and being significantly higher than any other network type. Finally, (e) an analysis of street connectivity attributes of eye clusters yielded the following results. (1) There was a highly significant effect of stimulus type on street segment density ($F_{4,1337} = 147.5$, $P < 0.001$, partial $\eta^2 = 0.3062$), with the curvilinear grid having the lowest density. There was no significant effect of gender or Gender × Stimulus type interaction. (2) The same results were obtained for the total street intersection density, where the stimulus type had a significant effect ($F_{4,1253} = 56.42$, $P < 0.001$, partial $\eta^2 = 0.153$), with the curvilinear grid having the lowest density. Finally, (3), with respect to the dead end density per cluster, the stimulus type had a significant effect ($F_{4,592} = 14.89$, $P = 0.001$, partial $\eta^2 = 0.091$), with the supergrid having the highest density. There was no significant effect of Gender or Gender ×Stimulus type interaction.

## Discussion

This work contributes to the field of spatial cognition, particularly to human map exploration. Images of the environment may be stored in spatial memory as cognitive maps (Tolman 1948). This is a more complex issue than a simple mental representation of a conventional map, which led Tversky (1993) to call the mental representation a cognitive collage. Mental models derive from different informational sources. For example, humans can construct cognitive maps from cartographic maps and spatial descriptions (Taylor and Tversky 1992a, b, 1996). These researchers also discussed how the configuration of the environment may affect perspective choice (Taylor and Tversky 1996). An extension of this research led to the discovery of representational flexibility, that is, using spatial information in a goal-oriented manner (Taylor et al. 1999; Brunye et al. 2008). Brunye and Taylor (2009) further explored the fact that perspective goal, while studying a map, may lead to spatial memory difference. Specifically,

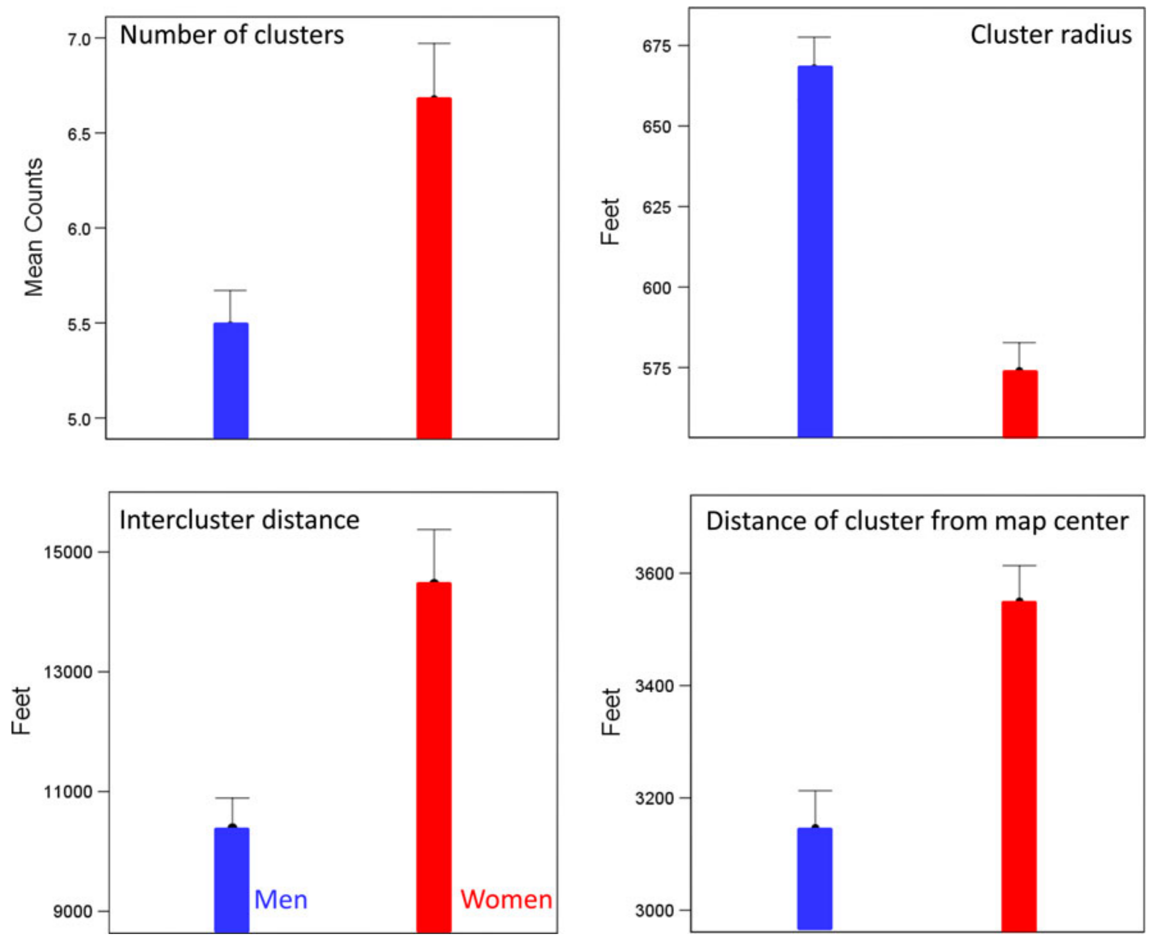


**Fig. 5** Eye position cluster differences between women and men (per response). *Bars* are means (±SEM). $N = 113$ trials for men and 115 trials for women

by monitoring eye position in a goal-oriented map study, they found that the perspective goals actively controlled the allocation of visual attention and gathering of information, resulting in goal-perspective specificity.

## Reading city maps

The increasingly frequent use of small-scale (handheld) visual navigation devices (such as GPS and iPhones) is currently dominated by tools that provide aids or instructions for reaching a specified destination. Of equal, if not greater, interest is the question of how these devices can support more open-ended patterns of exploration of an environment (e.g., when subjects look at Google maps to identify possible facilities of a given kind in their surroundings). In this study, we focused on how such "open ended" exploration patterns related to the spatial structure of the street network map, in the absence of any information on land use, physical 3D form or activity patterns.

Stimuli maps are essentially rich networks of straight or curved streets, arranged in various designs reflecting years of planned and/or spontaneous urban development. We used stimuli that are real maps of US cities and they represent distinct types of street network of US metropolitan areas. This study did not explore the urban network around the world; we leave that issue for future work. We used recordings of eye position as an indicator of the cognitive processes during map–user interaction. Specifically, we sought to identify strategies for navigation and exploration on maps and the diverse spatial structures of street networks that are typical in US cities. This exploration of the map was initiated by asking subjects to place a hypothetical city hall on a location of choice. In a way, by asking subjects to find a desired location for city hall, we were asking them to examine the map and identify some sort of "center of network gravity."

The various aspects involved in the analysis included the following: (a) global, categorical city map measures: map grid type; (b) space syntax measures of the stimulus as a whole; (c) global performance measure: decision time;

(d) intrinsic gaze cluster parameters (see "Methods"); (e) space syntax gaze cluster attributes (see "Methods"); and (f) space syntax city hall location (i.e., mouse click) attributes. We had the following objectives in analyzing the relationships between different factors and variables: (1) Effects on decision time: how do gender and map attributes (independent variables) affect the decision time (dependent variable)? How do specific space syntax features/attributes of the stimulus affect the decision time? (2) Effects on intrinsic gaze cluster parameters: how do gender, and city map grid type affect number of clusters and other cluster parameters? (3) Effects on cluster time: how does cluster time depend on cluster space syntax attributes? (4) Reasons for choosing a location: what are the space syntax attributes of the location chosen for city hall? We discuss our findings as follows.

## Location choices

Subjects placed city hall away from the stimulus center and, as we predicted, at locations that were easy to access. The buffer area around the chosen location had longer straight streets, more street length available within 1/6 of a mile and more street length available within two direction changes compared to the rest of the stimulus. In addition, subjects who spent more time exploring maps chose locations from which more street length is available within two direction changes. Thus, the expenditure of exploration effort seemed oriented toward a diagnosis of syntactic centrality. This result indirectly suggests that the processes of reasoning may be involved. Understanding how this work is an open question for further work. Our results, however, particularly those about gender differences, suggest that there are alternative processes that lead to similar outcomes, as discussed below.

## Gender differences

We found that both women and men chose city hall locations with very similar space syntax attributes. But previous research suggests that men and women tend to explore maps differently, and they tend to select different environmental features to guide their behavior. For example, women tend to use topological cues such as landmarks, whereas men tend to use cardinal references (e.g., compass points) (Choi and Silverman 1996; Dabbs et al. 1998). Similar differences are found when men and women learn a new route: men need fewer trials to learn a designated route, whereas women remember more details about landmarks along the path (Galea and Kimura 1993). In summary, men tend to navigate with preference to the geometrical properties of space, whereas women prefer specific objects to find their way (Kimura 1999). Similar findings were reported by Mueller et al. (2008), namely that women employ a navigational strategy based on memory, whereas men rely on spatial relations. Finally, Brandner (2007) examined gender-related differences of exploratory strategy. It was found that women rely primarily on a local searching strategy, whereas men rely on a global strategy.

By using maps which offer no information on landmarks or other details about an environment, we document striking gender differences regarding map examination strategies which shed new light on the topic. Women appear more efficient than men in reading relatively abstract patterns of network geometry and connectivity. Compared to men, women decide faster, use more eye clusters per map, at greater distances from the center of the map and from other clusters, with smaller but more "street packed" clusters, that is, with a higher density of street segments, intersections, and dead ends.

The most intriguing difference between men and women is the way in which they respond to the complexity of the different types of street networks compared to regular grids: men increase cluster size for a smaller number of clusters and women increase inter-cluster distances for a larger number of clusters. This implies that men proceed by tracking street extensions and connections over a smaller set of expanding areas while women proceed by adding more comparisons of local conditions across the map as a whole. How these two radically different processes of exploration lead to similar final outcomes remains an open question. Further research is needed on map exploration logic as well as the interaction of map exploration logic and the intrinsic structure of street networks.

Our results also suggest some underlying cognitive constraints. The fact that both men and women spend more time per cluster in curvilinear grids, suggests that the hierarchy of streets is less evident when the extension and pattern of intersections of the street segments covered by a cluster has to be tracked over directions and direction changes set at unpredictable angles relative to one another. This interpretation is corroborated by the fact that clusters in curvilinear grids are associated with smaller densities of street segments and intersections; thus, the expenditure of more time cannot be attributed to the presence of more information. It is more likely linked to the nature of the information examined.

Thus, the exploration of city maps is a rich process involving interactions between gender-specific map exploration strategies, types of street networks, and space syntax attributes.

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