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SEEING THE AXIAL LINE:
Evidence from wayfinding experiments

078

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Abstract

Space-geometric measures are proposed to explain the location of fixations during wayfinding. Results from an eye tracking study based on real world stimuli are expanded to include findings based on the location of fixations. The gaze bias shows that attention is paid specifically to structural elements in the built environment. Three space-geometric measures are proposed: sky area, floor area and longest line of sight. Together with the finding that participants choose the more connected street, a relationship is proposed between the individual cognitive processes that occur during wayfinding and relative street connectivity measured through space syntactic techniques.

Keywords: *Wayfinding, spatial configuration, spatial geometry, eye tracking, space syntax.*

Theme: *Spatial Cognition and Behaviours*

1. Introduction

Space syntax analyses of urban environments offer a successful way of examining aggregate pedestrian and vehicular movement. Whilst space syntax techniques do not, in themselves, account for individual motivation, the hypothesis has been proposed that the variables upon which space syntax techniques are based, are the same as those used by individuals (Penn 2003). This paper offers initial experimental evidence in support of this hypothesis, for the case of pedestrian navigation in urban environments.

The paper examines findings from an eye tracking study based on real world stimuli; behavioural decisions and eye tracking data during wayfinding at city street corners are included. The location of the fixations is shown to be related to structural elements of the viewshed. Together with the finding that decisions tend towards the more connected street (Emo et al. 2012), a relationship is proposed between individual spatial decision-making and structural properties of the built environment based on space-geometric measures.

The paper begins with a discussion of relevant previous work on spatial decision-making and the impact of structural properties of the environment. An overview of the data collection method and the main results is given. The main body of the paper examines the location of the fixations; the role of the spatial geometry of the viewshed is highlighted. The paper ends with a discussion of the relevance of the paper for the space syntax community.

1.1 Wayfinding

Wayfinding is not purely random; it follows psychological patterns based on visual perception. It can be defined as the decision-making process stage of navigation, where navigation is composed of locomotion and wayfinding (Montello 2001); wayfinding is necessarily related to choices made by the individual. Several factors are known to affect wayfinding behaviour; some of the most salient are:

i) the type of available spatial knowledge, whether landmark, route, or survey (Siegel and White 1975);
ii) the level of familiarity with the environment; a change in wayfinding behaviour between novices and familiar users has been shown (eg. Hölscher, Brösamle and Vrachlotis 2012);
iii) the level of spatial ability; this has been shown to affect wayfinding performance (eg. Hegarty, et al. 2002); and
iv) the type of task; a taxonomy of wayfinding tasks has been proposed to help classify studies that use different tasks (Wiener, Büchner and Hölscher 2009).

Wayfinding behaviour is also affected by the structure of the environment itself. The role of environmental variables for navigation was identified in Weisman's seminal study (1981). Environmental variables play an important role in space syntax techniques, which offer a way of measuring spatial configuration.

1.2 Spatial configuration

The concept of spatial configuration suggests that the layout of the environment itself affects the choices that individuals make. Spatial configuration refers to the way every space in the built environment relates to every other. Research has shown that our cognitive understanding of the environment is affected by topological connectivity; this has led to a large body of research on the nature of the cognitive map (see Kitchin and Freundschuh 2000 for a review). Furthermore, the strong affinity between the topological connectivity upon which space syntax variables are based and that of cognitive maps has been highlighted (Kim 1999; Kim and Penn 2004).

Space syntax proposes ways of measuring spatial configuration based on relative street connectivity (Hillier and Hanson 1984). The space syntax technique uses the topological structure of the urban grid to examine its social use. At an urban scale, space syntax uses structural elements of the environment to predict pedestrian flow within the urban grid, with no other type of information (such as land use or traffic flow) included. The technique has proved accurate at the aggregate level, although it seems likely that it is also relevant at the individual level, given that it seems to reflect the way that humans interact with their surroundings (Penn 2003). The issue of developing the space syntax model so as to make it relevant equally at the level of the individual has gained importance in the space syntax community (see Dalton, Hölscher, and Turner 2012). Two important experiments have, using space syntax, directly related spatial configuration with the navigational performance of subjects in open and directed search tasks in a hospital setting (Peponis, Zimring and Choi 1990; Haq and Zimring 2003). The need for a closer examination of individual differences in space syntax analysis was revealed by the analysis of pause behaviour at junctions in different virtual worlds (Conroy 2001). Further research refining space syntax analyses takes into account the relevance of the individual (Hillier and Iida 2005). Moreover the use of space syntax as a post-hoc analytic tool has shown that an analysis of spatial configuration can explain aspects of wayfinding behaviour (Hölscher et al. 2012).

This paper provides experimental evidence relating space syntax measures to decisions made by individuals. It aims to propose a link between real world wayfinding behaviour and spatial configuration.

1.3 Spatial geometry

Viewshed analysis offers a way of measuring the structural information in the environment, and is particularly relevant at an individual scale. Isovists have been used to analyse geometric information in the environment (eg. Benedikt 1971; Turner et al. 2001; Franz and Wiener 2008); a correlation between isovist properties and navigation has been suggested (eg. Hölscher et al. 2012; Wiener et al. 2007; Meilinger, Franz and Bülthoff 2009).

Whilst isovist analysis and visibility graph analysis (which examines the interrelation between individual isovists, see Turner et al. 2001) provide an accurate measurement of the geometric properties of a viewshed, they tend to be based on an architectural representation of the environment. For studies undertaken in a virtual environment, the viewsheds match the perceptual information the participant is presented with. However, in the real world, the different forms of isovist analyses currently used do not match a subject's sensory information; street furniture, moving obstacles, contrasting light conditions and overhead obstructions are all examples of how the structural properties of a real world viewshed might differ from the viewshed drawn from architectural or geographical representations of the environment. A recent development seeks to adapt existing techniques to the challenges of real world experiments. Six image properties have been proposed that represent a set of geometric properties of the urban environment as perceived by the viewer: depth of view, visual connectivity, percentages of visible sky and floor areas, the ratio of sky to floor area and the longest permeable route (Emo 2010). In a similar approach, but using virtual stimuli, Wiener et al. (2012) propose the depth profile, in conjunction with the number of edges, as a useful measure of geometric information in the environment as perceived by the viewer.

The space-geometric measures proposed in this paper are a refinement of those proposed in Emo (2010), adapted for the type of stimulus used in this study (which offer a forced-choice left/right alternative as opposed to the 360 degree view of the scene). Three measures are explored: sky area, floor area and longest line of sight.

1.4 Specific aims

i) To examine, in detail, where people look during wayfinding.
ii) To test the relevance of space-geometric measures on the fixation data (see below).
iii) To propose a relationship between individual spatial decision-making and spatial configuration.

2. Methods

2.1 Experimental procedure

15 participants view photographs of street corners and choose which way to go[1]. Eye tracking data records where participants fixate while making wayfinding decisions. The hypothesis that the spatial geometry of the scene draws significant levels of attention during spatial decision-making is tested. Control studies account for the influence of bottom-up and top-down viewing behaviour. A desktop-based ASL EyeTrac 6000 pan/tilt optics remote eye tracker is used.

The stimuli are 28 photographs taken at urban street corners in the City of London, and taken specifically for the study. Each stimulus presents a decision point with a distinct binary choice of one left and one right path alternative. A number of criteria are used to determine the location and specific angle of each photograph; the final stimulus set includes a version of each stimulus that is mirrored on the vertical axis to test for any left/right bias.

Participants respond to two spatial tasks. The undirected task relates to the most basic form of wayfinding activity. Participants are asked “which way would you go?” with no other information being provided. A directed spatial task specifically sets out to test the role of street connectivity on wayfinding behaviour. Participants are asked “which way would you go to find a taxi rank?”[2]

2.2 Analytic methods

Behavioural decisions are assessed according to whether or not they follow the more connected path. The more connected path is the one that is more integrated according to one of four space syntax measures: integration radius n; integration radius 100m; choice radius n; and choice radius 100m. A segment angular model of the City of London, with a catchment area of 3 miles to avoid any edge effects, was used[3]. For each stimulus, the total number of decisions that could be modelled according to spatial configuration is recorded.

1 The full experimental instructions are provided in Emo (2012).
2 Post-study interviews revealed that participants responded as if they were in situ. An avenue for future work is to test the validity of these results when compared to data collected in the physical environment itself.
3 Greater detail on the measure of the more connected street is given in Emo et al. (2012).

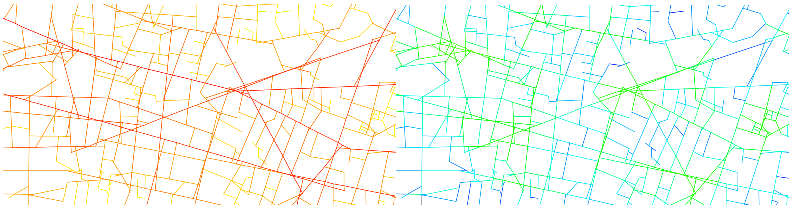

Figure 1: Segment angular map of the centre of London based on integration at global (left) and local (right) radii.

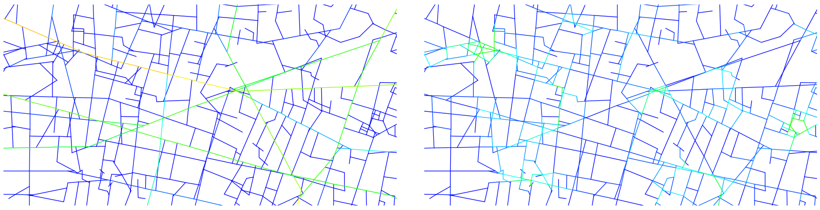

Figure 2: Segment angular map of the centre of London based on choice at global (left) and local (right) radii.

A time-course analysis of the eye tracking data is given. The location of the fixations are examined. Several space-geometric measures are offered as a way of explaining the data.

3. Results

The main body of this section discusses the location of fixations. For completeness, a summary of existing results relating to the behavioural data and time-course pattern is given; refer to Emo (2012) for a greater discussion of these results.

3.1 Behavioural data

The behavioural data shows that the decisions are not random. The majority of decisions, 75% ($p<0.01$), are consistent even when the stimulus is mirrored on the vertical axis. Thus the majority of subjects choose the same path regardless of whether it is shown as the left hand or right hand path choice. The average response time is 2.67 secs.

Results show that two thirds of all decisions made are towards the more connected street. The measure of spatial configuration for which this is highest is global integration (77%); local integration and global choice both show a strong connection at the 70% mark. A reduced number of decisions (54%) follow the space syntax measure of local choice. The number of choices that follow local choice does not achieve the 1% significance threshold ($p=0.018$); this is due to the fewer number of choices that could be explained according to this measure.

Table 1: Decisions made independent of task

	Integration r=n	**Integration r=100m**	**ln Choice r=n**	**ln Choice r=100m**
No. of decisions	21.53	19.93	19.67	15.13
%	76.9	71.19	70.24	54.05
p value	<0.01	<0.01	<0.01	<0.02

Additional findings reveal that:

i) More decisions follow measures of spatial configuration in the directed search task than in the undirected search task; overall 70% of the decisions could be explained using space syntax measures.
ii) There is no significant effect of lighting conditions on participants' decisions; 80% ($p<0.01$) are not affected by the light conditions.
iii) Decisions strongly favour attractors where these are present; 92% ($p<0.01$) of decisions follow attractors.

3.2 Eye tracking data

3.2.1 Time course pattern

On average, there are 4.20 fixations (±1.95) per participant per stimulus, lasting 0.34 seconds (±0.04 secs). There is a significant tendency to look left first; on average each participant looks left first in 70% of cases ($p<0.01$). This is coupled with a tendency to place the last fixations towards the path eventually chosen; this occurs in 70% ($p<0.01$) of cases. More attention is directed towards the chosen path; on average, each participant spends 12.0 secs compared to 9.07 secs at the eventually chosen path alternative. On average, each participant crosses the centre line 1.65 times (±0.73).

The average viewing behaviour for each stimulus of the study can be described as looking left initially, crossing the centre line almost twice per stimulus, and viewing the eventually chosen path last, having spent more time in the eventually chosen half.

3.2.2 Location of fixations

The gaze bias is not random. Across all stimuli, fixations are concentrated at two areas of interest.

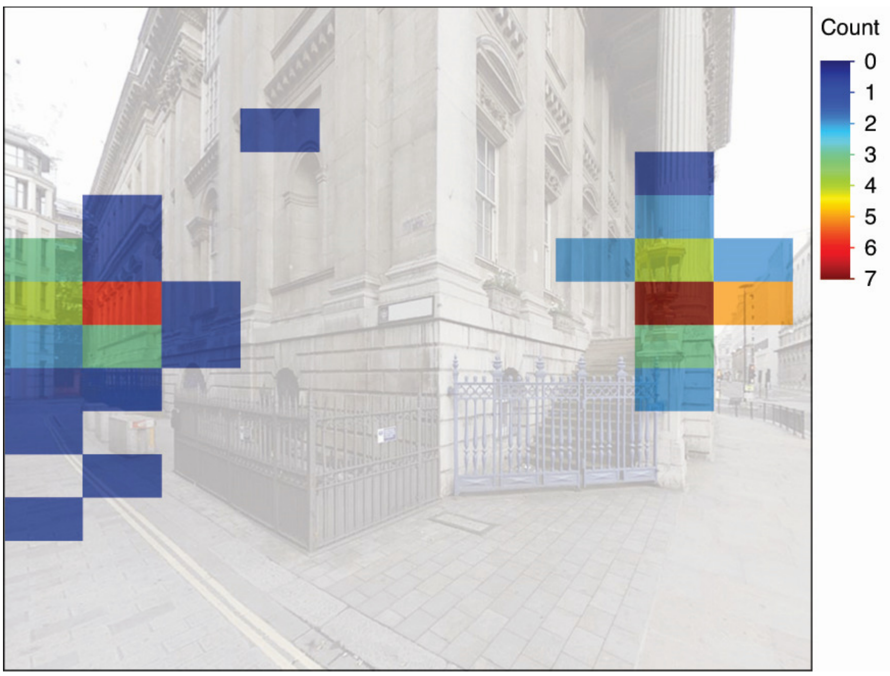

Figure 1: Example fixation distribution for one stimulus

Along the y axis, fixations are focussed in between the horizon and sky lines; this finding is in keeping with results from a previous study (Wiener et al., 2012) as well as with knowledge based on the universal viewing behaviour of photographs. Along the x axis, fixations are concentrated at two points, one on the left hand side and another on the right. These two areas of interest loosely correspond to the two path alternatives in each stimulus. The distribution of fixations along the x and y axes is easily illustrated through fixation density graphs; these are shown as histograms where each axis is divided into 30 bins.

Figure 2: Example gaze bias with accompanying fixation density graphs

On the whole, no discerning difference is found in the location of fixations between the type of spatial task. Only marginal differences are identified in 32% of stimuli, in which some fixations during the undirected spatial task are in the central area and/or directed at the floor area of the stimulus.

Figure 3: Comparison of gaze bias between the undirected (white) and directed spatial tasks (black fixation and bars)

A subsequent stage of analysis explains the peaks on the fixation density graphs based on the structural information in the scene. This evidence-based approach is a development of Emo (2010). Both the left and right hand areas of interest in each stimulus are located around the longest line of sight. Existing studies emphasise the role of depth of view for pedestrian navigation (eg. Golledge 1995; Dalton 2003). Moreover, variation in the peaks of the fixation density graphs along the x axis corresponds to changes in the floor line. The relevance of a measure based on the floor line for the analysis of spatially-related gaze bias is reported in Wiener et al. (2012).

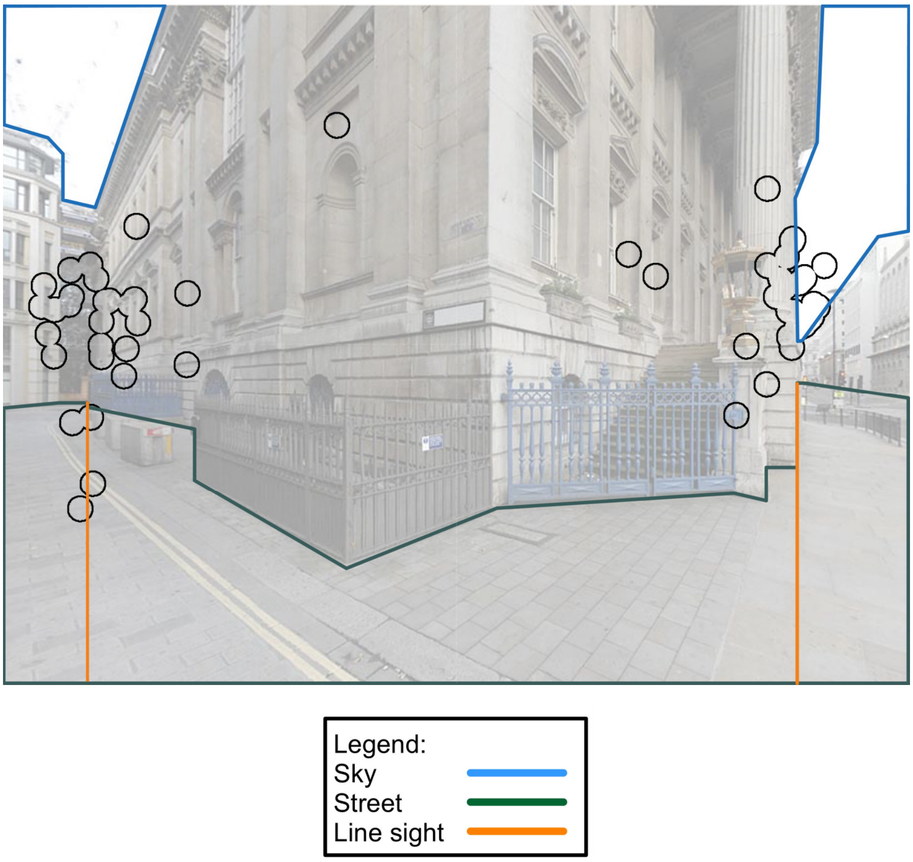

Figure 4: Three space-geometric measures: sky area floor area, and longest line of sight

In the analysis to date, three space-geometric metric measures are used in the analysis of the fixation data: sky area, floor area and longest line of sight. The floor line is held to be of particular importance for three reasons: i) the minimum point splits the image into a left and right hand path alternative; ii) its maximum point on each side indicates the longest line of sight; and iii) changes in the line are linked to gaze bias patterns.

4. Discussion

The analysis of the location of fixations suggests that special attention is paid to the structural information in the image. For each stimulus, there are two areas of interest, corresponding to the two path alternatives. On the vertical axis, fixations are focussed in between the horizon and sky lines; on the horizontal axis, fixations are clustered around the longest lines of sight. Three space-geometric measures are used to explain the gaze bias: sky area, floor area and longest line of sight. The approach is a development of that used in Emo (2010). The findings are supported by existing research on the relevance of i) the longest line of sight for wayfinding (eg. Dalton 2003) and ii) the floor area for examining gaze bias during wayfinding (Wiener et al. 2012).

These observations gain in significance when coupled with the finding that participants choose the more connected street (Emo et al. 2012). For each stimulus, 86% of participants choose the same path; two thirds of those decisions select the more connected street. Thus a relationship is offered linking individual spatial decision-making, relative street connectivity and the spatial geometry of the built environment. People choose the more connected street, and when making that decision, pay attention to the spatial geometry of the built environment.

Space syntax measures have been used extensively when analysing aggregate pedestrian movement. The relevance of such a form of analysis for decisions made by individuals is an area of increasing research (eg. Dalton, Hölscher and Turner 2012). One aim is to test the hypothesis that axial integration reflects how we internalise spatial configuration (Penn 2003). This paper offers real world experimental evidence and a proposed methodology for addressing the issue. Findings show that the spatial geometry of the scene is important during wayfinding: participants direct their attention to the spatial structure of the scene. Given that participants also favour the more connected street, a tentative link is proposed between space-geometric measures and spatial configuration. Further work should expand on this, and develop the space-geometric measures so as to test to what extent the spatial geometry of the viewshed corresponds to the information present in space syntax measures.

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