Spatial Predictors of Eye Movement in a Gallery Setting

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Abstract. The impact of space on our behaviour and cognition is not yet fully understood. The problem is particularly interesting in the context of art galleries, where the spatial context of artefacts is probably the most impactful curatorial tool available, which greatly contributes to the visitors' final experience. Space Syntax - a set of methods for quantitative description of spatial environments - was used to extract various properties of objects' locations from a gallery's layout. Among other variables, eye-tracking measures were obtained from participants freely exploring the space. The results of our analyses show that the spatial arrangement of objects is highly correlated with the number of glimpses occurring at given location. The implications of this are relevant to researchers in real life eye-tracking studies interested in setting up highly controllable experimental spatial environments.

1 Introduction and the Context

The role of museum curators is to arrange objects into exhibitions within the possibilities and constraints offered by the available spaces. These spaces have often been designed, prior to any curatorial endeavours, by a studio of architects with an entirely different set of goals. Each group has its own priorities and assumptions of the effect the exhibition space might have on the eventual visitor. Hence, the intersection of curation, building design and visitor behaviour remains an area awaiting greater understanding. This project attempts to explain this relation by investigating the influence of spatial layout of art galleries[1] on human memory and attention for exhibitions.

To what do we attend [1] and what do we 'get out of it' [2] are perhaps the most crucial factors in determining a usable and effective museum space. In psychological terms this problem is tightly linked to the notions of visual attention and memory. The connection between these two processes, even though established [3, 4], remains only partially explained. Moreover, as it is widely acknowledged, the findings from laboratory studies might not always be generalisable to real-life activities [5]. And since mobile eye-tracking research is in growing demand [6] it becomes critical to establish cognitive results (and causes) of our oculomotor behaviour in real world environments. All of these aspects are at the centre of interest among museum curators whose task it is to facilitate the above mentioned processes through the manipulation of space and artefacts it contains.

Landmark research seem to be a fertile starting point for these investigations as they focus on describing what type of objects draw our attention in real life spaces and remain in the accessible memory after we change our position [7]. As it has been suggested, our attentional resources are not necessarily drawn by the salience of the object but more likely by its spatial position [8, 9]. This general conclusion is in line with eye-tracking studies of 2D scenes, where the concept of the salience map [10] does not provide the satisfactory explanation to where we look [5]. Concurrently, the fact that objects' salience might be given an overestimated importance has been suggested in

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1 We refer to 'art galleries' as the subset of all 'museums', studies of which are also often relevant here.

the museum context [11]. Yet, it still would come as a surprising finding that what shapes our experience of a museum exhibition is more the 'spatial container' than the contents.

The environment of art galleries, compared to other everyday spaces we experience, is fairly deprived of visual distractors. Paintings hanging on the walls are intuitive and obvious candidates to fixate one's attention on - they are the reason we come to art galleries in the first place. As the result of this visual simplicity, the arrangement and configurational relationships between smaller parts of the larger space become the most powerful curatorial tool available [12]. This tool has been already shown to distinguish the way knowledge is transmitted by the exhibits [13], as well as facilitate the movement [14] and engagement [15] of the visitors. Experimental approach like the one we here present can enrich the long tradition of visitor studies conducted with observational methods and post-visit questionnaires [1]. Eye-tracking can reveal much more precise insights into what the visitors of an art gallery really saw. This, as we attempt to show, is largely affected by how the space was arranged for them.

2 Method

Thirty-two participants (13 female, *mean age* = 30.75, *SD* = 11.73; one removed from the data analysis due to previous exposure to the space) divided into 2 groups individually explored a private art gallery wearing Tobii Glasses mobile eye-tracking device. Later, they undertook two unanticipated memory tests: a computer recognition task (where reaction times were recorded) and a test similar to the 'Tour Integration' task described in [16] - participants were given a printed layout of the visited space together with miniatures of the pictures seen inside and were asked to place them onto their recollected location.

Fourteen pictures (Fig. 1) were hung in the gallery, on the locations presented in Fig. 2. All participants saw the same pictures, but the sequence (i.e. placement at the specific location) was randomised for each person. Knowing what was the location of each picture in the gallery for the given participant allowed gaze movement and the subsequent memory test results to be coded in two ways, separately: as location-oriented variables (Which **locations** attracted more fixations; which **locations'** content was memorised better?), and as picture-oriented variables (Which of the **pictures** generated more fixations; which **pictures** were memorised better?).

Fig. 1. Pictures used in the study

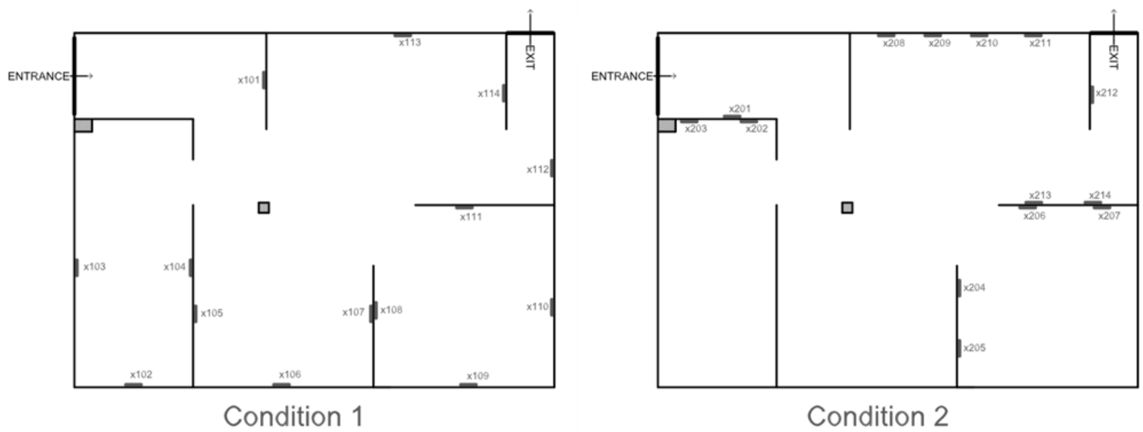

Fig. 2. Locations of the pictures in both conditions (Cond. 1 has a single picture located towards the centre of a wall, Cond. 2 has multiple pictures occuring at the same wall).

To investigate the relation between space and oculomotor behaviour in this paper, we focus mainly on the location-oriented variables. Analysed eye-tracking measures involved (mean values for each location were obtained):

1. *total dwell time* (defined as the sum of all fixation times within the picture's boundaries; linked previously to the meaning of the viewed area, its informativeness and interest [3], as well as the memory for object's position [4]);
2. *normalised total dwell time* as the percentage of the whole time spent inside the gallery;
3. *number of dwells* on each location (defined as the discrete number of times eyes' scanpath entered each object's boundaries and at least one fixation occurred; related to object's informativeness and the confidence levels in object recognition [3]);
4. *normalised number of dwells* for each location as the percentage of all dwells.

Space Syntax measures used are derived from the concept of the visibility graph [17] and Benedikt's formulation of the isovist [18]. For the Visibility Graph Analysis (VGA) [17] the layout of our gallery is divided into a small grid, and each of the grid's cells (equivalent to $\sim$0.5 m^2 in real space) can be treated as a node of a highly connected graph. For example, the number of other nodes which can be 'seen' by any single node (given the walls' constraints) contributes to that node's *connectivity* value. DepthMap 10.14.00b [19] was used for spatial analysis.

Another important concept used in the analysis is the isovist together with its properties [18]. An isovist is a 2D polygon bounding the area visible from a particular point (the centre point of each picture's location in this case). Purely geometrical characteristics of this polygon (such as its area) can be extracted. *Point 2nd moment* for example reflects the dispersion of isovist's perimeter [18], and APR (area/perimeter ratio) is a commonly accepted measure of jaggedness (although various transformations exist, e.g. [20]). We explain the crucial measures while discussing the results, but please refer to the original papers [17–19] for a detailed description.

3 Results

Four two-way ANOVAs with picture and condition as independent variables were conducted: one for each of the four eye-tracking dependent variables. Three of them (except *normalised number of dwells*) showed a significant effect of the condition at at least $p < .05$.

Table 1 and Table 2 present Pearson's Product-Moment Correlation values calculated separately for Cond. 1 (locations x101–x114; $N = 14$) and Cond. 2 (locations x201–x214; $N = 14$) as well as jointly for both conditions ($N = 28$).

Table 1. Pearson's Product-Moment Correlation values for Dwell Time; *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$

	Mean Total Dwell Time			Mean Normalised Total Dwell Time		
	Cond.1+2	Cond.1	Cond.2	Cond.1+2	Cond.1	Cond.2
Other Objects Within Isovist	0.14	0	0.69**	0.09	-0.22	0.51
Visual Clustering Coefficient	-0.03	0.02	-0.24	-0.1	0.09	-0.38
Visual Control	0.42*	0.65*	0.42	0.48*	0.63*	0.45
Visual Controllability	0.47*	0.49	0.66**	0.54**	0.51	0.64*
Visual Entropy	-0.40*	-0.56*	-0.07	-0.23	-0.39	0.04
Visual Integration	0.57**	0.62*	0.64*	0.57**	0.58*	0.56*
Visual Mean Depth	-0.58**	-0.64*	-0.67**	-0.60***	-0.60*	-0.65*
Connectivity	0.52**	0.55*	0.67**	0.56**	0.55*	0.63*
Isovist Area	0.52**	0.56*	0.67**	0.56**	0.56*	0.63*
VCA Area	0.43*	0.4	0.48	0.58**	0.62*	0.52
Isovist Compactness	-0.39*	-0.37	-0.41	-0.38*	-0.26	-0.47
Isovist Max. Radial	0.46*	0.32	0.57*	0.54**	0.39	0.64*
Isovist Min. Radial	0.36	0.56*	0.49	0.47*	0.5	0.62*
Isovist Occlusivity	0.46*	0.49	0.5	0.48**	0.44	0.53
Isovist Perimeter	0.49**	0.51	0.58*	0.52**	0.45	0.59*
Point First Moment	0.54**	0.58*	0.67**	0.60***	0.60*	0.64*
Point Second Moment	0.56**	0.58*	0.67**	0.61***	0.62*	0.62*
Area/Perimeter Ratio (APR)	0.37*	0.21	0.71**	0.45*	0.3	0.65*

4 Discussion and Conclusion

The results of ANOVA suggest the importance of spatial configuration in differentiating the visual experience of a gallery visit.

Those spatial variables which generated similar correlation values for both conditions are the most promising candidates for spatial predictors of eye-motion, as they seem to remain stable in different spatial settings. *Connectivity* and *Isovist Area* are essentially the same concepts calculated in two different ways [17, 18]. Their high correlation with *number of dwells* can be explained with regard to pure probability: assuming any random path through the studied environment and the biological constrains of our visual system, objects whose isovist covers a larger proportion of the area, are more likely to fall in sight. This event does not, however, determine the total length of such gaze and hence the correlation values with *total dwell time* are lower. Other factors (such as

Table 2. Pearson's Product-Moment Correlation values for Number of Dwells; *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$

	Mean No. of Dwells			Mean Normalised No. of Dwells		
	Cond.1+2	Cond.1	Cond.2	Cond.1+2	Cond.1	Cond.2
Other Objects Within Isovist	0.26	0.06	0.69**	0.41*	-0.06	0.71**
Visual Clustering Coefficient	-0.01	0.12	-0.22	-0.11	0.12	-0.28
Visual Control	0.71***	0.78***	0.82***	0.79***	0.76**	0.86***
Visual Controllability	0.77***	0.77**	0.93***	0.81***	0.69**	0.91***
Visual Entropy	-0.34	-0.47	-0.1	-0.27	-0.48	-0.17
Visual Integration	0.80***	0.82***	0.84***	0.78***	0.74**	0.85***
Visual Mean Depth	-0.75***	-0.84***	-0.78***	-0.74***	-0.78**	-0.81***
Connectivity	0.80***	0.81***	0.91***	0.81***	0.73**	0.90***
Isovist Area	0.80***	0.82***	0.91***	0.82***	0.74**	0.90***
VCA Area	0.84***	0.84***	0.90***	0.82***	0.83***	0.86***
Isovist Compactness	-0.44*	-0.28	-0.56*	-0.45*	-0.3	-0.61*
Isovist Max. Radial	0.60***	0.65*	0.55*	0.59***	0.68**	0.61*
Isovist Min. Radial	0.25	0.14	0.53	0.31	0.09	0.47
Isovist Occlusivity	0.59***	0.56*	0.65*	0.61***	0.57*	0.69**
Isovist Perimeter	0.68***	0.62*	0.79***	0.70***	0.59*	0.82***
Point First Moment	0.85***	0.90***	0.91***	0.86***	0.84***	0.90***
Point Second Moment	0.87***	0.92***	0.88***	0.86***	0.89***	0.87***
Area/Perimeter Ratio (APR)	0.60***	0.53*	0.76**	0.60***	0.45	0.74**

personal preference) might be at play in case of this variable. Taking into account Salience Rating of the investigated pictures (assessed in our separate study, not reported in this paper) suggests that objects' salience is not one of them.

In addition to *Isovist Area*, its version restricted to a 60 degree visibility cone was calculated, similarly to previous suggestions in spatial analyses of gallery settings [21]. This measure - here called *Visibility Catchment Area (VCA)* - attempts to capture the field of meaningful visibility and ignore the size of the area from which a picture cannot be seriously visually investigated or at least distinguished from other pictures. *VCA* generated a bit higher correlation values from *Isovist Area*, which is an empirical confirmation of its aforementioned theoretical advantage.

The highest correlation values for *number of dwells* was, however, reached by *Point Second Moment* (see definition above). This suggests, that it is not necessarily the pure size of the isovist, but also its shape that accounts for our visual behaviour. Although it must be noted that, in both of our layouts, *Isovist Area* was highly correlated with *Point Second Moment* ($r = .93$), and this situation is not always true. Since *Point Second Moment* is a concept much worse described in the literature, we recommend *Isovist Area* and it's derivatives, such as *VCA* to be used as spatial predictors of visual behaviour. At the same time, shape of the isovist requires more thought, especially considering the fact that *APR*, which is a more commonly used measure of isovist jaggedness did not generate meaningful results in the case of our study.

Various isovist properties have been recently shown to predict the memorability of displayed words and images from public displays [22], navigational behaviour [20] and spatial decision making while viewing 2D scenes [23], so the discussion of the issue is ongoing.

Presented high correlation values between spatial predictors and oculomotor behaviour can have an important impact on the future research in mobile eye-tracking. Space Syntax can be a feasible tool helping to control experimental environments or aid curators in their tasks when unintentional preference given to the spatial presentation of some objects over others is undesired.

References

1. Bitgood, S.: An attention-value model of museum visitors. Technical report, Center for the Advancement of Informal Science Education. (2010)
2. Vergo, P.: The Reticent Object. In Vergo, P., ed.: The New Museology. Reaktion, London (1989) 41–59
3. Holmqvist, K., Nyström, M., Andersson, R., Dewhurst, R., Jarodzka, H., Van de Weijer, J.: Eye tracking: A comprehensive guide to methods and measures. Oxford University Press, Oxford (2011)
4. Tatler, B.W., Gilchrist, I.D., Land, M.F.: Visual memory for objects in natural scenes: from fixations to object files. The Quarterly Journal of Experimental Psychology **58A**(5) (July 2005) 931–60
5. Land, M.F., Tatler, B.W.: Looking and acting. OUP, Oxford (2009)
6. Tatler, B.W.: On the perception of natural scenes: an introduction to the special issue. Journal of Eye Movement Research **2**(2) (2008) 1: 1–4
7. Caduff, D., Timpf, S.: On the assessment of landmark salience for human navigation. Cognitive processing **9**(4) (December 2008) 249–67
8. Janzen, G.: Memory for object location and route direction in virtual large-scale space. Quarterly journal of experimental psychology (2006) **59**(3) (March 2006) 493–508
9. Miller, J., Carlson, L.: Selecting landmarks in novel environments. Psychonomic bulletin & review **18**(1) (February 2011) 184–191
10. Itti, L., Koch, C.: A saliency-based search mechanism for overt and covert shifts of visual attention. Vision Research **40**(1012) (June 2000) 1489–1506
11. Newhouse, V.: Art and the Power of Placement. The Monacelli Press, New York (May 2005)
12. Zamani, P.: Architecture as Curatorial Device. In Koch, D., Marcus, L., Steen, J., eds.: Proceedings of the 7th International Space Syntax Symposium, Stockholm, KTH (2009) 134:1–12
13. Peponis, J., Hedin, J.: The layout of theories in the Natural History Museum. 9H **3** (1982) 21–25
14. Hillier, B., Major, M., Desyllas, J., Karimi, K., Campos, B., Stonor, T.: Tate Gallery, Millbank: a study of the existing layout and new masterplan proposal. Technical report, UCL (January 1996)
15. Wineman, J., Peponis, J., Conroy Dalton, R.: Exploring, Engaging, Understanding in Museums. Space Syntax and Spatial Cognition Workshop: Spatial Cognition '06 (2) (2006) 33–51
16. von Stülpnagel, R., Steffens, M.C.: Can Active Navigation Be as Good as Driving? A Comparison of Spatial Memory in Drivers and Backseat Drivers. Journal of Experimental Psychology-Applied **18**(2) (2012) 162
17. Turner, A., Doxa, M., O'Sullivan, D., Penn, A.: From isovists to visibility graphs: a methodology for the analysis of architectural space. Environment and Planning B **28**(1) (2001) 103–121
18. Benedikt, M.: To take hold of space: isovists and isovist fields. Environment and Planning B **6** (1979) 47–65
19. Turner, A.: A program to perform visibility graph analysis. In Peponis, J., Wineman, J., Bafna, S., eds.: Proceedings of the 3rd Space Syntax Symposium, Atlanta, University of Michigan (2001) 31.1–9
20. Wiener, J.M., Franz, G., Rossmanith, N., Reichelt, A., Mallot, H.A., Bülthoff, H.H.: Isovist analysis captures properties of space relevant for locomotion and experience. Perception **36**(7) (2007) 1066 – 1083
21. Stavroulaki, G., Peponis, J.: The spatial construction of seeing at Castelvecchio. In: Proceedings of the 4th International Space Syntax, London (2003) 66:1–13
22. Dalton, S., Marshall, P., Conroy Dalton, R.: Measuring Environments for Public Displays : A Space Syntax Approach. In: CHI '10 Extended Abstracts, New York, ACM (2010) 3841–3846
23. Wiener, J.M., Hölscher, C., Buechner, S.J., Konieczny, L.: How the Geometry of Space controls Visual Attention during Spatial Decision Making. In: Annual Meeting of the Cognitive Science Society. (2009)