C. M. Herr, N. Gu, S. Roudavski, M. A. Schnabel, *Circuit Bending, Breaking and Mending: Proceedings of the 16th International Conference on Computer-Aided Architectural Design Research in Asia,* 555-564.

AGENT-AGENT INTERACTION AS A COMPONENT OF AGENT-ENVIRONMENT INTERACTION IN THE MODELLING AND ANALYSIS OF PEDESTRIAN VISUAL BEHAVIOUR

ARASH JALALIAN,[1] STEPHAN K. CHALUP[2] and MICHAEL J. OSTWALD[3]
The University of Newcastle, Callaghan, NSW, Australia
1. arash.jalalian@uon.edu.au
2. stephan.chalup@newcastle.edu.au
3. michael.ostwald@newcastle.edu.au

Abstract. This multidisciplinary project involves concepts from architectural design, statistical learning, machine vision, and human ecology. The focus is on analysing how pedestrians' dynamic behaviour in space is influenced by the environmental design of different architectural scenarios. This paper presents a multi-agent pedestrian simulation and analysis system that supports agent-to-agent interactions, different spatial desires, and interpersonal distance. The system simulates and analyses pedestrian spatial behaviour with combined focus on movement trajectories, walking speed, and the visual gaze vector. The analysis component relies on learning a statistical model characterising normal/abnormal behaviour, based on sample observations of regular pedestrian movements without/with the impacts of significant visual attractions in the environment. Using the example of Wheeler Place in Newcastle (Australia) our pilot experiments demonstrate how pedestrian behaviour characteristics can depend on selected features in the visual environment. The presented system will allow architects and urban designers to obtain better assessment of planned urban spaces and streetscape characteristics and their impacts on pedestrian behaviour.

Keywords. Agent interaction; pedestrian behaviour; analysis.

1. Introduction

Environmental perspective is an extremely important viewpoint of human spatial behaviour analysis. This view assumes that the physical characteristics of an environmental setting influence our attitudes and actions more than a biological or cultural trait. Spatial behaviour modelling focuses on the visible, *static* and *dynamic* properties of the physical environment as important factors, since socio-cultural variables are harder to measure and less obvious across behavioural settings. Analysing this behaviour in indoor and outdoor areas is an important facet of architectural and urban design.

The simulation of pedestrian behaviour allows us to investigate spatial visual behaviour without the difficulties of real-world data analysis. Planning pedestrian environments requires assumptions about how real pedestrians will respond to characteristics of the planned environment. Placing virtual pedestrians in architectural space simulation significantly aids in making the assumptions more real (Thiele, 2002).

A number of methodological approaches have been proposed to model pedestrian behaviour: *Analytical models* (Antonini et al, 2006, Ness et al, 1969), *Cellular automata* (Francesca Camillen et al, 2009, Wang and Chen, 2009), and *Agent based simulation* (Bonabeau, 2002, Francesca Camillen et al, 2009, Yannis and Golias, 2009). Advantages and disadvantages of using each method and a more detailed literature review of the proposed pedestrian behavioural models have been discussed in our previous works (Jalalian et al, 2011).

Representation of the physical space plays a central role in modelling pedestrian spatial behaviour. In "public" places, including external environments (streets and plazas) and internal spaces (malls and museums), "attractors", like billboards or display stands or even a group of people, can distract pedestrians from following a direct path towards their destinations. While there are a range of possible names for these visual distractions, we describe them as "attractive objects". In urban spaces the attractive objects have different *conspicuity* areas (Yantis, 1998). For instance a high-rise tower in the centre of a town may attract more attention from greater distance than a poster on a nearby wall (Ratti, 2004). Previously we have taken the variety of conspicuities into account by defining different "levels of attraction" for attractive objects (Jalalian et al, 2011, Jalalian et al, 2010).

In the present paper we propose an innovative approach to equip simulated objects with *dynamic* levels of attraction. Pedestrian-environment interactions in parallel with pedestrian-pedestrian interactions have significant impact on pedestrian spatial behaviour and walking patterns (Baldassare, 1978). Since vocal interactions are harder to measure and depend on many geometrical and cultural variables, we focus on the visual part of pedestrian-pedestrian interactions. We investigate the dynamics of human head pose and eye gaze behaviours which can provide significant insight into the context of a spatial behaviour. It has been shown that gaze direction and eye contact are essential features of group communication, as they help to elicit behavioural characteristics from others (Doshi and Trivedi, 2009, Argyle and Dean, 1965, Kendon, 1967, Ballerini et al, 2008).

Sudden changes in gaze direction may or may not be linked with attractive objects. A substantial amount of research in psychology has examined whether such behaviour is caused by internal stimuli (such as changing the route) or by external stimuli (Itti and Koch, 2000, Peters and Itti, 1999, Navalpakkam and Itti, 2005, Rothkopf et al, 2007). While attractive objects take up a significant portion of visual external stimuli, other peoples' gaze direction could be considered as another important category of external stimuli to attract a pedestrian's gaze (Yantis, 1998). As the number of people looking at an attractive object increases, the object can attract more attention. The presented system incorporates our previously proposed pedestrian simulation system (Jalalian et al, 2011). The new system described in this paper, has been designed to support pedestrian-pedestrian visual interaction and models the impacts of eye interactions in changing pedestrian spatial behaviour. The purpose of the simulation is to model and analyse this spatial behaviour in order to have a better assessment of a planned urban design and its impacts on pedestrian behaviour.

2. Simulating pedestrian visual attention

The simulation generates a set of behavioural characteristics – for example walking, running, standing, getting attracted to an obstacle, and associated changes of the gaze direction. Our analyser software evaluates the simulated behaviours in order to identify the impacts of different walking environments on pedestrian behaviours.

2.1 ATTENTION AND EYE MOVEMENTS

The fact that eye movements are linked by attention doesn't mean that these two systems are completely mutually dependent. (Helmholtz, 1962) confirms that observers can direct their visual attention to different areas of visual space even while the eyes remain fixed. Thus the relationship between attention and eye movements is one of partial interdependence. Attention is free to move independently of eyes, but eye movements require visual attention to precede them to their goal (Hoffman, 1998).

While pedestrians are walking in an urban space their eyes scan their surroundings using saccadic eye movements. Saccadic eye movements occur at rate of about 3-4 per second (Becker, 1991). The eyes are essentially blind during these movements and the information from the scene is acquired only at fixation points. (Yarbus, 1967) pointed out that the location and sequence of saccades is not completely random. Eye movements from one fixation point to another are fast enough that in the simulation, we can assume that all the objects in certain range are scanned during a timestamp (4 seconds). The range of this scan varies from one person to another (Klein and Pontefract, 1994) and it mainly depends on the location that the pedestrian is looking at while walking. This is modelled by defining different effective ranges for "useful field of view" (UFOV) (K. Ball and Owsley, 1991). In the initial stage of the simulation a *sight category* is assigned to each agent. The sight category is a random number which limits the minimum and maximum range of UFOV. The number of sight categories can be defined and changed by the user in the provided *user interface* of our analyser software.

2.2 GOAL-DRIVEN VS. STIMULUS-DRIVEN ATTENTION

According to (Yantis, 1998), visual attention is either goal-driven or stimulus-driven. Attention is said to be goal-driven when it is controlled by an observer's intention and needs. For instance if the observer is hungry and looking for food, automatically all the food shops will direct his attention. In the simulation, pedestrians' goal-driven attentions are modelled by the "agent need vector" (ANV) and the "object category vector" respectively. These vectors are assigned to agent and object at the initial stage. Each element of the ANV reflects a category of need for the agent. The value assigned to each element expresses how desperate the agent is to satisfy that particular type of need. In the object category vector each element expresses how much the object is able to satisfy an agent's need.

In contrast, stimulus-driven attention is controlled by visual attributes of the object that are not necessarily relevant to the observer's perceptual goal. In the previous example, if all the food shops tended to be fast food restaurants, then a single Persian restaurant among them would capture the observer's attention automatically. Stimulus-driven attention is modelled by the "object level of attraction". A bigger value for the object level of attraction means the object has a stronger impact on an agent's attention.

2.3 CROWD ATTRACTION AS A VIRTUAL ATTRACTIVE OBJECT

The social group is a fundamental and universal feature of human social life. Group formation is the expansion of bonds of interpersonal attraction due to the existence of common desires among individuals (Hogg, 1985). Having the same goal-driven attentions could be considered as one of the major determinants of group formation in urban environments (Carwright and Zander, 1968). In our simulation we assume that agents who are visiting the same attractive object can form a group.

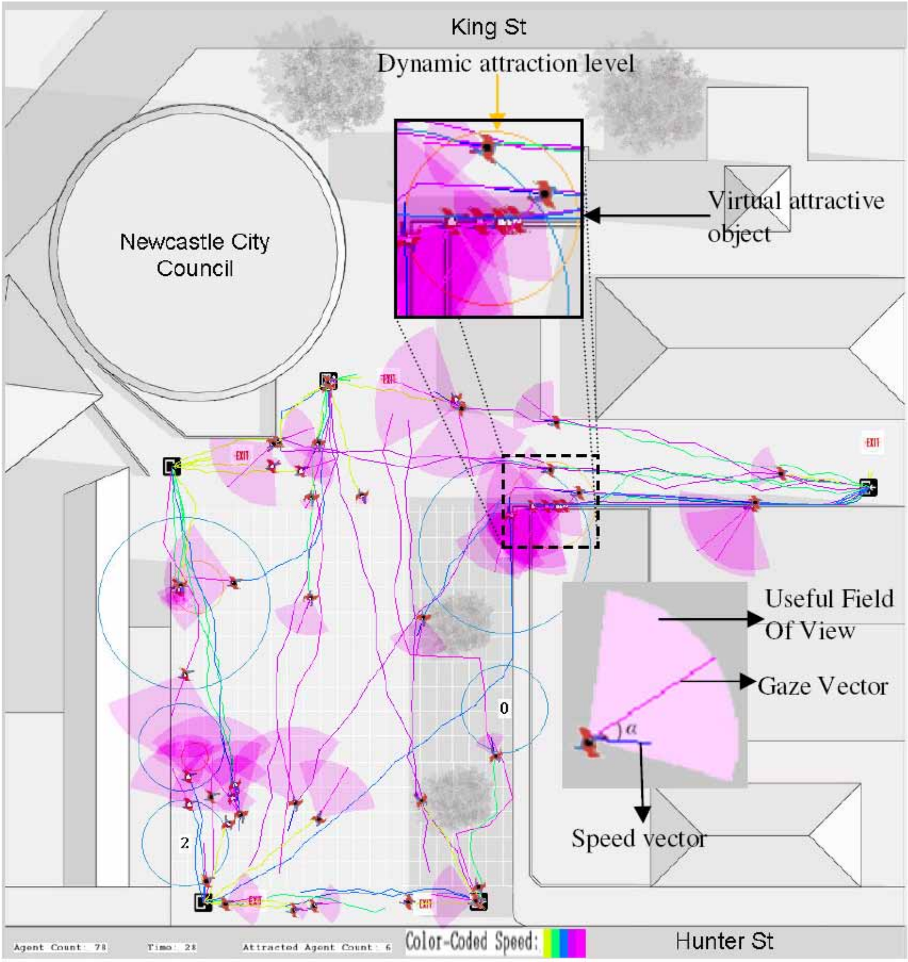

Figure 1. Wheeler Place simulation in scenario2

Group size is an important variable for capturing attention: Large groups are able to draw more attention than small groups. In order to model how *group formation* and *group size* impact on pedestrian spatial behaviour, we consider a group of people as an attractive object with a *dynamic* attraction level and call it a *virtual attractive object* (Figure 1). A virtual attractive object (VAO) has the same feature set as an *actual attractive object.* However, in the case of VAOs, the location and level of attraction vary according to the location and number of agents in the group. As agents are walking in the scene they may get attracted to a selection of attractive objects (virtual or actual). The selection depends on agent needs, agent location, sight category, UFOV, object location, object category, and crowd locations. Agents consider attractive objects as temporary destinations. Once they finish visiting the attractive objects they will continue their way towards exit points.

2.4 OBJECT SELECTION PROCESS IN THE SIMULATION

Attractive object selection starts by calculating the distance of agent's **UFOV** and the level of attraction of all the attractive objects that the agent can see. Among the objects, the one which minimises this distance is the "best object". We assume that actual attractive objects have higher priority than VAOs. Therefore the search for finding the "best object" is done over the real objects first, then over virtual objects.

Once the "best object" is found, the *Euclidean distance* between the ANV and object category vector is calculated. If this distance is less than a *threshold* it means that the agent likes/needs the object and its state will be changed to "becoming attracted", otherwise it will be changed to "not becoming attracted". Agents show the same behaviour if the selected object is a VAO, but instead of studying the object it will join the group and this will increase the level of attraction of the VAO.

3. Agent behaviour analyser

In order to analyse pedestrian behaviour, we have previously proposed and applied a new approach for outlier detection of pedestrian spatial behaviour (Jalalian et al, 2010). Our system analyses pedestrian behaviour with a combined focus on agent location (x_t, y_t), direction of movement (β_t), speed $\frac{T_i \bullet T}{\|T_i\|\|T}$, the angle between direction of movement and gaze vector (α_t) and the angular velocity ($d\alpha_t / dt$) associated with the gaze vector of individuals in large groups of simulated pedestrians. The system learns a statistical model characterising normal behaviour, based on sample observations of regular pedestrian movements without the impact of significant visual attractions in the environment. Irregular pedestrian behavioural characteristics, mainly caused by detection of visually attractive objects, are considered as abnormal behaviour. We employed one-class support vector machines (SVMs) (Schoelkopf et al, 2001) combined with Dynamic Time Warping (DTW) (Keogh and Pazzani, 2001) to separate agents into two classes; *attracted agents* and *normal agents*.

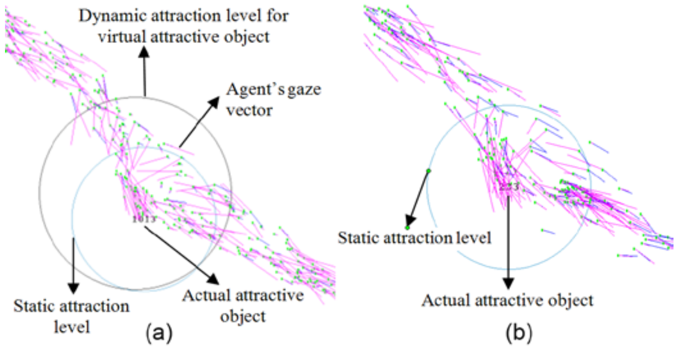

Figure 2. Agent's behavioural characteristics with (a) and without (b) the impact of a VAO

4. Experimental results

The new software system runs a pedestrian simulation on a plan of Wheeler Place. We have selected this place because: The space is next to Newcastle's Civic Theatre and City Council Chamber. These two buildings have made this area one of Newcastle's most crowded public spaces. Here *crowd attraction* is a common behaviour, and there are several places of different levels of attraction such as the City of Newcastle Information Centre and Climate Meter, Juicy Beans Restaurant and Internet Cafe, a big public art work, the Civic Theatre and Civic Theatre Restaurant.

Figure 2(a) shows the impact of "dynamic attraction level" on agent trajectory. Agents who are looking at an attractive object may form a group and this is shown as a virtual attractive object. The level of attraction of a virtual attractive object changes according to the number of agents in the group. Agents can be distracted by VAOs as well as by actual attractive objects. As shown in Figure 2(b) some agents who have a small *sight value* might miss the attractive object. In Figure 2(a) the dynamic level of attraction is large enough to direct all agents' attention and therefore all agents can see the attractive object. Agents' behavioural response to virtual attractive objects models pedestrian behaviour in the real world where crowd attraction is a significant component of visual behaviour.

Figure 3 illustrates typical simulated behavioural characteristics of an agent with and without the impact of VAOs. It shows the speed of movement ($\|s\|$) and the speed of the angle between the movement direction and gaze vector ($d\alpha / dt$). The period that the agent was attracted by an attractive object is called the visiting period. Just before this period there is a "becoming attracted" period. In this period the agent moves towards the object with the highest allowed speed defined in its speed category (see the black curve in Figure 3). Agents might turn their attention to the VAOs prior to the actual ones. The patterned area in Figure 3 represents this behaviour. As shown in this figure ($d\alpha$ / dt) shows significant change once an agent's attention is directed to a virtual/actual attractive object. This describes a pedestrian's behaviour when he suddenly changes his gaze to a visually attractive object. Our proposed analyser can detect this behaviour.

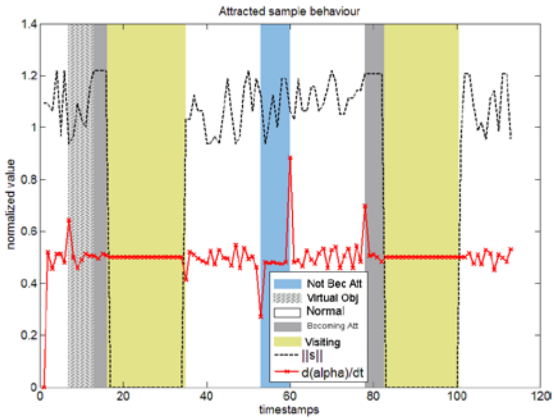

Figure 3. Simulated behavioural parameters; becoming attracted to a virtual attractive object (patterned area), becoming attracted to an actual attractive object (grey area), visiting period (green area), and attention without becoming attracted (blue area)

Table 1 Average probability of attraction

VAO	ANV	SC1	SC2	SC3	SC4	SC5	SC6	SC7	SC8	SC9	SC10
NO	NO	0.49	**0.52**	0.46	0.47	0.47	0.45	0.46	0.47	0.44	0.45
NO	YES	0.25	**0.26**	0.24	0.19	0.25	0.22	0.24	0.25	0.18	0.21
YES	NO	**0.54**	**0.57**	**0.52**	**0.53**	**0.55**	**0.51**	**0.54**	**0.54**	**0.50**	**0.52**
YES	YES	**0.24**	**0.32**	**0.30**	**0.25**	**0.24**	**0.27**	**0.24**	**0.23**	**0.29**	**0.23**

In previous work we defined 10 possible scenarios (SC1-SC10) that were considered in our simulation experiments of Wheeler Place. The scenarios describe the permutations of the positions of five selected attractive objects (blue circles in Figure 1) (Jalalian et al, 2011). In the present paper we employed them again with the new system to show the effects of VAOs and ANVs on the number of attracted agents. Table 1 shows the average probability of attraction for different positions in different scenarios with respect to the number of simulated agents. The results in this table were obtained from simulating 5000 pedestrians for each scenario. These results suggest three conclusions: I) The introduction of ANVs always decreases the average probability of attraction. II) The introduction of VAOs (i.e. step from row 1 to row 3 or from row 2 to row 4 in Table 1) Increases the average probability of attraction in the absence of ANVs for all scenarios. However, in the presence of ANVs this increase was not consistently observed. III) Scenario 2 (shown in Figure 1and SC2 in Table 1) has the highest probability of attraction independently of the presence or absence of VAOs or ANVs. Our pilot experiments also confirm that if we increase the number of agents in the scene, the average probability of attraction will be increased. This clearly shows the impact of crowd attraction on pedestrian spatial behaviour.

5. Conclusion

In this paper the dependency of attention and visual gaze direction was discussed. We have proposed and tested an innovative model to simulate goal-driven attention and stimuli-driven attention with the "agent need vector" (ANV) and the "object level of attraction". The proposed model includes "group formation" and the effects of "group size" on directing pedestrian's attention. The simulation was run for a real-world space, Wheeler Place in Newcastle. Different scenarios with different configurations and the impacts of considering crowd attraction on pedestrian behaviour were presented and discussed. The experimental results demonstrate that the new system can provide significant support for understanding how changes in the configuration of the physical/visual built environment are reflected by measurable changes in agent behaviour.

Acknowledgement

This project is supported by ARC DP1092679 "Modelling and predicting patterns of pedestrian movement: using robotics and machine learning to improve the design of urban space".

References

Antonini, G., Bierlaire, M. and Weber, M.: 2006, Discrete choice models of pedestrian walking behavior, *Transportation Research Part B: Methodological,* **40**: 667–687.

Argyle, M. and Dean, J. 1965. Eye–contact distance and affiliation. Sociometry, 28, 289–304.

Baldassare, M. 1978. Human spatial behavior. *Annual Review of Sociology,* **4**: 29–56.

Ballerini, M., Cabibbo, N., Candelier, R., Cavagna, A., Cisbani, E., Giardina, I. and Lecomte, V.: 2008, Interaction ruling animal collective behaviour depends on topologocal rather than metric distance, *Proceeding of National Academy of Sciences,* 1232–1237.

Becker, W.: 1991, Saccades, R.H.S.Carpenter (ed), *Vision andvisualdysfunction,*.CRC Press, Florida, 97–137.

Bonabeau, E. 2002. Agent–based modeling: Methods and techniques for simulating human systems, *Proceedings of the National Academy of Sciences of the United States of America,* **99**: 7280–7287.

Cartwright, D., and Zander, A.:.1968, Group dynamics: Research and theory, Harper & Row, New York.

Doshi, A. and Trivedi, M. M.: 2009, Head and gaze dynamics in visual attention and context learning. *IEEE Computer Society Conference on Computer Vision and Pattern Recognition Workshops,* IEEE, USA.

Camillen, F., Capre, S., Garofalo, C., Ignaccolo, M., Inturri, G., Pluchino, A., Rapisarda, A. and Tudisco, S.: 2009, Multi agent simulation of pedestrian behaviour in closed spatial environments, *Science and Technology for Humanity (TIC–STH),* IEEE Toronto.

Helmholtz, H.: 1962, *Treatise on physiological optics*, 3rd edn, New York.

Hoffman, J. E.: 1998, Visual attention and eye movements, H. Pashler (ed) *Attention,* San Diego, Psychology Press.

Hogg, M. A.: 1985, Interpersonal attraction, social identification and psychological group formation, *European Journal of Social Psychology,* **15**: 51–56.

Itti, L. and Koch, C.: 2000, A saliency–based search mechanism for overt and covert shifts of visual attention, *Vision Research,* **40**: 1489–1506.

Jalalian, A., Chalup, S. K. and Ostwald, M. J.: 2010, Intelligent Evaluation of Urban Streetscape Designs by Analysing Pedestrian Body Dynamics. *The Third International Workshop on Advanced Computational Intelligence,* China, IEEE.

Jalalian, A., Chalup, S. K. and Ostwald, M. J.: 2011, Architectural evaluation of simulated pedestrian spatial behaviour, *Journal of Architectural Science Review*, **53**.

K. Ball and Owsley, C.: 1991, The useful field of view test: a new technique for evaluating age–related declines in visual function, *Journal of American Optometric Association*, **64**: 71–79.

Kendon, A.: 1967. Some function of gaze direction in social interaction, *Acta Psychol,* **26**: 22–63.

Keogh, E. J. and Pazzani, M. J.: 2001, Derivative dynamic time warping, *First SIAM International Conference on Data Mining*.

Klein, R. M. and Pontefract, A.: 1994, Does oculomotor readiness mediate cognitive control of visual attention? revisited!, Umilta, C. (ed.) *Attention and Performance XV,* MIT Press.

Navalpakkam, V. and Itti, L.: 2005, Modeling the influence of task on attention, *Vision Research,* **45**: 205–231.

Ness, M. P., Morral, J. F. and Hutchinson, B. G.: 1969, An analysis of central business district pedestrian circulation patterns, *Highway research record,* **283**: 11–18.

Peters, R. J. and Itti, L.: 1999, Modeling and prediction of human behvaior, *Neural Computation,* **11**: 229–242.

Ratti, C.: 2004, Urban texture and space syntax: some inconsistencies, *Environment and Planning B: Planning and Design*, **31**: 1–12.

Rothkopf, C. A., Ballard, D. and Hayhoe, M.: 2007, Task and context determine where you look, *Journal of Vision,* **7**: 1–20.

Schoelkopf, B., J C Platt, J Shawe–Taylor, A J Smola and Williamson, R. C.: 2001, Estimating the support of a high–dimensional distribution, *Neural Computation,* **13**.

Thiele, L.: 2002, Virtual people and architecture representation, Luther, M., Dawson, T., Ham, J., Moore, M., Rollo, J. and Treloar, G. (eds) *36th annual conference of the Australian and New Zealand Architectural Science Association (ANZAScA)*, Deakin University, School of Architecture and Building, Geelong, Australia.

Wang, T. and Chen, J.: 2009, An improved cellular automation model for urban walkway bi–directional pedestrian flow, *International Conference on Measuring Technology and Mechateronics Automation,* IEEE, China.

Yannis, G. and Golias, J.: 2009, A critical assessment of pedestrian behaviour models. *Transportation Research Part F: Traffic Psychology and Behaviour,* **12**: 242–255.

Yantis, S.: 1998, Control of visual attention, Pashler, H. (ed) *Attention,* Psychology Press. Baltimore.

Yarbus, A. L.: 1967, *Eye movements and vision,* Plenum Press New York.