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Visual angle as determinant factor for relative distance perception

Elton H. Matsushima[*1], Artur P. de Oliveira[2], Nilton P. Ribeiro-Filho[2], José A. Da Silva[1]

[1] Universidade de São Paulo at Ribeirão Preto, Brazil
[2] Universidade Federal do Rio de Janeiro, Brazil.

Visual angles are defined as the angle between line of sight up to the mean point of a relative distance and the relative distance itself. In one experiment, we examined the functional aspect of visual angle in relative distance perception using two different layouts composed by 14 stakes, one of them with its center 23 m away from the observation point, and the other 36 m away from the observation point. Verbal reports of relative distance were grouped in 10 categories of visual angles. Results indicated visual angle as a determinant factor for perceived relative distance as observed in the absence of perceptual errors to distances with visual angle equal or larger than 70 degrees that could be attributed to a combination of sources of visual information. Another finding showed a possible intrusion of non-perceptual factors (observer's tendencies), leading to compressed estimates to relative distances with visual angles smaller than 70 degrees.

In general, research on visual perception of space is accomplished on homogeneous spaces, characterized by presentation of isolated stimuli in front of observers in order to investigate functional aspects of visual space. Homogeneous environments are not representative of real world conditions which can be better represented by visual scenes. Visual scenes are composed by a set of objects, whose locations are defined by a coordinate system which is independent of observer position.

Biederman (1972) stated that one can produce two different conditions of natural scenes: real-world scenes and naturalistic ones. Real-world scenes are defined by the context and array of natural environments, e.g., when walking through a neighborhood, one must evaluate the dimensions of buildings, streets, and the distances between landmarks (Lynch, 1960). An experimental naturalistic environment is defined by a scene built following a schema to get it close to a real-world scene, such as the large outdoors experimental environments used in some researches (Da Silva, 1985; Loomis, Da Silva, Fujita, & Fukusima, 1992; Foley, Ribeiro-Filho, & Da Silva, 2004; Toye, 1986; Wagner, 1985).

[*] Address: Elton H. Matsushima. Universidade de São Paulo. Faculdade de Filosofia, Ciências e Letras de Ribeirão Preto. Avenida Bandeirantes, 3900. CEP: 14040-901. Vila Monte Alegre, Ribeirão Preto, SP, Brazil. E-mail: tolitoli@uol.com.br

Usually, a scene is defined by the locations of its stimuli and the dimensions of these stimuli, as well as the absolute and relative distances of these stimuli. The physical environment where the stimuli are located is named *spatial layout* (Haber, 1985). Estimates judging the spatial metrics of stimuli locations on this spatial layout produce a perceived scene, named *perceived layout*. Stimuli locations, physical or perceived, can be defined by a system of Euclidian coordinates. Analyses on judgments of spatial dimensions of perceived layout allowed the construction of a geometry of perceived space (Wagner, 1985), as well as the investigation of motor behaviors toward visual targets, such as navigation of subjects with or without visual deficits (Haber, 1985; Loomis et al., 1992).

One of the strongest perceptual phenomena associated to perceived layout is known as the *anisotropy of visual space*. It describes a pattern of perceived dimensions of the layout in which horizontal ones are perceived accurately or slightly overestimated, while vertical ones and depth are severely undershot (Loomis & Philbeck, 1999; Matsushima, 2003). This perceptual pattern resists to several conditions, even the ones when natural full-cue scenes were presented to subjects (Matsushima, 2003). Only few theories tried to explain this phenomenon. One of these stated that visual angle comprised between stimuli and observer's eyes is the source of these differences, since frontoparallel distances presented larger visual angles than depth distances (Levin & Haber, 1993). Others relied on the fact that perceived depth dimensions must be reconstructed from the bidimensional information in the retinal image and that this reconstruction is incomplete.

Investigating the visual angle hypothesis we designed a spatial layout of 14 stimuli with different sizes and locations to assess the accuracy in verbal reports of relative distances between stimuli. Those different stimuli locations provided 91 relative distances that comprised different magnitudes of visual angles. Those angles were inserted into categories in order to verify whether different spatial orientations of interobject distance produced the differences in judgments of relative distance, as predicted by visual angle hypothesis (Levin & Haber, 1993).

METHOD

Participants. 80 observers, aged from 18 to 28 years old (Md = 23 years), all of them from the community of students and technicians of Universidade de São Paulo at Ribeirão Preto, randomly sampled. Participants passed through visual acuity tests in a Bausch-Lomb Ortho-rather, then included in the sample when meet the criteria of 20/20 visual acuity. All subjects were naive to the methods and objectives of the research.

Experimental Environment. Outdoors experimental environment was a large field, even and free from natural obstacles, under natural illumination, whose dimensions were 18 m wide and up to 500 m in depth without visual obstacles to horizon. The spatial layout was built on a portion of the environment whose dimensions were 18 x 18 m. Observers could be placed in two different observation points. The first one, named proximal, was located 23 m away from the center of the layout, and the second one, named distal, 36 m away from the center of the layout. 14 cylindrical white stakes, fixed vertically to the floor, composed the spatial layout of stimuli.

Four stakes, each one on the mean point of each side of the experimental area, defined two orthogonal relative distances. Remaining stakes were randomly assigned over the layout area. It generated an image of the physical spatial layout through its Cartesian coordinates extracted by a MDS procedure. Figure 1 depicts a scaled representation of physical locations of each stake with the origin of the two dimensions, depth (dimension Y) and width (dimension X), placed in the center of spatial layout.

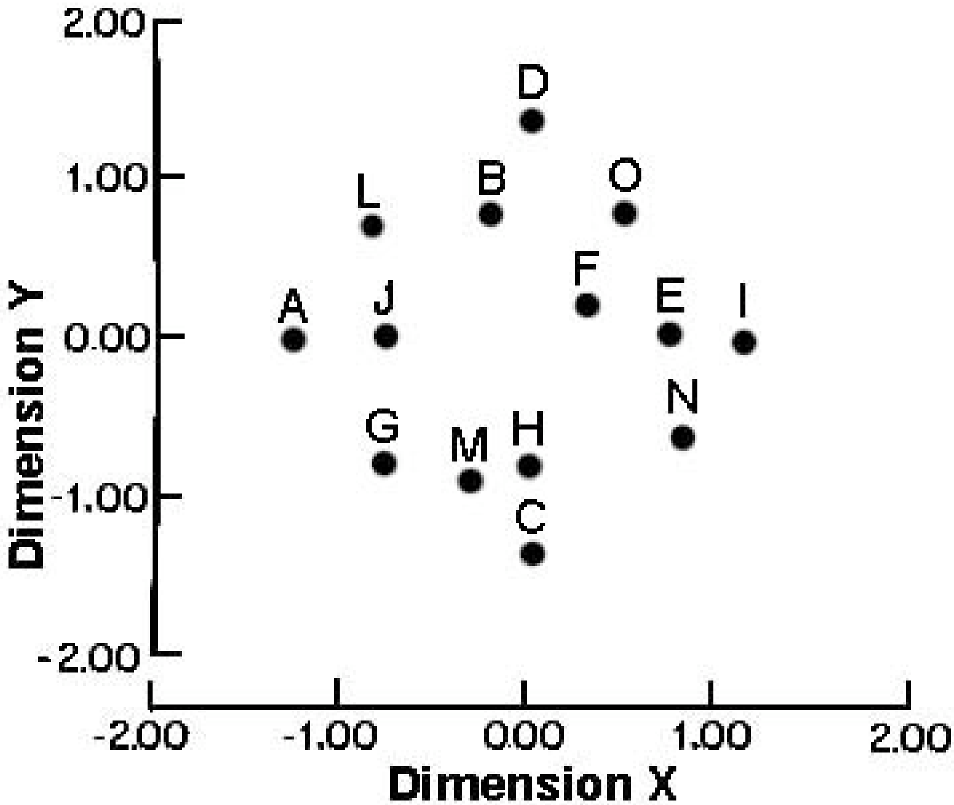

Figure 1. Graphical representation of physical spatial layout of stimuli into two spatial dimensions, depth and width, Y and X axis[1], respectively, whose origin was located in the center of spatial layout. Observer position was considered from the center of the layout.

[1] Each unity in dimension X was equal to 1.14 unities of dimension Y.

Stimuli and apparatus. All stakes had 0.035 m wide with seven different heights ranging from 0.40 to 1.60 m (arithmetic ratio of 0.20), totaling seven pairs of stakes equal in size. In top of each stake, there was a triangular prism with squared faces, 0.15 width x 0.30 m height. These prisms were all white with black letters covering an area of 0.18 m^2. Two stakes of 1 m length and 0.035 m wide was fixed near observer's left foot, one laid on the floor and the other stood vertically at one ending of the laid one.

Design. We used a two between-subjects factors design, *observation point* and *viewing condition.* For observation point conditions, we considered observer's position relative to the center of the spatial layout, in two levels of this factor, namely proximal (23 m far from the center), and distal (36 m far from the center). For viewing conditions we considered the number of eyes used during observation of spatial layout, namely monocular and binocular conditions. For within-subject factor, we considered the visual angle of relative distance as defined by Haber (1985) and Przeorek (1986). They defined this visual angle as the angle between main visual line up to mean point of the interobject distance and the interobject distance itself. By this definition, there was 91 interobject distances for the total of 14 stimuli. Data analysis were run over the median of estimates due to the fact that few observers in some conditions gave reports that seemed to be outside the normal distribution of the other reports (Foley et al., 2004). We divided visual angles into nine categories with 10 degrees of range and estimates in each category were presented in their medians.

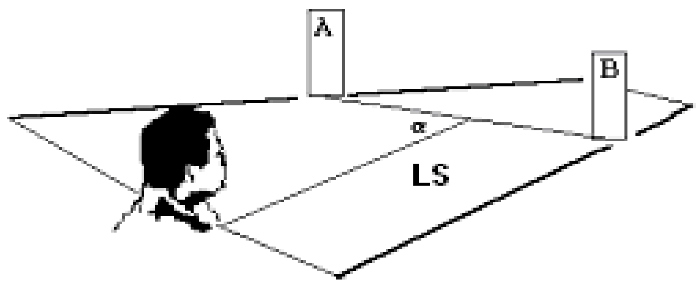

Figure 2. Graphical representation of criteria for radial and horizontal dimensions. Objects A and B were stakes, LS is the line of sight (the median of the triangle whose vertices were observer position and stakes A and B). The angle □ was the critical angle for the classification of distances into radial or horizontal categories.

Procedures. After their agreement in participation, all observers passed through visual acuity tests, and then were randomly selected to one of the experimental groups. An assistant handed out the instructions to observers to read them. Objective instructions asked observers to verbally estimate the distances between pairs of stakes that would be indicated by the letters on top of them. Observers verbally estimated the 91 pairs of stakes in a random sequence. The two between-subjects factors and their levels generated four experimental groups.

RESULTS

One can notice a larger undershooting for observer position at 36 m from the center of layout, indicating that as absolute distance of the scene increases, estimates get more compressed. We also found a strong relation between visual angle and perceived relative distance: as visual angle increases, errors in perceived relative distance diminish. This finding corroborated previous results (Foley et al., 2004; Levin & Haber, 1993; Loomis & Philbeck, 1999; Loomis et al., 1992; Philbeck, 2000; Toye, 1986; Wagner; 1985).

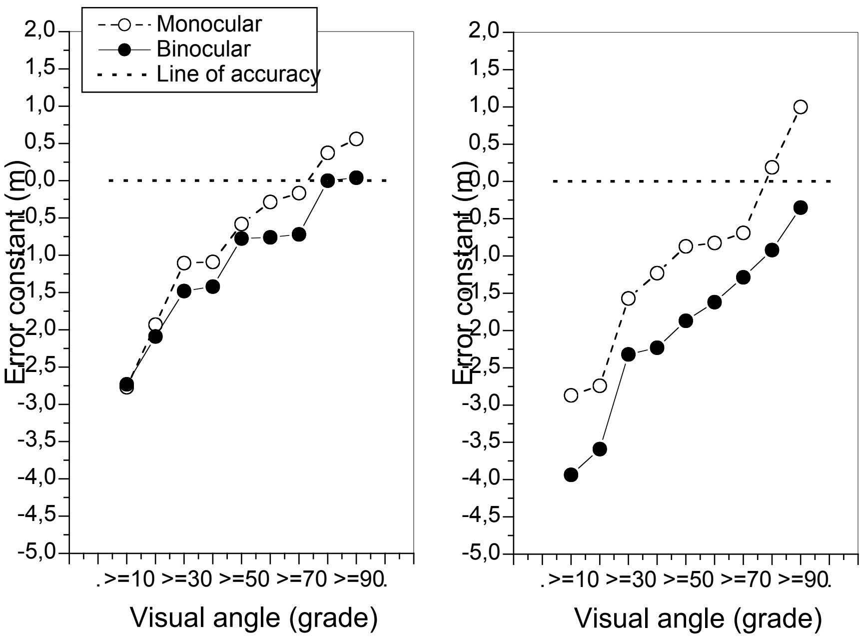

Figure 3. Constant errors of median verbal estimates as a function of visual angle categories of relative distances. Left Panel depicts the median constant errors for observer position 23 m from the center of spatial layout and Right Panel, for observer position 36 m from the center of spatial layout.

A two-way ANOVA (observation point x viewing condition) on the median estimates of visual angle categories did not produced any reliable differences between main factors and the interactions between them. These analyses produced reliable effects only for within-subjects factor, visual angle categories, $F(8, 608) = 74.162$, $p = 0.000$, and for the interactions visual angle categories x viewing conditions, $F(8, 608) = 2.369$, $p = 0.016$, and visual angle categories x viewing conditions x observation point, $F(8, 608) = 2.047$, $p = 0.039$.

DISCUSSION

In general, verbal judgments of spatial dimensions are very susceptible to non-perceptual factors and inferential processes, like observer's tendencies. This tendency occurs in the absence of effective sources of visual information specific for the stimulus distance and with increasing absolute distance of the scene (that causes the loss of efficacy of many visual cues).

For the relative distances, proximal scenes provided observers with more effective visual information, leading to more accurate judgments, while, in distal scenes, visual cues lost its efficacy and compromised judgments. Verbal reports usually are susceptible to inferential influences, such as observer's tendencies. Respective to relative distances, there is an observer's tendency, namely equidistance tendency, in which, taken two objects in a scene, those objects will appear to be located in the same distance to observer. Considering a more complex scene, this tendency is likely to shrink the depth dimension of the whole scene. This inferential tendency is better seen in distal conditions, whose judgments with larger undershooting presented evidence for this. This process is usually seen in the absence of a specific cue for relative distance, such as fusional vergence (Da Silva, 1989). The influence of this process was more evident in relative distance oriented in or near depth, and diminished when the orientation angle tended to a frontoparallel plane. In this latter orientation, distance judgments were often overestimated and this could be described as an influence of compensatory processes of eye movements. This process is a function of different amounts of retinal exchanges during head movements accomplished in the same orientation of the relative distance (Wallach, 1987). It may have cooperated with other sources of information specifics to the spatial dimension, whose efficacy diminished with increasing absolute distance (Cutting & Vishton, 1995).

For the results found, it can be justified to segregate our visual scenes into two main dimensions, a radial or depth dimension and a width or horizontal one. The perceived versions of these two spatial dimensions could be characterized by different observer processes, whereas, for depth dimension, observer's tendencies are critical, and for horizontal dimension, a retinal framing phenomenon, the compensatory processes, is critical. Our findings were in agreement with others found by Loomis and associates (1992).

A second factor that allowed the intrusion of non-perceptual processes was the perceptual attitude induced on observers through instructions. The present investigation used objective instructions that can be better described as the observer judged the distance trying to provide equivalence between physical distance and his percept, thus allowing verbal reports of size and distance influenced by cognitive processes. In our experimental conditions, verbal judgments of spatial dimensions were generally inaccurate, and this is likely to be a characteristic of *perceived layouts,* due to the large number of sources of visual information implied in these environments. Biederman (1972) identified nine sources of information that can integrate to each other and produce cue conflicts, thus modifying distance judgments in an invariant way (as the pictorial sources of information) or in a variable way with efficacy diminishing with increasing absolute distance (as binocular sources of information).

Summarizing, the analyses of perceived spatial dimensions from different perceived layouts, produced by the combination of all factors, observation points and viewing conditions, showed a critical effect of visual angle in the pattern of perceived distances: the larger the visual angle, the more accurate was the perceived distance. This visual angle was a main determinant factor for perceived distances (Haber, 1985). Another main finding was the intrusion of high-order factors in judgments of relative distance for observation point 36 m away from the center of layout, expressed by the larger undershooting in distance judgments, a pattern not observed in proximal condition (23 m away from the center of layout).

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