Depth Cues Changes Circle Size Judgment Measured by Psychophysical Scaling

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Abstract: The aim of our study was to investigate whether different circle sizes, in conditions of pure size judgment and in a simple contextual judgment with an interfering depth suggesting background, produce different size perceptions. We used the magnitude estimation to obtain the apparent size of circles under two different experimental conditions: with a neutral black background and with a convergent gradient to generate an artificial horizon to evoke depth cues. Twenty-two subjects with normal or corrected-to-normal visual acuity (mean age = 21.3 yrs; SD = 1.6) were tested. The procedure consisted of two gray circles at luminance of 40 cd/m2, separated 10 degrees of visual angle apart from each other. On the left side was always present the reference circle (visual angle of 1.1 degree) in which was assigned an arbitrary value of 50 was assigned. The subjects' task was to judge the size of the circles appearing in the right side of the monitor screen assigning a number proportional to the perceived altered size, relative to the reference circle. Seven different sizes (0.6, 0.8, 1.0, 1.1, 1.3, 1.4, 1.5 degrees) were presented in each condition. Our results have shown a high correlation for circle size and depth conditions (R = 0.987 and R = 0.997) between the logs of the stimuli and the subjective magnitude estimated values. The exponents obtained by the Power Law were 0.79 and 1.09, respectively to each condition. Additionally, a gender effect was observed in which males had showed an expansive perception of size with no dependence on the background. We concluded that in the induced depth condition, the perception of the circle sizes were judged subjectively closer to their respective physical size than in the condition of free visual cues. Our data reinforces the integrative manner of perceptual system when working with the sensory information.

Keywords: Depth perception, magnitude estimation, size judgment, p psychophysical scaling, spatial vision.

INTRODUCTION

The human visual system can take viewing distance into account when judging apparent size. It is interesting to note that the shape and the size of objects are judged independently but both are also under influence of the distance presented [1, 2].

Studies investigating the environmental, physiological and mental functions related to these perceptual variances were performed generating two opposite hypothesis. The moon size illusion is one of the many phenomena related with the apparent size changes in different surrounding contextual seeing situations [3]. In this illusion, the size of the moon appears bigger when it is viewed near the horizon and smaller when it is at the top of the sky. Previous explorations were based on the retinal images and spatial code interactions and led the authors suppose that spatial coding mechanisms modulate the retina output [4] and in the absence of contextual references the retinal circuity had less information to compare spatially and the output to the visual cortex were biased. On the other hand, other study found that environmental size is determined prior to the mental scaling suggesting that the subjective size of moon is built up in higher perceptual levels [5].

Interesting results were obtained in a study where the relative sizes of objects were judged in different high positions. As a main result, the horizon is a strong reference in judging the relative sizes of the objects supporting the second hypothesis presented [6]. Also a previous study shows that background texture could modulate the size perception for motion stimuli [7].

In visual arts, the inductions of depth and of the relative distances are based not only on backgrounds inducing depth but also in size changes of the painting elements among other pictorial cues [8]. These findings suggest that the sizes are based on the input computation of spatial cues and could be explained in terms of spatial circuitry presented in lower levels of sensation mechanisms.

Despite the absence of a consensual mechanism supporting the size judgment, some interesting results could be added as important information to this issue. Subjective scaling of white circle sizes in a black background was

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performed by Stevens [9]. He found a Power Law exponent of 0.7 for a square size, suggesting a not very good size perception which, in this case, meant a perceptual change of 3.5 times when the physical size changed 6 times. However, there are no studies calculating the magnitude perceived in contextual conditions.

Since the measurements previously performed have shown an underestimation of the size without visual cues, we aimed to measure the Power Law exponents under depth induced by a convergent background. We hypothesized that small changes in the perceptual magnitude (Power Law exponent) with the background present could be more related to a simple circuitry processing at lower levels of visual system. Instead, bigger changes in the perceived size would suggest a more perceptual, higher level, visual processing.

METHODS

Subjects

We evaluated 53 volunteers with a mean age of 21.3 years (SD = 3.1 yrs; 28 females), recruited among the students of the University of São Paulo. Inclusion criteria were best-corrected visual acuity of 20/20 or better measured monocularly at 4 meters using an ETDRS chart - tumbling E (Xenonio, Sao Paulo, Brazil), refraction of ≤ 3.0 diopters considering the spheric equivalent of astigmatism values, absence of ophthalmological diseases and absence of known neurological and systemic diseases.

All subjects gave a signed informed consent to participate in the experiment. All were naive to the specific experimental question. This study is also in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and was approved by the local Ethical Committee (CEPH-IPUSP 240.412; 26/11/2012).

Equipment and Procedures

The stimuli were generated by the software MatLab version 7.8.0 (R2009a, The MathWorks Inc., USA) installed in a PC computer. The stimulus consisted of two circles with gray , luminance of 40 $cd.m^{-2}$; separated 10 degrees apart from each other. On the left side was the reference circle (visual angle of 1.1 degree of visual angle at 50 cm) presented in a LED screen. Seven different circle sizes (0.6, 0.8, 1.0, 1.1, 1.3, 1.4, 1.5 degrees of visual angle) were presented.

We used the Direct Magnitude Estimation (DME) to assess the subjective magnitude related to the differences between the circle sizes. The DME method was developed by SS Stevens [9, 10], in which numbers are directly addressed to the subjective magnitude regarding a stimulus presented. The relation between the subjective magnitude and the physical manipulation of the stimulus can be expressed by the Power Law function:

$\psi = K\varphi^n$ (Eq.1)

This means that the magnitude estimated ψ grows as the physical φ raised to a power of n.

Direct Magnitude Scaling (DME) is a very simple procedure and consists of arbitrarily associating a number to a particular dimension, in our case, the circle size. The subject task was to judge the next dimensions relating then to the first dimension, adjusting the number to match their impression. If the first dimension was numbered as 10 and the second dimension appears to have three times more sensation, the subject have to give a corresponding number, in this case 30. For more detailed explanation regarding the method see [9, 11].

A preliminary training session was performed for each subject to guarantee that they had understood the procedure and would be able to perform it. The preliminary training consisted of a DME procedure in a task of judging the line length in a series of ten lines. As expected by the study of Stevens & Harris [11], all subject performed these judgments satisfactorily which means a Power Law exponent of 1.0 (data not presented in this paper). The line length judgment is a simple task that can be performed for any subject and the exponent obtained must be around 1.0. This previous training is recommended when the subjects were not experienced in that psychophysical task or when the dimension under judgment is more abstract.

In the test session, the reference (modulus) circle was chosen as the gray circle with size of 1.1 degree and it always appears in the left side of the screen. To make the ratio judgment possible, an arbitrary number of 50 was associated to the reference size. The subjects were instructed to look at the center of the screen and compare the circle size presented in the right side of the screen with the modulus circle by giving a number corresponding to the magnitude of their impression of the circle size difference. The subjects were instructed to be as precise as they can which means that they could use fractions or decimal numbers. The circle sizes were randomly presented and the geometric mean of two presentations was used as the subject judged values.

The subjects randomly performed the circle size judgment in two different conditions: free background condition in which the background of the screen was totally black (Fig. **1A**) and in the condition of a convergent lines texture gradient to induce the depth perception (Fig. **1B**).

In the depth perception condition, the subjects were instructed to make the circle size judgment and not a distance or depth perception judgment that could appear in some situations.

Statistical Analysis

Statistical analysis was performed with the software Statistica (v11. StatSoft Inc. Tulsa, USA). Statistical differences were verified by a Repeated Measurements ANOVA considering the dependent variables the background condition and the gender and the independent variable the Power Law exponents. A Pearson-Moment Correlation was used to verify the relationship between magnitude estimation values and the physical circle size.

RESULTS

All subjects performed the two conditions satisfactorily. For the circle size judgment free of background we measured an exponent of 0.79 with a significant positive correlation ($r = 0.974$; $p < 0.001$). In the condition with the textured background the exponent measured was 1.09 ($r = 0.999$; $p < 0.001$). The power functions and the correlation coefficients are shown in Fig. (**2**).

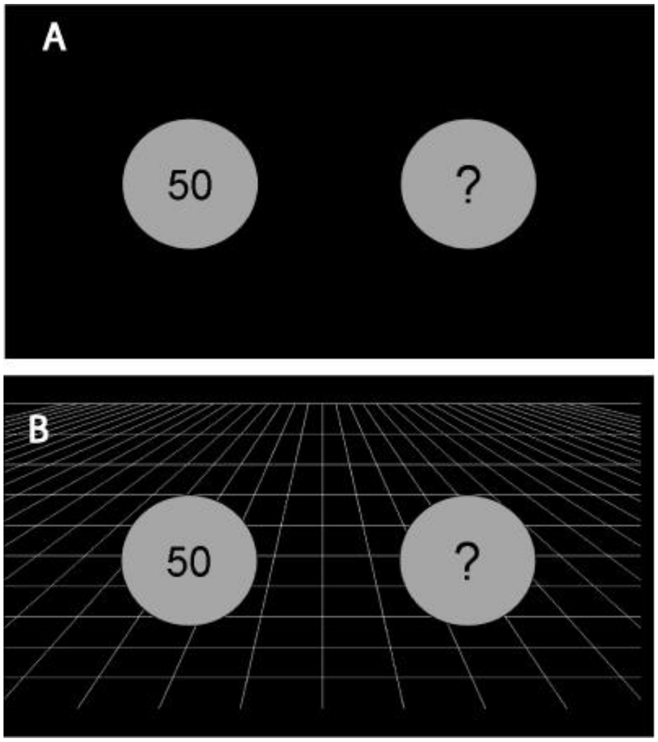

Fig. (1). Screen view from the subjects' point of view showing the stimulus conditions without (**A**) and with background (**B**). The left circle was the modulus and was associated with a reference number of 50. The subject's task was to give a number representing the magnitude of the size change in the right circle.

Gender differences in circle size scaling were analyzed. Significant differences were found between genders for the scaling exponents (F = 16.7, p = 0.002). We also found differences when comparing the exponents obtained with different background conditions. In the no background condition the exponent of magnitude scaling of males was 1.67 and females was 1.21. Similar result was found with background condition, in which the exponent measured for males, 1.33 is significantly different from those of females, 0.86. The statistical significance comparing the background conditions was F = 29.85, p < 0.001 (Fig. **3**). However, no interaction effect was observed between gender and background condition.

Intra-subject variability was evaluated by a Pearson-moment correlation coefficient obtained for each gender between the judgments in those background conditions. The correlation coefficients are presented in Table **1**.

DISCUSSION

Contextual information as the background texture could induce the perception of depth in pictorial images. The relative size of objects also induces depth perception. Thus, a reasonable question is whether the texture could influence the size judgment by inserting a depth cue in the visual context. We have investigated the effect of the background texture in the relative size of circles measuring their subjective magnitude for two conditions – with and without depth cues in the background. Our results show a significant change in the circle size judgment approaching the perceptual size to the physical size with a little

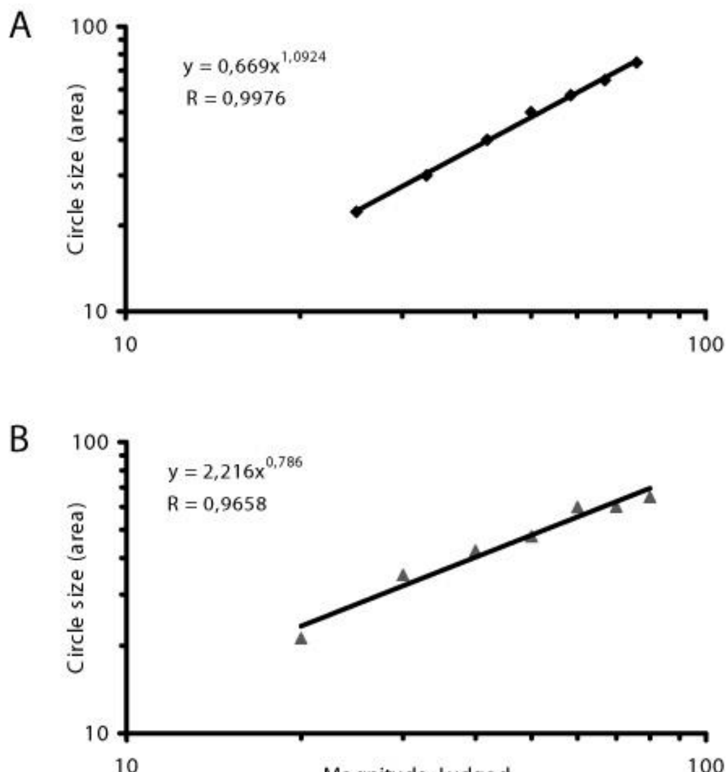

Fig. (2). Psychometric functions of the power law obtained for the two viewing conditions. Without background the exponent was 0.79 with a high correlation coefficient (r = 0.965) and with background inducing depth the circle sizes judged follow a magnitude of 1.09 (r = 0.997).

Table 1. Pearson correlation coefficient for intrasubject viriiability.

	Male	Female
No Background	r = 0.997	r = 0.997
	P < 0.001	P < 0.001
No Background	r = 0.996	r = 0.998
	P < 0.001	P < 0.001

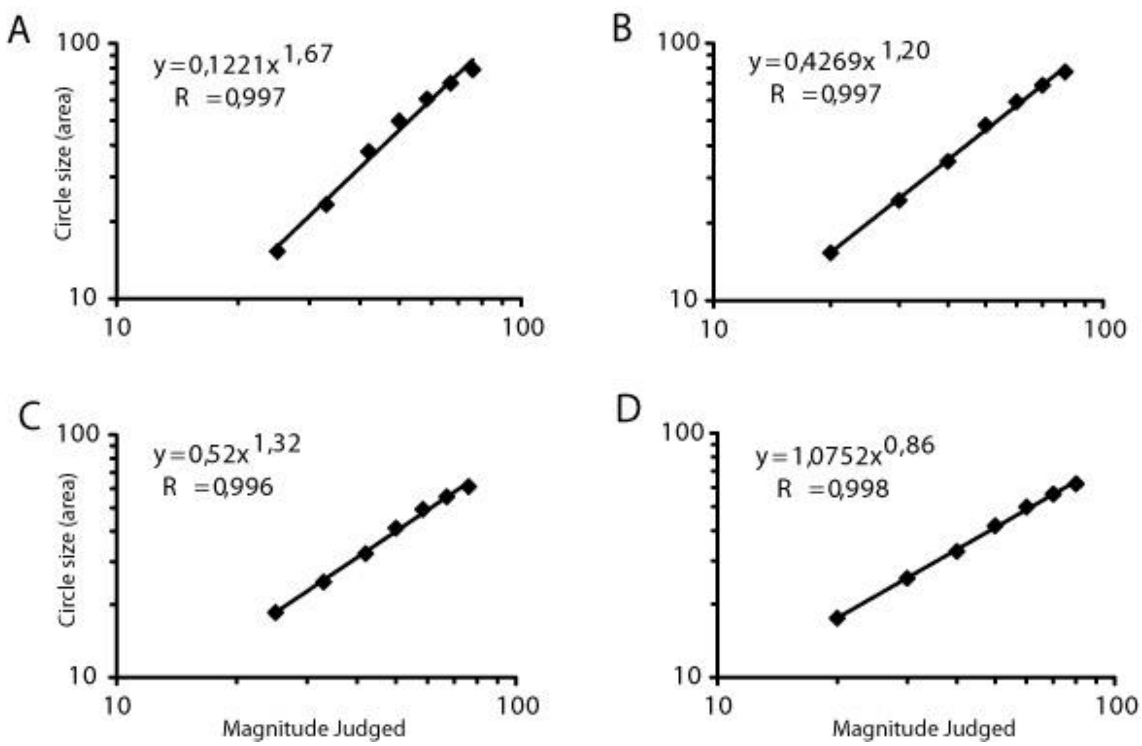

Fig. (3). Gender differences found for both stimulus conditions. Males showed an higher expansive perception with no background (**A**) than with background (**C**) Females also had an expansive size perception without background (**B**) but, differing from males in the background condition, they showed a compressive perception (**D**).

overestimation, evidenced by a change in the exponent value from 0.79 to 1.09. The exponent of 0.79 obtained in the background free condition means that the physical size of the circle increases, for example, 6 times and the perceived circle size increases about 4.1 times. In the depth induced background the exponent goes to 1.09 which means an increase of 7 times in the perceptual size at a 6 time increase in the physical size meaning a very close approach between the physical and the perceptual sizes.

An interesting study found that the width and the height of a cylinder with depicted texture demonstrates an illusory shrinkage with the change of a depth cue [12]. This result is, in some sense, in line with our study since it showed that depth cues may determine the size of 3D elements. In our study, we found that the depth cue changes the perceptual size of circles in an improving fashion , approaching the perceptual size to the physical size. One explanation for our results is that the background texture creates a slant. Studies found that the slants induce depth perception [13]. Another explanation based on the literature [14] could be that the sizes of objects intercepting the horizon line are jugdeg with overestimation. Since all of our stimuli intercepted the horizontal line of our texture background an increase in the perceptual size could explain the improvement in circle size judgment at the background condition.

The importance of the depth cues in size perception was investigated by Farran *et al*. [15]. In that study, the authors performed a same-different measurement for size judgment with no background and with three different depth cue conditions: height in the visual field, linear perspective, and texture gradient. They found that texture gradient had an effect on increasing the accuracy of size judgment. That result is in line with ours.

The difference in the size judgment with background texture means an increase of three times in the perceptual size which could be considered a huge change for a relatively complex contextual scene. That amount of perceptual change could not be related only to the retinal size of the image and, of course, to the retinal circuitry, but it is much more related to the perceptual process based on mental sizes. The study of Bennett & Warren [5] manipulating retinal and environmental images sizes suggests that environmental size is determined prior to mental scaling. Based on this study, our more complex scene composed by a background texture feeds the perceptual systems with enough information to recalculate the size of the circles, making circle size comparisons more reliable.

Gender differences that we found are strongly supportive for differences in the underlining mechanisms of size perception in males and females. Males showed an expansive perception of size with no dependence on the background. However, the expansiveness of males was reduced in the presence of the background. We could interpret that result as a correction for a smaller size. Females had a quite different effect. They also had an expansive perception with no background, similar to males, but showed a slightly compressive effect with background. These results suggest a strong power of the contextual stimulus adjusting the perceptual size close to the physical size which is an evidence of a more common and probably basic mechanism of apprehending sizes in contextual situations. Studies had reported invariance to spatial stimuli both for spatial frequency [16] and for spatial judgment of quantity [17]. However, independence of size and distance judgment had also been found [18]. Our results suggest that males maintain the invariance in judgment of size, even with the reduction in the expansive perception. Females, on the other hand, change from expansive to slightly compressive perception of sizes in the presence of depth texture in the background. The differences between males and females in judging sizes in contextual conditions could reflect adaptive and evolutionary differences showed by innumerous studies but not intended to be discussed here.

Visual art is a complex environment in which our brain extracts information to represent a vivid deepness of many attributes of the real world. In this sense, the study of visual arts could be a way to understand our mental structure about visual perception. Our results show a strong change in perceptual size based only on a textured background adding depth information. Color mode changes by depth cues [19] and by color perception integrating depth and form vision [20] are rich grounds in which visual perception could lean.

CONCLUSION

Perceptual sizes are changed by the introduction of a textured background inducing depth perception. Our scaling measurements found a two-fold change from an underestimated size perception to a size perception almost equaling the physical size. Gender differences were also observed in which males showed more expansive judgment of size perception than females. Males also had invariance in size judgment while females exhibited a change to a compressive perception with background.

CONFLICTS OF INTERESTS

The authors confirm that this article content has no conflict of interest.

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