SPATIAL AND CHROMATIC DEPENDENCIES ON VISUAL REACTION TIME (*)

E. HITA, J. L. GÓMEZ, L. JIMÉNEZ DEL BARCO, J. ROMERO

SUMMARY: In this work, the visual reaction time has been analyzed as a function of two experimental parameters: size of the field and chromaticity of the stimulus. With regard to the first one, field sizes of 0.72, 1.25, 2, 3.5, 5 and 7.5 degrees were studied. The results show that reaction time decreases when the field size increases, also for values above the limits of Ricco's law. On the other hand, the reaction time was measured for chromatic stimuli with dominant wavelengths at 472, 500, 547, 571, 602 and 634 nm. In this case, no correlation between reaction time and chromaticity was found. The fact that these results were in agreement with those obtained for achromatic stimuli at the same luminance was analyzed in terms of color vision models, especially the opponent-colors theory.

INTRODUCTION

The influence of different parameters on response time to a luminous stimulus, or visual latency, has been widely studied by various authors whom have found diverse functional dependencies with major or minor repercussions. The multitude of factors that can affect visual latency can be grouped in three major categories: a) geometric and spatial type (retinal area affected, size and shape of the test, etc.), b) temporal factors (duration of the stimulus analyzed, temporal distribution of the incident energy...) and c) photometric (luminance of the background and the stimulus, chromaticity of both,...). Of all factors probably the most analyzed has been the stimulus luminance and it is accepted that the relation that ties both parameters is the well-known Pieron's law: \( T - T_0 = kL^b \).

Notwithstanding, recently a singular interest has been paid to the study of other parameters for reasons very different in nature. On one side has been the study of the phenomenon in itself, for a better comprehension of it, and on the other side is the analysis of the dependencies encountered with the existing visual models. This is of interest in the interpretation of the experimental dependency phenomena, and also for the confirmation of visual models through the experiments that have been done.

Along these lines, the objective of the current study lies in analyzing the influence of field size and chromaticity upon visual latency. In the experimenter's judgement, the reasons for studying these parameters are justified based on an analysis of the existing bibliography dealing with this subject.

Even though the observation field size has been studied, Hufford [1], Matin [2], Ueno [3], the obtained conclusions are limited by the retinal zones that were stimulated, in some cases, and in other cases by the small margin of angular sizes that were used. Also, given the structure of the fovea, it seems advisable to enlarge the field size trying to obtain an "optimal field" that would permit a study of other parameters independently of it. The usual understanding of "optimal field" is that which minimizes visual latency.

(*) A partial summary of this work has been presented as a poster in the VIII ECVP (Peniscola, Spain).
With respect to the dependency phenomenon on the test chromaticity, the bibliography, with being so large, leads to significant discrepancies in the results reported by different authors and also in their interpretations, which were based on different visual models. There exist experiments along these lines that indicate dependencies with the chromaticity of the stimulus utilized for the determined retinal areas that were excited, Sperling and Jolliffe [4], but also found are studies in which no such dependency is shown, Connors [5] and Mansfield [6]. With respect to the interpretation of Stiles [7] experiments, they are explained based on the Young-Helmholtz theory, while the Sperling and Harwerth [8] and King-Smith and Carden [9] results rely on the opponent colors theory to find a satisfactory explanation. Whichever the case, the experimental results of these authors were obtained from diverse experiments based on obtaining intensity thresholds.

The pointed out disparities in results are sufficient, in our opinion, to justify the analysis of this problem under a new experimental point of view different from those used by other authors. In the first place the current experiment will be conducted under suprathreshold luminance, which seems to be most like the everyday experience which is what is trying to be interpreted. In the second place, the inhibitory effect of the adaptation field suggests realizing experiments where it isn't utilized, King-Smith and Carden [9].

The objective of the current experiment is double, first to study the dependency of visual latency with the field size on foveal excitation and for fields up to 7.5°, which guarantees a wide foveal sampling, and second to analyze the possible chromaticity-visual latency dependency utilizing six dominant wavelengths for fields of 43' and 2°, which will translate into a more simplicity of conditions than that used by Sperling-Jolliffe [4] and Mansfield [6].

For that, an experimental study of both parameters for different luminance values has been performed which also permitted to verify the validity of Pieron's law for the different test sizes and chromaticities.

**EXPERIMENTAL DEVICE AND METHOD**

**Apparatus**

The instrumental device fundamentally consists of two parts which are as independent as possible: one corresponds to the observer and the other to the experimenter. To exclude the observer from any type of control over the stimuli production system and to avoid tactile effects, Le Grand [10], he was placed in a contiguous room and used a sordine that isolated him acoustically. For the stimuli presentation, a box with white painted internal walls was constructed which had only one exit to the exterior which consisted of a diaphragm with an aperture adjustable between 40' and 7.5°. As luminance source an incandescent lamp was used, and at the exit a ground glass was used to homogenize the field. Finally, a small red luminous sign was used as a fixation point, and a chin-rest permitted to control the retinal zone that was to be stimulated. Used to control field luminance were neutral filters and two polarizers whose relative position could be modified by turning one of them.

The response times were measured by a chronometer with three entrances: one for starting, another for stopping the stimuli which was at the disposition of the observer, and a final switch to reset the chronometer which could be used by the experimenter. The oscillation frequency was adjusted to 1 KHz which gives a 1 msec sensitivity.

A double relay allowed the initiation of the luminous stimulus and also started the chronometer, in such a way that the time difference between them remained constant. To calculate this time difference, the quicker relay contact was connected to "start" on the chronometer and the second contact to the "stop". This showed that the luminous stimulus started 2 msec before, and the zero error was easily corrected.

Measurement of stimuli luminance was done by an EG & G photometer. To select and calibrate the stimuli chromaticity, filters were chosen that represented a large sweeping of the visible spectrum and also which had a high degree of saturation. Table 1 shows the colorimetric characteristics of the chromatic stimuli employed, refered to the 1931 CIE system.

<table>
<thead>
<tr>
<th>Dominant Wavelength (nm)</th>
<th>Excitation Colorimetric characteristics of the chromatic stimuli</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Purity, S, L.</td>
</tr>
<tr>
<td>472</td>
<td>0.95, 0.44, 0.61, 0.97, 1.00, 1.00</td>
</tr>
<tr>
<td>500</td>
<td>602, 634</td>
</tr>
</tbody>
</table>

**Planning and development of the experiences**

Three observers well trained in this type of experiment were used for the trials. All observers had normal vision with the exception of corrected ametropias. The Ishihara 1973 edition, Perales et al. [11], demonstrated no chromatic anomalies.

After a 15 min dark adaptation period, given the stimuli luminance level, and after large series of preliminary trials, the session was started. The stimulus was exposed until detected by the observer who shut it off by means of a switch connected to the "stop" on the chronometer. Once the reaction time was recorded and the chronometer reset, the experimenter proceeded to present a new stimulus. To avoid the possible effect of fatigue on the measurements for a determined field size and chromaticity, series of 27 trials for each determined luminance value were done, and after the sequence of the series for the different luminance values were repeated in the reverse order. Eliminating the two highest and lowest reaction time values for each serie, 50 data for each case were obtained. The time between stimulus presentations was variable with an average time of 3.5 s, also variable was the time between each of two series due to the interruption of modifying the filters and controls of the apparatus for the next sequence.
Data analysis

Following the described manner for each chromaticity or field size, 7 or 8 visual latency values corresponding to the different luminance values were obtained and they are the arithmetic averages of 50 determinations. The data thus obtained were adjusted to the expression given by Pieron’s law, verifying, in each and every case, that this type of dependency made maximum the correlation coefficient in respect to the other trials (exponential, logarithmic, etc.). The adjustment procedure used was that of minimum squares with asymptotic reaction time “$T_\infty$” as the parameter, figure 1.a.

Figure 1.b shows the results obtained for one of the observers, and the error bars at the 95% confidence level are included for each value. These error bars were calculated after testing that the measurements followed a normal distribution (Kolmogorov-Smirnov test), by the formula:

$$I = \left( \bar{x} \pm Z_{\alpha/2} \frac{\sigma}{\sqrt{n}} \right)$$

where $\bar{x}$ is the average value, $\alpha$ is the significance level, $Z_{\alpha/2}$ is the area under the standard normal curve, $\sigma$ is the standard deviation and $n$ is the number of data.

The dashed curves in figure 1.b limit the confidence area, at the 95% confidence level, of the adjusted curve. For each of the luminance levels analyzed, the value of the reaction time and its error have been taken from the curves obtained in each experimental case.

In order to facilitate graphic representations, the luminance values are shown in the logarithmic form with respect to the value $L_0 = 0.5 \text{ mFL}$ (L (dB) $= 10 \log L (\text{mFL})/L_0 (\text{mFL})$), Mansfield [6]. Either the analysis of the dependency of the reaction time with the field size or with the chromaticity of the test, figures for $L = 58 \text{ mFL}$ and $L = 0.05 \text{ mFL}$ are only included.

RESULTS AND DISCUSSION

Field size

In this part the dependency of the reaction time on the field size was studied. The objective was double, first to amplify the range of the study to 7.5°; second to extract information about the distribution of photoreceptors in the fovea, particularly the cones which are apparently the most important in these trials, Gouras [12], Hansteen [13].

The subtended angles for the achromatic stimuli utilized were 0.72, 1.25, 2, 3.5, 5 and 7.5°. The evolution of the reaction time with the stimulus luminance for the different test sizes follow very similar potential curves confirming that visual latency follows this type of dependency, independently of the field size.

Figure 2 shows two examples of the evolution of the reaction time with field size under constant luminances. In these and the other cases not shown, a decrease in reaction time when the subtended visual angle increases can be observed, a decrease that is less significant when working with elevated luminance.
values. It seems interesting to point out that the reaction time continues to depend on the retinal area stimulated even when this strongly surpasses the limits established by Ricco's law. This can be easily seen if the difference between the average values for the visual angles 0.72°, 3.5°, and 7.5° are determined together with their intervals of error at the 95% confidence level.

These results, shown in table II, were calculated by the formula:

\[ I = \left( \bar{x}_1 - \bar{x}_2 \right) \pm Z_{\alpha/2} \sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}}. \]

**Table II**

<table>
<thead>
<tr>
<th></th>
<th>Differences between means corresponding to different field sizes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>L = 58 ftL</strong></td>
<td>( \bar{x}_1 - \bar{x}_2 ) ± 15 ± S ( \bar{x}_2 - \bar{x}_3 ) ± 9 ± S ( \bar{x}_1 - \bar{x}_3 ) ± 24 ± S</td>
</tr>
<tr>
<td><strong>L = 0.05 ftL</strong></td>
<td>( \bar{x}_1 - \bar{x}_2 ) ± 27 ± S ( \bar{x}_2 - \bar{x}_3 ) ± 17 ± S ( \bar{x}_1 - \bar{x}_3 ) ± 44 ± S</td>
</tr>
</tbody>
</table>

(*) \( \bar{x}_1, \bar{x}_2 \) and \( \bar{x}_3 \) are the means for the three observers and field sizes of 0.72°, 3.5°, and 7.5° respectively.

The attempts to adjust the experimental data to a simple theoretic curve have been deficient. A generic curve, using the absolute threshold of \( Lx^\alpha \) = constant, was tried. In this expression \( L \) is the stimulus luminance, \( \alpha \) is the subtended angular size for the field and \( k \) is the exponent that varies according to the range in which \( \alpha \) is done. Given that the visual system needs the spatial integration of the critical energy so that the stimulus can be detected and recorded in the chronometer, a type of dependency similar to the threshold detection energy was expected. Notwithstanding, no \( k \) value was found that could be generalized since this value varied with the aperture ranges and with the observer. This result should be expected if one considers the large number of factors that influence the measurement of reaction time, and also the suprathreshold character of the experiment.

Another point of view is that no simple curve might exist that can be adjusted to these experimental results. This wouldn't be unusual if one considers that the retinal zone studied is not homogenous, and has an appreciable decrease in cone density and an increase in rod density when we move away from the central foveal zone. Given that the luminance levels utilized are sufficient enough to stimulate the cones, and also taking into account results obtained by aforementioned authors, Gouras [12], Hansteen [13], it should be considered that the cone photoreceptors are responsible for the visual response. The decrease in cone density, and the possibility that their contribution is modulated by some type of potential dependency on the distance from the centre of the fovea (Matin [2], Graham, Brown and Mote [14]) could explain the observed dependency between reaction time and field size, which is less abrupt when the target size increases. Also for the larger fields, a slight dazzling appears for high luminance values, which could explain the final "irregularity" in some of the graphs.

In any case, the graphs are sufficiently significant to accept that for increasing values in the test size, those above the valid limits of Ricco's law, decreasing reaction times were obtained. This fact indicates the necessity to accept some type of summation when above Ricco's critical area.

On the other hand, the irregularities encountered in the graphs as to apertures 1° and 5° can be explained.
based on the distribution of photoreceptors in the fovea. The estimated limits for the fovea and foveola, 5° and 54°, respectively, coincide with the sizes of the subtended angles when the curves become more irregular. Nevertheless, as can be observed, the differences mentioned fall into the error bars which suggests that these irregularities only can be considered significative in the sense that they appear for all the observers.

**Stimulus chromaticity**

In the second experiment the reaction time dependency on the stimulus chromaticity was analyzed. Dominant wavelengths of the chromatic stimuli were 472, 500, 547, 571, 602 and 634 nm, and the average value for the three observers of the achromatic stimulus was introduced for comparison purposes. For these stimuli, the reaction time was obtained under constant luminance values of 0.002 fL, 0.05 fL and 58 fL, the same way as in the previous experiment. From the obtained results for field size, it was decided to use two apertures for this second phase, one 43° located in the central fovea and a 20° that extended to a more wide region of the fovea.

Analyzing the achromatic stimulus results in relation to the evolution with luminance, we fixed our interest of studying the low and intermediate luminance value zones, thus reducing the number of data points, which correspond to the asymptotic zone of the curve, which as can be noticed in figure 1, b was almost flat.

Observing the figures 3 and 4, that correspond to the two fields (43° and 20°), the results are similar and they seem to point out that the rods do not intervene in stimuli detection. Also for the 20° field reaction times were smaller when the luminance and wavelength of the stimuli are the same as those in 43°. This could be due to the spatial integration extending to a wider zone of the retina and confirms the obtained results in the previous section with achromatic stimuli.

**FIG. 3.** Reaction time as a function of chromaticity of the test with field size of 0.72° and luminance values L = 58 fL (a) and L = 0.05 fL (b). Together with the data for the three observers, the average values for the different chromatic stimuli (+---+) and for the achromatic stimulus (---) are shown.

**FIG. 4.** Reaction time as a function of chromaticity of the test with field size of 20° and luminance values L = 58 fL (a) and L = 0.05 fL (b). Together with the data for the three observers, the average values for the different chromatic stimuli (+---+) and for the achromatic stimulus (---) are shown.

In figures 3 and 4 are the reaction time values in function with the dominant wavelength, using as parameters the stimulus luminance and angle size subtended for the field. The general conclusion that can be drawn from analyzing these data is that no systematic tendencies exist in the evolution of reaction time in function with the dominant wavelength employed. Also there are no significant differences in reaction times obtained for chromatic stimulus as compared to achromatic stimulus.

It is difficult to explain these results based on Young-Helmholtz color vision model; it would only be possible by admitting that the transmission velocity of the signals emitted by each type of photoreceptor
is the same. This explanation is not plausible if other works in this field are considered. Boynton [15] showed that the transmission of information proceeding from "blue" photoreceptors arrived in the brain with a major delay as compared to the other types of photoreceptors. Other experiments, by King-Smith and Carden [9], using a white adaptation background or a total darkness adaptation demonstrate a different degree of adaptation to white for each type of cones, which explains the different sensitivity curves obtained in each case. In consequence to these difficulties, it is easier and more reasonable to accept that the visual detection process can be analyzed in terms of two parallel systems, luminance (achromatic) and opponent colors. The stimulus would be detected when its energy exceeds the threshold of one of the two systems. This way our detection system has access to the luminance signal and the opponent color ones of Hering's theory. Kelly and van Norren's [16] experiment clearly shows the existence of these types of channels and also give valuable information about their characteristics. Based on these experiments and those by King-Smith and Carden [9] it seems reasonable to conclude that in our experimental conditions the visual detection was realized by the luminance channel. Given that the sensitivity curve of this type of visual detection practically coincides with the sensitivity curve of the eye, therefore the logical conclusion is that the reaction time, for a chromatic stimulus and would be equal to times obtained for achromatic stimulus of equal luminance. Consequently, the current results can be explained based on this model and at the same time confirm this model when treated as a different type experiment than those realized for the study of the visual models.

Here it should be pointed out that the Sperling and Jolliffe's [4] experiment was one of the motives of doing this experience. In that work the absolute detection threshold were measured, and the experimental conditions favored the actuation of chromatic channels. The 450 nm stimulus was more effective than the 650 nm one, due to the higher chromatic channels sensitivity for the first wavelength. Beside that, in King-Smith and Carden's [9] study is demonstrated that the luminance channel sensitivity increases with the decrease in the dimensions of the stimulus. This could explain that Sperling and Jolliffe [4] found a dependency of the 43' foveal target on the wavelength, and that is not appreciated for the 4.5' case. The last could also explain the systematic tendencies observed in figure 4.b, where the "low" value of the luminance and the field size (2') are near to the experimental conditions required for the chromatic channels action.

REFERENCES