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# Visual Reaction Time as a Function of Locus, Area, and Complexity of Stimulus

Antonio Tartaglione, Emilio Favale, and Arthur Benton

Clinica Neurologica dell'Università, I-16132 Genova, Italy, and
Department of Neurology, University of Iowa, Iowa City, IA 52242, USA

**Summary.** Reaction time (RT) of normal subjects to square-wave gratings of two different frequencies were related to locus of presentation, area, and stimulus complexity. Each frequency was presented to either side of the horizontal meridian (half size stimulus) or both sides simultaneously (full size stimulus). The two different frequencies were also flashed simultaneously to both hemifields (compound stimulus). Stimulus position affected RT with the 1 c/deg stimulus, RT being faster for the lower hemifield. With presentation on both sides of the horizontal meridian simultaneously or of the two spatial frequencies, the resulting RT was equal to that of the faster component. Implications of the results for the functional organization of the visual system are discussed.

**Key words:** Visual reaction time – Parameters of visual stimulation – Visual field – Upper versus lower hemifields.

**Zusammenfassung.** Reaktionszeiten gesunder Versuchspersonen nach optischer Kontraststreifenreizung mit zwei verschiedenen Ortsfrequenzen (1 und 3 Perioden/Grad) wurden nach Ort, Größe und Komplexheit des Reizes verglichen. Jede der Ortsfrequenzen wurde entweder nur im oberen oder unteren Gesichtsfeld dargeboten oder aber in beiden Halbfeldern gleichzeitig. Außerdem wurden beide Reize gemeinsam in beiden Halbfeldern appliziert. Die Reaktionszeit wurde durch den Reizort bei einer Ortsfrequenz von einer Periode/° Reiz beeinflußt, mit kürzeren Reaktionszeiten im unteren Halbfeld. Bei gleichzeitiger Reizung im oberen und unteren Gesichtsfeld mit derselben oder verschiedenen Ortsfrequenzen entsprach die Reaktionszeit derjenigen der schnelleren Komponente. Ausdehnung und Komplexität hatten nur geringen Einfluß.

Die Bedeutung der Ergebnisse für die funktionelle Organisation des Sehsystems, für Asymmetrien der Gesichtsfelder bei Teilfeldreizen und für pathologische Veränderungen wird diskutiert.

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**Schlüsselwörter:** Reaktionszeit – Gesichtsfeld – Obere und untere Gesichtsfeldteile – Reizparameter.

## Introduction

In neurology, the recording of visually evoked potentials is now a routine method for the diagnosis of multiple sclerosis and for objective perimetry. Visual reaction times are used rarely for neurological diagnosis but it may be of interest to the neurologist to compare the dependence of the reaction times on various stimulus parameters with evoked potential latencies.

It has long been known that simple visual *reaction time (RT)* changes as a function of the position of the stimulus in the visual field. This is true not only of RT differences between the central and peripheral retina but also of differences between the nasal and temporal hemiretina (Berlucchi et al., 1971; Maddess, 1975; Mansfield, 1973; Payne, 1966; Rains, 1963). It has also been found that RT to unpatterned flashes varies according to whether the lower or upper hemifield is stimulated, RT to stimuli in the lower hemifield being faster than those to stimuli at corresponding points in the upper hemifield (Payne, 1967). Although direct evidence is lacking, this difference in sensorimotor performance probably reflects a general asymmetry of function between the upper and lower hemifields. The demonstration by Julesz et al. (1976) of perceptual differences between the upper and lower hemifields supports the idea. Their results also indicated that such anisotropy of function is related to the particular stimulus conditions employed and that the relationship between RTs to stimuli presented in the upper and lower hemifields may change as a function of the stimulus. Thus it is possible that the RT difference between hemifields shown by unpatterned flashes may disappear or even reverse if other visual parameters are manipulated.

With these considerations in mind, we investigated RT differences between the upper and lower hemifields to patterned visual stimuli. It has been demonstrated (Breitmeyer, 1975; Lupp et al., 1976; Tartaglione et al., 1975; Vassilev and Mitov, 1976) that RT to a brief presentation of gratings depends on their spatial frequency, its variation closely paralleling more direct measures of visual performance such as contrast sensitivity. The frequency which corresponds to maximal perceptual sensitivity produces the fastest RT, as can be seen by comparing RT data (Breitmeyer, 1975) with the sensitivity curve for the detection of briefly presented gratings (Kulikowski and Tolhurst, 1973; Nachmias, 1967). Thus grating patterns of different spatial frequencies were flashed to either hemifield to determine whether RT to spatial properties of the stimulus could be modified by the position of patterns in the visual field. Given the close relationship between speed of motor reaction and perceptual sensitivity, any positional effect on RT to such stimuli would support the existence of differences in visual processing corresponding to either hemifield.

Finally, given the possibility that RT measures would reflect a functional difference of structures related to the two hemifields, it seemed pertinent to investigate how the simultaneous activation of both hemifields would affect motor performance. Such a test could provide data relevant to the question of whether information from either hemifield is transferred to the motor system through separate channels or whether an interaction among them, such as summation, occurs. If energy summation occurs at any stage of the processing, as some data suggest (Teichner, 1954; Teichner and Krebs, 1972), RT to the compound pattern should be significantly faster than to any of the components. On the other hand, if coded messages are processed independently at a visual stage and separately transferred to the motors areas, RT to a combination of the two signals should be equal to the faster component. For that reason, RT to the simultaneous presentation of the same or different spatial frequencies to the upper and lower hemifield was also measured.

## Method

### *Stimuli*

Grating stimuli with square-wave luminance profiles were prepared and tachistoscopically presented according to a previously described technique (Tartaglione et al., 1975). Five different stimuli were employed, all covering a square area of 2° × 2° at a viewing distance of 75 cm. Two stimuli, which shall be referred to as half size (HS) stimuli, consisted of 1 c/deg and 3 c/deg frequencies respectively, presented above the horizontal meridian while the lower half-field was left unpatterned, its average luminance matching as closely as possible the mean value of the patterned area. In the other three stimuli, the pattern extended symmetrically on both sides of the horizontal meridian. The full size (FS) stimuli were obtained by extending each of the HS stimuli into the lower hemifield. The third pattern, the compound stimulus (CS), was a combination of the two HS stimuli, 1c/deg being in the upper half and 3 c/deg in the lower half. (Although the broad bar stimuli present only one or two cycles in all combinations, they are designated as gratings of 1 c/deg spatial frequency.)

On half the trials the stimuli were presented as described above, on the other half they were presented upside down. Thus on half the trials the patterned area of the HS stimuli was presented below the horizontal meridian, with the higher frequency of the CS stimulus appearing in the upper half of the stimulus and the 1 c/deg in the lower half. The first configuration will be referred to as the not-inverted presentation (NIP) to be distinguished from the inverted presentation (IP) of the same stimuli.

The fixation field, whose luminance and color were adjusted to equal the space average luminance and color of the stimuli, was used as a pre- and post-exposure field. It consisted of a gray card with a black dot in the center of a square defined by four corner brackets. Each side of the square subtended 2°.

The stimuli were exposed for 50 ms. The contrast between horizontally placed bars was set at 0.37. The average luminance of both the fixation and the stimulus field was set at 1.5 ft. lambert. The luminance of the fields was repeatedly measured during each experimental session in order to compensate for possible variations in the performance of the fluorescent bulbs. Changes occurring during an experimental session were found not to exceed ±0.05 ft. lambert from the pre-set value.

### *Procedure*

The subjects were 11 righthanded University students (10 males, one female) with normal acuity and phoria. The subject was seated before the tachistoscope with his head resting against the viewing hood. The right index finger was used to press a reaction time key and stimuli were viewed binocularly. He was instructed to fixate the central dot of the fixation field and to release the key as quickly as possible whenever any pattern appeared. RT was recorded by a millisecond timer. Each subject participated in one test session which was divided into 10 blocks, five for *NIP* and five for *IP* in random sequence. Further procedural details have been previously described (Tartaglione et al., 1975).

## Results

The individual median RTs for all the stimulus conditions (each derived from 20 measures) were subjected to a treatment × treatment × subject analysis of variance. Treatment A corresponds to the modes of presentation of stimuli (i.e., NIP and IP). Treatment B refers to the different stimuli. The differences between individual pairs of means were tested through a modified "t" test as suggested by Lindquist (1953), unless otherwise stated.

The summary of the analysis and the mean scores are given in Table 1. As can be seen, both main factors proved to be significant. However, the highly significant interaction ($P < 0.001$) between patterns and their position in the visual field shows that the effect of one variable depended upon the other.

### *RT to HS Stimuli as a Function of Position and Spatial Frequency*

Figure 1 shows the results obtained with HS stimuli, presenting the RTs for each frequency on both sides of the horizontal meridian. It can be seen that RT to 1 c/deg changed as a function of its position in the field, being faster when it is presented in the lower hemifield. The difference between the means was highly significant ($t = 3.80$, $P < 0.01$). This difference in RT was shown by nine of 11 subjects. In contrast, RT to 3 c/deg patterns showed the reverse trend, RTs being faster with the stimulus in the upper field. However, the difference between the two hemifields did not reach significance ($t = 1.84$, ns). Thus motor performance seemed to depend on the hemifields only in the case of the low frequency grating.

**Table 1.** (a) Summary of analysis of variance of median RT scores for modes of presentation and stimuli

| Source of variation | *df* | ms | F |
|---|---|---|---|
| Modes of presentation (A) | 1 | 379.07 | 7.6** |
| Stimuli (B) | 4 | 426.61 | 14.2*** |
| Subjects (S) | 10 | 6846.45 | — |
| A × B | 4 | 431.07 | 9.9*** |
| A × S | 10 | 49.53 | — |
| B × S | 40 | 30.08 | — |
| A × B × S | 40 | 43.49 | — |

b) Means of median RT scores for stimuli in NIP and IP

| | 1 c/deg FS | 1 c/deg HS | CS | 3 c/deg HS | 3 c/deg FS | Mean |
|---|---|---|---|---|---|---|
| NIP | 221.43 | 229.41 | 228.89 | 226.23 | 228.06 | 226.8 |
| IP | 218.75 | 218.0 | 214.81 | 231.76 | 232.11 | 223.09 |
| Mean | 220.09 | 223.70 | 221.85 | 229.0 | 230.09 | |

** $P < 0.003$
*** $P < 0.001$

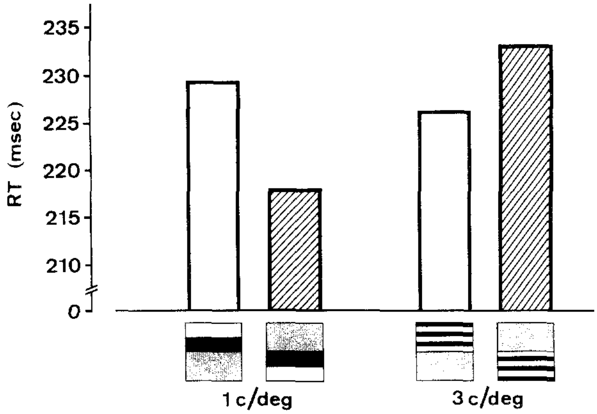

**Fig. 1.** Reaction times to HS stimuli as a function of position in the visual field for two frequencies (1 c/deg and 3 c/deg)

A further difference is seen in the comparisons of RTs to both HS stimuli when presented in the same hemifield (cf. white bars and striped bars in Figure 1). There was no significant difference between RTs to the two spatial frequencies in the upper hemifield ($t = 1.36$, ns) but the two spatial frequencies produced different RTs when presented in the lower hemifield ($t = 5.88$, $P < 0.001$). Thus in the range explored in this experiment, motor performance was affected by changes of spatial frequency only when the gratings were presented in the lower field.

### *FS vs HS Stimuli*

With respect to the FS stimuli, Table 1 shows that mode of presentation did not affect RT to either the 1 c/deg pattern ($t = 0.89$, ns) or the 3 c/deg one ($t = 1.37$, ns). Figure 2 presents the findings for the two FS stimuli. Each graph reports the mean of individual medians drawn from the pooled RT values of NIP and IP. As can be seen, the low frequency produces faster RT than the high frequency (correlated "$t$" $= 6.01$, $P < 0.001$).

Comparison of the findings for FS and HS patterns of the same spatial frequency indicates that doubling of the area did not produce any systematic change of motor performance with respect to the halved stimuli. None of the differences between HS and FS means by modes of presentation were significant for the 1 c/deg ($t = 1.34$, ns) or for 3 c/deg patterns ($t = 0.40$ ns).

Examination of Figures 1 and 2 suggests a more direct relationship between the two kinds of stimuli. It can be seen that, with respect to the 1 c/deg frequency, RT to the FS pattern was close to the value obtained for the corresponding HS pattern presented below the horizontal meridian but not to the value obtained from the same halved pattern presented above the horizontal meridian. Statistical evaluation of the differences between individual means confirmed this impression. The RT to the 1 c/deg HS pattern in the upper field was significantly different from the values obtained with FS patterns (correlated "$t$" $= 4.42$, $P < 0.01$).

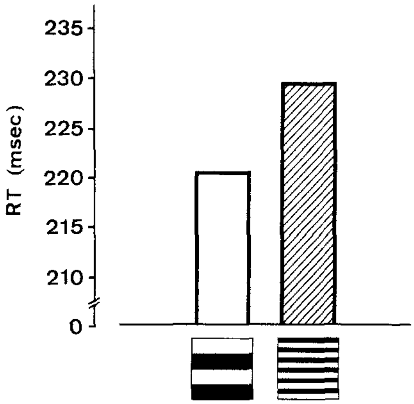

Fig. 2. Reaction times to FS stimuli as a function of frequency

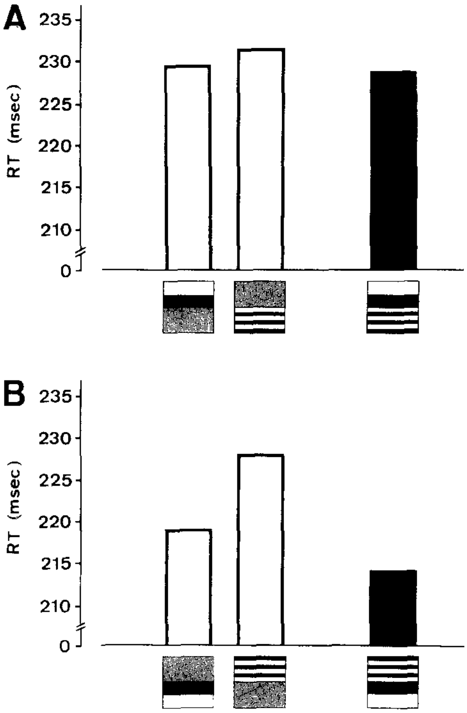

Fig. 3. Reaction times to CS stimuli (*black bars*) in the not-inverted presentation (A) and in the inverted presentation (B), compared to the reaction times to their components (*white bars*)

On the other hand, with respect to the 3 c/deg frequency, there were no significant differences between HS and FS patterns. Thus an independent role of the component halves, falling on different hemiretinas, in determining the motor performance to the FS pattern is suggested. In the case of 1 c/deg frequency, where the upper and the lower halves give rise to different motor performances, RT to the FS pattern coincides with that of its faster half. In the case of 3 c/deg frequency, where the two halves correspond to identical values, RT to the FS pattern does not differ from any of its components.

### *CS vs HS Stimuli*

Analogous findings were observed for the simultaneously presentation of different spatial frequencies to the two sides of the horizontal meridan in the case of the compound stimulus (CS). Figure 3 compares RT to CS in both presentations to the values corresponding to its components. As can be seen, in the NIP where the component frequencies do not differ significantly from each other, RT to CS was similar to the values of its two halves ($t = 0.22$, ns for 1 c/deg; $t = 0.75$, ns for 3 c/deg).

In the IP the component frequencies of the CS corresponded to significantly different RTs, the faster being the 1 c/deg frequency flashed in the lower field. As can be seen, the inversion of CS caused a significantly faster RT ($t = 4.70$, $P < 0.001$) which is similar to the value of the faster component. In this case the difference was not significant ($t = 1.36$, ns). Conversely, the RT difference between CS and its upper component, i.e., 3 c/deg frequency, was highly significant ($5 = 7.25$, $P < 0.001$).

## Discussion

The results show that RT to HS grating patterns changes as a function of the position of the stimulus with respect to the horizontal meridian. This outcome is related to the spatial frequency of the stimulus. RT to the low frequency grating was faster in the lower than the upper hemifield, confirming the findings of the study of Payne (1967) employing unpatterned stimuli. In contrast, no significant difference was found in the case of 3 c/deg patterns, although there was a trend in the opposite direction. The effect of spatial frequencies changed strikingly in the two hemifields. In the lower hemifield the two patterns give rise to significantly different motor performances, but the RT difference disappears in the upper visual field. However, it must be acknowledged that, although our findings support these conclusions, a wider range of frequencies should be investigated in order to specify the nature of the functional relationship between RT and spatial frequency, in the upper and lower fields.

Recent evidence (Julesz et al., 1976) has shown the existence of an anisotropy of function between upper and lower hemifields which suggests that differences of motor performances may be related to functional asymmetry of the visual system. Relevant to this possibility are data obtained using visual evoked potentials (VEPs). It is well known that VEPs to patterned stimuli show different properties depending on whether the upper or the lower hemifields are stimulated (MacKay and Jeffreys, 1973). Eason et al. (1970), using a checkerboard pattern as stimulus, have shown that an interaction between the position of stimulus and the size of checks is responsible for changes in the amplitude of the VEP. Given the close relationship which has demonstrated between VEP amplitude and RT (Donchin and Lindsley, 1966; Eason et al., 1967), we shall consider the results of their patterns of 39 and 9.4 min of arc, since these patterns approach the dimensions of bars in our 1 c/deg and 3 c/deg stimuli respectively.

Eason et al. (1970), demonstrated that in the lower hemifield the two stimuli correspond to VEPs of quite different amplitude, the wider check pattern resulting in significantly larger potentials. In contrast, in the upper hemifield the two stimuli give rise to substantially identical VEPs. This difference seems to reflect differences of the two hemifields specifically related to the wider check pattern. Smaller checks do not produce any difference in VEP amplitude in the two hemifields, agreeing with the data of Campbell and Maffei (1970). White (1974) confirmed these findings, pointing out that the differential VEP results of the Eason's et al. (1970) study were mainly related to the upper and lower 1.5° of central retina, which corresponds to the retinal area stimulated by our patterns.

Although the difference between the stimulus used by Eason et al. (1970) and our gratings limits the comparison of RT and VEP data, it is worth noting that both parameters change in the same way to analogous variations of the spatial properties of the pattern, i.e., similar modifications of the dimensions of the target (bars and checks respectively) cause significant and parallel variations of RT and VEP to occur in the lower hemifield, with little or no comparable change in the upper hemifield. In both the cases this outcome is associated with the differential result obtained with the low frequency patterns in the two hemifields. The parallel variations of RT and VEP data suggest that the observed changes in motor performance may depend upon functional properties of the visual system.

The findings of Michael and Halliday (1971) suggest that the data of Eason et al. (1970) are complicated by the topographical relationship between the active dipoles which generate VEP and the position of the recording electrodes. However, since the VEP differences at the same electrode site depend on the combined effect of hemifield and stimulus properties, these variations may reflect differences in the manner of processing high and low spatial frequencies between structures corresponding to the two hemifields. Eason et al. (1970) explained the different effect of check size on VEP in terms of differences in the size of receptive fields in retinal areas projecting respectively to upper and lower visual fields. The hypothesis is not supported by neurophysiological findings (Fiorentini and Maffei, 1973; Maffei and Fiorentini, 1972) showing that analysis of contrast in a patterned stimulus is likely to occur at levels of the visual pathway beyond the retina.

There is also evidence (Campbell and Maffei, 1970; Campbell et al., 1973; Maffei and Campbell, 1970; Maffei and Fiorentini, 1973; Mecacci and Spinelli, 1976) showing that VEP to gratings follows the properties of cortical units selectively tuned to a limited range of spatial frequencies. Thus it is conceivable that the difference in RT, so closely paralleling the VEP results, reflects an anisotropy of function of cortical areas related to the processing of low spatial frequencies within each hemifield. Since RT to low frequencies (Breitmeyer, 1975; Tolhurst, 1975) has been related to the activity of transient detectors (Tolhurst, 1973), it may be suggested that changes of motor performance in the two hemifields, shown by the RT to 1 c/deg stimulus, depend on different properties of transient detectors in the cortical areas related to the processing of signals from the upper and lower hemifields.

A second result stems from a comparison of RT to halved stimuli with RT to whole ones, either full-size or compound patterns. Stimuli presented simultaneously on both sides of the horizontal meridian produce the same performance as that of their component halves. Specifically, the faster component prevails whenever the pattern is composed of halves which produce different RTs, as in the case of 1 c/deg and CS (inverted presentation). When the stimulus is composed of halves which elicit identical speeds of motor reaction, as 3 c/deg and CS (not-inverted presentation), the RT to the whole pattern matches the value of any of its components.

The result was unexpected in view of the perceptual differences between halved and whole stimuli. In addition, it is known that an increase in stimulus area or in number of simultaneous stimuli (Teichner, 1954; Teichner and Krebs, 1972) produces a faster response. Our results indicate that the speed of motor response was not affected by a change of patterned area or of complexity occurring across the horizontal meridian. The doubling of the same patterned area, as in the case of FS stimuli, did not produce faster RTs, as would have been expected on the basis of spatial summation demonstrated by the studies of Teichner (1954) and Teichner und Krebs (1972). However it will be recalled that total flux always remained the same. Nor is the simultaneous activation of different and independent cortical dimension detectors (Campbell, 1974), as in compound patterns, followed by a summation stage as might be suggested by the results of simultaneous multisensorial stimulation (Berstein et al., 1976).

Thus the data do not show an interaction between the structures related to the upper and lower hemifields at any stage of visual processing or during the transfer of information to the motor areas. No modification of motor performance to the whole stimulus as compared to the halved ones was found even when the two component halves correspond to identical performances. Instead the results suggest that in a RT task the two halves of a stimulus, each falling on either side of the retinal horizontal meridian, are treated as independent signals, the corresponding information being transmitted to the motor output through different channels.

Our aim was to study RT to stimulation of the upper and lower hemifields either separately or simultaneously, using patterns with different spatial properties. The results confirmed a difference in motor performance between hemifields which is confined to the low spatial frequency gratings. The parallel behavior of VEP suggests that the RT is the expression of a more general asymmetry of function of the visual system related to the processing of dimensional properties of stimuli. Furthermore, the simultaneous activation of the two hemifields demonstrated the existence of independent processing and transfer of information about signals delivered to either hemifield.

The results may also be of clinical interest since square wave visual stimuli are now the standard method of eliciting visually evoked potentials in multiple sclerosis and other diseases of the visual system.

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