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HUMAN REACTION TIME TO NEGATIVE CONTRAST STIMULI

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Abstract. Simple motor reaction time (RT) to 100% negative contrast stimuli was measured for various background luminances as well as after bleaching a fraction of retinal photopigments. RT decreased to asymptotical value with the increase of background intensity. The intensity-dependent portion of RT behaved identically for 100% positive and negative contrast. Moreover, RT to 100% negative contrast was extended by bleaching and falls down during the adaptation to the lower background luminance. The results were discussed on the basis of the Pulfrich latency researches.

INTRODUCTION

Simple motor reaction time (RT) has been studied for both onset and offset of a light target. In the case of reaction time to the offset, the subject always sees, during the interstimulus intervals, a test target and reacts to its offset as soon as possible. A particular case of study of reaction time to light offset is a situation in which the subject sees, during the interstimulus intervals, a large, uniformly illuminated field (i.e., background) and the stimulus consists in extinguishing the illumination only of its central part. This stimulus we will call, according to Vicards and Lit (15), a 100% negative contrast stimulus. Similarly, in a situation in which the stimulus is defined as the appearance of the test target viewed against a black background, we will speak about the 100% positive contrast stimulus. Contrast is defined by the ratios

$\frac{L_T - L_B}{L_T + L_B} \times 100\%$, where L_B — background luminance and L_T — test luminance. Contrast may change, therefore, from -100% to $+100\%$. If the test luminance is higher than background luminance ($L_T > L_B$) we deal with the positive contrast stimulus, if not, contrast may be equal to zero ($L_T = L_B$) or negative ($L_T < L_B$). In particular contrast has the value of 100% when $L_B = 0$ and -100% when $L_T = 0$.

The study of reaction time to 100% negative contrast stimuli is very interesting, since the results may be directly referred to results obtained for the Pulfrich situation. This is because the study of the Pulfrich effect was carried out frequently for the pendulum of negative contrast (i.e., a black target moving against a light background).

The Pulfrich illusion is a simple observable stereophenomenon described first in 1922 (10). If one eye is covered by a filter which attenuates the light reaching this eye, then the pendulum bob swinging in the fronto-parallel plane seems to move beyond the actual plane, along the ellipse-like path. The illusion was explained by Fertch who assumed that the information from the uncovered eye reaches brain sooner than from the covered eye. In other words, reduction of illumination causes the extension of perception time. Thus the eye covered with the filter perceives the bob in a position that lags behind the position signalled by the uncovered eye. Therefore, at any given moment, the information about excitation is carried to the brain from two disparate retinal points. This disparity causes depth perception. Hence, it is possible to measure visual latency of one eye relative to the other if perceptual depth is measured. A detailed analysis of the geometric relationship involved in the Pulfrich stereophenomenon was given in previous works (5, 10).

In the simplest case it may be assumed that only changes in sensation time (Empfindungszeit, perception lag) are responsible for RT changes, while other components of RT (decision time and motor response) add only constant delay independent of input stimulation (14). Therefore, RT changes should follow exactly the changes of Pulfrich latency.

The author knows only one paper devoted to the study of RT to the 100% negative contrast stimuli (15). Vicards and Lit (15) found that RT depends on the background intensity: the higher the background luminance, the lower the RT value.

Therefore, the purpose of the present experiment was to investigate the following issues:

1. The relation between RT to 100% negative contrast stimuli and

background intensity plus an attempt to present a quantitative description of this relation.

2. The behavior of RT to 100% negative contrast stimuli after bleaching a fraction of photopigments.

3. The comparison of our results of RT and those of the relative latency obtained by Pulfrich effect investigators.

METHOD

Subjects

Two subjects were used in the experiment: female EW and male PJ (the author). Both were very well practised at the task, but one of them was naive to the purpose of the experiment. They were emmetropic and had no defects in color vision. Furthermore, it was stated that their dark adaptation course runs normally.

Apparatus

The schema of the two-channel optical system used in the experiment was presented in Fig. 1*A*. In each channel the light from a 150 W halogen tube (*S*) passed trough lenses (*L*), diaphragms (*D*) and a filter holder (*H*) to form a sharp circular image in the ground glass screen (*Sc*). The transilluminated light image from the screen of Channel I was projected to the left eye of the observer by means of a mirror (*M*) which was put up at the angle of 45° to the line of sight of the observer. In the centre of the mirror a circular gap was drilled. When the light in Channel II was extinguished, the observer saw a bright annulus with the inner dia. of 0.75° and the outer dia. of 8°. The screen of Channel II (*Sc*) was in front of the subject and at the level of his/her eyes. The subject looked through the hole in the mirror (*M*) at the screen of Channel II. The luminance of the screen of Channel II. was chosen so as to be equal to the luminance of the background annulus. Therefore, the subject saw a uniformly illuminated plate, 8° in diameter; since the hole in the mirror was drilled at the 45° angle to the mirror plane, the observer looking through the gap did not see any black annulus around the central part of the background, i.e., around the test target. The stimulus was the offset of the light in Channel II. The stimulus array during pulse and in the interstimulus interval was presented in Fig. 1*B*.

To facilitate fixation, two red light points were used. They were located symmetrically on both horizontal sides, 0.5° from the center of the test target.

The optical system was put in a box. The observer was seated in a dark room, at a laboratory table on which the apparatus box was placed. He/she viewed monocularly, through a circular tube in a wall of the box, stimuli occurring in the visual field. The tube was fitted with a 3 mm artificial pupil. On the outer surface of this wall special goggles were mounted to support the subject's head.

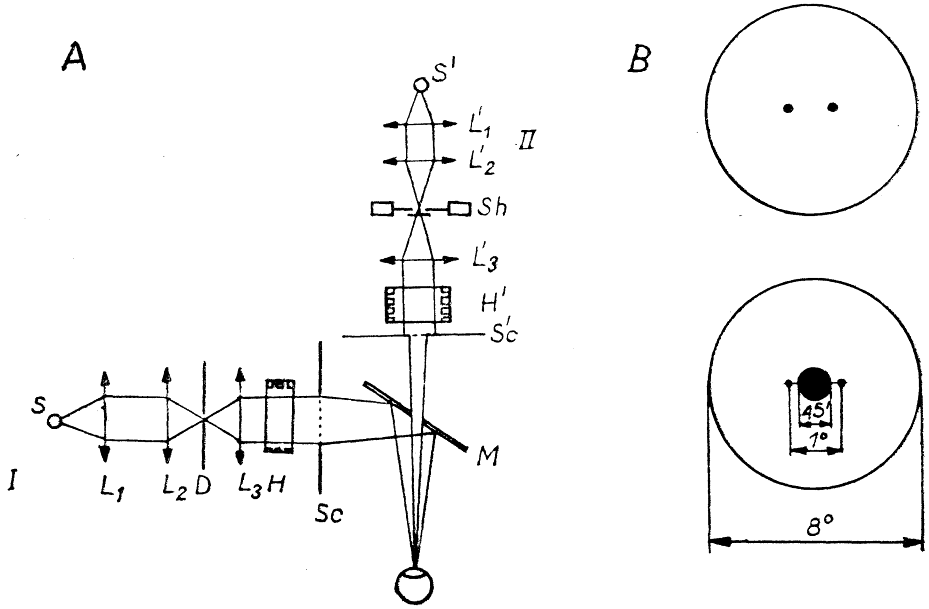


Fig. 1. The schema of optical system (*A*) and stimulus array (*B*). L_1–L_3, L_1'–L_3', lenses, *S*, *S'*, light sources, *H*, *H'*, filter holders, *Sc*, *Sc'* screens, *M*, mirror, *Sh*, electromagnetic shutter, *D*, diaphragm. At the top of *B*, stimulus array in the interstimulus intervals, below — during the pulses. Two black dots located symmetrically on both sides of the test target marked the fixation points.

The light was flashed by an electromagnetic shutter which was put in Channel II. The shutter was controlled by a random generator which sent 100 ms pulses at random intervals. The pulse leading edge closed the shutter and also served as a START-signal for an electromagnetic clock. The pulse trailing edge opened the shutter. The subject was allowed to stop the clock by pressing a key with the thumb of his/her dominant hand. The intertrial intervals varied from 2.8 to 4.5 s, an average of 3.0 s. To mask the sound of the apparatus that might serve as timing cues, white noise was presented through earphones worn by the subjects. Each subject kept the noise at such a decibel level as to eliminate shutter clicks.

Procedure

In the first part of the experiment, the efect of background luminance on RT to the 100% negative contrast stimuli was studied. The subject was initially adapted to darkness for 15 min and then to the first background luminance used. The subject was asked to respond to perceived offset of the central part of the visual field as fast as possible. In the course of this session the background luminance varied in the range of 4.3 log td to −1.0 log td (troland is a unit of retinal illuminance. It is equal to product of visual field luminance in cd/m^2 and the pupil area in mm^2. Thus, for example, −1.0 log td (i.e., 0.1 td) corresponds to luminance of 0.014 cd/m^2 when the pupil diameter is equal to 3 mm). For one background value, a block of 15 identical stimuli was presented to the subject. The intensity level in each block varied irregularly, but low intensity never followed the highest one.

In the second part of the experiment, the effect of bleaching on RT was investigated. After a 15 min period of dark adaptation the subject was adapted to the intensity of 600,000 td or 160,000 td for 3 min. This caused the bleaching of about 100% and 80% of cone photopigments respectively, according to Rushton and Henry (12) results. Then the pre-adaptation light was extinguished and the subject viewed the background of one of the three intensities used. The offset of the central part of the background was a stimulus to which the subject responded. In the beginning, the subject did not see any test target. However, after a while, because of the adaptation to a new luminance level, the subjects could react to the stimuli. Since then reaction time measurements were recorded approximately every 3 s. The record was kept for 1–2 min from the moment at which the subject first responded to the stimulus. Four experimental conditions were used. For the bleaching of 80% cone photopigments, RT was measured when the field retinal illuminance was equal to 0.0, 0.5 or 1.5 log td. For the bleaching of 100% photopigments it was measured when background intensity remained at the level of 0.0 log td. For every combination of conditions ten identical sessions were carried out.

RESULTS

In Fig. 2 the dependence of RT on background retinal illuminance is displayed for PJ (Fig. 2*A*) and for EW (Fig. 2*B*). The standard error varied in the range of 10–40 ms. It was maximal for the lowest background intensities and minimal for the highest ones. As is shown there, reaction time systematically decreases to the asymptotical value of about

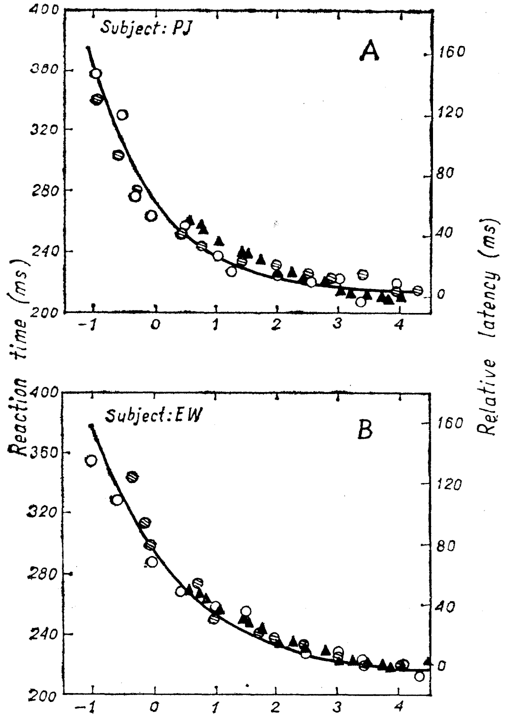


Fig. 2. Dependence of reaction time on retinal illuminance for 100% positive contrast (dark, lined circles) and negative contrast (empty circles) stimuli. (A) The data for PJ, (*B*) the data for EW. In the abscissa, the background or test retinal illuminance is marked in log td, for negative and positive contrast, respectively. The solid line drawn through points is determined by equation $t_R = 213 + 59 \times I^{-0.40}$ for PJ and $t_R = 214 + 81 \times I^{-0.31}$ for EW. Each point represents the mean value of 15 measurements. Triangles in Fig. 2*A* and *B* refer to Lit's data (5), Table I, subject C.G.M.) for Pulfrich situation. Every point represents a difference between visual latency for a given intensity and the latency for the background retinal illuminance of 3.98 log td. The time axis on the right refers to relative latency calculated for Pulfrich effect.

200 ms when the background intensity increases. For comparison, on the graph the dependence of RT upon test retinal illuminance is plotted for 100% positive contrast. The positive contrast curve for EW is shifted upwards by 20 ms to show the similarity of both curves. The data for positive contrast were taken from our recent experiment carried out on the same subjects (4). In the case of positive contrast we used the test target in the form of a circle, 0.75° in diameter. The stimulus duration was 100 ms.

The power function is considered to give the best mathematical description of the relation between reaction time and intensity for positive contrast. It is expressed by the formula:

$$t_R = t_\infty + kI^{-\beta}$$

where I — test retinal illuminance, t_R — reaction time, t_∞, k and β — parameters (6, 7).

Considering the similarity of the curves for positive and negative contrast, we estimated the parameters of function (1) fitted to empirical points for both types of contrast. In the case of negative contrast, I indicates the background retinal illuminance rather than the test retinal illuminance. The fitting was made by the numerical method, which allows to estimate the parameters of function (1) and their variances (13). We tried to find such parameters t_∞, k and β for which the weighted sum of deviation squares from line (1) was minimal. The weight of the sum component corresponding to the given intensity value was the reciprocal of variance of the RT measurements obtained for this intensity. This manner of fitting causes the line preferably to pass nearest the points of small measuring uncertainties. The estimated parameters and their standard errors are given in Table I. For each curve the test of goodness of fit was performed. It was found that at the level of $\alpha = 0.01$ the hypothesis of goodness of fit cannot be rejected. The differences between parameters referring to positive and negative contrast for each subject, were small. We found, using James' test (3) that these differences are not significant at the level of $\alpha = 0.05$. For subject EW, however, a significant difference occurs between asymptotes t_∞. We do not know why it occurred. However, the asymptote is considered to be determined by the decision processes and by the motor response and probably is affected only by the factors independent of the input stimulation (14). Therefore it is possible that this difference is due to some fluctuation of the motor response or decision process. Comparing the interpersonal differences we found that the differences between the parameters k are significant at the level of $\alpha = 0.01$. Since these differences occur for both types of contrast, they are due presumably to interpersonal rather than intersessions va-

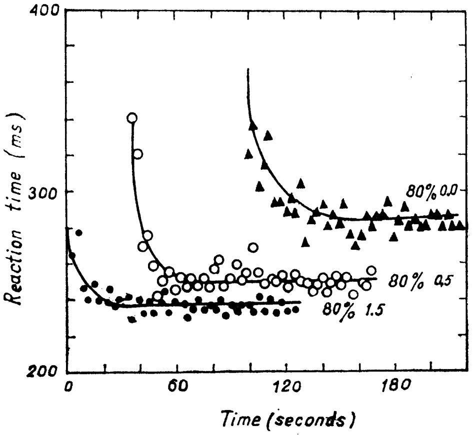
TABLE I

The parameters of t_R function (1) and their standard errors

	Subject PJ		
	t_∞	k	β
Negative contrast	213±1	59±4	0.40±0.05
Positive contrast	213±4	60±2	0.30±0.03
	Subject EW		
	t_∞	k	β
Negative contrast	214±6	81±7	0.31±0.03
Positive contrast	193±4	95±7	0.34±0.03

riation. It would be interesting to search the source of these variations. Further investigations are, however, necessary to this aim.

To determine whether Pulfrich latency and latency measured by reaction time vary with retinal illuminance in the same way, we calculated relative latency for Pulfrich paradigm on the basis of Lit's data (5), Table I, subject C.G.M. We used Lit's data for two reasons: (A) Lit employed the negative contrast stimulus (i.e., black rod moving against illuminated background) and (B) he presented the whole set of results in a Table. The calculation was carried out by the method of succesive summation of latency difference in a manner similar to that employed by Alpern (1) as well as Brauner and Lit (2). The results are plotted in Fig. 2 by triangles. The time axis on the right refers to the relative latency calculated on the basis of Lit's data. As is shown, the agreement is good. However, it must be emphasized that the RT data are a bit noisy and therefore subtle differences between RT and Pulfrich latency behavior may be invisible. Furthermore, the lowest intensity used by Lit (0.38 log td) is high relative to ours (—1.0 log td) and the comparison does not comparise a very interesting range. In spite of that, it is clearly demonstrated that the performance decreases with the increase of background intensity.



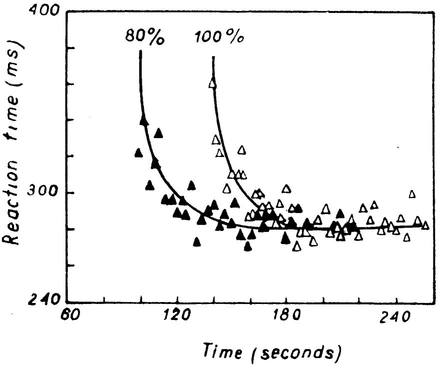


Fig. 3. Changes of RT for 100% negative contrast in the course of adaptation to different levels of background retinal illuminance (0.0, triangles, 0.5, empty circles, 1.5, filled circles) por pre-adaptation light intensity of 160,000 td. The data for PJ.

Fig. 4. Changes of reaction time to 100% negative contrast stimuli in the course of adaptation to a level of background intensity for two different pre-adaptation light intensity (filled triangles — 160,000 td, 80% bleaching; empty triangles — 600,000 td, 100% bleaching). Both curves were carried out for the same background intensity of 0.0 log td. The data for PJ.

Figures 3 and 4 display the variations of RT during adaptation to the background intensity after prior bleaching for subject PJ. The results for EW were very similar to those for PJ. Although the test target appeared at random intervals (see Method) the mean values of RT obtained during different sessions were calculated as if they had been flashed exactly every 3 s. Thus any point of every curve represents the mean of reaction time measurements taken at the same moment after the offset of preadaptation light in ten identical sessions. Since the subject saw the first test target after a different time-span for every session we accepted as data point only the means calculated for five responses, at least. Therefore, the first of the two earliest points were the mean value of less than 10 but more than 4 reaction time measurements. Figure 3 shows curves obtained for subject PJ when the preadaptation light intensity was equal to 160,000 td; the background retinal illuminance to which each subject was adapted during sessions was a parameter. As was shown, the higher the new level of background intensity, the shorter the time preceeding the subjects' first response. From that moment, when the subject views the test target for the first time, his/her reaction time falls down to the constant value very quickly. According to the results obtained in the previous part of the experiment, the higher the background intensity, the faster the RT in the flat portion of the curve.

In Fig. 4, two curves were presented, obtained for the same value of visual field intensity but for two distinct pre-adaptation light intensities. As previously (Fig. 3), RT decreases to a constant value. The curve for 160,000 td begins sooner than that for 600,000 td. Both curves approach, however, the same constant value, when time in darkness is extended.

DISCUSSION

The results obtained in the present study show that reaction time to 100% negative contrast decreases to an asymptotical value, when the background intensity increases. This finding is consistent with Vicards and Lit's results (15). Moreover, we found that the dependence between these variables may be very well described by the power function with the negative exponent. When we plotted the relation between RT to 100% positive contrast and test target intensity on the same graph, both curves overlapped. However, for one subject a significant difference between asymptotes was revealed. This finding forces us to conclude that only the intensity-dependent portion of RT (i.e., $t_R - t_\infty$) for negative contrast is identical with that for positive contrast.

When the target luminance in the case of positive contrast decreases, the perceived contrast decreases. Similarly, the decrease of background luminance for negative contrast paradigm infers the decrease of perceived contrast. Therefore, one may argue that the similarity of the curves for positive and negative contrast is obvious. However, it must be emphasized that, in general, no simple relation between perceived contrast and RT was stated (15). Furthermore, some effect of area of stimulus array might occur.

Bleaching a fraction of photopigments causes the increase of RT to negative contrast and during the adaptation to a new, lower level of illuminance RT decreases to an asymptotical value within several seconds. Asymptotical RT and adaptation time passing before the subject's first response depend on the fraction of photopigments bleached and the intensity level to which the subject is adapted during every session.

The results of RT to negative contrast stimuli were compared with those obtained in the Pulfrich situation. It was revealed that relative Pulfrich latency follows the RT changes in the whole range compared. A similar comparison may be carried out in a situation when the performance is measured after preadaptation to a more intense background. RT decreases, as we said, in the course of adaptation to lower intensity. However, Rogers and Anstis' (11) data indicate that Pulfrich latency increases with time after offset of preadaptation light until it reaches the maximal value for full adaptation to lower intensity. Identical conclusion may be drawn for the comparison of RT and perception time behavior when the latter is measured with the non-stereoscopic method developed by Prestrude (8), Prestrude and Baker (9) and Wilson and Anstis (16), in which visual latencies may be measured as differences in the positions of a moving target. Using a black target moving against a white background, they found that sensation time may be decreased by bleaching a fraction of photopigments (9) or by increasing background intensity (8, 9, 16). Therefore, after bleaching, the behavior of perception time is qualitatively distinct from RT. One possible explanation of this inconsistence could be a suggestion that perception time becomes shorter for the more light-adapted eye, but when the test is hardly detectable, the decision or motor process, rather than perception time, becomes longer and this extension is so large that the eventual perception time shortening prevails. Hence, reaction time which is composed of not only perception time may be elongated for the more light-adapted eye, although Pulfrich latency, which is considered to be a perception time, is shorter.

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