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REACTION TIME AND VISUAL BRIGHTNESS: WITHIN-SUBJECT CORRELATIONS[1]

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Summary.—An experiment was conducted to compare visual reaction time and visual brightness within the same subjects. Simple reaction times and magnitude estimates of brightness were obtained in response to 1000-msec. flashes of 60.7, 67.5, 76.4, 85.1, and 93.4 dB re 10^{-10}L white light. The relationship between reaction time and stimulus intensity was best described by a negative logarithmic function, while the relationship between magnitude estimates of brightness and stimulus intensity was best described by a power function. Linear correlations between reaction times and magnitude estimates indicated that visual reaction time and brightness are not proportional within all subjects. Previous reports of proportionality between these two measures were discussed as possibly being the result of inappropriate cross-experiment comparisons.

Visual reaction time has long been known to be a negatively decreasing function of stimulus intensity (Cattell, 1886; Berger, 1886; Froeberg, 1907; Pieron, 1920). As intensity increases reaction time (RT) reaches an irreducible minimum value. The total reaction time minus the "irreducible minimum" (L_o) is known as the "reducible margin" (L-L_o) and represents the effect of stimulus intensity on latency.

Pieron (1952) suggested that the reducible margin of visual response latencies is closely related to visual brightness, and Vaughan (1966) and Stevens (1970) concluded that response speed (the inverse of the reducible margin) is directly proportional to brightness. Empirical evidence in support of these statements has been found in the similarity of functions obtained from different experiments relating either visual latency or visual brightness to stimulus intensity. Yet, in spite of the extensive literature concerning the effects of stimulus parameters on visual reaction time (see review by Teichner, 1954; Macleod & Alderman, 1961; Teichner & Krebs, 1972) and the equally extensive literature on the effects of stimulus parameters on visual brightness (see Marks, 1974), no direct comparison of visual reaction time and brightness has been made within the same experiment or with the same subjects.

Magnitude estimates of visual brightness have repeatedly shown that brightness grows as a power function of luminance. The exponent of this function varies with flash duration, having a value of approximately one-third for long

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(>1 sec.) flash durations and one-half for short (<10 msec.) flash durations (Raab, 1962; Aiba & Stevens, 1964; Katz, 1964; Stevens & Hall, 1966). In addition, the value of the psychophysical exponent can vary among experiments, among subjects, and even *within* subjects over periods as short as 24 hr. (Teghtsoonian & Teghtsoonian, 1971).

Vaughan and Hull (1965), Vaughan (1966), Vaughan, Costa, and Gilden (1966), and Mansfield (1970) have demonstrated that simple visual reaction time and latency of visual-evoked cortical potentials are power functions of stimulus intensity, with exponent values close to —⅓. However, unlike the exponents for brightness, the exponents of latency functions do not vary with flash duration, at least within the range of flash durations from 300 μsec. to 100 msec. (Mansfield, 1970). Additional support for this exponent invariance of visual latency functions has derived from a reanalysis of Bartlett and Macleod's (1954) reaction time data by Vaughan, *et al.* (1966). These data, obtained in response to 575-msec. flashes, conformed well to a power function with an exponent of —⅓ (Vaughan, *et al.*, 1966).

Although the reanalysis of Bartlett and Macleod's (1954) data support the exponent invariance of visual latency functions, the original analysis of these data led Bartlett and Macleod (1954) to conclude that visual latency was a negative logarithmic function of stimulus intensity. This relationship had previously been reported by Pieron (1952) for numerous reaction time studies with animals and has also been used to describe visual reaction times under both monocular and binocular viewing conditions (Minucci & Connors, 1964). Since Bartlett and Macleod (1954) and Minucci and Connors (1964) used longer flash durations than other investigators, it is not clear whether the difference in the form of the latency function is related to differences in flash duration or to other experimental variables.

At present it is impossible to make a definitive statement concerning the relationship between visual latency and subjective brightness. Any consideration of this relationship must bear in mind that visual latencies are affected by a wide range of subject and experimental variables, including instructions, response set, duration of foreperiod and background illumination. Such variability, combined with variability in brightness exponents across experiments, subjects, and time, underscores the futility of comparing latency data and brightness data obtained from different experiments. Any valid comparison of visual latency and brightness must be made from data obtained under the same experimental conditions, with the same subjects, and during the same experimental session.

METHOD

Subjects

Two males and two females between the ages of 19 and 29 yr. volunteered as subjects. All were students at the University of Massachusetts/Amherst, and all were right-handed.

Apparatus and Stimuli

The light source was an incandescent lamp housed behind a white presentation panel/reduction screen. The light from the source was projected through an aperture in the panel and illuminated a white translucent disk which served as stimulus. Although the stimulus was an incandescent source that was gated on, the effect of gradual rise and fall times was deemed minimal due to the long stimulus duration that was used (1000 msec.). The panel and disk were located 36 cm from the midpoint between the subject's pupils, and the stimulus subtended a visual angle of 6°. The stimulus intensities were 93.4, 85.1, 76.4, 67.5, and 60.7 dB re 10^{-10}L (as measured by Macbeth Illuminometer). The adapting field of the presentation panel was illuminated by an incandescent source located behind the subject, and the adapting intensity of the field was 60.0 dB re 10^{-10}L.

An electronic clock was used to measure the latency between the onset of the stimulus and the manual release of the telegraph key. All latencies were measured to the nearest millisecond. Stimulus duration was controlled by an electronic timer, and stimulus intensity was varied by interposing Wratten neutral density filters between the light source and the stimulus disk. White noise (35 dB) was presented binaurally to the subject through earphones, in order to mask any possible auditory cues.

Procedure

Subjects were run for four sessions. Sessions 1, 2, and 3 were practice sessions, during which the subject performed only the reaction time task. Session 4 was the experimental session.

Practice sessions.—Practice sessions were required to both minimize and stabilize reaction times prior to testing. The subject sat at the apparatus and was given written instructions. He then positioned his head in a metal restraint and focused on the darkened stimulus disk in the center of the adapting field for 10 min. Upon a signal from the experimenter, the subject depressed the RT key with his right thumb and signalled that he was ready. After a variable foreperiod the stimulus was presented. Durations of the foreperiod were distributed exponentially and ranged from 1.0 to 3.0 sec.

Stimuli were presented in random order and each stimulus was presented six times. The interstimulus interval was 30 sec., excluding foreperiod. During this time the subject re-adapted to the background field.

Experimental session.—The reaction time procedure in the experimental session was identical to that used during practice sessions. However, in addition, the subjects gave magnitude estimates of the brightness of the stimuli either prior to or following the entire series of latency measurements. Although the magnitude estimates were obtained in response to the same series of stimuli, each stimulus was presented only twice during this part of the experiment so as to eliminate the constraint of repeated judgments. No modulus was assigned for the magnitude estimates.

Results

Table 1 shows median reaction times and geometric mean magnitude estimates for each stimulus and subject. The reaction time data are plotted in Fig. 1. This figure shows the relationship between reaction time and stimulus intensity for each subject. Reaction times have been normalized so that the longest median RT for each subject has a value of 1.0.

TABLE 1

MEDIAN REACTION TIMES (IN MSEC.) AND GEOMETRIC MEAN MAGNITUDE ESTIMATES FOR EACH STIMULUS AND SUBJECT

Stimulus Intensity (dB re 10^{-10}L)	Subject DP		Subject FS		Subject RS		Subject CM	
	Mdn RT	Geom. *M* Magn. Est.	*Mdn* RT	Geom. *M* Magn. Est.	*Mdn* RT	Geom. *M* Magn. Est.	*Mdn* RT	Geom. *M* Magn. Est.
93.4	149.0 14.5*	17.32	194.0 11.5*	15.00	162.5 15.1*	17.32	162.0 7.6*	17.68
85.1	170.5 18.8*	12.24	189.0 12.0*	8.36	160.5 5.1*	12.24	167.0 25.3*	12.50
76.4	177.0 10.0*	7.07	216.5 16.1*	7.07	186.0 9.5*	8.36	184.5 27.3*	2.50
67.5	199.0 21.1*	5.00	242.0 22.5*	3.87	186.5 14.6*	3.87	197.5 32.0*	0.61
60.7	243.0 23.3*	1.41	284.5 26.3*	1.00	227.5 43.6*	1.00	211.5 11.6*	0.0025

*Average absolute deviations about the median.

Reaction times can be seen to be a negatively accelerated decreasing function of stimulus intensity for all four subjects. In addition, for Subjects CM, RS, and FS the latency curves appear to have reached asymptote, while for Subject DP this does not appear to be the case. However, examination of Subject DP's latency data over practice sessions indicates that his shortest latency is probably near asymptotic value. In light of this fact and in order to avoid biasing the analyses of the data, the minimum median RT of each curve was taken as the asymptotic value (L_o) for each subject. To ensure non-zero data points at the shortest latency, the actual values of L_o were 148, 188, 159.5, and 161 msec. for Subjects DP, FS, RS, and CM, respectively. Values of L-L_o were then plotted against stimulus intensity, which was specified as the intensity of the stimulus minus the adapting intensity (I-I_o), and least squares fits of linear, logarithmic, and power functions were made to the data. The coefficient of

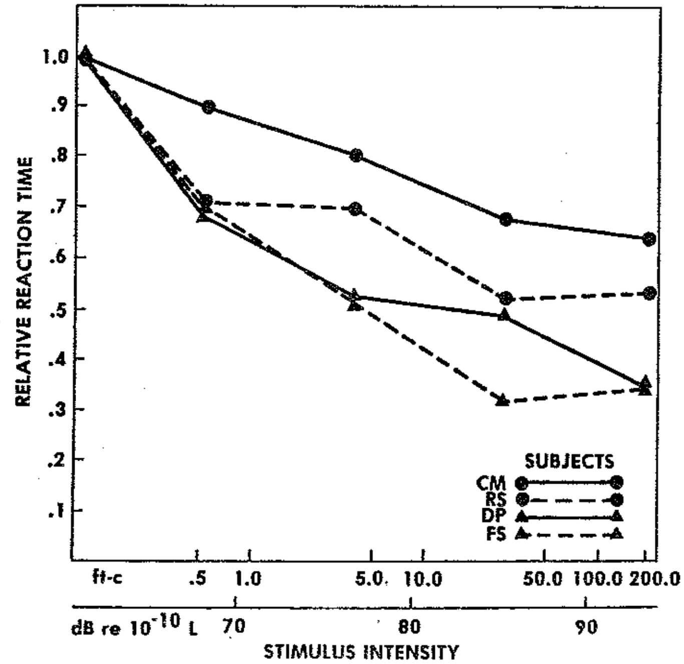

FIG. 1. Median reaction time as a function of stimulus intensity for all four subjects. Reaction times have been standardized so that the longest reaction time for each subject has a value of 1.0.

determination (r^2) for each of these fits is shown in Table 2, along with the exponent (n) of the best-fitting power function. The probabilities of these r^2 values were determined by a t statistic (Croxton, 1959) and are also shown in Table 2. A one-way repeated-measures analysis of variance on Z-transforms of the r values showed a significant effect for the type of function fitted ($F = 77.8$, $df = 2/3$, $p < .05$). Multiple comparison tests on the Z-values using the Tukey B method indicated that a logarithmic function is a significantly better description of the relationship between $L\text{-}L_0$ and $I\text{-}I_0$ than either a linear

TABLE 2

LEAST SQUARE FITS OF LINEAR, LOGARITHMIC, AND POWER FUNCTIONS TO RELATIONSHIP BETWEEN REACTION TIME ($L\text{-}L_0$) AND STIMULUS INTENSITY ($I\text{-}I_0$)

Subject	Linear		Logarithmic		Power		n
	r^2	p	r^2	p	r^2	p	
DP	.451	<.20	.970	<.001	.727	<.05	–.404
FS	.293	<.40	.942	<.001	.658	<.10	–.403
RS	.302	<.40	.900	<.005	.771	<.025	–.389
CM	.492	<.20	.979	<.001	.817	<.02	–.392

function ($p < .05$) or a power function ($p < .05$). No difference was found between the fits of linear and power functions.

A similar analysis was performed on the geometric means of the magnitude estimates of brightness (ME) as a function of stimulus intensity ($I\text{-}I_o$) for each subject. The obtained values of r^2 and p for each fit are shown in Table 3. A repeated-measures analysis of variance on the Z-transforms of these

TABLE 3
LEAST SQUARE FITS OF LINEAR, LOGARITHMIC, AND POWER FUNCTIONS TO RELATIONSHIP BETWEEN GEOMETRIC MEAN OF MAGNITUDE ESTIMATES AND STIMULUS INTENSITY ($I\text{-}I_o$) FOR ALL FOUR SUBJECTS

Subject	Linear		Logarithmic		Power		n
	r^2	p	r^2	p	r^2	p	
DP	.717	<.10	.948	<.01	.975	<.005	.258
FS	.791	<.05	.909	<.02	.959	<.005	.271
RS	.682	<.10	.957	<.005	.969	<.005	.300
CM	.733	<.10	.799	<.05	.915	<.02	.923

data showed a significant effect for the type of function fitted ($F = 21.3$, $df = 2/3$, $p < .05$). Multiple comparison tests of means showed both the power function and logarithmic function to be significantly better descriptions of the relationship between ME and $I\text{-}I_o$ than the linear function ($p < .05$). However, no significant difference was found between the power function and logarithmic function, even though the r^2 values for all four subjects were greater for the power fit than the logarithmic fit.

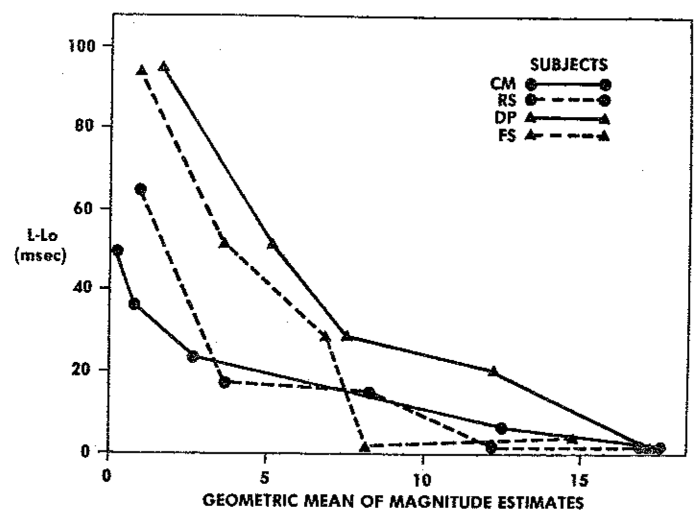

FIG. 2. Reaction time ($L\text{-}L_o$) as a function of the geometric mean of the magnitude estimates for all four subjects

Fig. 2 shows median reaction time ($L-L_0$) plotted against the geometric mean of the magnitude estimates for each subject. Pearson product-moment correlation coefficients for the linearity of these two measures were —.729, —.768, —.849, and —.853, for Subjects DP, FS, RS, and CM, respectively. The coefficients for Subjects RS and CM are significant at the .05 level, the coefficients for Subjects DP and FS are not.

Discussion

The finding that reaction times are a negative logarithmic function of stimulus intensity confirms the earlier results of Bartlett and Macleod (1954) and Minucci and Connors (1964). It should be noted that both of their experiments, as the present one, involved stimuli of long duration. Those studies which have employed very short stimulus durations (Vaughan, 1966; Vaughan, *et al.*, 1966; Mansfield, 1970) have reported latency functions which are well described by power functions. A systematic investigation of the relationship between visual reaction time and stimulus intensity as a function of a wide range of flash durations is needed to assess the basis of the apparent difference among these studies.

One interesting aspect of the latency data is that, although the fits of logarithmic functions were significantly better than the fits of power functions, the latter had exponent values ranging between —.38 and —.40 for all four subjects. These values are very similar to those reported previously by Liang and Pieron (1947), Vaughan, *et al.* (1966), and Mansfield (1970). Thus, if only power functions were fitted to the data, support for the exponent invariance of visual latency as a function of flash duration might be inferred, in spite of the fact that these long-flash duration data are better described by a logarithmic function. Furthermore, since the absolute values of these exponents are similar to previously determined brightness exponents, proportionality of response speed and visual brightness might be assumed.

Although not significantly different from the fit of a logarithmic function, the fact that coefficients of determination for the fit of a power function to the relationship between magnitude estimates and stimulus intensity were greater for all four subjects is consistent with numerous earlier studies by Stevens and his collaborators. In addition, the exponents of the power functions for Subjects DP, FS, and RS are similar to previously reported brightness exponents. The exponent of .92 for Subject CM seems anomalous. However, the data of 9 of 11 subjects tested subsequently in only the magnitude estimation part of this experiment were better fitted by power functions than logarithmic functions, and all 11 had exponents which ranged from .25 to .47. Thus, the obtained exponent for Subject CM appears to be a valid individual difference, rather than an artifact of the experimental procedure.

The fact that the latency data for all four subjects were significantly better fitted by a logarithmic function, while the magnitude estimation data were best described by a power function suggests that visual latency (or its inverse, respond speed) and perceived brightness are not proportional. However, linear correlations between these two measures were statistically significant for two subjects. The explanation of these apparently incongruous results lies in the mathematical similarity between a logarithmic function and a power function with an exponent of $\cong .33$. Sampling error about the points on each function can result in two sets of data that are significantly correlated with one another, in spite of the fact that the "true" functions relating each set of data to a third, common variable (stimulus intensity in this instance) may be different.

The previous contentions of Pieron (1952), Vaughan (1966), and Stevens (1970), concerning the proportionality of visual latency and brightness, are partly justified by the significant linear correlations between visual reaction time and magnitude estimates found for two of the subjects in this study. However, the failure to find a significant linear correlation for the other two subjects, combined with the facts that reaction times were unquestionably better fitted by a logarithmic function and magnitude estimates of brightness were best fitted by a power function suggests that the proportionality between the two measures may be spurious. This possibility seems more likely when it is considered that previous contentions of the proportionality of visual latency and brightness have been based on comparisons of these two measures across experiments rather than on direct tests of their linearity within individual subjects. A more detailed examination of individual latency and brightness functions for a large sample of subjects is necessary before claims of their proportionality can be adequately assessed.

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