Journal of Experimental Psychology:
Human Perception and Performance
1980, Vol. 6, No. 2, 235–243

Perceptual Delay: A Consequence of Metacontrast and Apparent Motion

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Temporal-order judgments were used to demonstrate that a later visual stimulus can delay the perception of an earlier one when the two stimuli together produce the phenomenon of metacontrast or of apparent motion. The perceptual delay is the same for movement and metacontrast and for one or two characters appearing to move or to be masked.

Metacontrast is the phenomenal suppression or decrease in discriminability (masking) of a visual stimulus (the target) by a subsequent stimulus (the mask) that spatially surrounds or bilaterally flanks the target. We will use the word *masking* to denote these effects of the second stimulus on the first. When target and mask luminous energies are about equal and well above threshold, maximum masking usually occurs when the onset of the mask follows the onset of the target by about 50 to 150 msec (Kahneman, 1968). The time from target onset to mask onset is commonly called stimulus onset asynchrony (SOA; Kahneman, 1967). The function that relates the amount of masking to SOA typically has the shape of an inverted U, with little or no masking occurring at very high (greater than 150 msec) and very low (less than 50 msec) or negative SOAs. Similarly, when subjects were asked to rate the "goodness" of perceived movement in presentations of two consecutive stimuli that produce apparent motion phenomenon, Kahneman (1967) reported that an inverted-U-shaped function (similar to the metacontrast function) relates the goodness of perceived movement to SOA.

The present study seeks to investigate another possible similarity between metacontrast and apparent motion, specifically the perceived onset time of the pair of stimuli. It seems reasonable that when a target truly is not seen, subjective onset of visual activity would be different than when it is seen. For example, the subjective onset of a target–mask stimulus pair with an unseen target might be determined by the onset of the mask rather than by the onset of the target. When the perceived onset of a stimulus pair occurs with greater delay (with respect to the physical onset of the first stimulus) than the perceived onset of the first stimulus when it is presented alone, the phenomenon is called perceptual delay.

Kahneman (1968) noted a paradoxical aspect of apparent motion analogous to perceptual delay. When an observer experiences apparent motion, the perceived object appears to be in motion at its onset (rather than appearing to be stationary until the onset of the second stimulus, as one might expect if the visual system were processing each stimulus consecutively). In the absence of a clairvoyant processor, utilization of information about the stationary-first stimulus must somehow be delayed until information about the second stimulus is available to the processes that lead to the perception of an object in motion. Insofar as there is delayed utilization, we may expect to observe its consequences in both metacontrast and apparent motion.

There are at least two ways to approach the problem of measuring the time of sub-

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jective stimulus onset: Ask the subject to make a simple response to the onset of the stimuli, or to make a temporal-order judgment relative to some other event. Studies of response time to stimuli masked in metacontrast paradigms (Fehrer & Biederman, 1962; Fehrer & Raab, 1962) show no effect of the second stimulus. That is, even though a masked target is not consciously perceived, simple response time to it is no longer than simple response time to the onset of an unmasked target. Similarly, the simple response time to a stimulus seen in apparent movement (due to the subsequent occurrence of an adjacent stimulus) is not different from the response time to that stimulus alone (Fairbank, 1969).

That response time experiments do not show perceptual delay for either metacontrast or apparent motion is an interesting and significant observation. To further probe the problem, the present study employs a temporal-order judgment paradigm to seek whether any perceptual delay may be measured by this method.

Method

Subjects

Three paid volunteers, who were naive as to the purpose of the experiment, and one of the authors (RD) served as subjects.

Types of Visual Presentations

Three categories of visual presentation, designated as *control*, *metacontrast*, and *apparent motion*, were employed. Control presentations consisted of a single stimulus exposure; the other categories of presentation contained two stimuli. All stimuli were composed entirely of arrangements of a "zero" character, which consisted of a rectangle with a diagonal line through it.

Stimulus Elements

Stimuli were composed of lines produced on a cathode ray oscilloscope controlled by a PDP-15 computer. The oscilloscope had a white P4 phosphor with a measured decay time constant of less than 1 msec. Stimuli were presented for 20 msec, that is, refreshed 10 times at 2-msec intervals. Room illuminance was approximately 2.3×10^{-3} lux; background luminance of the display screen was approximately 4.6×10^{-4} cd/m^2. The luminous energy of one 20-msec display of the stimulus lines was approximately 3.27×10^{-4} cd sec/m (Sperling, 1971). Characters were 1.3 cm (30 min) high, .8 cm (18 min) wide, and viewed binocularly from about 1.5 m. They were well above threshold and clearly visible.

Spatial Arrangements of Stimuli

The presentation patterns, drawn to scale, are shown in Figure 1. Each row of characters in Figure 1 illustrates the spatial arrangement of characters in one type of presentation. There were seven types of control presentations and two types each of the other categories of presentation. On a given trial, the visual presentation appeared randomly (with $p = .5$) either 2 cm above (center to center) or below the fixation point.

Auditory Temporal-Reference Stimulus

In all conditions, the onset of a presentation was either preceded by, followed by, or coincident with a click that was presented binaurally through earphones. The click was approximately 60 dB above its threshold. In control conditions, the times (Δt) between the onset of the visual presentation and the onset of the click were −90, −60, −30, 0, 30, 60, and 90 msec. (A negative Δt indicates that the click preceded the onset of the visual presentation.)

Experimental Stimuli

Metacontrast and apparent motion categories of presentation consisted of two consecutive stimuli

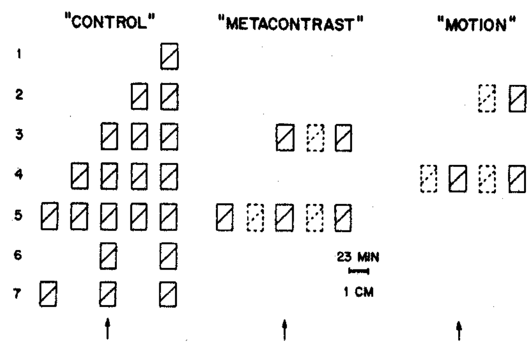

Figure 1. Visual presentation patterns. (Characters with dashed lines are members of S1 in a two-flash presentation (S1, S2). Rows 2–5 of control presentations correspond to what the metacontrast or motion presentation [shown on same row] would be at zero stimulus onset asynchrony [simultaneous onset of S1 and S2]. The two laterally displaced rows 1 and 6 correspond to the set of S1 configurations presented in isolation; rows 1, 6, and 7 correspond to the set of S2 configurations. Arrows indicate the lateral position of the fixation point. Maximum display width is 2.6 degrees [6.8 cm viewed at 150 cm]; the inset shows the scale to which figures were drawn.)

(S1, S2); each stimulus duration was 20 msec. The time from the onset of S1 to the onset of S2 (SOA) was varied from trial to trial. The SOA values employed were 30, 60, 90, 120, and 150 msec.

The metacontrast presentations were arranged so that S1 had one or two characters, each of which was bilaterally flanked by two S2 characters. The apparent motion presentations were arranged so that each S1 character was followed by an S2 character that flanked it to the right. For at least one and usually several of the SOAs, the metacontrast presentations consistently produced perceived metacontrast (S1 appeared much dimmer than S2 or was absent entirely), and the apparent motion presentation consistently produced perceived motion.

Trial Description

A trial consisted of the presentation of 1 of the 11 visual presentation patterns (with one of the six SOAs, including zero) and a click (with a light-to-click interval, Δt). The range of Δt values (onset of S1 to click) for both metacontrast and apparent motion trials was [-90 msec, $90 + \text{SOA}$ msec]. All integer multiples of 30 msec in this range were included as Δts. The experiment was run in a mixed list design so that every combination of presentation type by SOA by Δt of click occurred exactly once in a block of 229 trials. Each subject received 2 practice blocks plus 20 experimental blocks in the course of eight 1-hr sessions.

The beginning of a trial was indicated by a plus sign that appeared superimposed on the fixation point and remained on for 500 msec. After the plus sign was turned off, there was a random foreperiod (uniformly distributed between .5 and 1.5 sec), followed by the visual stimuli and the click.

Subjects' Task

The subject was instructed to fixate the fixation point and to attend primarily to the visual modality. The task of the subject was to judge whether the click occurred before or after the earliest onset of any visual stimulation. This temporal-order judgment was followed by a confidence judgment, indicating how much confidence the subject had in the temporal-order judgment. The five judgment categories consisted of four confidence categories and an error category: (a) certain, (b) moderately certain, (c) uncertain (indicating that although the subject did not think the auditory stimulus occurred at the same time as the visual activity onset, there was uncertainty as to which occurred first), (d) simultaneous, (e) error (indicating that the wrong temporal-order button had been pressed or that the subject had not attended to the stimuli). The confidence judgment was to be made independently of the temporal-order judgment; that is, subjects were required to make an order judgment even if they thought the stimuli were simultaneous.

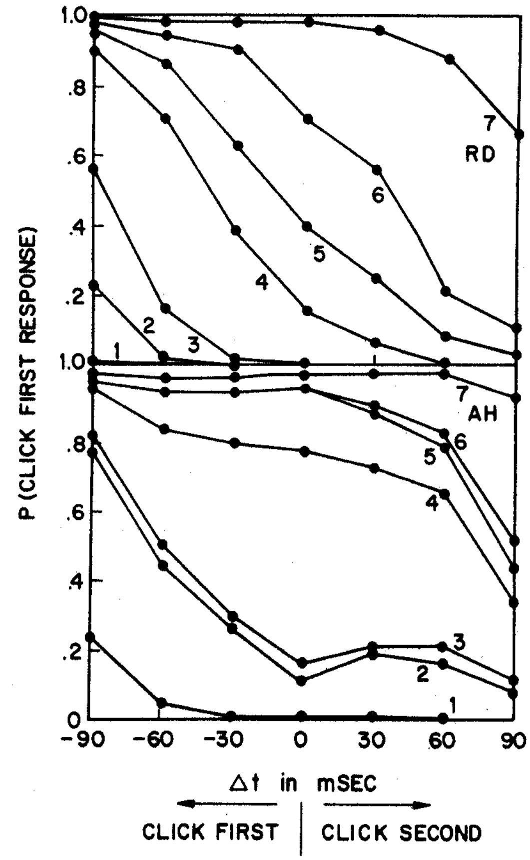

Figure 2. Psychometric functions $P_i(\Delta t)$ of combined control conditions as a function of Δt for Subjects RD and AH. (The parameter i is the confidence level that ranges from 1 ["click first" with highest confidence] to 7 ["light first" with highest confidence], and 4 is the level that separates "click first, simultaneous" from "light first, simultaneous.")

Results

Psychometric Functions, $P_i(\Delta t)$

We define the psychometric function $P_i(\Delta t)$ for a visual stimulus condition as the proportion of "click first" responses with at least a particular level of confidence (i) as a function of Δt. Psychometric functions were computed separately for each combination of subject and condition. (Every combination of SOA and presentation type constitutes a separate condition, yielding 27 Conditions $\times$ 4 Subjects.)

Since subjects can respond "click first" or "light first" at any of four confidence levels, there are eight confidence intervals (from "click first" with highest confidence to "light first" with highest confidence) that are separated by seven criterion levels. Therefore, seven psychometric functions, each based on a different criterion level, can be generated for each subject for each visual stimulus condition. The psychometric functions of the combined control conditions for the two subjects who were most consistent in their use of confidence categories are shown in Figure 2. Because three of the four subjects did not develop the full range of consistent confidence categories, we restrict subsequent analysis of their data to just that single criterion level that they used with greatest precision, namely click first with medium or high confidence (i.e., Criterion level 2 in Figure 2). This is the only criterion level that yields psychometric functions for the combined control condition data from *all* four subjects suitable for testing the main hypotheses. We use $P_2(\Delta t)$ to refer to the psychometric functions with this criterion.

Differences Among Control Conditions

The first test of the data employed the chi-square statistic to determine if there was a difference in psychometric functions [$P_2(\Delta t)$] among the seven control type conditions for a given subject. (In this and all other data analyses, judgments designated as Category e, error, were discarded; this category represented less than 1% of the data.) Chi-square was determined by comparing the number of click first responses for a single type of control presentation and Δt to the average number of such responses across all seven control presentation types at that Δt. The chi-square was not significant for three of the subjects ($p > .2$), indicating that for these subjects the various number of characters and spatial arrangements of characters in the control stimulus did not have any significant effect on temporal-order judgments. For the other subject, the control condition with just one character was different from the other six. The difference is small, however, so that the average of all seven is hardly different from the average of six. With this one possible exception, the different number and spatial arrangement of characters does not affect $P_2(\Delta t)$, and we therefore collapse $P_2(\Delta t)$ across control conditions. Differences in $P_2(\Delta t)$ between control conditions and experimental conditions are not attributable simply to the number or spatial arrangement of characters.

Differences Between One and Two Characters Masked or Moving

Similarly, the psychometric functions within metacontrast presentations were compared to each other, in pairwise fashion, for all SOAs (i.e., for a given subject and SOA, the function derived from metacontrast in which one character was masked was compared to the metacontrast presentation in which two characters were masked). A corresponding set of tests was made for differences between apparent motion presentations. None of the 40 chi-squares were significant ($p > .1$). This implies that it makes no difference to $P_2(\Delta t)$ whether (a) one or two characters are masked in metacontrast or (b) one or two characters appear to move in apparent motion. This allows us to collapse $P_2(\Delta t)$ across the number of characters in S1.

Differences Between Control and Experimental Conditions

The psychometric functions collapsed over number of characters appear in Figure 3. Even a cursory look at Figure 3 indicates that nearly all points on all experimental functions lie above the control function. The only exception is for Subject AH for whom the data at positive Δts are distributed on both sides of the control function. That experimental data points lie above the control data in Figure 3 means that a click must occur later in a metacontrast or apparent motion presentation than in a control presentation in order to be judged equivalently. In other words, there is a highly consistent degree of perceptual delay in apparent motion and metacontrast presentations as compared to the control presentations.

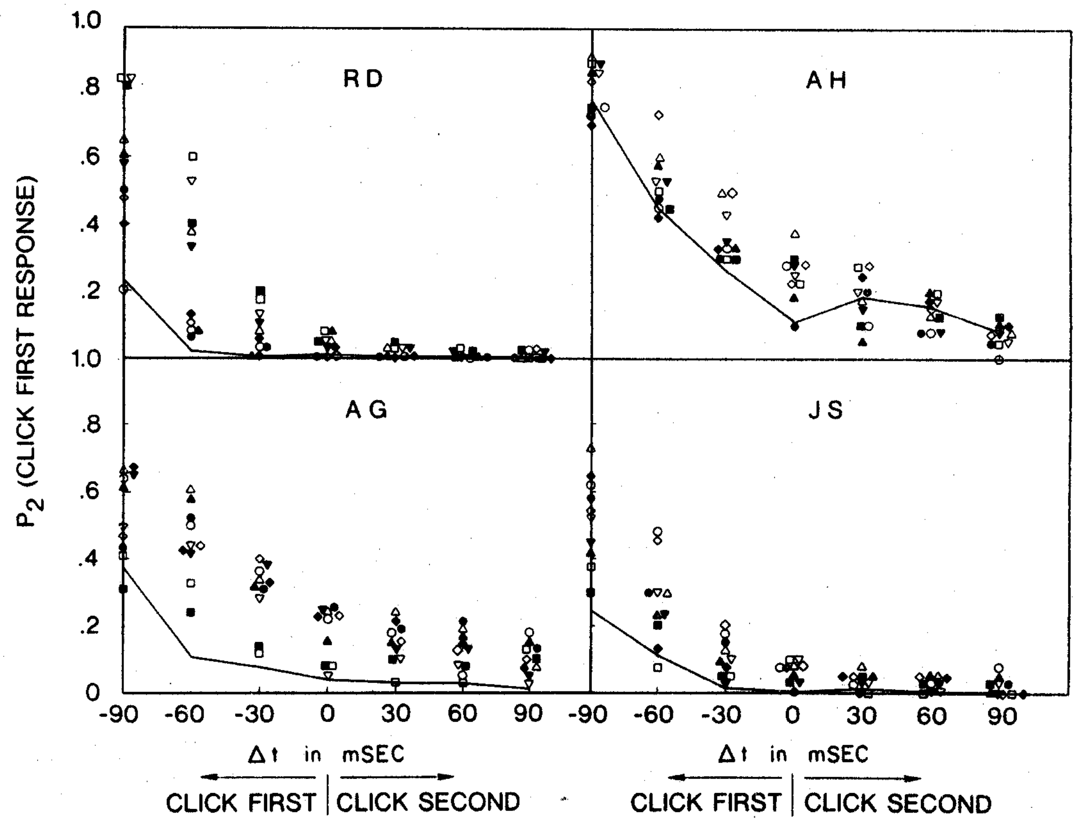

Figure 3. Psychometric functions $P_2(\Delta t)$ for control and experimental conditions. (Data of seven combined control conditions are represented by heavy solid lines. Data of "metacontrast" conditions are combined over one or two characters masked. Data of "apparent motion" conditions are combined over one or two charactes appearing to move. Points of the metacontrast $P_2(\Delta t)$ are represented by open symbols; points of the apparent motion $P_2(\Delta t)$ are represented by solid symbols. The symbol shapes represent SOA: □■ = 30 msec, ▽▼ = 60 msec, △▲ = 90 msec, ◇◆ = 120 msec, and ○● = 150 msec.)

The differences between control versus apparent motion and control versus metacontrast psychometric functions shown in Figure 3 were assessed by the Friedman one-sided rank sums analysis for treatments versus control designs (Hollander & Wolfe, 1973). The Friedman procedure allows us to simultaneously test the differences between control psychometric functions and psychometric functions derived from an experimental presentation at all nonzero SOAs. Table 1 shows that these test results are significant ($p < .01$) for all subjects except AH. For Subject AH the metacontrast data just failed to reach significance ($.05 < p < .1$), and the apparent motion data were not significant ($p > .1$).

To assess which SOAs metacontrast and apparent motion $P_2(\Delta t)$ psychometric functions differed from the control psychometric functions, individual one-tailed chi-square tests were performed according to a complicated procedure involving likelihood ratios, described by Chernoff (1954). The results of these tests are summarized in Table 2. Table 2 shows that all subjects displayed perceptual delay at one or more SOAs for metacontrast and for apparent motion.

Differences Between Metacontrast and Apparent Motion

The final series of tests were two-tailed chi-square tests of whether, for each subject

Table 1
Stimulus Onset Asynchronies (SOAs) of Visual Presentations That Produce the Largest Perceptual Delays

	Metacontrast				Apparent motion			
Subject	Σ ranks(SOA*) −Σ ranks(control)	SOA*	*N*	*p*	Σ ranks(SOA*) −Σ ranks(control)	SOA*	*N*	*p*
RD	22	30	6	<.01	20.5	30	5	<.01
AH	15	120	7	<.10	10	90	7	>.10
AG	23	90	7	<.01	27	90	7	<.01
JS	22.5	120	7	<.01	24	90	7	<.01

Note. Data are results of the Friedman test of one-sided rank sum differences in treatment versus control designs. SOA* is the SOA (in msec) for which $\sum_{\Delta t}$ rank (Δt, SOA) − $\sum_{\Delta t}$ rank (Δt, control) is maximum. *N* is the number of Δts used (i.e., Δts for which the floor effects did not make all ranks the same, max[*N*] = 7). The number of data points (proportions of click first responses) being ranked at each Δt is 6: 1 combined control plus 5 SOAs.

and SOA, metacontrast psychometric functions (collapsed over number of characters) differed from the apparent motion functions (similarly collapsed). Our inspection of these data suggested a small trend toward greater delay in metacontrast than apparent motion, but none of the 20 such tests revealed a significant difference ($p > .10$).

Table 2
Statistical Significance of Differences Between Control and Other Conditions

		Metacontrast			Apparent motion		
Subject	SOA	x^2	*df*	*p*	x^2	*df*	*p*
AG	30	11.39	3	<.005	2.43	3	>.1
	60	21.63	3	<.001	55.70	4	<.001
	90	49.12	4	<.001	53.31	4	<.001
	120	44.38	4	<.001	46.69	4	<.001
	150	39.33	4	<.001	39.45	3	<.001
RD	30	110.99	2	<.001	130.48	2	<.001
	60	122.57	2	<.001	73.02	2	<.001
	90	86.27	2	<.001	36.51	1	<.001
	120	19.27	1	<.001	19.35	1	<.001
	150	—[a]			19.27	1	<.001
JS	30	4.03	1	<.05	3.88	2	<.1
	60	32.60	2	<.001	11.20	2	<.001
	90	60.90	3	<.001	24.36	2	<.001
	120	62.15	3	<.001	62.26	3	<.001
	150	64.33	3	<.001	30.64	2	<.001
AH	30	5.32	7	>.2	8.15	7	<.1
	60	8.02	6	<.1	9.33	7	<.05
	90	21.19	6	<.001	3.38	7	>.2
	120	17.94	6	<.001	4.36	7	>.2
	150	6.11	6	>.1	.36	7	>.2

Note. One-tailed chi-squares are based on differences between psychometric functions, $P_2(\Delta t)$. SOA = stimulus onset asynchrony.
[a] Too few data to evaluate.

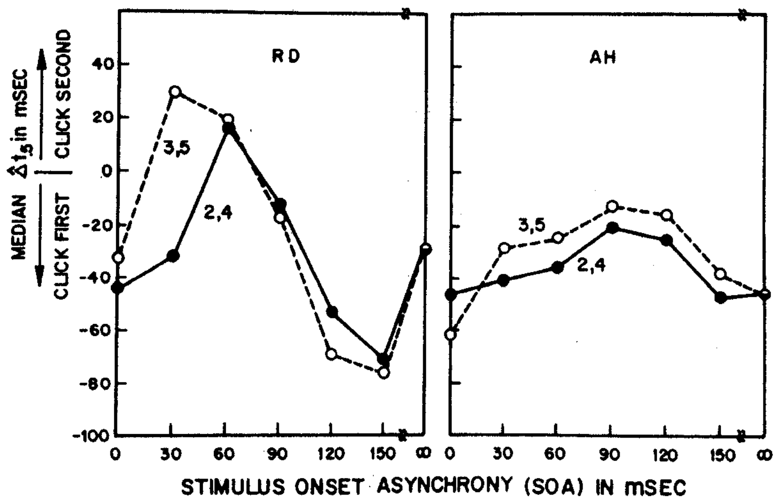

Figure 4. PROBIT-estimated medians $\hat{\Delta t}_{.5}$ as a function of SOA for Subjects RD and AH. (The symbols represent experimental conditions: ○ = "metacontrast," ● = "apparent motion." Except at infinite SOA, metacontrast points represent the average of Display Types 3 and 5 [see Figure 1] and apparent motion points of Display Types 2 and 4. Infinite SOA is the average of Display Types 1 and 6.)

Thus there does not appear to be a reliable difference between the amount of perceptual delay in metacontrast and apparent motion.

Perceptual Delay as a Function of Δt

A post hoc analysis was performed to estimate the amount of perceptual delay as a function of SOA for the metacontrast and apparent motion conditions. This was accomplished by subjecting the P(Δt)s to a probability unit (PROBIT) analysis (Finney, 1971; IBM, 1970). We use the PROBIT analysis to estimate the parameters of cumulative normal distributions that best fit our obtained psychometric functions, $P_i(\Delta t)$. The medians of these obtained functions are denoted as $\hat{\Delta t}_{.5}$. A median estimates the relative time of occurence of a click that would be judged—at a particular confidence level—to be earlier than the onset of the light flashes .5 of the time and later than the onset of the light flashes .5 of the time. The reason we use PROBITS to estimate these medians (instead of estimating medians directly from the psychometric functions by eye or by some other procedure) is that PROBITS use the data more efficiently and with less bias than other procedures (Finney, 1971).

To obtain reliable PROBIT estimates of medians, the observed psychometric functions must attain values both below and above .5, and they must be approximately normal. These requirements are marginally satisfied by Subject AH in the collapsed control conditions by the same $P_2(\Delta t)$ used in the other analyses (click first with at least medium confidence) and well satisfied elsewhere. For Subject RD, $P_2(\Delta t)$ is less than .5 in the range of interest (see Figure 2) and either of P_3, P_4, P_5, or P_6 could serve adequately; P_4 was used. Subjects AG and JS had no psychometric functions $P_i(\Delta t)$ that satisfied the requirements because the range of experimentally investigated Δts was not large enough.

Figure 4 shows the PROBIT-estimated medians, $\hat{\Delta t}_{.5}$ for Subjects RD and AH as functions of SOA. Data are collapsed over number of characters but plotted separately for motion and metacontrast conditions. Figure 4 also shows the PROBIT-estimated medians of the two control conditions that correspond to infinite SOA, that is, to an S1 only. These S1s are the same for apparent motion and for metacontrast displays; hence, the two functions necessarily converge for large SOAs.

The inverted-U shapes of the functions in Figure 4 are typical of graphs of the strength of effect versus SOA for both metacontrast and apparent motion (Kahneman, 1968). The reader may recall that Subject AH showed the weakest effect and is the only subject whose data does not yield a significant result on the Friedman test. Subject RD's data, as shown in Figure 3, are similar to those of Subjects AG and JS. Presumably, Subjects AG and JS would have yielded PROBIT-estimated medians similar to RD's, had a wider range of Δts been available.

Discussion

The results indicate that perceptual delay, as indicated by temporal-order judgments, is a consequence of both metacontrast and apparent movement. It is not surprising that perceptual onset of a visual stimulus, in which metacontrast obtains, does not always correspond to the onset of a portion of the stimulus, the target, that is not seen. It is interesting, however, that a similar effect is observed in apparent motion, where one does experience something that appears to be moving from a position near that of the first stimulus.

Results are Different From Those of a Previous Study

The results of this experiment appear to disagree with those of Matteson and Flaherty (1976), who performed a similar study that dealt only with metacontrast. In their experiment, two subjects judged the temporal order of a test stimulus presented to the right eye and a visual comparison stimulus presented to the left eye. The test stimulus was followed or preceded by a surround field at various SOAs. Only one of their two subjects produced a perceptual delay at SOAs between 50 and 100 msec, and the authors did not regard this as related to metacontrast. In fact Matteson and Flaherty do not report whether or not the surround (which was always dimmer than the test) actually produced metacontrast. Matteson and Flaherty's lack of stronger positive results may have been due to poor masking (perhaps because their test fields all had more luminous energy than their masks). An additional difficulty in their procedure is the possibility of interaction between the target and the temporal reference stimulus. They used a visual reference stimulus that was similar to the target stimulus in shape. Lewis, Matteson, and Dunlap (1977) pointed out that unimodal temporal-order judgments in vision may be accomplished by perceiving the direction of stroboscopic motion between the target and time-reference stimulus; stroboscopic motion is presumed to occur at a different (and possibly more peripheral) stage of visual processing than intermodal temporal-order judgments (Sternberg & Knoll, 1973).

Conclusions

When we combine the results of this experiment with those of Fehrer and Biederman (1962) and Fehrer and Raab (1962), we find that a stimulus that is suppressed (as in metacontrast) or is perceptually delayed (as in apparent motion and metacontrast) can elicit a simple response with the same reaction time as a stimulus that is neither delayed nor masked. Simple reaction time and temporal-order judgments appear to result from different processes affected by different operations. That is, a masking stimulus that produces a profound effect on temporal-order judgments does not alter simple reaction times.

The results of this study are consistent with Kahneman's (1968) suggestion that metacontrast and apparent motion have much in common, perhaps being mediated by the same mechanism: Both metacontrast and apparent motion displays produce no change in reaction time to the first stimulus, but temporal-order judgments to this stimulus exhibit significant perceptual delay. The elucidation of how two such apparently elementary responses as temporal-order judgment and reaction time can be governed by such different processes, and how such perceptually different experiences as metacontrast and apparent motion are governed by such similar processes, poses an interesting problem for further research.

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Received March 14, 1979 ■