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DIFFERENT ENCODING MECHANISMS FOR PHASE AND CONTRAST

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Abstract—Phase sensitivity was assessed over a large range of exposure durations by means of a 2AFC staircase procedure where the observer had to detect the relative position of sinusoidal gratings relative to a superimposed thin, dark line. Phase discrimination thresholds decreased as a function of exposure duration although the contrast of the stimuli was weighted for equal detectability at all durations. Phase sensitivity improved markedly with contrast, as opposed to the degradation with contrast seen in contrast discrimination paradigms. The contrast and time functions of phase sensitivity both support the hypothesis that phase is processed separately from contrast by a pathway with different temporal and contrast characteristics. We propose a model where phase sensitivity depends on a luminance subtraction process with a time constant of about 130 msec.

Phase Position Contrast Critical duration Pattern recognition

INTRODUCTION

The analysis of visual patterns requires encoding of both the presence of components in a pattern and of the relative position of the components. It is well established that the visual system contains parallel mechanisms that are simultaneously localised in position and also band-limited in terms of spatial frequency content (Kulikowski and King-Smith, 1973; Shapley and Tolhurst, 1973; Stromeyer and Klein, 1974; Nachmias and Weber, 1975; Wilson, 1980).

Do these mechanisms encode both the presence and the position of a pattern, or is additional processing required to extract the position information? The latter alternative has plausibility, because relative position encoding requires comparisons between the mechanisms detecting separate components of the pattern. On the other hand, detection requires activation of only a single mechanism. To answer the question of additional processing for position encoding, we focus on the temporal aspects of the process, and introduce the paradigm of adjusting the contrast as a function of stimulus duration so that the stimuli are all equated in relation to detection threshold.

If position encoding involved a direct readout from the band-limited mechanisms, the threshold for detecting changes in position should then remain constant for all durations. Such a direct process could operate on the basis of a local retinal sign for each band-limited mechanism. Conversely, if the position threshold varies with duration when the stimuli are weighted for equal detectability, it would suggest the presence of further processing to obtain position information from the output of the band-limited mechanisms. The form of the deviation from a constant position threshold can provide clues to the temporal characteristics of the position encoding process. Encoding of *relative* position of band-limited mechanisms eliminates the need to postulate local retinal sign information.

The stimulus we chose to examine the properties of position encoding was the sinusoidal grating, which should optimally stimulate one class of band-limited mechanism tuned to its spatial frequency. In this context, position may be described in terms of the spatial phase of the grating relative to some position marker. We will therefore use the terms "phase" and "position" interchangeably in describing the results. If visual stimuli are processed solely by band-limited channels, this identity would apply to all stimuli, but in other analytic frameworks it would have more limited generality.

Phase processing and contrast

Evidence that position or phase sensitivity is derived from the relative luminance of the local features of the pattern has been provided for

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simple patterns by Marr and Hildreth (1980), Watt and Morgan (1983), and Watt *et al.* (1983). Badcock (1984a, b) has proposed that phase sensitivity for complex patterns of two sinusoidal components involves a contrast differencing operation derived from the relative contrast signals for key features of the pattern (although his model is not presented in a quantitative form that could be implemented by other investigators). The model implies that phase processing is based on processing for local contrast, and should therefore be subject to the non-linear contrast transducer function described by Legge (1981).

It is important to distinguish between the idea that phase processing is based on local contrast and the idea that it is equivalent to, or identical with, contrast discrimination. When contrast is increased, in fact, contrast discrimination thresholds are degraded (Legge, 1981) while phase discrimination improves. The effects of varying contrast go in opposite directions for the two tasks. The form of the opposite changes conform to a fixed contrast ratio for contrast discrimination as opposed to the fixed contrast difference for phase discrimination (Badcock, 1984b), when the base contrast is assumed to follow the nonlinear transducer function. This processing difference is *prima facie* evidence that phase processing involves a mechanism that must at some level be separate from that processing contrast differences in Legge's (1981) paradigm.

Such results imply that phase processing involves a differencing operation on the output of the suprathreshold contrast transducer. Equating the stimuli for equal contrast detectability should place the stimulus at the same point on the contrast transducer function (CTF) provided that it is independent of duration. This procedure should therefore equate phase sensitivity as a function of duration. Such independence would imply that the CTF is a static nonlinearity tied to the contrast threshold. This characterization of the CTF as a time-invariant nonlinearity is an important assumption for the paradigm, which will be tested empirically for our stimulus conditions.

The assumption was tested by Legge and Kersten (1983), using single bar stimuli, who found the contrast transducer function to be similar for 10 and 200 msec presentations when adjusted for the difference in contrast threshold, although there was some tendency for an increased exponent at the shorter duration. This increase may perhaps be discounted as a result of insufficient familiarity with the 10 msec condition, which was run on only a few sessions, since Swift and Smith (1983) have shown that the exponent declines to an asymptotic value with practice and familiarity with the stimulus. We therefore included various contrasts at all durations tested in our study of phase sensitivity, to equalize the practice effects. The results will be shown to verify the assumption that the contrast transducer function is a static nonlinearity.

The stimulus used throughout the present experiments was a combination of a one-dimensional sinusoidal grating and a thin, dark, reference line whose position had to be judged with respect to the peak luminance of one of the bright bars of the periodic stimulus. Figure 1 shows the luminance profile of the stimulus. Given this physical configuration, our experimental task can be considered to lie at the border between typical phase discrimination and typical acuity tasks. It therefore provided an experimental link between the two theoretical approaches described above.

METHODS

Stimuli

Vertical, sinusoidal gratings of 0.8 and 4.3 c/deg were displayed together with a vertical dark reference line 21″ arc in width (Fig. 1). The sinusoidal gratings and the reference line were generated by means of an Apple II+ computer on the face of a Hewlett-Packard CRT (HP/1332A) with green phosphor. They were seen through a circular aperture 2.25° in diameter at 230 cm from the observer. The average luminance of the whole display, including a large surround matched in chromaticity to the inspection field, was 40 cd/m^2. Two distinct

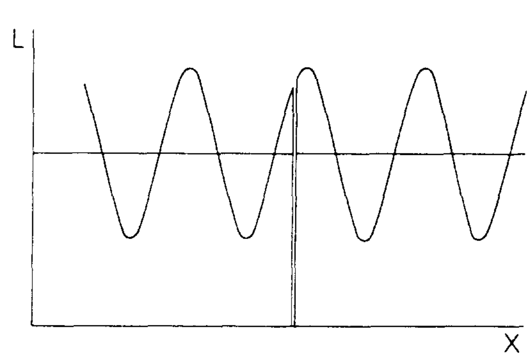

Fig. 1. The luminance profile of the stimulus used in all experiments.

experiments were run. The first consisted in measuring contrast sensitivity for a range of exposure durations extending from 7.5 to 1000 msec. Detection thresholds were measured in the presence of the dark reference line, which was always well above its detection threshold. In the second experiment, phase sensitivity for different contrasts was measured over the same range of exposure durations. At each duration, stimulus contrast was weighted by a factor of either 1.25, 2.5, 5 or 10 times its detection threshold to ensure equal detectability independent of exposure duration.

Procedure

The two authors served as observers in all experimental conditions. Both contrast-detection and phase-discrimination thresholds were assessed by means of 2-alternative forced choice (2AFC) staircase method. In the detection experiments the contrast of the stimulus was always increased by 0.06 log unit for a wrong response and decreased by the same amount with a probability $P = 0.33$ for a correct response. This is equivalent to the more conventional rule requiring three correct responses in a row for one contrast step decrease, and produces an average detection level of 79% correct on the psychometric function. The same paradigm was applied in the phase discrimination experiments, where the contrast was kept constant and phase was varied in steps computed as a ratio of the absolute extent (in arc min) of one cycle of the stimulus.

In both cases the threshold estimate was computed as the mean value of the last 40 trials in a 50-trial sequence, the first 10 being allowed for convergence on the threshold level. Each measured point in the figures is the mean of at least two estimates, or three in occasional instances where the first two differed by more than a factor of two.

In the contrast detection experiments the stimulus was presented in one of two temporal intervals. In the phase discrimination experiments one trial consisted of one single temporal interval with the reference line displayed at the left or at the right of the peak luminance of one of the cycles of the grating. The observer had to determine the relative position of the reference line (right or left). To avoid any positional cues provided by the edges of the display, the reference line was randomly shifted between trials within a range corresponding to half of the period of the grating. Spatial frequency and presentation times were randomly varied from run to run.

Threshold estimation was limited in three ways. One limitation was due to the maximum resolution of the display, i.e. 0.3 arc min. The second was inherent to the nature of the task, where relative phase displacements larger than $\pm\pi/2$ could not be used without introducing an ambiguity as to which cycle the line should be referred. Finally, a third limitation was inherent in the relatively low contrast range in which the phase discrimination could be performed, as a result of the limited range of contrast ratios available at the shortest durations.

RESULTS

Figure 2 displays contrast-threshold/duration functions for the two spatial frequencies and the two observers. The smooth curves adjusted to the data are predictions of a model for contrast detection developed elsewhere (Gorea and Tyler, 1983, 1986). Since the predicted threshold

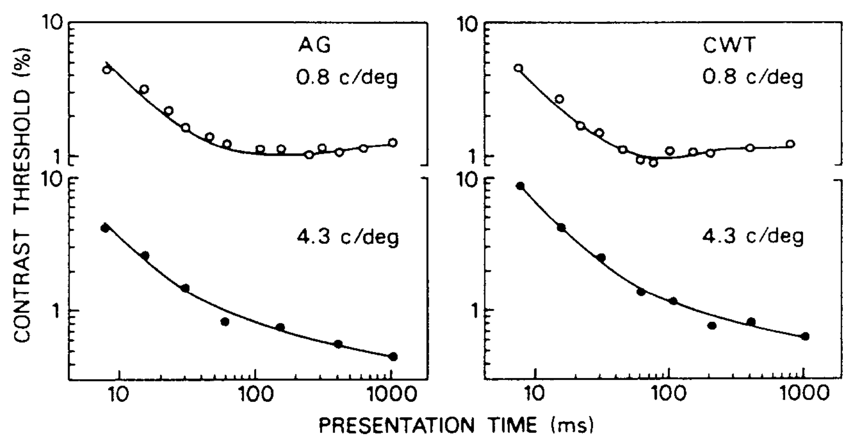

Fig. 2. Contrast thresholds as a function of duration for 0.8 and 4.3 c/deg stimuli (open and solid circles, respectively). The smooth curves are predictions from a model described elsewhere (Gorea and Tyler, 1986). Observers A.G. and C.W.T.

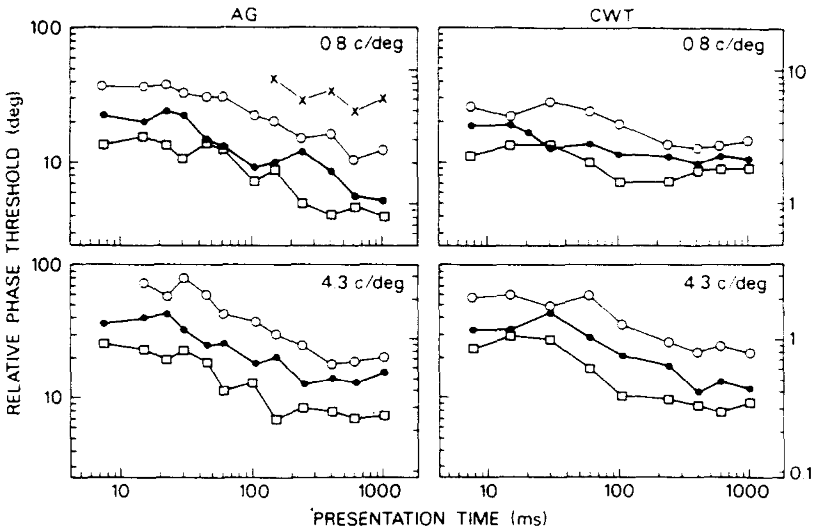

Fig. 3. Phase thresholds as a function of duration for 0.8 and 4.3 c/deg stimuli (upper and lower panels, respectively). Stimulus contrast at each duration was weighted in proportion to contrast threshold by 1.25, 2.5, 5 and 10 times (stars, open circles, solid circles and squares). Observers A.G. and C.W.T.

values are in good agreement with the data, they were used as a reference level for the phase discrimination experiments. The contrast of the stimulus was set at a fixed ratio to the contrast threshold at each duration, and phase difference was used as the dependent variable. The advantage of this approach is that the measurement for any one contrast ratio should always be made at the same point on the contrast transducer function. Nonlinearities of this transducer will therefore not perturb the results as a function of stimulus duration. This procedure is only possible when measuring a separate variable, such as phase. It could not have been used for the more usual measurement of contrast sensitivity for a fixed phase, since contrast cannot simultaneously be varied and held constant.

Figure 3 displays phase thresholds obtained with 0.8 and 4.3 c/deg stimuli (upper and lower panels) at 1.25, 2.5, 5 and 10 times their detection threshold for the two observers (left and right panels). Phase discrimination thresholds for stimuli 1.25 times the detection threshold could be measured only for A.G. and only with the 0.8 c/deg grating for durations longer than 100 msec. The limitations in phase discrimination at low contrasts are mainly due to the nature of the task, as discussed above.

The overall shapes of the phase-discrimination/duration functions are similar for

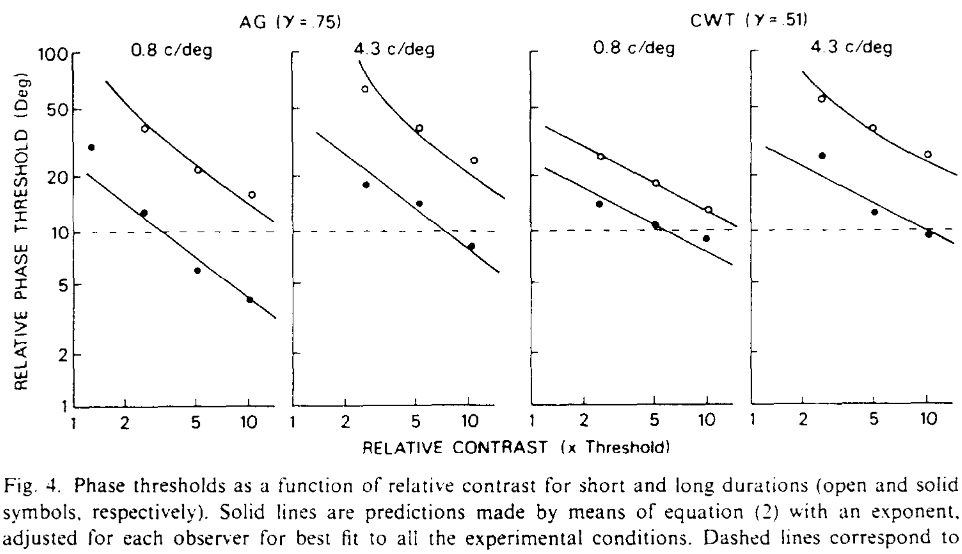

Fig. 4. Phase thresholds as a function of relative contrast for short and long durations (open and solid symbols, respectively). Solid lines are predictions made by means of equation (2) with an exponent, adjusted for each observer for best fit to all the experimental conditions. Dashed lines correspond to predictions for constant Weber ratio.

both spatial frequencies. They show a plateau up to about 30 msec and also beyond 200–400 msec, with a shallow negative slope between these limits, despite the fact that stimulus contrast was weighted to be equally detectable at all exposure durations. At long durations phase thresholds decrease by an average factor of 3.5 and 2.2 for observers A.G. and C.W.T., respectively. It can thus be inferred that phase processing mechanisms are, at least partly, distinct from the contrast detecting ones.

At higher contrasts and long exposure durations, phase thresholds can be as low as 4–7° (i.e. between 2 and 4% of the maximum 180° phase displacement). When expressed as an absolute displacement, phase thresholds can be as low as 17 arc sec (observer A.G., 4.3 c/deg). These values are comparable to thresholds obtained in conventional phase discrimination tasks using complex grating stimuli (e.g. Badcock, 1984a, b). They are also similar to those where the observer had to detect the minimum displacement for sinusoidal gratings (Westheimer, 1978). As might be expected given the relatively low contrast stimulus used in this experiment, they are higher than typical hyperacuity thresholds (Westheimer, 1977; Westheimer and McKee, 1977a, b; Watt and Morgan, 1983).

The relationship between phase sensitivity, as measured here, and spatial frequency is not clear. When expressed in degrees of phase angle, phase sensitivity decreases by a factor of about 2.5 for a spatial frequency increase from 0.8 to 4.3 c/deg (a factor of 5.4). This is less than the 1 to 1 relationship reported by Westheimer (1978) for spatial frequencies ranging from 3 to 25 c/deg, but more than the null relationship reported by Burr (1980).

Finally, Fig. 4 demonstrates the effect of relative contrast on phase discriminability at short (open symbols) and long (solid symbols) exposure durations and for the two spatial frequencies. Each datum point for short and long durations was obtained by averaging the phase discrimination thresholds at each contrast level across the three shortest (7.5, 15, 22.5 msec) and the three longest (400, 600, 1000 msec) presentation times, respectively. Given the flat regions of the phase-threshold/discrimination functions within these duration ranges, the averaging operation was designed to increase the reliability of the threshold estimates.

Had phase discrimination thresholds followed Weber's Law, in the form of the ratio of integrated luminances to the left and to the right of the reference line, phase thresholds should have been independent of the overall contrast of the stimulus (parallel to the dashed line in Fig. 4). Inclusion of a contrast nonlinearity in the Weber ratio would predict an increasing threshold with contrast (Legge, 1981). Clearly the measured thresholds do not display this type of behavior, but decrease substantially with contrast. The same type of decrease in threshold with contrast is seen in tasks involving relative phase discrimination between two components (Badcock, 1984a). While the involvement of local luminance comparisons in the type of task described in this study has been questioned (Westheimer and McKee, 1977b), the marked increase in phase sensitivity with contrast in Fig. 4 shows that the phase processing stage must take the local luminance into account in the threshold determination. This observation, together with the fact that phase sensitivity is time dependent even for equally detectable stimuli, support the conjecture that, although phase discrimination requires the initial input of contrast information, it involves an additional stage of processing with different threshold behavior and temporal characteristics.

ANALYSIS

An additional stage

It has been recently suggested that the relative position of an object in the visual field might be computed from the zero-crossings in the convolution of the retinal light distribution with the second derivative of a Gaussian (Marr and Hildreth, 1980; Watt and Morgan, 1983). Moreover, spatial location cannot be accounted for in terms of the peak of the retinal light distribution (Watt and Morgan, 1983) which suggests that modifications are needed if Badcock's (1984a, b) approach is to have more general application. Although the computation of the zero-crossings is shown to be psychophysically plausible, these authors report results that can also be explained in terms of a model where the location is assigned to the arithmetic mean of a given light distribution. The zero-crossing and the mean models cannot always be distinguished from each other.

In our experimental condition the zero-crossing operation alone could not account for the data displayed in Fig. 4. The location of the zero-crossings is independent of contrast and, as a consequence, the phase thresholds should also have remained constant. It is thus convenient to assume that both processes, extraction of zero-crossings and local luminance integration, are effectively implemented in processing phase/location information.

We propose a model where the visual system integrates the luminance to the left and to the right of the reference line out to the point where the luminance profile crosses the mean luminance level ($-\pi/2$ and $\pi/2$). (This is designed to be a reasonable approximation to the convolution of our stimulus with the receptive field profiles that have the optimum discrimination between the two positions (Klein and Levi, 1985), which may perhaps be odd symmetric fields centered near the reference line.) To decide whether the reference line is to the left or to the right of the peak of a given cycle, the comparison between the two integrated luminances must be made operational. One way to achieve this would be to compute their ratio, but this operation is inconsistent with the data of Fig. 4. Another way to make the comparison would simply be to compute their difference, as suggested by Badcock (1984a), for somewhat arbitrarily defined local luminance peaks. If the contrast input to this process is assumed to follow a power nonlinearity, C^{γ}, then the threshold for the differential luminance integration process is described by

$$K = \int_{-\pi/2}^{\phi} C^{\gamma} \cos\theta \, d\theta - \int_{\phi}^{\pi/2} C^{\gamma} \cos\theta \, d\theta = 2C^{\gamma} \sin\phi \quad (1)$$

from which

$$\phi = \arcsin(K/2C^{\gamma}). \quad (2)$$

The γ exponent is unknown and was estimated to obtain the best fit for the phase threshold improvement with contrast under all conditions for each observer. Heavy lines in Fig. 4 are predictions from equation 2 with estimated γ exponents of 0.75 and 0.51 for observers A.G. and C.W.T., respectively. These functions are approximately straight lines in log coordinates, with a small curvature caused by the arcsin expression in equation 2. The exponents correspond to the nonlinearity observed for the contrast transducer function and are well within the range previously observed (Wilson, 1980; Legge, 1981; Badcock, 1984a, b). Note that for each observer there is no evidence for a change in the slope of the CTF between short and long durations, or between low and high spatial frequencies. This verifies our initial assumption that the CTF is a static nonlinearity and that compensating the stimulus contrast for equal detectability places the response at the same point on the CTF under all four stimulus conditions.

Since the argument of the arcsin function cannot be smaller than -1 or greater than $+1$, the contrast C, which is positive by definition, will be limited by the relation:

$$C \geqslant (K/2)^{1/\gamma} \quad (3)$$

This inequality specifies the minimum contrast that can be used in phase discrimination experiments.

Analysis of temporal characteristics

It is natural to suppose that the subtracting operation described by equations 1 and 2 may be time consuming. The variation of phase sensitivity with stimulus duration at constant relative contrast (Fig. 3) supports the idea of this additional stage for phase processing. We therefore expand our previous model for the temporal properties of contrast detection (Gorea and Tyler, 1983, 1986) to include a diverging pathway for phase detection (Fig. 5). This pathway includes the same mechanisms for a nonlinear threshold operation and probability summation over independent detectors that we proposed for contrast detection. The extra stage in the phase pathway is the mechanism for computing the phase difference from the luminance profile, as proposed above. This phase mechanism will have a particular impulse response by which the information it receives is transformed and passed to the following stage.

In a serial system, such as the phase pathway in Fig. 5, the impulse response of the overall system is given by the convolution of the impulse responses of each stage of the system.

Temporal integration functions

To gain some insight into such a phase processing stage, we make the initial assumption that its impulse response is a monophasic response of low order (number of poles). From this it follows that the overall impulse response should be of a similar form to that of the contrast process alone, since the latter is of higher order (Watson, 1982). The adequacy of this assumption will be tested when we fit the data, but it allows an approach to the question of the time characteristics of the phase stage

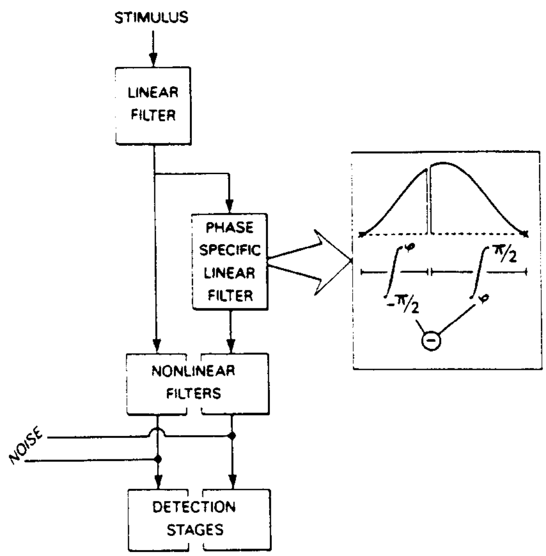

Fig. 5. Block diagram of the model discussed in the text.

corresponding to the analysis of Fig. 6. As shown, the difference between the phase and contrast detection response characteristics can be described by differences in their time constants. If the temporal integration characteristic, or threshold/duration function, of the mechanism is plotted on double logarithmic coordinates, a change in the time constant of an impulse response will produce a uniform shift of this function along the time axis (Fig. 6). Phase sensitivity should therefore be degraded relative to contrast sensitivity in proportion to the ratio between the original and shifted functions at each stimulus duration. (Note that although the phase sensitivity/duration functions were measured here in terms of phase thresholds, their measurement at a constant ratio to detection threshold means that the contrast nonlinearity of equation 2 should be the same for all phase thresholds. Phase sensitivity is therefore unperturbed by the contrast nonlinearity, and can be regarded as a direct reflection of the temporal characteristics of phase processing.)

With compensation for contrast sensitivity, the sensitivity of the phase stage is thus modeled by the ratio between the curves in Fig. 6. There are two free parameters in this simple model: (i) the absolute phase sensitivity at a given duration or vertical position of the curve, and (ii) the difference in time constants between the contrast and overall impulse response. The phase sensitivity data were therefore fitted by adjusting the time constant difference between the pairs of theoretical threshold/duration curves of Fig. 6 for least squares fit of their ratio to the data.

The data used were the phase discrimination thresholds of Fig. 3 pooled across the three (or four) contrast levels (geometric means) and normalized with respect to the highest threshold for each spatial frequency (Fig. 7). Averaging

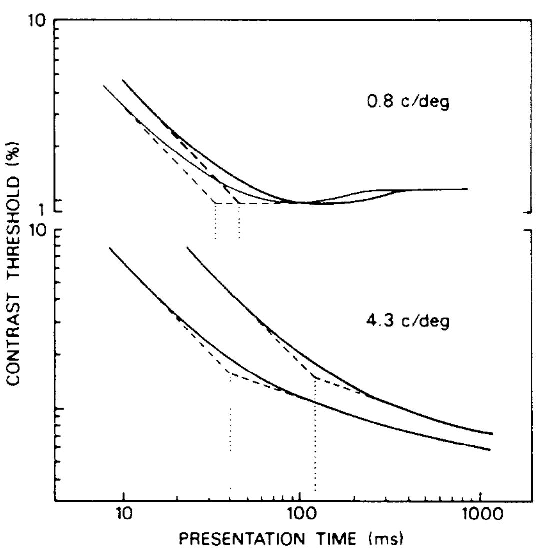

Fig. 6. Pairs of constant threshold/duration functions at two spatial frequencies from Fig. 1, showing the shift in time constant required for phase processing (righthand curve of each pair) to model phase sensitivity. Dashed lines are asymptotes intersecting at the relevant critical duration for each condition (dotted lines).

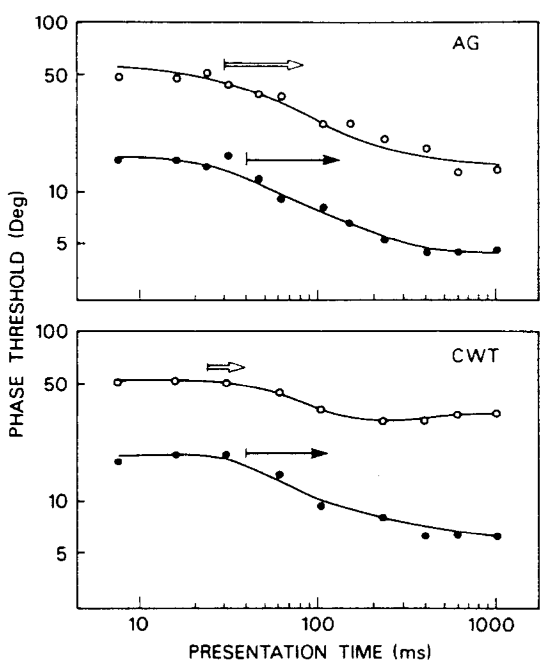

Fig. 7. Phase threshold/duration data averaged across all contrast levels and predictions of the "time constant shift" model described in the text. Open and solid symbols are 0.8 and 4.3 c/deg gratings, respectively (observers A.G. and C.W.T.).

was possible because the phase-threshold/duration functions were essentially shape invariant with contrast. The full curves in Fig. 7 show the predictions of the "temporal shift" hypothesis, which provides a rather good fit to several features of the data. These include the duration at which phase sensitivity begins to improve from the initial plateau, the duration at which the final plateau occurs, the rate of improvement in between, and the presence of a slight upturn in the low spatial frequency data for C.W.T. which is absent for A.G. All these features are controlled by the shape of the contrast functions and are otherwise independent of the time constant hypothesis *per se*. The initial contrast time constant and required time constants for the overall phase response are shown respectively by the tails and heads of the arrows of Fig. 7 (see Table 1).

DISCUSSION

The good fit of the time constant hypothesis to the data suggest that the assumption of similarity in form of the two impulse responses is sufficiently close for the present purposes. Moreover, threshold/duration functions are rather insensitive to the precise shape of the impulse response, apart from its time constant and the ratio of excitation to inhibition (Gorea and Tyler, 1983, 1986). Since we now have an estimate of the time constant of the overall impulse response for the phase pathway, we can obtain certain information about the impulse response of the phase processing stage alone. The first thing we can definitely say is that its impulse response at high spatial frequencies must be monophasic, since convolution of the monophasic contrast response with a biphasic phase response would result in a biphasic overall response for the phase mechanism. The phase sensitivity at high spatial frequencies would then be predicted to continue to increase above 400 msec, while the data show a pronounced levelling in this region.

The data are also consistent with a monophasic impulse response for the phase processing stage at low spatial frequencies, since the convolved impulse response would now be biphasic, although with a longer time constant, as implied by the data. For parsimony we therefore propose that the phase processing stage has a monophasic impulse response at all spatial frequencies. To obtain an initial prediction of the effects of the phase stage with spatial frequency, we further assume that the impulse response of the phase stage is that of a first order integrator $[h_p(t) = t \cdot e^{-at}]$.

At high spatial frequencies, the implied critical durations for the overall impulse response for phase discrimination according to our model are 145 and 120 msec for A.G. and C.W.T. respectively. These should be compared with

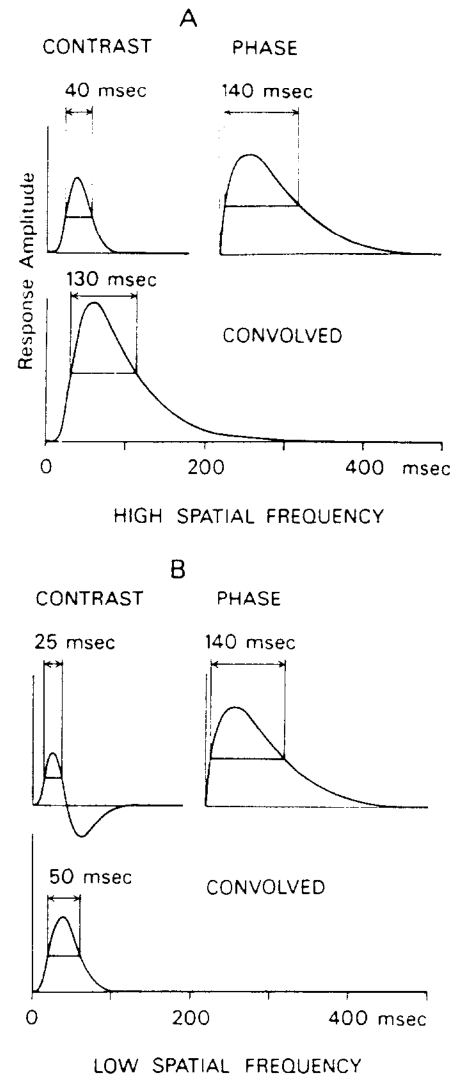

Fig. 8. Effect of convolving the proposed phase impulse response with a contrast impulse response from Watson (1982). The time constants (Υ) are defined as the width of the positive peak at half height, corresponding roughly to the critical duration for each impulse response (Gorea and Tyler, 1986). (A) High spatial frequency. Convolution of a first-order phase integrator (Υ_c = 130 msec) with Watson's monophasic ninth order contrast integrator (Υ_c = 40 msec). The convolved output response has a time constant of 130 msec. (B) Low spatial frequency. Convolution of the first-order integrator with Watson's biphasic response (Υ_c = 27 msec). The same phase time constant gives a predicted output response of 48 msec, much shorter than at high spatial frequencies.

values of about 40 msec for both observers for contrast detection at high spatial frequencies (Gorea and Tyler, 1986). Figure 8A shows that when the second stage convolution is much longer than the first, its time constant dominates the convolved impulse response under these conditions, for the impulse responses forms obtained by Watson (1982). We can therefore infer that the time constants of the phase processing stage alone are also about 145 and 120 msec for the two observers (Table 1).

These estimates of the phase time constant can now be used to predict the overall impulse responses under low spatial frequency conditions. Convolving the biphasic impulse responses for such stimuli (time constants of 30 and 25 msec respectively) with the proposed monophasic phase responses should predict the implied time constants of 85 and 44 msec for A.G. and C.W.T. derived from the model (Figs 6 and 7). Using Watson's impulse responses again, the results are shown in Fig. 8(B). The predicted time constants are 53 and 43 msec, in reasonable agreement with the model results, particularly for C.W.T.

Clearly, our model gives results in the appropriate range, justifying the initial assumption that the phase mechanism has a monophasic response of low order.

Table 1. Measured and predicted time constants

	0.8 c/deg		4.3 c/deg		
	Contrast	Phase	Contrast	Phase	Predicted phase
A.G.	40	145	30	85	53
C.W.T.	40	120	25	44	43

Critical durations in msec for contrast detection (from Gorea and Tyler, 1986) and phase discrimination (from present phase model). Last column shows phase time constant predicted from convolution of phase impulse response derived at low spatial frequencies with high spatial frequency contrast response.

CONCLUSION

We have proposed that phase processing can be accounted for in terms of a local luminance (or contrast) subtraction operation (equation 2) and that this operation is characterized by its own temporal impulse response. Both propositions are contrary to the idea that phase thresholds are determined at the contrast detection stage, but are compatible with current theories where phase processing depends on the outputs of more than one local region. The neural network we suggest to account for phase processing is intermediate between the serial and parallel approaches. The parallel, phase processing stage appears to have temporal characteristics independent of spatial frequency, with a time constant of approximately 130 msec.

The presence of a specific phase mechanism encoding relative position means that no local retinal signs are required for visual position information. This mechanism operates with high efficiency between discrete bar and sinusoidal stimuli (position thresholds as low as 1/4 arc min). This level of performance on a mixed stimulus supports the idea that the same type of process underlies grating phase and bar position coding.

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