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RESEARCH NOTE

TEMPORAL INTEGRATION CHARACTERISTICS IN SPATIAL FREQUENCY IDENTIFICATION*

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Abstract—Spatial frequency detection and identification performances were measured simultaneously as a function of exposure duration. Detection and identification sensitivity/duration functions appeared to be parallel over durations ranging from 10 to 1000 msec, independent of both spatial frequency and spatial frequency difference between the stimuli to be discriminated. The results are compatible with both a simultaneous or a serial processing of the two types of tasks. In the former case, detection and identification would take place at the same neural level and they would, therefore, be indistinguishable. The second alternative implies that the identification stage must have a time-constant substantially shorter than the detection stage. Both possibilities are compatible with the concept of spatial frequency labelled detectors.

Vision Detection Identification Spatial frequency Temporal integration

INTRODUCTION

Much interest has been focused in the last few years on the relationship between detection and identification in vision. Detection/identification experiments have been performed along physical continua such as orientation (Thomas and Gille, 1979; Thomas *et al.*, 1982; Regan and Beverley, 1985), spatial and/or temporal frequency (Thomas and Gille, 1979; Watson and Robson, 1981; Olzak and Thomas, 1981; Thomas *et al.*, 1982; Wilson and Gelb, 1984; Wilson and Regan, 1984), velocity (Thompson, 1981) and direction of motion (Watson *et al.*, 1980; Green, 1983; Ball *et al.*, 1983; Gorea, 1985a).

In some of these studies the measurement of identification performance at the detection threshold was used as an experimental tool to reveal sub-system bandwidth characteristics. Nevertheless, such inferences cannot be made without a basic understanding of (or basic assumptions on) how identification is performed by the underlying mechanisms. When identification performance is measured at the detection threshold, these basic assumptions can be formulated in terms of (presumably) known properties of the detection process. As a consequence, models of the identification process are strongly dependent on the detection model adopted which, generally speaking, can be either of a high threshold or a signal detection type.

High threshold assumptions will possibly lead to the postulation of *labelled detectors* (Watson and Robson, 1981) whose activation is sufficient to elicit an identification response exclusively determined by their label. This formulation implies that at the detection threshold only one single detector is activated. Since detection and identification processes are equivalent within this framework, they should also have equivalent time-courses independently of the detection-to-identification sensitivity ratio. Indeed, while the time-course of the two processes is strictly determined by the temporal characteristics of the activated detector, the detection-to-identification ratio depends on the probability of activating that given detector with either of the two (or more) stimuli to be discriminated.

Models of identification as a comparison process (e.g. Wilson and Gelb, 1984; Mandler and Makous, 1984) do not lead to any explicit or implicit assumption of this kind. It is perfectly possible that the temporal impulse

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response (and therefore the integration time constant) of the identification process is independent of the comparisons put forth by these models. When such models are developed within the framework of signal detection theory (see Luce, 1963; Green *et al.*, 1977; Thomas and Gille, 1979; Thomas *et al.*, 1982), it is even less clear whether they can generate any prediction whatsoever about the temporal aspects of the computations they postulate. This is so because these computations are not necessarily meant to describe real time-developing processes. Moreover, signal detection models cannot account as yet for identification performances obtained with nonorthogonal stimuli (i.e. which induce a detection-to-identification sensitivity ratio much greater than 1; Green and Birdsall, 1978).*

The present study is concerned with the discrimination of patterns which differ only in their spatial frequency. Simultaneous detection and identification performances were measured as a function of presentation time. Small (0.5 octave or less) and large (1.2 octave) spatial frequency differences were used in the low and medium spatial frequency range. The results indicate that, independently of the experimental condition, detection and identification time-courses are essentially identical.

METHODS AND PROCEDURE

Stimuli

These were patches of vertical sinusoidal gratings generated by a Picasso CRT Image Generator under computer control (M/OS-80 Mostek microsystem) and displayed on a Tektronix 608 monitor (P4, white phosphor) at a mean luminance of 88 cd/m^2. Their spatial extent was confined by a circular window 2.50 in diameter at 115 cm from the observer. The whole inspection field was surrounded by a large (100 × 80 cm) white surface of about equal brightness. Fixation was facilitated by means of four tiny black dots 1 cm apart. Two spatial frequency pairs were used in the low (0.5–0.75 and 0.5–1.15 c/deg) and in the medium (5–7.5 and 5–11.5 c/deg) spatial frequency range. The spatial frequency pairs were chosen so as to presumably activate strongly overlapping and non-overlapping detection channels (Watson and Robson, 1981). Six equally spaced (in log units) presentation times were chosen so as to span a time range from 10 to 1000 msec. All stimuli were viewed binocularly by three well trained observers, one of which was the author. All three observers had normal or corrected to normal vision.

Procedure

Detection and identification thresholds were measured by means of a 2 × 2 alternative forced choice (2 × 2AFC) staircase procedure. The stimulus appeared in one of two temporal intervals, the beginning and end of which were marked by auditory tones. It could be one of the two members (arbitrarily called 1 and 2) of a given spatial frequency pair. In order to prevent identification responses based on local cues, the phase of the stimuli was varied randomly from trial to trial over one period interval of the given spatial frequency. The observer had to decide which of the two intervals contained the stimulus (*detection* response) and to identify the stimulus as 1 or 2 (*identification* response). Auditory feed-back was provided for incorrect detection and identification responses. Four independent staircases were used concurrently. Two of them were detection dependent and the other two were identification dependent. Each trial was randomly selected to belong to one of them. Three consecutive correct (detection or identification) responses resulted in a 2 dB contrast decrease, whereas one incorrect response resulted in an identical increase. This produces detection and identification levels of 79.6% on the psychometric function (Wetherill and Levitt, 1965). Since the shape of the psychometric function obtained for the two types of task is typically invariant (Watson and Robson, 1981; Gorea, 1985a) detection and identification performances were exclusively expressed in terms of the respective contrast thresholds as obtained through averaging the reversal points in each staircase.

One experimental session consisted of at least 240 trials equally distributed among the two stimuli to be discriminated and the two response dependent rules. Presentation times for each

*It is meant here that models of d' summation for non-orthogonal stimuli/channels have not, as yet, been developed. Instead, Thomas *et al.* (1982) suggested a way to get round this problem. Their procedure consisted in determining the contribution of both optimal and nonoptimal stimuli to the output of different (orientation or spatial frequency, etc.) *overlapping* (and thus not independent) channels and then in computing the overall sensitivity of the system through the standard d' summation procedure *as if* these channels were independent.

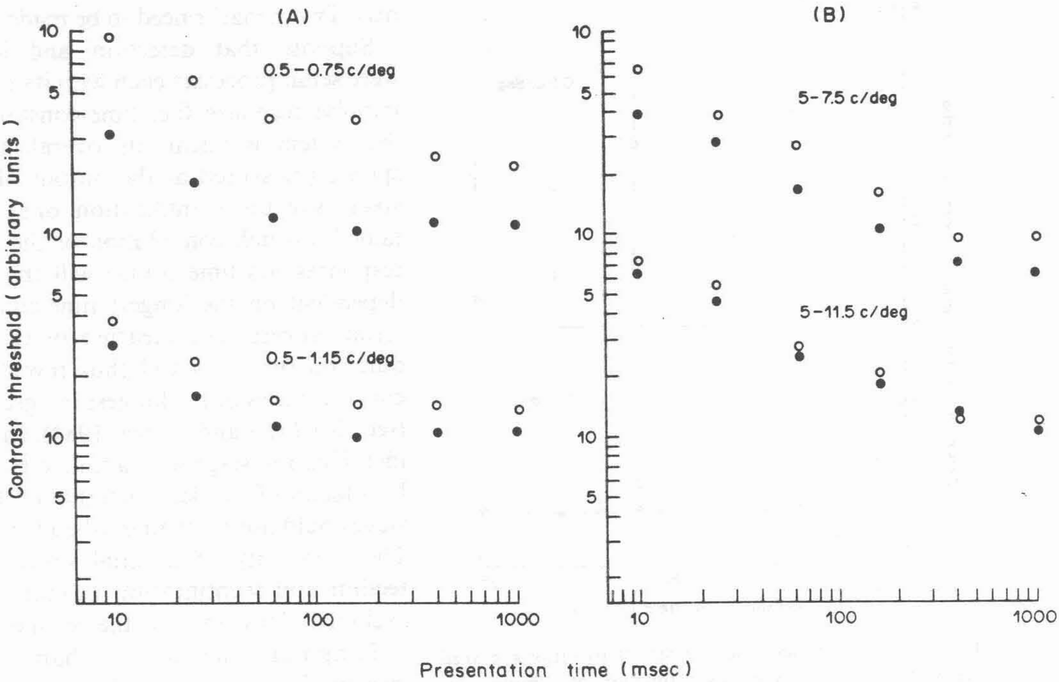

Fig. 1. Detection (solid symbols) and Identification (open symbols) relative thresholds as a function of stimulus duration. Results obtained with the low frequency reference [0.5 c/deg, (A)] and with the high frequency reference [5 c/deg, (B)]. Each datum point is the geometrical mean of the performances obtained for each stimulus in a stimulus-pair. Datum points obtained with pairs of stimuli 0.5 (i.e. 0.5–0.75 c/deg and 5–7.5 c/deg) and 1.2 (0.5–1.15 c/deg and 5–11.5 c/deg) octaves apart are displayed at the top and at the bottom of each panel, respectively. Observer A.G.

stimulus pair were randomly chosen from session to session. Once a whole set of time/sensitivity functions for a given stimulus pair was collected, another stimulus pair was randomly chosen. Some experimental conditions were repeated at intervals as long as one month to check observer's reliability over time.

RESULTS AND DISCUSSION

Figure 1 displays relative detection and identification thresholds (solid and open symbols, respectively) obtained by the author. The other two observers had very similar performances. Each datum point is the geometric mean of the (detection or identification) performances obtained for each stimulus in a pair. Since the observers do not have equal absolute sensitivity for the two stimuli in a pair, the mean thresholds are displayed in relative units.

Panels A and B display results obtained in the low and medium spatial frequency range, respectively. In each panel, top and bottom datum points are for frequency pairs 0.5 octave (i.e. 0.5–0.75 c/deg and 5–7.5 c/deg) and 1.2 octaves (0.5–1.15 c/deg and 5–11.5 c/deg) apart. As expected, the detection-to-identification ratio is much higher in the former than in the latter case.

Note that the overall shape of both the detection and the identification threshold vs duration functions depends on the spatial frequency range where they were obtained. They level off after having attained a minimum at about 200 msec for low spatial frequencies [with one exception in the identification function at the top of Fig. 1(A)], but continue to decrease for high spatial frequencies [Fig. 1(B)]. This typical behaviour has been recently accounted for by a model including transient- and sustained-type responses elicited in these two frequency ranges (Gorea and Tyler, 1985).

Figure 2 displays the detection-to-identification ratios averaged across the three observers for the four experimental conditions. The main observation is that the ratios *do not* depend on the presentation time whatever the experimental condition. An analysis of variance confirmed the lack of any significant effect of stimulus duration on the detection-to-identification ratio ($F_{5,10} = 1.44$; $P > 0.1$). The hypothesis according to which identification/

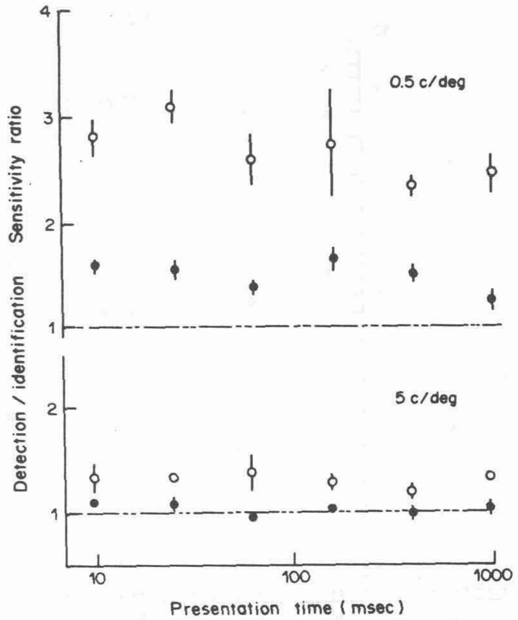

Fig. 2. Detection-to-identification sensitivity ratios averaged across the three observers as a function of stimulus duration. Ratios obtained for small and large spatial frequency differences are shown as open and solid symbols, respectively. Measurements obtained in the low (0.5 c/deg) and medium (5 c/deg) spatial frequency range are displayed in panels a and b, respectively. A ratio of 1, dotted line, indicates perfect discrimination.

duration and detection/duration sensitivity functions are parallel and are therefore characterized by identical time integration constants cannot thus be rejected. No interaction was found between either the spatial frequency or the spatial frequency difference factor and stimulus duration ($F_{5,10} = 1.68$ and $F_{5,10} = 0.71$; $P > 0.1$). As is already clear from inspection of the figure, the mean detection-to-identification ratio significantly varied with both spatial frequency ($F_{1,2} = 85.8$; $P < 0.025$) and spatial frequency differences ($F_{1,2} = 25.8$; $P < 0.05$). The systematically higher ratios obtained with the low spatial frequencies are consistent with previous data indicating larger bandwidths for the channels operating in this frequency range (e.g. Watson and Robson, 1981) but the strength of the effect is probably reinforced by the small number of cycles visible in these conditions (Hirsch and Hylton, 1982).

The present results suggest that spatial frequency detection and identification are two indistinguishable processes. It is therefore convenient to propose that they are both elicited at the same neural level. This conclusion implies the existence of labelled spatial frequency channels. Two remarks need to be made at this point.

Suppose that detection and identification were serial processes each with its own temporal impulse response (i.e. time-constant). Then, if the system is linear, its overall temporal response (measured at the output of the second stage, say the identification one) will be obtained through convolution of the two impulse responses. Its time-course will then be heavily dependent on the longest time-constant in the serial process. The measure of the sensitivity/duration functions will thus reveal mainly the characteristics of the longest integration process (see also Tyler and Gorea, 1984). In practice, an identification stage with a time-constant shorter by a factor of 5 or less than that of the detection stage could not be distinguished from this latter. The possibility of a serial processing of detection and identification cannot therefore be excluded. This leads to the second remark.

Temporal integration characteristics (as measured in this study) describe how contrast (in this case) is summated over time. They are irrelevant as to the specification of the temporal characteristics of any hypothetical transfer of this (integrated) information to a further processing stage. The literature on masking usually refers to such a stage as to an *encoding* one (for a review on this topic see Breitmeyer, 1984). Masking experiments currently run in our laboratory (Gorea, 1985b) revealed that the spatial frequency detection-to-identification sensitivity ratio is a reversed U-shaped function of the stimulus onset asynchrony (SOA) with a maximum at SOAs of about 20 msec (i.e. backward masking). This finding supports the hypothesis of serial processing of the integrated information. Note that this view is perfectly compatible with the existence of labelled detectors. It only implies that, to the extent that more than one labelled detector is activated (which is certainly true for the suprathreshold stimuli used in the masking experiments), some further processing of their outputs is required to achieve an identification criterion. As explicitly stated in different studies (e.g. Boynton and Kaiser, 1968; Regan and Beverly, 1984; Mandler and Makous, 1984) this second processing stage might be related to the computation of the relative activation in the stimulated channels.

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REFERENCES

Ball K., Sekuler R. and Machamer J. (1983) Detection and identification of moving targets. *Vision Res.* **23,** 229–238.

Boynton R. M. and Kaiser P. K. (1958) Vision: The additivity law made to work for heterochromatic photometry with bipartite fields. *Science* **161,** 366–368.

Breitmeyer B. G. (1984) *Visual Masking. An Integrative Approach.* Oxford Univ. Press, New York.

Gorea A. (1985a) Spatial integration characteristics in motion detection and direction identification. *Spatial Vision* **1.**

Gorea A. (1985b) Temporal integration and encoding characteristics of spatial frequency discrimination. *Perception* **14,** A5.

Gorea A. and Tyler C. W. (1985) A new look at Bloch's law for contrast. *J. opt. Soc. Am.* To be published.

Green D. M. and Birdsall T. G. (1978) Detection and recognition. *Psychol. Rev.* **85,** 192–206.

Green D. M., Weber D. L. and Duncan J. E. (1977) Detection and recognition of pure tones in noise. *J. acoust. Soc. Am.* **62,** 948–954.

Green M. (1983) Contrast detection and direction discrimination of drifting gratings. *Vision Res.* **23,** 281–289.

Hirsch J. and Hylton R. (1982) Limits of spatial frequency discrimination as evidence of neural interpolation. *J. opt. Soc. Am.* **72,** 1367–1374.

Luce R. D. (1963) Detection and Recognition. In *Handbook of Mathematical Psychology, Vol. I* (Edited by Luce R. D., Bush R. R. and Galanter E.). Wiley, New York.

Mandler M. B. and Makous W. (1984) A three channel model of temporal frequency perception. *Vision Res.* **24,** 1881–1887.

Olzak L. A. and Thomas P. (1981) Gratings: why frequency discrimination is sometimes better than detection. *J. opt. Soc. Am.* **71,** 64–70.

Regan D. and Beverley K. I. (1985) Postadaptation orientation discrimination. *J. opt. Soc. Am.* **A2,** 147–155.

Thomas P. and Gille J. (1979) Bandwidth of orientation channels in human vision. *J. opt. Soc. Am.* **69,** 652–660.

Thomas P., Gille J. and Barker R. A. (1982) Simultaneous visual detection and identification. *J. opt. Soc. Am.* **72,** 1642–1651.

Thompson P. (1981) Detection and discrimination of moving gratings. *Acta psychol.* **48,** 5–13.

Tyler C. W. and Gorea A. (1984) Contrast and temporal characteristics of a mechanism for phase hyperacuity. *Perception* **13,** A10.

Watson A. B. and Robson J. G. (1981) Discrimination at threshold: labelled detectors in human vision. *Vision Res.* **21,** 1115–1122.

Watson A. B., Thompson P., Murphy B. J. and Nachmias J. (1980) Summation and discrimination of gratings moving in opposite directions. *Vision Res.* **20,** 341–347.

Wetherill G. B. and Levitt H. (1965) Sequential estimation of points on a psychometric function. *Br. J. Math. Stat. Psychol.* **18,** 1–9.

Wilson H. R. and Gelb D. J. (1984) Modified line-element theory for spatial frequency and width discrimination. *J. opt. Soc. Am.* **A1,** 124–131.