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COMPLETE ADAPTATION TO PATTERNED STIMULI: A NECESSARY AND SUFFICIENT CONDITION FOR WEBER'S LAW FOR CONTRAST

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Abstract—Incremental (masking) and adaptation contrast thresholds were measured for sinusoidal gratings of different spatial frequencies presented either in an on–off mode or reversed in contrast, at different temporal rates. It is shown that whenever the masking grating stimulates other mechanisms than those concerned with the detection of the test stimulus, the ratio of Δ contrast (test)/contrast (mask) is not constant, thereby indicating a departure from Weber's law. It is concluded that Weber's law directly reflects complete adaptation of the stimulated pattern and/or movement mechanism.

Key Words—pattern vision; masking; pattern adaptation; Weber's law.

INTRODUCTION

Campbell and Kulikowski (1966) have found that the incremental contrast threshold for a 10 c/deg grating presented on and off at a rate of 0.5 Hz increases proportionally with the suprathreshold contrast of an identical adapting background grating presented steadily in phase with the test grating and being thus taken to be a mask stimulus. This could be called the Weber's law for contrast since it signifies a constant ratio of the incremental threshold (ΔC) at a given masking contrast C: $\Delta C/C$ = constant (see Kulikowski, 1969, 1976).

However, Bodis-Wollner, Hendley and Kulikowski (1972) noticed a departure from Weber's law for a 6 c/deg grating modulated at 8 Hz which made them to imply that the adapting effect of the mask was not entirely effective in this case. This raised the question as to whether some other mechanisms not affected by the masking steady grating could have contributed to the detection of the test grating.

Since the lower the spatial frequency the less its detection is dominated by pattern-detecting mechanisms (Kulikowski and Tolhurst, 1973), and adaptation to a steady grating decreasingly affects the detection of low spatial frequency gratings (Blakemore and Campbell, 1969), the above-mentioned departure from Weber's law for the 6 c/deg grating modulated at 8 Hz and for other coarse gratings (Bodis-Wolner and Hendley, 1975) could be explained in terms of an increasing participation of a movement detecting mechanism, which is not adapted by the steady grating (see also Tolhurst, 1973).

The purpose of the present investigation is to test directly this hypothesis and thereby to show that complete adaptation of one or more detecting mechanisms is the main condition for Weber's law to hold. It will be shown in particular that the progressive participation of movement-detecting mechanisms depends on the spatial and temporal frequencies of the test, mask and preadapting stimuli.

Three types of experimental conditions have been chosen with respect to their efficiency to affect gradually either pattern or movement mechanisms or a combination of both. This was done by taking into account previous results which have shown that pattern detection depends on contrast itself whereas movement detection depends on changes in contrast (Kulikowski and Tolhurst, 1973). It is thus obvious that a steady grating will be a good stimulus only for the pattern detecting mechanisms while an on–off or a grating reversed in contrast may also stimulate the movement mechanisms. In turn, a reversing grating will stimulate the movement mechanisms twice as well as the on–off type of stimulation (Kulikowski and Tolhurst, 1973).

METHOD

Subjects

In most experiments JK (a 37 yr corrected myope) served as a subject. Some additional experiments were carried out with RA (a 25 yr corrected myope) who was not informed about the aim of the experiments. Binocular viewing without artificial pupils was adopted in all experiments.

Stimuli

Sinusoidal gratings subtending 3° 45′ of visual angle were generated on the face of oscilloscope (phosphor P31) and were used as preadapting, mask and test stimuli. The mask and test gratings (when displayed simultaneously) were produced as a result of electronic addition rather than optical [as it was in the original study—Campbell and Kulikowski (1966)]. Their spatial and temporal frequencies changed from one experiment to another (see Table 1) as well as their mode of presentation (see Procedure). Mean screen luminance was kept constant at 10 cd/m^2. A PDP12 computer controlled the stimulus presentation and monitored the responses.

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Procedure

The experiments combined the method of masking (Campbell and Kulikowski, 1966; Kulikowski, 1969) with the method of adaptation (Gilinsky, 1968; Pantle and Sekuler, 1968; Blakemore and Campbell, 1969). In the initial phase the subject adapted for 2 min either to (A) a steady "masking" grating or to (B) a grating reversing in contrast at a rate of 8 Hz. The contrast of these preadapting gratings was gradually incremented from trial to trial in steps from threshold to a contrast of 0.5. Depending on the type of preadaptation (steady or reversal), different sequences of stimuli were subsequently presented:

A_{1a}—the subject adjusted the incremental contrast threshold of a test grating switched on and off and added to the background of a masking steady grating of the same spatial frequency and phase as the test (mask trial);

A_{1b}—immediately after the incremental threshold adjustment (A_{1a}), the background grating disappeared and the subject adjusted the contrast of the on–off test grating to reach its (absolute) threshold (adaptation trial);

A_{2a}—similar to A_{1a} except that in both cases the test stimulus was now reversed in contrast (mask trial); this means that for very small contrasts of the background grating the resulting stimulus is contrast reversal of the test grating, but when the background grating is set at a higher contrast than the test, the resulting stimulus will be a grating with its contrast being increased and decreased as in the condition A_{1a} (except that the test contrast is now subtracted and added to the background).

A_{2b}—immediately after the incremental threshold adjustment (A_{2a}) the background grating disappeared and the subject set the contrast threshold of the reversal test grating (adaptation trial);

B_a—the subject adjusted the incremental contrast threshold of a test grating reversing in contrast at the same rate as an identical reversing background (mask trial). In order to distinguish between the test and the background gratings the former was periodically switched on and off at a rate of 0.5 Hz;

B_b—after this first adjustment the background disappeared and the subject set the contrast of the reversing test grating to reach its absolute threshold as in A_{2b}.

In all adaptation trials the subjects had to set the thresholds within a period of 5–10 sec (see Kulikowski, 1976). The experimental conditions A_1, A_2 and B were usually repeated 10 times for each preadapting and mask contrast level.

RESULTS

Figure 1 shows the results obtained with a 5 and 10 c/deg grating under different modes of presentation. It is obvious that for the 10 c/deg grating, the on–off incremental threshold is proportional to the contrast of the steady masking grating over its suprathreshold range (i.e. above the contrast threshold for the mask itself—the arrow in Fig. 1A). Thus, the incremental threshold function in this case has a slope of one (computed by using the least square method). The slope of the incremental threshold of the same grating reversed in contrast is however less than one (slope = 0.90) indicating a departure from Weber's law. This departure is even more accentuated for the 5 c/deg grating (Fig. 1B) whose on–off incremental threshold function has a slope of only 0.82. Even less steep slopes are obtained for the 5 c/deg grating reversing in contrast (0.65). It will also be seen in Fig. 1(B) that as soon as the difference between the reversal and on–off incremental thresholds reaches a factor of two, the slope of the on–off function decreases and becomes similar to the slope of the reversal function; from this point the detection of both these males is evidently carried out in a similar way (most likely by means of transient changes in contrast—see Discussion). Note that the difference between the on–off and reversal incremental thresholds must ultimately reach a factor of two at some high value of background contrast at which both the on–off and reversal presentations are detected by a change in contrast. This level, however, and the slopes of the corresponding threshold functions (although interrelated) are different for various spatial frequencies.

Table 1 summarizes the masking and adaptation slopes for all the experimental conditions. It will be seen that both the decrease in the spatial frequency and an increase in the frequency of presentation of the test grating reduces the slope of the masking functions (probably by favouring more the detection through transient mechanisms which are less, or not at all, adaptable to a steady grating). For a 7.5 c/deg grating a small increase in the presentation rate from 0.5 to 1 Hz already reduces the slope of the masking function (Table 1, experiments 2 and 3). A discrepancy between adapted and tested mechanisms affecting the slope is even more striking for a 5 c/deg grating especially when reversed in contrast at 8 Hz on a steady background (Table 1, experiment 6). When, however, the subject is adapted to the same 5 c/deg grating but this time reversed in contrast (thereby adapting both pattern and movement mechanisms) Weber's law is restored (slopes of about one; Table 1, experiment 9). The same point is illustrated in the experiments with a 0.6 c/deg grating which is almost entirely detected by the movement system (Kulikowski and Tolhurst, 1973). Predictably, there is almost no masking effect when the reversal is detected on a steady background grating (Table 1, experiment 9). However, as soon as a reversing background is introduced, Weber's law is restored once more (slope of about one; Table 1; experiment 10). Thus in both these cases the 8 Hz reversal presentation has proved

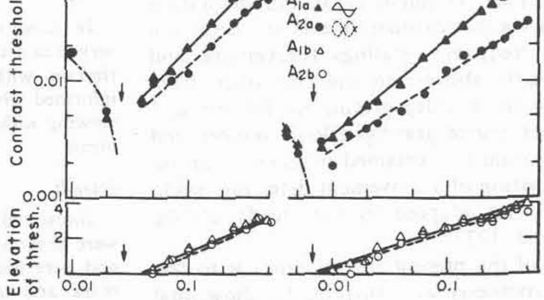

Fig. 1. Effects of simultaneous masking (incremental contrast thresholds; filled symbols, upper panels) and adaptation (empty symbols, lower panels) on the thresholds for gratings; (A) 10 c/deg and (B) 5 c/deg, presented either in the on–off (triangles) or in the reversal mode (circles) at a rate of 0.5 Hz. The vertical arrows indicate the contrast threshold of the steady background (masking) grating alone; the curves to the left of the arrows are obtained with the background grating at subthreshold contrasts.

Table 1. Slopes and standard errors of the incremental (masking) and adaptation threshold functions for all the experimental conditions

					Slopes and standard errors of the incremental and adaptation thresholds			
					(1) On–off presentation		(2) Reversal presentation	
Experiment	Mode of temporal presentation of the mask stimulus	Subject	Spatial frequency of mask and test (c/deg)	Temporal frequency of test (Hz)	(a) Mask	(b) Adapt	(a) Mask	(b) Adapt
1	(A) Steady	JK	10	0.5	1.00 ± 0.04	0.44 ± 0.03	0.90 ± 0.04	0.45 ± 0.03
2		JK	7.5	0.5	1.00 ± 0.06	0.37 ± 0.02	0.84 ± 0.05	0.36 ± 0.02
3		JK	7.5	1.0	0.92 ± 0.05	0.37 ± 0.10	0.83 ± 0.04	0.50 ± 0.05
4		JK	5	0.5	0.82 ± 0.02	0.34 ± 0.02	0.65 ± 0.03	0.32 ± 0.02
		RA	5	0.5	0.70 ± 0.07	0.15 ± 0.04	—	—
5		JK	5	1.0	0.62 ± 0.04	0.17 ± 0.03	—	—
		RA	5	1.0	0.70 ± 0.08	0.47 ± 0.02	—	—
6		JK	5	8.0	—	—	0.52 ± 0.05	0.19 ± 0.03
		RA	5	8.0	—	—	0.41 ± 0.10	0.14 ± 0.08
7		RA	0.6	1.0	0.003 ± 1.006	0.045 ± 0.02	—	—
8		JK	0.6	8.0	—	—	0.003 ± 0.01	0.005 ± 0.02
9	(B) 8 Hz Reversal	JK	5	8 Hz Reversal	—	—	0.99 ± 0.10	0.35 ± 0.12
		RA	5				1.00 ± 0.08	0.36 ± 0.06
10		JK	0.6	+0.5 Hz On–Off	—	—	0.96 ± 0.01	0.43 ± 0.05

to be a good adapting stimulus for the transient system [this would not be the case if the temporal frequency was much below 5 Hz—see Kulikowski (1977), Fig. 8.5].

It is finally to be noted that the adaptation slopes are generally related to the masking slopes even though they are much less steep, and that these two effects start at similar levels of background contrast, thereby illustrating the connection between these two effects.

DISCUSSION

Slopes of the masking and adaptation functions

The experiments presented here clearly support the hypothesis already advanced in the introduction, namely that the departures from Weber's law observed in these experiments are due to the fact that the mechanisms activated by the test stimuli and by the masking stimuli are different and partially separate. Consequently, as the masking stimulus increases in contrast, there is an increasing difference between the degree of adaptation of these corresponding mechanisms.

The reciprocal formulation of such a finding is that Weber's law reflects complete adaptation of all the mechanisms involved in the detection of a given stimulus. As soon as this condition is fulfilled the masking curves approach a slope of one thus showing Weber's law. Whenever a given stimulus can be detected through the contribution of an alternative mechanism, distinct from the mechanism which has been adapted, a departure from Weber's law will be noticed. This is the case, for instance, when the 10 c/deg grating, usually detected by pattern mechanisms, is reversed in contrast. Since the change in contrast is twice that of the on–off mode at a given masking contrast, this presentation partly favours the movement-detection mechanism. Due to this alternative possibility of detection, by a mechanism not previously adapted, Weber's law will not hold (Table 1, experiment 1). It should also be stressed that a sufficient period of preadaptation is usually required for Weber's law to hold; when the viewing time is short [e.g. during the forced-choice method—see Kulikowski (1976), Fig. 7], a departure from Weber's law occurs. (Note that in the original investigation by Campbell and Kulikowski, 1966, no special preadapting procedure was carried out, but the setting of the incremental contrast thresholds was relatively slow, thereby allowing the subject to adapt to a given masking contrast.)

The case with the adaptation slopes is somehow different. Even though the minimal contrast required to demonstrate masking has been shown to be the same as that required to demonstrate after-effect, or adaptation (Kulikowski, 1976), thresholds after adaptation never increase in proportion to the adapting contrast. This simply shows that the masking after-effect is always weaker than the masking effect itself.

What does adaptation demonstrate?

Barlow, Macleod and van Meeteren (1976) doubted the usefulness of adaptation, as it makes us less, not more sensitive to contrast differences. However, de Valois (1977) has recently demonstrated some disinhibitory or facilitatory effects of adaptation to one spatial frequency upon the detection of other spatial frequencies, different by more than one octave. The disinhibitory effects have previously been described in experiments with two adapting or masking spatial frequencies (Tolhurst, 1972; Kulikowski and King-Smith, 1973). The presence of such disinhibitory effects between spatial frequencies which differ by more than one octave strongly suggest that the adaptation effects on similar spatial frequencies result from some inhibitory interactions. The adaptation effect is potentiated by using patterns stimulating selectively representing a relatively large part of the visual field. Maffei and Fiorentini (1973) have indeed shown the inhibitory interactions (causing adaptation) as originating from the areas much broader than the size of the single-unit receptive field in the cat visual cortex.

A spatially repetitive stimulus, such as grating, is specially effective in adapting the detection mechanisms tuned to one size and orientation over its spatial extent. [Note that masking or adaptation are not so effective when a single line is detected on a corresponding grating, since the spatial frequency tuning of a line detector is not so narrow; see Kulikowski (1969) and Sullivan, Georgeson and Oatley (1972)]. Likewise the adaptation to the movement detecting mechanism requires certain minimum temporal repetition rate (above 3 Hz) to produce a strong effect, although repetitive stimuli are not common in practice. It seems, therefore, that the complete adaptation studied here is an extreme case, useful to study inhibitory interactions between the detection mechanisms, but not usually encountered in normal vision.

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