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The time course of the lower threshold of motion during rapid events of adaptation

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Abstract

To examine how the time course of rapid events of adaptation affect motion vision, the lower threshold of motion (LTM) was measured for suprathreshold sinusoidal gratings in presence of transient and steady glare. In the case of the transient condition, glare and stimulus were presented separated in time by a variable extent (SOA: 50–450 ms). A two alternative forced choice paradigm using the method of constant stimuli was adopted to measure the LTM. It was found that LTM follows the characteristic Crawford's time course of adaptation. Results are similar for two stimulus duration (300 and 500 ms). It was proposed that the increment of contrast threshold for displacing gratings (C_{tq}) due to the loss of sensitivity produced by the sudden onset of the glare source can explain the results.

Keywords: Adaptation; Glare; Transient; Motion; Displacement threshold; Contrast

1. Introduction

One of the most important properties of the visual system is its ability to maintain high sensitivity to small contrasts over an extremely large range of ambient light levels that occurs in the normal environment. To maintain sensitivity, response gain of visual neurones must be kept at a high level; but, because of the limited dynamic range of neurones, this sometimes produces a saturated response. It is known that if a subject is adapted to a dimly lighted background and then a sequence of two flashes of light separated in time by a variable extent are presented, the effect of these two flashes on one another follows a characteristic time course. If the first flash is thought of as a conditioning field and the second flash is thought of as a test stimulus, it can be shown that the conditioning flash will increase the contrast threshold for detection of the test flash if the test flash is presented just at or near enough in time to the onset of the conditioning flash (Hart, 1992). These temporal characteristics of adaptation have been explored extensively (for review, see Hood & Finkelstein, 1986; Graham & Hood, 1992). In one of the most influential of these experiments on dynamics, Crawford (1947) measured the increment threshold for a brief test light presented before, during and after the presentation of a larger background light. Crawford's results show evidence for saturation just at the onset of the conditioning field. He found that the test threshold was highest near the onset of the conditioning field and, soon after, the process of adaptation seemed to rescue the response from this saturation and the threshold decreased substantially over the next 200 ms or so.

More recently, this effect was investigated by Bichao, Tager, and Meng (1995) who explored the phenomenon using an indirect conditioning field (glare). They found that their results were qualitatively similar to Crawford's results obtained with a direct conditioning field. The loss of sensitivity in the fovea produced by the sudden onset of a glare source was significantly greater than the effect from a steady glare source of the same illuminance.

A previous study (Barraza & Colombo, 2000) extends these transient effects of brief flashes and glare sources to motion perception. It reports lower threshold of motion (LTM) for temporally windowed sine gratings

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in presence of transient glare caused by shining a bright light on the eyes. They found that LTM increases in presence of transient glare in a wide range of spatial frequencies. Moreover, no difference was found between the LTM obtained without glare and the LTM obtained in presence of a static glare source. The retinal contrast reduction due to glare cannot explain these results since retinal contrast does not depend on whether glare is steady or transient. On the other hand, it was shown that LTM for transient glare is always greater than LTM obtained without glare, in a wide range of contrasts (2–25%). Authors suggest that the contrast threshold for displacing gratings (C_{tq}) is increased by transient glare and, according to Nakayama and Silverman (1985), this can be interpreted as a reduction of effective contrast in the contrast transducer of the detectors that feed into the motion-analysing system.

A question arises here: does the effect of transient glare on the LTM follow the characteristic Crawford's time course?

To answer this question, we propose to measure the LTM for sine gratings in presence of transient glare, varying the delay between the glare onset and stimulus presentation (SOA: stimulus onset asynchrony). These results will be compared with those obtained in presence of a static glare source.

2. Methods

2.1. Stimuli

Stimuli were luminance gratings displayed on a Eizo T560i-T monitor at a field rate of 120 Hz. Patterns were generated using an RGB framestore which was part of a purpose built display controller, the Cambridge Research System's VSG 2/3. VSG 2/3 has two palette chips operating in parallel. Adding together the two palette outputs with different gains, a higher resolution output is obtained. This operating mode produces the effect of 12 bits of grey level resolution per pixel which was used to give more precise control of contrast.

Stimuli were presented within a circular patch, the diameter of which subtended 4° at the 2 m viewing distance. The mean luminance of the stimulus was 2 cd·m^{-2}. The gratings were vertical sinusoidal modulations of luminance (spatial frequency = 1 cyc deg^{-1}) generated using the method previously described by Cox and Derrington (1994). These were displayed using stimulus durations of 500 and 700 ms. The contrast of the pattern (25%, peak value) was controlled by a gaussian function of time with standard deviations of 150 and 250 ms. The effective duration of the stimulus is expressed as twice the time constant giving effective durations, for both time constants, of 300 and 500 ms respectively (Derrington & Goddard, 1989).

2.2. Conditioning field

A glare source was used as an indirect conditioning field. Glare was generated using an incandescent lamp located 10° away from the line sight. Glare and stimulus were onset separated in time by a variable extent (SOA). This was achieved controlling the glare source by the computer's parallel port. Fig. 1 shows a scheme of the stimulus and glare presentation in an interval of a trial, for a 250 ms value of SOA. The upper curve represents the modulation of contrast and the lower curve represents glare intensity. This Figure shows that the onset of the incandescent lamp is not abrupt, it has a time constant of 50 ms. The effective onset 50 ms was considered after the lamp is turned on.

2.3. Subjects and tasks

Two observers took part in this experiment, one of the authors and another person who was naive as to the purpose of the study. Both observers were experienced in visual motion experiments. The screen was viewed foveally and binocularly, with the head positioned on a chin-rest, and with natural pupil and accommodation.

The influence of SOA in presence of transient glare on the lower threshold of motion was analysed for direction-of-motion discrimination task. In the discrimination task, the stimulus was presented in two intervals; in one interval, chosen at random, the stimulus moved to the right, in the other, it moved to the left. The observer's task was to indicate, by pressing a key, the interval in which the grating had moved to the left. An audible feedback was given as to whether this response was correct or no. In each block of trials a set of five stimuli was used. Each stimulus was used a total of 25 times in each of two block of trials.

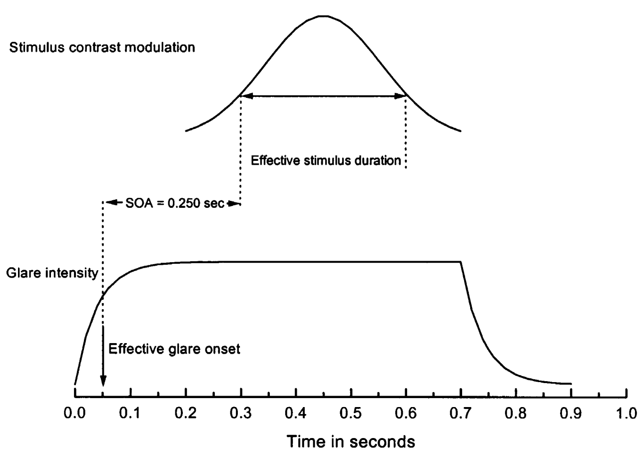

Fig. 1. Scheme of presentation of glare and test stimulus in a trial for a 250 ms value of SOA.

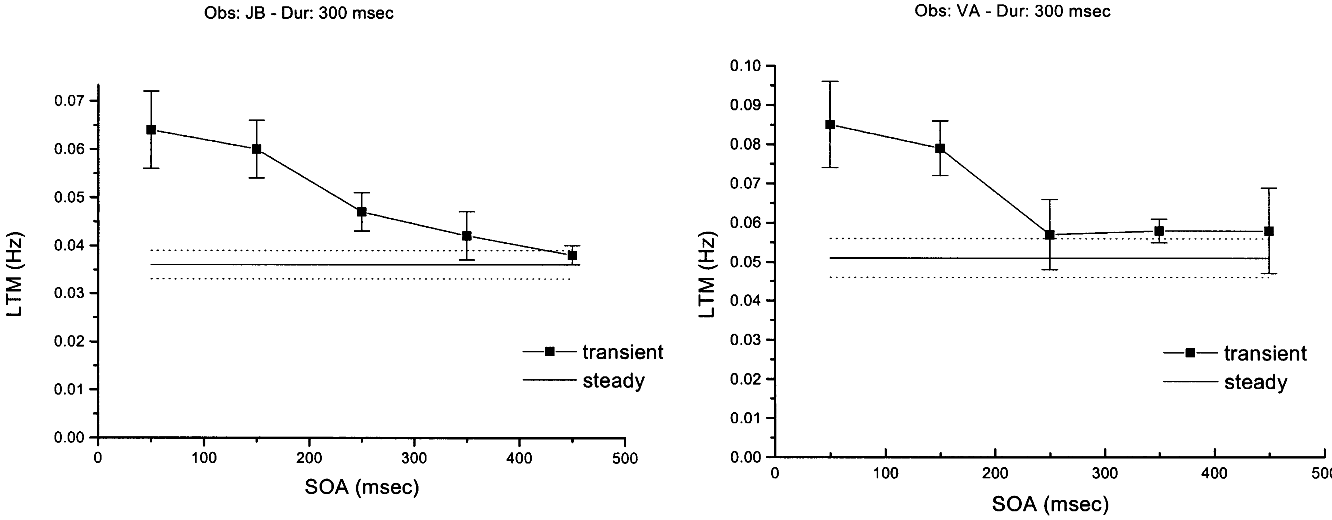

Fig. 2. LTM expressed as a temporal frequency, as a function of SOA, for both observers and for a 300 ms stimulus duration. LTMs measured in presence of transient glare are represented with symbols and the LTM obtained with static glare is represented with a continuous line. Dot lines represent the error in the determination of steady LTM.

Before each session, observers were required to fixate the line sight on the screen set to 2 cd m^{-2} for 5 min.

2.4. Procedure

A temporal two-alternative forced-choice paradigm using the method of constant stimuli was used to measure the psychometric functions, relating performance to temporal frequency.

To calculate thresholds, Weibull functions were fitted to percent-correct responses distributions. The Weibull function has valuable theoretical properties and is extensively used in vision research (for a review, see: Macmillan & Douglas Greelman, 1991).

3. Results

The lower threshold of motion (LTM) was measured as a function of SOA (50–450 ms) for a stimulus duration of 300 ms and a glare illuminance, produced by the glare source at a point between the two pupil centres, of 60 lx. Grating contrast was set in 25% (peak value). An additional measurement was carried out using steady glare of the same illuminance.

Results plotted in Fig. 2 show, with symbols, the transient LTM expressed as a temporal frequency, as a function of SOA, for both observers. With lines, are represented the LTM obtained with static glare (continuous line) and their errors (dot lines). Figures show that LTM is less as SOA is increased, tending in an asymptotic form to the LTM obtained with static glare. Results suggest that the condition can be considered steady from a certain value of SOA, approximately 200 ms. These results are similar to that showed by Crawford (1947).

In a previous work, the authors carried out a similar experiment, for a fixed value of SOA (50 ms) and found that the transient LTM is greater than the steady LTM for a wide range of spatial frequency. They explained their results arguing that C_{tq} rises due to the sudden onset of the glare source. Now, it was found that the difference between transient LTM and steady LTM depends on SOA describing a similar time course to that found by Crawford which strengthens the hypothesis stated in the previous work.

An alternative hypothesis can be stated taking into account the effect of stimulus duration on the LTM in the fovea. The LTM is greater as the stimulus duration decreases since motion thresholds are determined by a critical spatial displacement (Boulton, 1987). There are reasons to hypothesise that the saturation in ganglion cells, at the onset of glare, can produce an effect of reduction in the effective stimulus duration and therefore, an increment in the LTM. Current theories assume that a motion detector involves the comparison of the outputs of two spatiotemporal filters (Adelson & Bergen, 1985; Van Santen & Sperling, 1985; Watson & Ahumada, 1985). This spatiotemporal correlation needs a change in the stimulus luminance in time and space. During the saturation, no temporal changes in luminance could be recorded by saturated cells thus motion detectors would not be able to work. This time reduction is constant for a given glare intensity therefore its effect will be greater as the stimulus duration is less. In order to check this hypothesis, we propose to measure the LTM as a function of SOA for a greater stimulus duration (500 ms). The relation between transient LTM and steady LTM ($LTMT/LTMS$) is adopted as a measure of the transient effect of adaptation on the LTM. According to this hypothesis, it was expected that the ratio *LTMT*/*LTMS* for a duration of 300 ms will be greater than the ratio for a duration of 500 ms (for details see Appendix A). On the other hand, according to the first hypothesis, the ratio *LTMT*/*LTMS* should be the same for both stimulus duration (for details see Appendix A). Fig. 3 shows the LTM as a function of SOA for a stimulus duration of 500 ms. A similar behaviour to that obtained with a stimulus duration of 300 ms was found. Fig. 4 shows the ratio *LTMT*/*LTMS*, for both stimulus duration, as a function of SOA. Figures show, for both observers, that the effect of transient glare is very similar for both stimulus durations. This finding strengthens the first hypothesis and weakens the hypothesis of the time reduction.

4. Discussion

The time course of motion thresholds has been explored for rapid events of adaptation. To do this the lower threshold of motion of suprathreshold sinusoidal gratings displayed with a variable delay respect of the onset of an indirect conditioning field (glare) was measured. LTM was measured for five values of SOA, besides the steady glare situation. The LTM was found to follow the characteristic Crawford's time course of adaptation. It takes its highest value near the glare onset and then it decreases tending in an asymptotic form, to the value obtained under steady glare conditions. This finding extents the transient effects of brief flashes and glare sources to motion perception.

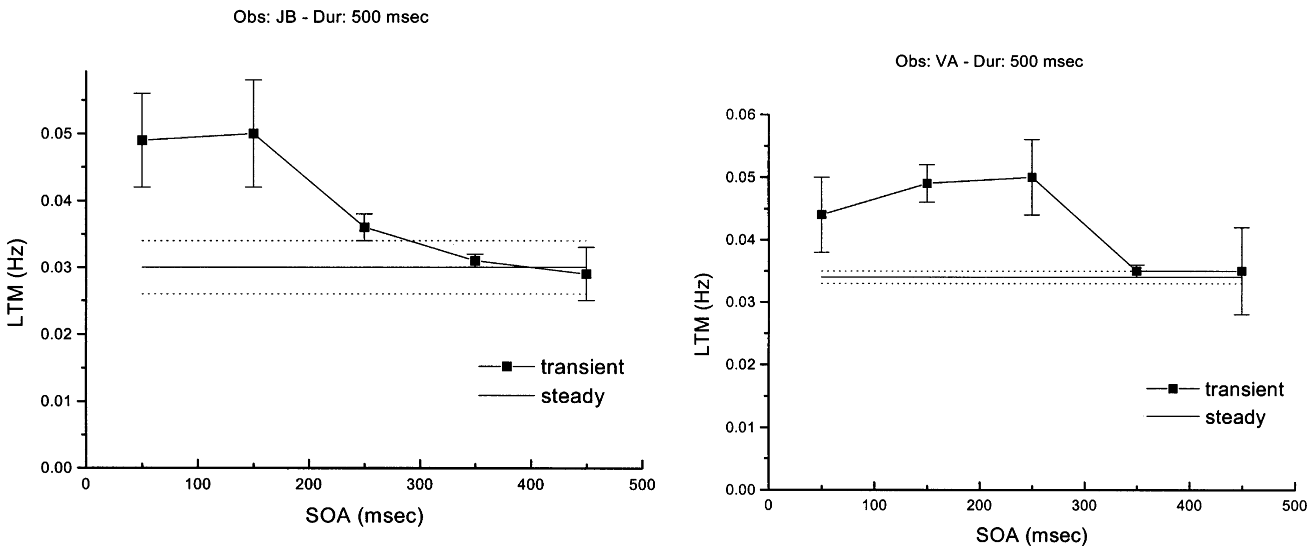

Fig. 3. LTM expressed as a temporal frequency, as a function of SOA, for both observers and for a 500 ms stimulus duration. LTMs measured in presence of transient glare are represented with symbols and the LTM obtained with static glare is represented with a continuous line. Dot lines represent the error in the determination of steady LTM.

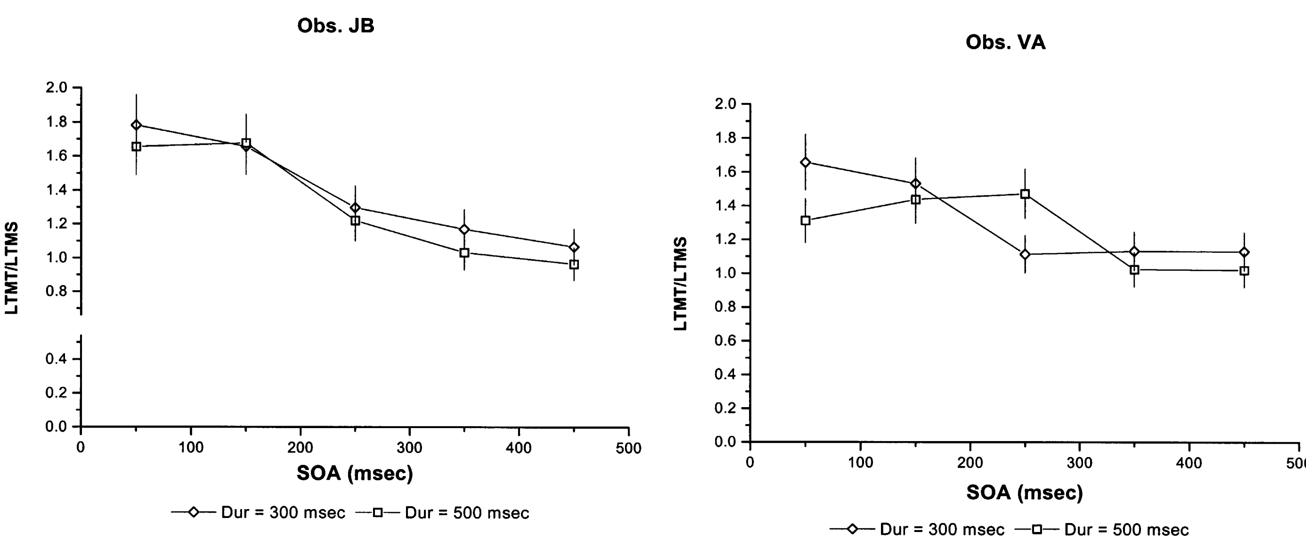

Fig. 4. The ratio LTMT/LTMS as a function of SOA, for both values of stimulus duration (300 and 500 ms) and for both observers.

Two hypotheses were stated to explain the effect of transient glare on the LTM. The first one suggests that the contrast threshold for displacing gratings (C_{tq}) is increased due to the loss of sensitivity produced by the sudden onset of the glare source. It is reasonable to hypothesise that the mechanisms underlying contrast threshold for simple detection during rapid events of adaptation, also govern the thresholds of contrast for detection of displacing gratings in transient adapting conditions. Physiological studies in cat retinal cells have shown evidences about where the rapid events of adaptation take place (Enroth-Cugell & Shapley, 1973). They measured the time course of gain adjustment in Y-type ganglion cell under scotopic conditions. It was shown that the gain had a peak at the time of the onset of the conditioning field and then rapidly declined within 200 ms. Similar results, in cat horizontal cells, indicate that light adaptation, at mesopic and photopic luminance levels takes place very rapidly, within about 200 ms (Lankheet, Van Wezel, Prickaerts, & Van de Grind, 1993). Just as the other mechanisms of adaptation, the Crawford's psychophysical observations can be already observed at the retina (for a review see: Shapley & Enroth-Cugell, 1984). If it was assumed that the output of retinal cells feeds the motion analysis system, it can be concluded that C_{tq} will be affected by saturation and gain adjustment of the retinal cells.

According to Nakayama and Silverman (1985), if C_{tq} increases, the minimum displacement of a grating will be increased for a given value of contrast. Therefore, if the variation of LTM with SOA was determined by C_{tq}, the LTM would follow the characteristic time course of adaptation found by Crawford (1947). The results show many similarities between the variation of LTM with SOA and this time course of adaptation even if the experimental conditions are quite different from that used in the Crawford's experiment. The most important difference is the test stimulus duration. In the present study, stimuli were not flashes but they were displayed for a relatively long time. In this experiment, the transient effect is integrated over the whole stimulus duration.

The other hypothesis suggests that the rising of LTM under transient adapting conditions is due to a reduction in the effective stimulus duration. There is general agreement that motion detection thresholds, for durations of movement between approximately 100 and 500 ms, are determined by a constant stimulus displacement (Johnson & Leibowitz, 1976; Johnston & Wright, 1985; Boulton, 1987). Therefore, if the effective stimulus duration decreases, the LTM will increase even if the minimum displacement keeps constant. For a given glare intensity the time reduction is constant. Therefore, the lesser the stimulus duration the more powerful the effect (see Appendix A). The ratio $LTMT/LTMS$ shows that the effect of transient glare on the LTM is similar for both stimulus duration which means that this hypothesis can not be confirmed. On the other hand, this finding confirms that the increment of LTM, under transient conditions, is due to the increment of C_{tq} since according to this hypothesis, the ratio $LTMT/LTMS$ does not depend on the stimulus duration (see Appendix A).

Appendix A

LTM can be expressed as:

$$LTM = \frac{D_{min} \cdot fs}{SDur} \quad (1)$$

where D_{min} is the minimum displacement, fs is the spatial frequency and $SDur$ is the stimulus duration. If it was hypothesised that the increment of LTM is determined by an increment of D_{min}, the transient and steady LTMs will be expressed as:

$$LTMT = \frac{D_{minT} \cdot fs}{SDur} \quad (2)$$

$$LTMS = \frac{D_{minS} \cdot fs}{SDur} \quad (3)$$

where D_{minT} is the minimum displacement for transient conditions and D_{minS} is the minimum displacement for steady conditions. Therefore, the ratio $LTMT/LTMS$ will be:

$$\frac{LTMT}{LTMS} = \frac{D_{minT}}{D_{minS}} \quad (4)$$

Eq. (4) shows that the ratio does not depend on the stimulus duration.

On the other hand, if it was hypothesised that the transient LTM is produced by a reduction of the effective stimulus duration, the LTMT will be expressed as:

$$LTMT = \frac{D_{minT} \cdot fs}{SDur - T_R} \quad (5)$$

where T_R is the time reduction. The LTMS will be:

$$LTMS = \frac{D_{minS} \cdot fs}{SDur} \quad (6)$$

Therefore, the ratio will be:

$$\frac{LTMT}{LTMS} = \frac{SDur}{SDur - T_R} = \frac{1}{1 - \frac{T_R}{SDur}} \quad (7)$$

In this case the effect of transient glare depends on the stimulus duration. Eq. (7) shows that, as $SDur$ increases, the ratio decreases.

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