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PERCEIVED RATE OF MOVEMENT DEPENDS ON CONTRAST

PETER THOMPSON*
The Psychological Laboratory, University of Cambridge, Cambridge, England

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Abstract—The perceived rate of movement of sine wave gratings has been measured over a range of contrasts. At temporal frequencies below about 8 Hz a decrease in contrast reduces apparent velocity. At 16 Hz a reduction in contrast increases perceived velocity.

INTRODUCTION

The appearance of moving patterns at contrast threshold has been examined by several investigators. Kulikowski and Tolhurst (1973) have reported that fast-moving gratings of low spatial frequency are seen to flicker at detection threshold whereas slowly moving gratings of high spatial frequency appear to be stationary at detection threshold. They have suggested that two different sub-systems, movement and pattern channels, detect these two different stimuli—hence the difference in their appearance at threshold. Although it seems reasonable that at contrast threshold only a single channel is responsible for detecting a stimulus, once above threshold the activity of more than one channel may contribute to the appearance of a stimulus. The present experiments examine the appearance of moving gratings above threshold and demonstrate that the perceived velocity of such stimuli is greatly affected by their contrast.

EXPERIMENT 1: VELOCITY MATCHING GRATINGS OF UNEQUAL CONTRAST

Methods and Results

Moving sine wave gratings were generated on the screens of two oscilloscopes placed side by side. Each screen had dimensions of 6×4 deg, separated by 1 deg. Subjects fixated an illuminated point between the two screens and varied the rate of movement of the grating on the right hand screen (the match grating) to match the rate of movement of the grating on the left hand screen (the test grating). Fuller details of the apparatus and methods are given in Thompson (1981). The match grating was of 0.25 contrast throughout, the velocity and contrast of the test grating were set by the experimenter. Test grating contrasts of 0.25, 0.178, 0.125, 0.088, 0.063 and 0.045 were used; each of these represents a 0.15 log unit step from its neighbour.

Eyemovement records obtained from a subject viewing moving gratings in the apparatus show no systematic variation with temporal frequency (Thompson 1976). This is not unexpected. Murphy (1978) has shown that gratings moving behind a stationary fixation point produce negligible eye drift which does not vary with the velocity of the grating.

To prevent the subject adapting to the stimuli, the gratings were presented for 2.5 sec, in which time he could be expected to make only a very approximate velocity match. Each presentation was followed by 17.5 sec during which both screens were maintained at their mean luminance (31.6 cd m^{-2}) without any grating present. During successive presentations of the gratings the subject was able to improve the velocity match until he was satisfied that the gratings appeared to be moving at equal velocity. The match grating velocity was then recorded and a new test stimulus presented.

When the test grating contrast was 0.25 the subject's task was simply to match gratings of equal contrast for velocity—these matches were regarded as baseline measures. In all other conditions the contrast of the test grating was less than that of the match grating. The experimental results plot the perceived velocity of the test gratings as a fraction of their perceived velocity when at equal contrast with the match grating. A velocity match of less than 1.0 indicates that the effect of reducing the test grating contrast is to reduce the perceived velocity while a value greater than 1.0 indicates that a reduction in test grating contrast increases its perceived velocity.

In Experiment 1 all gratings were of 2 c/deg spatial frequency. Five different test grating velocities were investigated, which at the six contrast levels given above produced 30 test stimuli. Each stimulus was presented at least four times and all were in random order. The results of this experiment are presented in Fig. 1. The results are clear. At temporal frequencies below about 8 Hz perceived velocity is reduced as contrast is reduced. At the highest temporal frequency investigated, 16 Hz, there is a marked overestimation of speed as contrast is reduced. Campbell and Maffei

* Present address: Department of Psychology, University of York, York, England.

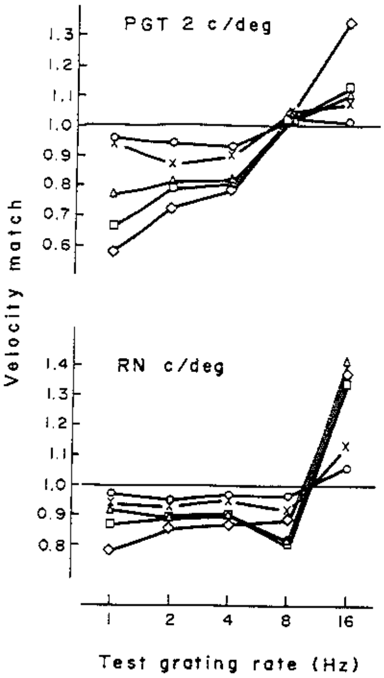

Fig. 1. Velocity matching at different contrasts. All gratings at a constant spatial frequency of 2 c/deg. Subject controlled grating of 0.25 contrast. Test grating contrasts of: 0.178 (O): 0.125 (×); 0.088 (△): 0.063 (□): 0.045 (◇). Subject P.G.T. Subject R.N.

(1981) have recently reported that, at very slow rates of rotary motion, increasing contrast increases perceived velocity, a result which concurs with the present finding.

For both subjects the changeover from underestimation to overestimation of velocity occurs around a temporal frequency of 8 Hz, which for 2 c/deg gratings is a velocity of 4 deg/sec. By repeating the experiment at other spatial frequencies we can discover whether this changeover depends on the temporal frequency or the velocity of the gratings. Figure 2 shows the results for gratings of 1, 4 and 8 c/deg. In each case the crossover from underestimation to overestimation occurs at a constant temporal frequency, around 8 Hz, and not at a constant velocity.

It could be argued that some aspects of these results reflect an artefact in the matching method employed. Suppose that, as well as the perceived velocity of the stimulus depending on its contrast, the perceived contrast of a stimulus depends on its velocity. Then, if several different velocities of the match grating are equally acceptable as a velocity match to the test grating, the subject might choose that velocity which most nearly matched the test grating for contrast. A second experiment was carried out using an estimation technique to demonstrate that the results of Experiment 1 are not contaminated by any effect of velocity on perceived contrast.

EXPERIMENT 2: VELOCITY ESTIMATION OF GRATINGS OF UNEQUAL CONTRAST

Method and Results

In Experiment 2 subjects fixated between the two screens as before but stimuli were presented only on the left hand screen. Two naive subjects were presented with 2 c/deg gratings of various contrasts moving at various speeds and were asked to estimate their perceived rate of movement. Prior to the experiment and periodically during it, the subjects were presented with a 10 Hz, 2 c/deg grating of 0.25 contrast which they were told to regard as a standard velocity of speed 10, with a stationary grating representing speed 0. Gratings of five rates of movement 1, 2, 4, 8 and 16 Hz, and three contrast levels 0.25, 0.15 and 0.1 contrast were presented in random order. The speed estimations of the 0.25 contrast gratings were regarded as a baseline measure, with the lower contrast gratings' speed estimations being expressed as a fraction of these baselines. The results are shown in Fig. 3; their similarity to the results shown in Fig. 1 indicates that the dependence of perceived velocity

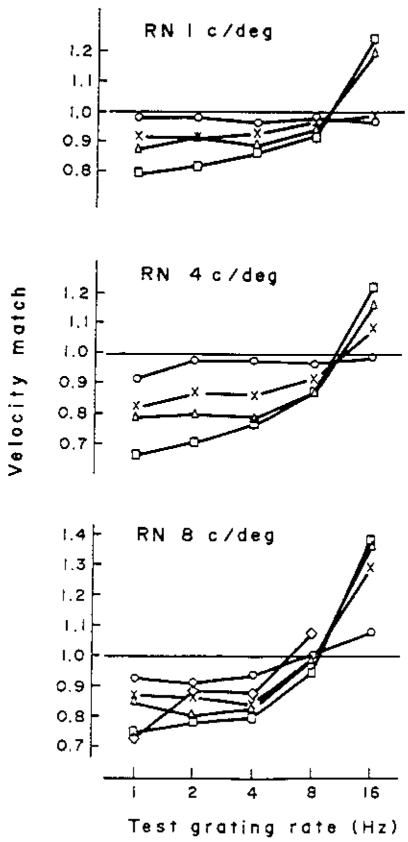

Fig. 2. Velocity matching at different contrasts. All gratings at a constant spatial frequency of: (a) 1 c/deg. (b) 4 c/deg. (c) 8 c/deg. Other details as in Fig. 1. Subject R.N.

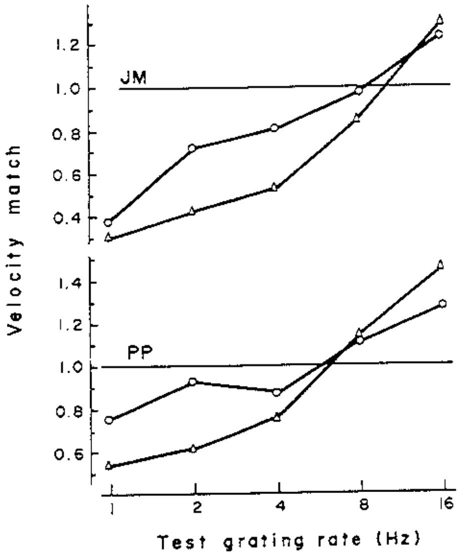

Fig. 3. Velocity magnitude estimations at different contrasts. All gratings at a constant spatial frequency of 2 c/deg. Grating velocities estimated at 3 contrast levels. Contrasts of 0.16 (O) and 0.1 (△) expressed as a fraction of their perceived velocity at 0.25 contrast. Subject J.M. Subject P.P.

upon contrast cannot be explained as an artefact of the matching procedure used in Experiment 1.

DISCUSSION

Perceived velocity clearly depends on contrast, but the mechanisms underlying this dependence remain obscure. The crossover from underestimation to overestimation around 8 Hz suggests that the temporal frequency rather than the velocity is the important stimulus parameter. One test of this might be to examine the perceived flicker rate of a uniform field as a function of temporal contrast. If similar results to those reported here were found then the present results could be seen as the dependence solely of temporal frequency upon contrast which gives rise to distortions in perceived velocity. Unfortunately it is almost impossible to make any kind of sensible or consistent match of temporal frequency between flickering fields of unequal contrast. I have tried and have failed and both Harris and Sidwell (personal communications) have also attempted to carry out similar measurements, without great success. Perhaps an experiment which attempted to measure flicker rate in some other way, (e.g. the cross-modal matching with auditory frequency flutter employed by Fukuda 1977) could provide an answer.

The results reported in this paper could also be the consequence of a dependence of spatial frequency upon contrast. Georgeson (1980) has reported large increases in the perceived spatial frequency of stationary gratings when their contrast was decreased. In Experiment 1, therefore, subjects were matching the perceived velocity of gratings which, while having equal real spatial frequencies, had different apparent spatial frequencies. Could this explain the reductions in perceived velocity found in Experiment 1? Georgeson argues as follows: suppose that spatial frequency channels are labelled, that is their spatial significance is invariant; now, if the optimal spatial frequency for a channel deceases as contrast is reduced, then at low contrast the optimal stimulus for a channel will be a spatial frequency lower than its labelled value. For example, a channel labelled 4 c/deg will be optimally stimulated by a grating of, say, 3 c/deg at low contrast. In other words, that 3 c/deg grating optimally excites a channel labelled as 4 c/deg and will therefore be perceived as a 4 c/deg grating. We can apply this line of argument to the present results. If the perceived velocity of a grating were determined by some comparison of its component temporal and spatial frequencies, then a dependence of perceived velocity upon contrast could be regarded as a purely spatial phenomenon. As contrast is reduced, perceived spatial frequency increases and, if temporal frequency remains unaffected, perceived velocity must decrease.

If such an explanation were to explain all the present data it would be necessary that as temporal frequency increased up to about 8 Hz the effects of contrast reduction on perceived spatial frequency would decrease and that at higher temporal frequencies contrast reduction would actually decrease perceived spatial frequency. There is no evidence for this.

It seems most likely, then, that the effect reported here is neither a purely spatial nor a purely temporal phenomenon. It could, however, be understood in terms of a simple two channel model comprising a "slow" channel, which is most sensitive to stationary and slow-moving patterns, and a "fast" channel sensitive to fast-moving patterns, (Fig. 4). At suprathreshold levels the perceived velocity of stimuli would be determined by the relative activity in these channels; this is by no means a new idea, having been discussed in general terms by Tolhurst *et al.* (1973). Suppose that below about 8 Hz the slow channel has a lower contrast threshold than the fast channel. Then reducing the contrast of a slowly moving stimulus will bias the relative activity in these channels, the slow channel becoming relatively more sensitive to the stimulus until at very low contrasts the stimulus will be detected by the slow channel alone. Therefore if perceived velocity depends upon the relative activity in these two channels, reducing the contrast of a slowly moving pattern should reduce its apparent speed, which is the result found. The same argument can explain the increase in velocity of fast moving stimuli when their contrast is reduced.

The experimental data suggest that there cannot be an exact correspondence between the two channels described here and the pattern and movement channels described by Kulikowski and Tolhurst (1973) and others. First, the switch from velocity underestimation to overestimation has been found to be independent

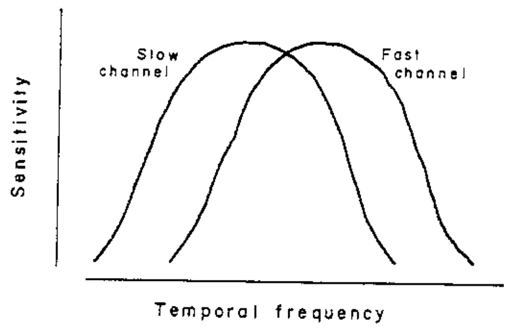

Fig. 4. A mechanism of the dependence of perceived velocity upon apparent contrast. Perceived velocity is determined by the relative activity in the two channels. It is assumed that both channels respond in the same way to changes in contrast. At low temporal frequencies, where the slow channel is more sensitive, reducing stimulus contrast will reduce the relative contribution of the fast channel, (and therefore the perceived rate of movement), until at very low contrast levels the stimulus is detected by the slow channel alone. At high temporal frequencies the position is reversed, reductions in contrast reducing the relative contribution of the slow channel's response. The crossover from the slow channel being more sensitive to the fast channel being more sensitive appears to be around 8 Hz. under the conditions presented here.

of spatial frequency, whereas the relative sensitivity of pattern and movement channels changes considerably over spatial frequency. Secondly, the change-over from underestimation to overestimation should have been around 2–4 Hz and not around 8–10 Hz as found.

That perceived velocity is dependent upon the stimulus contrast has important implications for our velocity judgements in the real world (e.g. driving in fog) as well as in laboratory experiments. As an example of the latter it might be noted that experiments on velocity aftereffects (the change in velocity observed following adaptation to movement) have confused changes in perceived velocity brought about by the adaptation to movement per use with changes in perceived velocity brought about by the contrast reducing effect of the adaptation stimulus, (Blakemore *et al.*, 1973). Interestingly, whereas the changes in perceived velocity resulting from contrast reduction appear temporal frequency tuned, the velocity aftereffects resulting from adaptation to movement are velocity tuned (Thompson 1981).

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