Pergamon

0042-6989(95)00297-9

Vision Res., Vol. 36, No. 15, pp. 2333–2336, 1996

Printed in Great Britain
0042-6989/96 $15.00 + 0.00

Short Communication

Directional Motion Sensitivity under Transparent Motion Conditions

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Received 4 November 1994; in revised form 21 June 1995; in final form 30 October 1995

We measured directional sensitivity to a foreground pattern while an orthogonally directed background pattern was present under transparent motion conditions. For both foreground and background pattern, the speed was varied between 0.5 and 28 deg sec^{-1}. A multi-step paradigm was employed which results in a better estimation of the suppressive or facilitatory effects than previously applied single-step methods (e.g. measuring D_{max} or D_{min}). Moreover, our method gives insight into the interactions for a wide range of speeds and not just the extreme motion thresholds (the *D*-values). We found that high background speeds have an inhibitory effect on the detection of a range of high foreground speeds and low background speeds have an inhibitory effect on a range of low foreground speeds. Intermediate background pattern speeds inhibit the detection of both low and high foreground pattern speeds and do so in a systematic manner. Copyright © 1996 Elsevier Science Ltd.

Suppression Motion transparency Directional sensitivity Motion

INTRODUCTION

Motion detectors that share common characteristics such as tuning to the same direction of movement or the same speed combine into specific channels (e.g. Moulden, 1980). Evidence that motion channels interact has been presented previously [e.g. Marshak & Sekuler, 1979 (mutual repulsion); Mather, 1980 (uni-directionality of the MAE of transparent motion)]. There are only a few psychophysical reports on the interaction between motion directions in relation to changes of motion sensitivity. In one attempt, Snowden (1990) investigated the detectability of a single horizontal displacement (D_{max}) of a pattern presented during a 200 msec display of a vertically moving pattern. The experiment was completed for background pattern speeds ranging from 0.4 to 25.6 deg sec^{-1}. In summary, Snowden (1990) reported that the detection of motion in patterns of high speeds was suppressed only by patterns with speeds higher than approximately 1 deg sec^{-1} and that the detection of motion in patterns with low speeds (below 1 deg sec^{-1}) was suppressed only by patterns with low speeds. The phenomenon is sometimes referred to as *mutual* suppression.

There are a number of reasons for deeper investigation of these findings. First, it is disputable whether Snowden's experiments really addressed *mutual* suppression. The method as used in that study is a confound of two paradigms. In that experiment, 400 background dots were moving vertically using a multi-step paradigm (i.e., dots making multiple steps). The test, however, was a single horizontal displacement of 400 foreground dots. In order to truly measure or at least have a better estimation of the mutual suppression, both patterns should be present at the same time and be as similar as possible: the presence of a foreground pattern is as likely to affect the systems responsible for detecting the background pattern as it is vice versa.

This difference in method (single-step vs multi-step pattern motion) can create a number of problems. For example, differences in populational recruitment effects; detectors tuned to larger displacements are activated later in the course of the stimulus presentation (van de Grind *et al.*, 1983). Also, Snowden's stimulus may have activated mechanisms responsible for priming (McKee & Welch,

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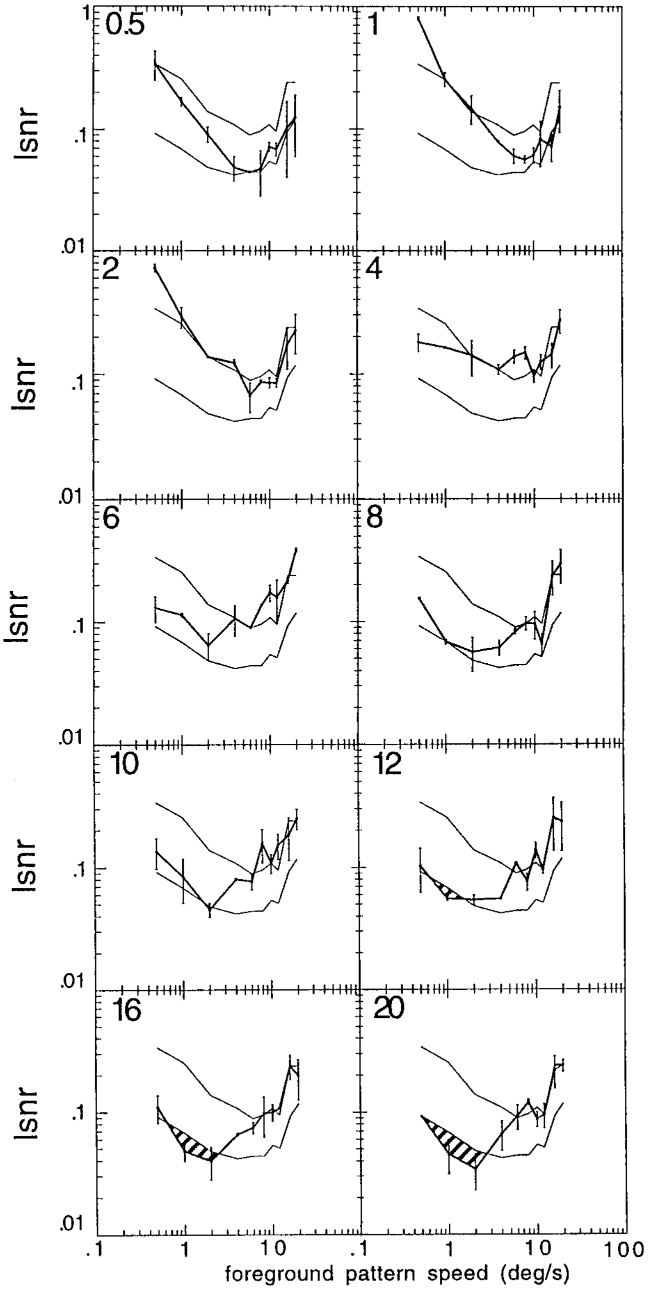

FIGURE 1. Results for subject FV. All combinations were measured twice (speeds ranging from 0.5 to 20 deg sec^{-1}). Each panel displays the curve of the sensitivity values of all speeds for the foreground pattern with a constant speed of the background (for example, the upper left panel represents foreground pattern speeds ranging from 0.5 to 20 deg sec^{-1} with a constant background speed of 0.5 deg sec^{-1}. The error bars represent standard errors of the mean.

1985). These two possible problems might arise for multi-step background motion but not for the single-step test. Although often ignored or taken for granted, an inherent problem arises when D_{max} or D_{min} are measured, the question being whether we can interpret a D_{max} value as a scalar speed. In other words, if we use a single-step D_{max} test, can we actually conclude that a certain background speed has an effect on a certain foreground speed? We think not: it can only be concluded that the background speed has an effect on the magnitude of the foreground displacement.

In this study we minimize the possible problems arising from the points discussed above. Both the background and foreground pattern are simultaneously present under transparent motion conditions in a multi-step paradigm. Instead of investigating only the extreme motion thresholds, we investigate interactions over a wide range of foreground/background speed combinations.

EXPERIMENT

Stimulus generation

The motion stimulus was generated using the same apparatus as used by Verstraten *et al.*, 1994a. The experiments were performed at a viewing distance of 2 m, so the screen subtended 4 deg of arc and each pixel subtended 0.94 min of arc. Mean luminance of the CRT display was 50 cd m^{-2}. The stimulus has been described in detail in Verstraten *et al.*, 1994a. A "checkerboard" of contiguous windows (here 1 × 1 pixels) displayed the patterns. If at least one of the patterns was moving, this was perceived as transparent motion (see Fig. 1 of van Wezel *et al.*, 1994).

Procedure and threshold measurement

We used a luminance signal to noise ratio (LSNR) method as introduced and described in detail by van Doorn & Koenderink (1982).* Half of the 256 × 256 pixels form the foreground pattern and the rest form the background pattern.

The thresholds were determined as follows. The foreground pattern moves at a speed ranging from 0.5 to 28 deg sec^{-1}. The background pattern moves with the same range of speeds, including a stationary condition (baseline measurement). Subjects indicate the direction of the foreground pattern, which is either in the 45 deg direction or in the 225 deg direction, in a two-alternative, forced-choice (2AFC) direction discrimination task. The background pattern is always moving along the 135–315 deg axis and is kept at full signal while the LSNR of the test (foreground) pattern is varied. The motion is continuously present for a total duration of 1 sec. After each stimulus presentation the pattern is replaced by a non-textured mean luminance (50 cd m^{-2}) pattern. The LSNR thresholds are determined using a staircase procedure that tracks a 79% correct level.

In order to decrease the duration of the experiment, a subset of all possible combinations of foreground and background speeds was presented to two of the three observers. The subjects first set the LSNR manually until it was close to but still clearly above perceptual threshold. This was the first LSNR value for the ensuing staircase procedure.

Three subjects participated in the experiment. All

*See also the Appendix of Fredericksen *et al.*, 1993 for the advantages of this method over a spatial SNR method.

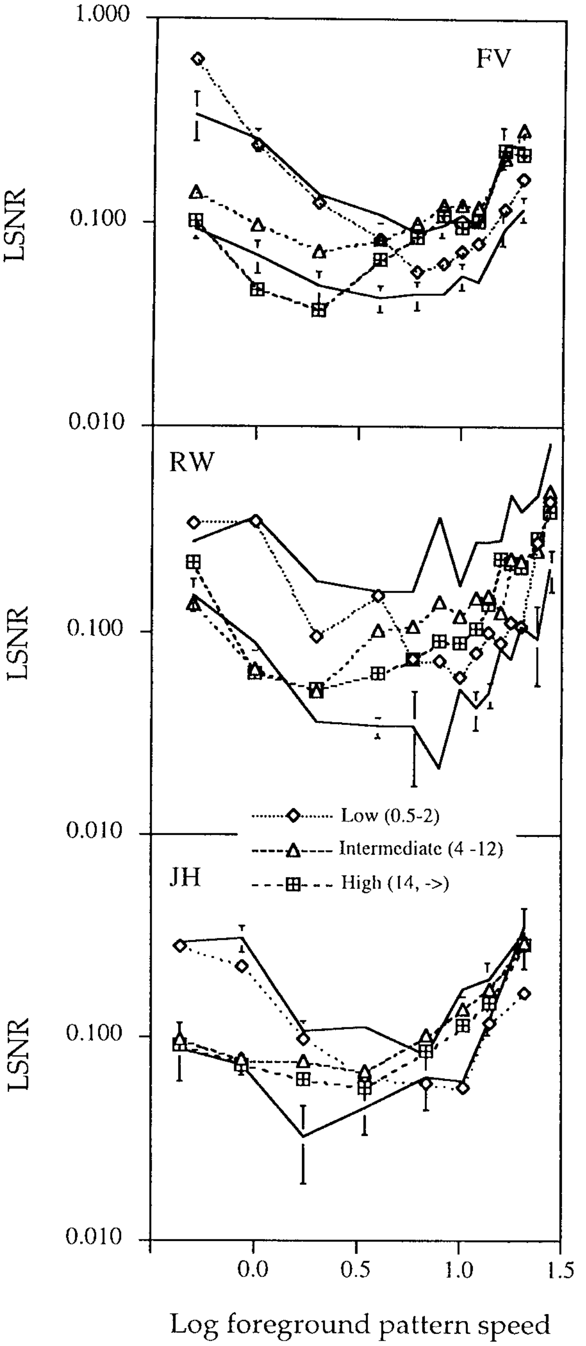

FIGURE 2. Results for all subjects. The background speeds are divided into three categories, low (background speeds up to 2 deg sec^{-1}), intermediate (4–12 deg sec^{-1}) and high (14 deg sec^{-1} and above). The baseline direction-sensitivity threshold and the same threshold under suppression conditions when both the foreground and the background pattern have the same speed (e.g., 2 vs 2 deg sec^{-1}) are shown for comparison. See text for details.

subjects had previous experience in related psychophysical experiments.

RESULTS AND DISCUSSION

Figure 1 shows the results for one subject. This subject measured all speed combinations for background and foreground twice (speeds ranging from 0.5 to 20 deg sec^{-1} for this subject). Each panel displays the LSNR values as a function of the foreground pattern speeds for a given constant speed of the background pattern (note that directional sensitivity = 1/LSNR). The lower of the two thin lines in the figure represents the baseline LSNR values (background stationary) and the upper line represents the sensitivity to the foreground pattern when both patterns are moving with the *same* speed (e.g. 2 deg sec^{-1} vs 2 deg sec^{-1}).

We find that low background velocities decrease the detectability of low foreground velocities and high background velocities have an inhibitory effect on the detection of high foreground velocities. Note that the change between low and high velocities is gradual, especially for the detection of low foreground speeds.

In Fig. 2 we have plotted data for all subjects. For reasons of clarity and space, we have divided the background speeds into three categories, low (background speeds up to 2 deg sec^{-1}), intermediate (4–12 deg sec^{-1}) and high (14 deg sec^{-1} and above). The curve representing the detection of lower speeds is mostly suppressed for low background speeds, with the suppression decreasing when the background speed is increasing. The opposite is true for the detection of the foreground pattern when the background speed is high. The detection of lower foreground speeds is nearly unaffected by the high background speeds. There might even be a facilitory effect of high background speeds on the detection of low foreground speeds. At intermediate background speeds, LSNR thresholds are between those for the low and high background speeds.

Two networks?

Although it is difficult to compare the data, Snowden (1990) found a sharp distinction in suppressive behavior around 1 deg sec^{-1}. He did not elaborate on the difference but suggested that the results might be explained in terms of two different networks; one network responsible for the processing of high speeds and another for low speeds. For reasons discussed in the Introduction, it is difficult to defend that position on the basis of measurement of D_{max} and D_{min}. Our results show that the sharp distinction as deduced from D_{max} in Snowden's report might not be so sharp after all. Our stimulus design allows us to more carefully assess the mutual impact of different motion channels over a range of velocities. Moreover, we find a more plausible gradual shift. For the idea of two mechanisms to be plausible, the tuning bandwidths of these mechanisms must overlap considerably. We must also keep in mind that the broader region of changeover in our results may reflect the difference between using a multi-step rather than a single-step foreground pattern, in combination with the finite spatio-temporal tuning bandwidth of the underlying motion detector population. The effect of the intermediate speeds leaves open an explanation in terms of multiple networks/channels and neither our nor Snowden's study can provide definitive evidence for either interpretation.

A facilitation effect?

Figures 1 and 2 also seem to show that there is some facilitation: the directional sensitivity to low foreground speeds increases (= LSNR values decrease) as compared to the baseline values if a high speed background pattern is present simultaneously. In Fig. 1 this is illustrated as the textured area between the baseline and the suppression curve. Snowden (1990) also found a facilitation effect. He reported that if the background speed is increased, D_{min} is decreased. This implies that the performance is better than when the background pattern is stationary. For our results, facilitations were visible at the lower end of the foreground speed range. A possible explanation for the facilitory effect in our study might be found by considering eye movements. In the case of the baseline measurement (stationary background pattern) for low foreground speeds, small eye movements in the direction of the foreground motion result in a small relative motion of the stationary dots in the opposite direction. Here one creates a condition that equals the situation where a low foreground speed and low background speed are simultaneously present and might, therefore, have a suppressive effect on the detection (compare the curve for the same speeds in Figs 1–2). In the case where the background is really moving with a high speed, this suppressive effect disappears because background and foreground speed differ to a greater extent. The resulting LSNR value might then be the actual baseline value. In this case the assumed facilitatory effect is not a facilitation but a release from inhibition.

Concluding remarks

We have given further insight into how interactions between motion channels depend on speed for fixed motion directions and a fixed disparity. Further research is required to determine how our visual performance depends on the other parameters. Manipulating direction, disparity and speed will undoubtedly show how they are represented along the path of visual motion processing: independent or interactive (see also Bradley *et al.*, 1995; Lindsey & Todd, 1995; and Verstraten *et al.*, 1994b).

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Acknowledgements—The research was supported by the Netherlands Organization for Scientific Research (NWO-SLW). Preparation of the manuscript was supported by a NWO/NATO-Science fellowship and the Niels Stensen Foundation. We thank Ans van Doorn, Otto-Joachim Grüsser and David Keeble for helpful comments.