J. J. McCann, R. L. Savoy and J. A. Hall, Jr.,

"Visibility of Low Frequency Sine-Wave Targets, Dependence on Number

of Cycles

and Surround Parameters,

Vis. Research, **18**, 891-894, 1978.

Reprinted from

VISION RESEARCH

Vol. 18, *No.* 7, *pp.* 891–894

VISIBILITY OF LOW-FREQUENCY SINE-WAVE TARGETS: DEPENDENCE ON NUMBER OF CYCLES AND SURROUND PARAMETERS

JOHN J. MCCANN, ROBERT L. SAVOY and JOHN A. HALL JR

Polaroid Corporation, Vision Research Laboratory, Cambridge, MA 02139, U.S.A.

PERGAMON PRESS
NEW YORK · OXFORD · FRANKFURT · PARIS
1978

Vision Research, Vol. 18, pp. 891–894
© Pergamon Press Ltd 1978. Printed in Great Britain

0042-6989/78/0701-0891$02.00/0

LETTER TO THE EDITORS

VISIBILITY OF LOW-FREQUENCY SINE-WAVE TARGETS: DEPENDENCE ON NUMBER OF CYCLES AND SURROUND PARAMETERS

(*Received* 23 *March* 1977; *in revised form* 3 *November* 1977)

Several papers have described experiments which have shown that human visual sensitivity to sinusoidal gratings is dependent on the number of cycles of sinusoid for low-spatial-frequency targets (McCann, Savoy and Hall, 1973; Hoekstra, van der Goot, van den Brink and Bilsen, 1974; McCann, Savoy, Hall and Scarpetti, 1974; Savoy and McCann, 1975). A recent article by Estevez and Cavonius (1976) presented the argument that dependence on the number of cycles occurred only in the presence of a dark surround. They reported a dependence on number of cycles with sinusoids that have a black surround, but they also reported a lack of dependence on number of cycles with targets that have average-luminance areas adjacent to the sinusoidal area. They pointed out that the majority of previous experiments had been performed with a dark surround.[1] The exception was one of the experiments by Savoy and McCann (1975) in which the luminance of the area surrounding the sinusoidal grating was equal to the average luminance of the grating. In this case, Estevez and Cavonius (1976) argued that a hairline edge of a mirror, which produced a faint visible line around the sinusoidal portion of the display, was having an effect very similar to that of a black surround. This Letter presents experimental results which replicate the Savoy and McCann (1975) data using targets without any visible line. This shows that the conclusions reached in the 1975 paper reporting a dependence on number of cycles are correct. Furthermore, the experiments show that the experimental data of Estevez and Cavonius are due to substantial differences in non-sinusoidal parameters of their displays compared to those used by Savoy and McCann.

We began by repeating the Savoy and McCann experiments without the hairline edge created by the mirror. William Wray, of our laboratory, in collaboration with John Hall designed a display system that provides stimuli without visible lines around the sinusoidal portion. The unusual property of this electronic display system is that it allows us to vary the luminance and the size of the average-luminance surround on all four sides of the sinusoidal portion of the display. Estevez and Cavonius displayed areas of average luminance on the left and the right, but not on the top and the bottom of the sinusoidal portion of the display. With Wray and Hall's apparatus we repeated and extended the experiments with the average-luminance surround described by Savoy and McCann. The results are shown in Fig. 1. We used five different viewing distances (three of which were the same as in the 1975 paper). We used a constant-size stimulus on the face of the display, so the five viewing distances resulted in five different angular sizes. The entire display was 8 cm square and was viewed at 0.18, 0.38, 1.07, 3.51 and 10.39 m. The sinusoid was 5.2 cm square and subtended 16°, 7.6°, 2.7°, 0.83° and 0.28°. When contrast sensitivity is plotted vs spatial frequency, all the cases coincide at high spatial frequencies (Fig. 1a). When the same contrast sensitivity data are plotted vs number of cycles, the five curves coincide at low number of cycles (Fig. 1b). In other words, we replicated the Savoy and McCann results without the visible line around the sinusoidal portion of the display, and we extended those results to larger and smaller targets.

Estevez and Cavonius's experiments used targets that were significantly different from those used by Savoy and McCann in at least three parameters. The first was the shape, namely the height and width, of the sinusoidal portion of the display. Estevez and Cavonius kept the height of the display constant (12°) and varied the width from $\frac{1}{6}$ of a degree to 20°. Savoy and McCann kept the shape constant and varied the size (7.6° × 7.6°, 2.7° × 2.7°, 0.83° × 0.83°). The experiments described in this Letter extend those results to targets subtending 16° and 0.28°. Thus, Savoy and McCann's observers always viewed a square target with a square sinusoidal portion. Estevez and Cavonius's observers looked at sinusoidal targets that had various rectangular shapes; the thinnest rectangle had a height to width ratio of 72:1. The second parameter that was different in the two sets of experiments was the proportion of average-luminance surround. When Estevez and Cavonius used an average-luminance surround, the sinusoidal portion and surround together always subtended 12° × 20°. When the sinusoidal portion subtended 10° in width, it was flanked by 5° of average-luminance surround on both sides. The ratio of sinusoid width to flank width was 2:1. When the sinusoidal portion was 9′ wide, the flank was 9° 55′ wide on each side, and the ratio was 1:66. Since Savoy and McCann kept the display constant and varied observer distance, all the proportions of the display remained constant, although flank width (in degrees) varied. The third parameter in

[1] The effects of using a black surround on the Fourier spectrum is discussed by McCann *et al.* (1974) and Savoy (1975).

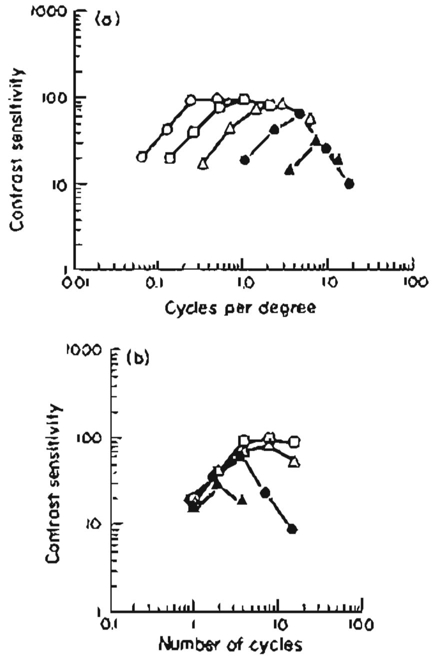

Fig. 1(a). Contrast sensitivity vs spatial frequency (cycles per degree). The data indicated by ○ were obtained when the square, sinusoid portion of the target subtended 16°; □ 7.6°; △ 2.7°; ● 0.83°; and ▲ 0.28°. The sinusoid was in sine phase. The luminance of the surround was equal to the mean luminance of the sinusoid, 9.3 cd/m^2. Two subjects were used. One, J.A.H., had been a subject in the previous experiments (Savoy and McCann, 1975). The other, C.R.S., was a naive subject. Subjects made 10 settings of contrast for each target for each of the following criteria: (1) turn the contrast up from zero until the target is just visible; (2) turn the contrast down from a suprathreshold value until the target just disappears; and (3) adjust the contrast up and down until the target is just discriminable from a zero-contrast target which is seen by pushing a switch. The three criteria resulted in very similar data. The data shown in the above graph are the grand means for 2 subjects, 3 criteria, 10 observations per target, resulting in 60 contrast settings per point. (b) Contrast sensitivity vs number of cycles. These data are the same as shown in Fig 1(a), except that the abscissa is the number of cycles in the target instead of the spatial frequency. The data for the middle three display sizes replicate the results reported by Savoy and McCann (1975). The data for the two new display sizes extend to both larger and smaller angular sizes the conclusion that contrast sensitivity depends on the number of cycles.

which the targets differed was luminance of the areas adjacent to the sinusoid. Estevez and Cavonius placed dark areas above and below the sinusoidal portion of the display, while Savoy and McCann used an average-luminance surround on all four sides.

In order to sort out which of the above parameters might account for the difference between Estevez and Cavonius's results and our own, we repeated their experiments using their stimuli on our display device. We were unable to replicate their data quantitatively; nevertheless, we found qualitative similarities. Both sets of data for 1-cycle targets, plotted as contrast sensitivity vs spatial frequence, are shown in Fig. 2. We have studied 1-, 2-, 4-, 8- and 16-cycle targets and find similar results in each case. We will report results for only 1-cycle targets to simplify the discussion. The upper curve is a plot of the data taken from Estevez and Cavonius, and the middle curve is our attempted replication of their experiments. The bottom curve is the data taken from the replication of Savoy and McCann (shown in Fig. 1). The two lower curves represent data obtained on the same display system using the same photometric calibration procedures[2] and using at least one subject in common. Differences between these two curves indicate different contrast sensitivities for targets having the same spatial frequency and the same number of cycles. In other words, the size or the shape or the proportions of the target and/or the surround are responsible for substantial differences in contrast sensitivity.

Which of the various values of size, shape and surround used by Estevez and Cavonius are responsible for the fact that their targets generate a variety of contrast sensitivities when the number of cycles is constant? Why do the values of size, shape and surround used in the Savoy and McCann targets generate a single contrast sensitivity when the number of cycles is constant? We will consider the two circled data points shown in Fig. 2. Although both sinusoids have 1 cycle and both have the same spatial frequency of 0.8 c/deg, they exhibit large differences in contrast sensitivity. In the Estevez and Cavonius target, the sinusoid portion is 12° × 1.25°; the entire target subtends 12° × 20° (see upper left in Fig. 3). In the Savoy and McCann type target, when the sinusoidal portion subtends 1.25° × 1.25°, the entire target subtends 2.0° × 2.0° (see lower left in Fig. 3).

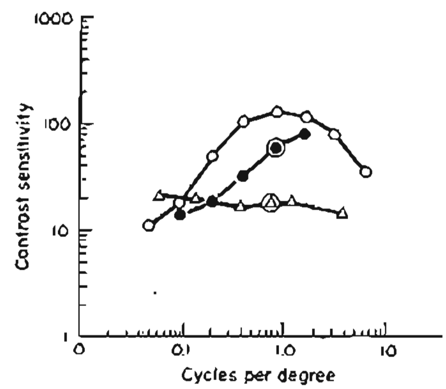

Fig 2. Three different plots of contrast sensitivity vs nominal spatial frequency. All data are from targets having only 1 cycle of sinusoidal luminance in sine phase. Data identified with ○ are taken from Estevez and Cavonius (1976). Data identified with ● are our attempts to replicate their experiments. These data are the average of 2 observers' results. See the text for the description of target dimension parameters. Data identified with △ are our replication of Savoy and McCann's (1975) data. We conclude from the lack of superposition of the two lower curves that parameters other then nominal spatial frequency and the number of cycles affect contrast sensitivity.

[2] We used two independent calibration procedures of Z axis voltage vs luminance contrast. The first technique used a scanning telephotometer, and the second used a stationary slit. These calibrations were in excellent agreement.

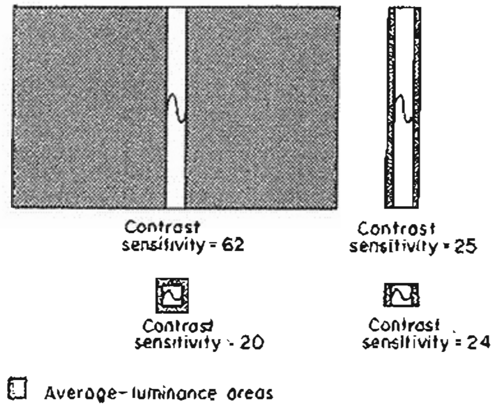

Fig. 3. Diagram of four targets that have 1 cycle of sinusoidal luminance, each with the same nominal spatial frequency. The targets are drawn to scale, and the value below each target indicates the average contrast sensitivity of the two observers.

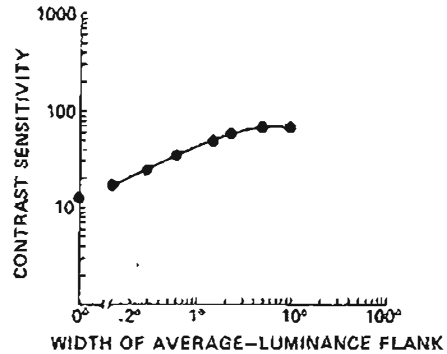

Fig. 4. Graph of average contrast sensitivity for two observers vs width of average-luminance flanks. In this experiment the size, shape, nominal spatial frequency and number of cycles of the sinusoid are held constant, while only the width of the average-luminance flanks is varied. These data show that changing the width of the flank from 0° to 9.4° produces a change in contrast sensitivity from 15 to 62. Thus, with these targets the contrast sensitivity of the sinusoidal gratings depends on the dimensions of non-sinusoidal portions of the display.

In order to transform the Estevez and Cavonius target to the Savoy and McCann target we must make three changes: (1) reduce the width of the average-luminance surround from 9.4° on each side to 0.38°; (2) reduce the height of the sine wave from 12° to 1.25°; and (3) on the top and bottom replace the dark surround with an average-luminance area 0.38° in height. Experiments showed that the width of the average-luminance flank had the largest effect on contrast sensitivity (McCann and Hall, 1977). This result is seen in an experiment in which the sinusoidal portion has a constant size and shape, namely 12° high and 1.25° wide. The sinusoidal portion has constant nominal spatial frequency and number of cycles, namely 0.8 c/deg and 1 cycle. We varied the width of both average-luminance flanks from 0° to 10°. Both flanks were equal in width. In Fig. 4 we plot contrast sensitivity vs width of the average-luminance flank. We find that increasing the width of the flank greatly increases the visibility of the sinusoidal portion of the target. Observers report a contrast sensitivity of 15 for the 1.5° by 12° sinusoid with a black surround. With a gradual increase in average-luminance flank width, starting with 0.15° and ending with 9.4°, there is an associated increase in contrast sinsitivity to a value of 62. Changing the flank width from 9.4° (used by Estevez and Cavonius) to 0.32° (equivalent to that used by Savoy and McCann) causes a change in contrast sensitivity from 62 to 25. The upper two targets in Fig. 3 illustrate this fact. The lower targets show that decreasing the height of the sinusoid—bottom right—has little or no effect,[3] while the addition of average-luminance areas on top and bottom—bottom left—has only a small effect.

In view of the experiments described in this Letter, what can we say about the conclusions reported in the Estevez and Cavonius paper? First, they claimed that our results with an average-luminance background were distorted because of a thin line around our display. We have shown in Fig. 1 that our earlier data have been replicated when the line was removed. Second, they conducted experiments which were intended to mimic ours, but which in fact used gratings of different shapes, surrounds of different widths, and average-luminance on two sides of the gratings instead of all four sides. For a particular spatial frequency, when they increased the number of cycles they also decreased the width of the average-luminance flank. The former causes an increase in contrast sensitivity while the latter causes a decrease in contrast sensitivity. We have discovered that it was the difference in the widths of the average-luminance sides which accounts for the differences between our original data and our repetition of Estevez and Cavonius's experiment.

In conclusion, our experiments supporting a dependence on the number of cycles have been repeated and completely replicated. With a black surround the dependence on number of cycles has been reported by numerous authors, including Estevez and Cavonius. With an average-luminance surround the problem is more intricate. The effects of the size of surround are well known for increment threshold (Crawford, 1940; Westheimer, 1967), but they are not widely discussed for low-spatial-frequency sinusoid thresholds. As shown in this Letter and as discussed in greater detail by McCann and Hall (1977), the amount of average-luminance flank can cause the threshold of the sinusoid to vary from 15 to 62 (Fig. 4) while both nominal spatial frequency and number of cycles are held constant. With low frequency sine-wave targets one must specify the non-sinusoid average-luminance areas in addition to spatial frequency, luminance and number of cycles in order to be able to predict observer contrast sensitivity.

Polaroid Corporation,
Vision Research Laboratory
Cambridge
MA 02139
U.S.A.

JOHN J. MCCANN
ROBERT L. SAVOY
JOHN A. HALL JR

[3] The effect of the height of the sinusoidal portion of the display was reported by Magnuski (1973).

REFERENCES

Crawford B. H. (1940) The effect of field size and pattern on the change of visual sensitivity with time. *Proc. R. Soc.* **129**, 94–106.

Estevez O. and Cavonius C. R. (1976) Low-frequency attenuation in detection of gratings: Sorting out the artefacts. *Vision Res.* **16**, 497–500.

Hoekstra J., van der Goot D. P. J., van den Brink G. and Bilsen F. A. (1974) The influence of the number of cycles upon the visual contrast threshold for spatial sine patterns. *Vision Res.* **14**, 365–368.

Magnuski H. S. (1973) Visual system analysis through use of finite field gratings. Ph.D. thesis (unpublished), Massachusetts Institute of Technology.

McCann J. J. and Hall J. A. Jr (1977) Visibility of low-spatial-frequency sine-wave targets: Dependence on size of average-luminance surround. *J. opt. Soc. Am.* **67**, 1408.

McCann J. J., Savoy R. L. and Hall J. A. Jr (1973) Visibility of low-spatial-frequency sine-wave targets: Dependence on number of cycles. *J. opt. Soc. Am.* **63**, 1297.

McCann J. J., Savoy R. L., Hall J. A. Jr and Scarpetti J. J. (1974) Visibility of continuous luminance gradients. *Vision Res.* **14**, 917–927.

Savoy R. L. (1975) Visibility of low-spatial-frequency targets: Dependence on number of cycles and implications for spatial-frequency channels. M.S. thesis (unpublished), Massachusetts Institute of Technology.

Savoy R. L. and McCann J. J. (1975) Visibility of low-spatial-frequency sine-wave targets: Dependence on number of cycles. *J. opt. Soc. Am.* **65**, 343–350.

Westheimer G. (1967) Spatial interaction in human cone vision. *J. Physiol., Lond.* **190**, 139–154.