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Letter to the Editor

Phosphor Persistence in Oscilloscopic Displays: its Luminance and Visibility

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Phosphor persistence and its potentially confounding effects in visual experiments were discussed recently in these pages (Groner, Groner, Müller, Bischof & Di Lollo, 1993). In that report, we showed that phosphor persistence can remain visible for extended periods (in the order of hundreds of msec) on oscilloscopic screens coated with P31 but not with P15 phosphor. In a dissenting research note, Westheimer (1993) dismisses our evidence as stemming from "very indirect experiments" and concludes that the persistence of P31 phosphor, as measured by a photometer, decays within about 2 msec. This 2-msec estimate could be easily taken as applying equally to photometers and to human observers. To obviate this misinterpretation, the generality of Westheimer's conclusion needs to be qualified.

A common reason for measuring the temporal course of phosphor decay is to provide engineering specifications for display oscilloscopes (e.g. Bell, 1970). For this purpose, the measuring instrument of choice is a photometer, not the human eye. As pointedly noted by Westheimer (1993), human eyes would supply only indirect estimates. We agree: instead of the direct luminance readings provided by a photometer, visual responses yield only *visibility* estimates that would have to be converted, in some way, to luminance values. The conversion would be complicated by such things as response compression and dynamic changes in gain arising from intensity changes throughout the period of measurement (Hood & Finkelstein, 1986). To wit, a photometer's gain is presumed to remain stable in time. By contrast, the gain of the visual system changes sizably and very rapidly in response to changes in intensity of stimulation (e.g. Baker, 1963). One might say that, for this purpose, the eye is not a suitable substitute for a photometer.

Another reason for wanting to know about phosphor persistence is to avoid a confounding in experiments concerned with temporal effects in vision (e.g. temporal integration). The objective, in this case, is to distinguish integration that takes place within the visual system (as a result of sensory processes), from integration on the oscilloscope's screen (as a result of phosphor persistence). In achieving this objective, what we need to know is whether the phosphor's persistence is still visible on the screen at any given time after stimulus termination. That is, we need information about the *visibility* of phosphor persistence as distinct from its luminance. A luminance reading would provide only an indirect measure: it would have to be converted, in some way, to an estimate of visibility. For the reasons noted above, such conversion would not be simple. An additional complication arises from the very high sensitivity that can be achieved in the visual system especially under the dark-adaptation conditions used in many experiments (e.g. Groner *et al.*, 1993). It has been known for some time that a visual response may be triggered by a single photon (Hecht, Schlaer & Pirenne, 1942). This degree of sensitivity is difficult to obtain in photometers such as that used by Westheimer (1993). At any rate, even with a supremely sensitive photometer, the issue of luminance vs visibility would be still unresolved. To pursue the comparison initiated above, one might say that, for this purpose, a photometer is not a suitable substitute for the eye.

This said, it should be clear how the photometric information supplied by Westheimer (1993) provides only an indirect index of the visibility of phosphor persistence. The same can be said for other luminance measurements, obtained with procedures not unlike those used by Westheimer, that have been available for some time in manufacturers' specifications of different types of phosphor (e.g. Bell, 1970). All these measurements must be regarded as indirect indices of visibility because, to be useful in a psychophysical experiment, a critical additional step is required: an estimate of visibility needs to be inferred from the luminance value. And this is just where photometric measurements can lead to—and have been shown to lead to—erroneous inferences with devastating consequences.

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Several such instances have been identified by Irwin (e.g. Irwin, Yantis & Jonides, 1983; Irwin, Zacks & Brown, 1990). We urge the reader to take note of this literature: in every case, the problem arose because, having accepted the photometric evidence that phosphor persistence decays almost completely within a few msec of stimulus offset, the researchers inferred—incorrectly—that the *visibility* of the trace to a human observer had also vanished within the same brief period. Regrettably, this is also the message conveyed in the concluding paragraph of Westheimer's (1993) research note. To be sure, the error is easy to make because, as is evident in Westheimer's recording (Westheimer, 1993, Fig. 1), beyond about 2 msec of stimulus offset, the photometer's output consists largely of noise. Yet, hidden in the photometer's noise is a residual signal that can be visible to a human observer. Just how visible that signal can be—and for how long it can remain visible has been shown in our earlier work (Groner *et al.*, 1993).

It must be emphasized that phosphor persistence cannot be dismissed lightly as noise that would have only marginal effects on performance. The decaying traces of P31 phosphor are remarkably visible and easily produced: here is a simple demonstration that requires no fancy equipment or elaborate arguments. In a dimly-lit room (scotopic or mesopic viewing) draw a 2-cm vertical line using the triangular-waveform output of a function generator as input to the Y-axis of the oscilloscope. Then move the line intermittently on the screen by turning the X-position knob manually. An image of the line will be seen to persist for some time in the pre-displacement screen location. In fact, by turning the X-knob in small rapid steps, it is possible to produce a series of lines of graded visibility. That the persistence is on the screen rather than solely in the beholder's eye, is indicated by the fact that no residual line is ever seen on a screen equipped with P15 phosphor.

Westheimer's conclusion that images displayed on P31 phosphor have "an effective decay time of 2 msec" is valid only in the trivial case in which the term "effective" refers to the photometric system and ambient conditions employed in the measurement. That conclusion is invalid—and potentially misleading—if the term "effective" is interpreted as referring to the human visual system. We reaffirm our earlier conclusion that the long persistence of P31 phosphor makes it unsuitable for investigating temporal integration in vision. We continue to regard P15 as the phosphor of choice for studying temporal factors in visual experiments.

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