LIGHT SPREAD AND SCATTER FROM SOME COMMON
ADAPTING STIMULI: COMPUTATIONS BASED ON
THE POINT-SOURCE LIGHT PROFILE

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Abstract—A point source of light is not so imaged on the photoreceptor mosaic. The light is distributed
over the retina by diffraction, imperfections in the optics of the eye, and scatter. The spatial distribution
of light is specified quantitatively by the point-source light profile, which can be used in convolution to
determine light spread from more complex visual stimuli. We use the Vos, Walraven and van Meeteren
[Vision Res. 16, 215–219 (1976)] light profile to determine spread light in specific regions within the spared
area of an illuminated surround, and within a thin spared ring in an otherwise uniformly illuminated
circular field. Surrounds of different sizes and rings of various widths and diameters are evaluated.

INTRODUCTION

The appearance of a light is determined by both
the light itself and the characteristics of other
lights nearby. A number of distinct mechanisms
are responsible for one light's influence on the
appearance of another (see Wyszecki, 1986, for
a review); the mechanisms may be classified for
present purposes as prereceptoral, receptoral, or
postreceptoral.

The results here focus on a prereceptoral
process that alters quantum absorption by photo-
receptors: physical addition of quanta in the
retinal area of a particular stimulus due to other
lights in the visual field. Sometimes this admix-
ture is intentional, as when an increment is
superimposed upon a background. More often,
however, the added quanta result from the
spread of light from other spatially distinct
stimuli. The spread of light is caused by
diffraction, imperfections in the optics of the
eye, and light scatter. The combined effect of
these prereceptoral factors is summarized by the
light profile of a point source. The profile gives
the spatial light distribution on the retina for a
point source of light.

Armed with the point-source light profile, one
can calculate by convolution the retinal light
distribution for more complex stimuli (e.g. an
annular surround). The particular point-source
light profile used for the convolution is, of
course, a critical question. Most luminance
profiles consider only distances very near the
geometrical image, within only a fraction of
a degree (Krauskopf, 1962; Westheimer and
Campbell, 1962; Campbell and Gubisch, 1966;
Gubisch, 1967; Westheimer, 1986). Scattered
light, however, can be important at much larger
distances. Published values extending out to
100° have been available for more than ten years
(Vos et al., 1976; see also Vos, 1984), but
relatively few calculations have exploited them.
In this paper we use the Vos et al. (1976) light
distribution to determine light profiles for stim-
ulus configurations used frequently in studies of
chromatic adaptation and color contrast.

METHODS

The calculations are straightforward. The
Vos et al. (1976) point-source light profile gives
the fraction of light that falls in a unit area
located a given distance away from the point
source. A table gives values for distances from
a few seconds of arc to about 8.7°; a simple
equation provides values for larger distances
though the present calculations require only
distances in the table. Vos et al. give results for
pupil sizes of 2.0, 3.0, 3.9, 4.9, 5.8 and 6.6 mm;
they assume a foveal image of a white point
source. Our calculations assume a 2 mm pupil
and that the published values are valid up to 5°
off the fovea.

The stimulus fields analyzed here are radially
symmetric with an illuminated area that is uni-
form (Fig. 1). The dark area of the original light
stimulus is referred to as the spared area. The terms "illuminated area" and "spared area" apply to the initial light stimulus prior to spread and scatter in the eye.

The term "spread light" is used henceforth to include all light distributed off the geometrical image, due to any and all processes (diffraction, eye's optics, scatter); it thus refers, by definition, to values given by the retinal light profile.

The computations in essence are a large summation. Calculations are made at each of many points spaced along a radius vector that begins at the center of the circular, radially symmetric stimulus field (dashed lines, Fig. I). For a given point on the radius vector within the spared area, the fraction of spread light from each point in the illuminated area is determined using the Vos et al. (1976) light profile. "Points" in the illuminated area are discretized as patches with area 1 square min, except when the distance between the radius point and the illuminated point is less than 10' in which case patches of area 0.01 square minute are used. The values from all points in the illuminated area are summed to give the total light per unit area at the radius point.

Radius points are spaced no more than 1 min apart (closer spacing is used near the illuminated-spared border to minimize interpolation error).

**STIMULUS FIELDS**

<table>
<thead>
<tr>
<th>Illuminated Area</th>
<th>Spared Area</th>
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Fig. 1. Schematic representation of the stimulus fields. The field on the left is a uniformly illuminated annular surround, specified by its inside diameter (I.D.) and outside diameter (O.D.); spread light is determined at locations within the spared area. The field on the right is a uniformly illuminated circular disk with a concentric spared ring within it; the disk is specified by its outer diameter (O.D.), the ring by its width (W) and diameter (D). The width of the ring is defined as half the difference between its outer diameter and inner diameter; the diameter of the ring is the mean of the ring's inner diameter and outer diameter. Spread light is determined within the spared ring. Dashed line with a point in the spared area is a radius vector, not part of the stimulus (see text).

The average level of spread light within a finite area (e.g. a central circular region of diameter 1') is determined by (1) computing the area of a thin concentric circular band that includes the radius point, (2) calculating the total light falling in the band by multiplying the band's area by the light per unit area at the radius point, and (3) figuring the average light in the finite area by summing light falling in contiguous concentric bands and then dividing by the bands' total area.

Two types of stimulus fields are evaluated: (1) an annular illuminated area surrounding a dark central disk of varying size (Fig. 1, left), and (2) an illuminated disk with an annular spared area of varying width W and diameter D (Fig. 1, right). The calculations include space-averaged spread-light estimates for specific regions within the spared area (e.g. the portion of the spared area within 10' of the illuminated area, or the central 1' of a 2' spared center).

**RESULTS**

**Annular illuminated surround**

Spread light from an annular surround with 7' outer diameter was determined for spared central regions of diameter 10', 20', 30', 40', 1.5', 2', 3', and 4'. The diameter of the spared region is, by definition, the inner diameter of the illuminated surround.

Figure 2 shows the amount of spread light (vertical axis) falling at a point a given distance from the center of the spared area (horizontal axis), starting from the point at the center of the spared portion and continuing out to within a minute of the illuminated region. The level of spread light is expressed as a percentage of the stimulus luminance. Spared region diameters from 40' to 4' are in the upper panel; diameters from 10' to 40' are in the lower panel (note change of scale on both axes). Each plot shows the light profile in the spared region.

The test field used in most experimental studies is a patch of finite area rather than a point stimulus. The test field may be relatively small and centered within the spared area (e.g. a 10' diameter spot centered within a 2' spared region) or completely cover the spared area (simultaneous contrast). Sometimes the test patch is viewed with a thin gap separating it from the surround (e.g. a 1' 40' test centered within a spared region of 2'). The space-averaged spread light under the test can be
Light spread from adapting stimuli

The level of spread light is expressed as a percentage of stimulus luminance. Each curve is for a different diameter of the spared region. Diameters from 40' to 4' are in the upper panel; diameters from 10' to 40' are in the lower panel (note change of scale on both axes).

computed easily from the light profile of Fig. 1. Space-averaged values are given in the top part of Table 1 for the central 1', 10', 20', 30', 40', 1', 1.5', 2', 3', and 4' within spared areas of diameter 10', 20', 30', 40', 1', 1.5', 2', 3', and 4'.

Each row of the table shows spread light values for a spared area of fixed size, such as 2', as a function of diameter of the central region within the spared area. For example, space-averaged spread light falling in the area of a circular target centered within a 2' spared region is 3.5% when the diameter of the target is 30' or less, but nearly doubles, from 3.5 to 6.8%, as target diameter goes from 30' to 2'.

Two general results may be noted. First, for central regions located at least 0.5' away from the illuminated portion, spread light depends relatively little on the size of the central region within the spared area. This is indicated by the constant values (or nearly so) toward the left of each row. Second, spread light is less when the spared region is larger, even for central regions located more than 0.5' from the spared-illuminated border. This is clear from scanning down a single column: values continue to become smaller even toward the bottom of the table. Taking the central 10' portion as an example, the spread light there is 6.6% with a 1' spared area, 3.5% with a 2' spared area, and 1.3% with a 4' spared area.

The lower part of Table 1 shows the space-averaged spread light when the 10' band nearest the illuminated-spared border is excluded. For example, the average spread light under a 1'40' diameter circular patch centered within a 2' spared area is 4.7%. The table further shows the average spread light in bands nearest the illuminated area. For example when the spared-region diameter is 2', the spread light that falls within 30' of the border (that is, in the 30' outer band) is 7.7%. The table covers many common stimulus configurations with a spared center and annular illuminated surround.

While the results are based on an illuminated area with 7' outer diameter, they are reasonable approximations with illuminated regions somewhat smaller or larger. With a 10' outer diameter and 4' spared region, a configuration that more than doubles the illuminated area compared to the tabled values with outer diameter 7', the amount of spread light is greater by a factor of 0.54 in the central 30' (2.00% rather than the tabled value of 1.30%), greater by a factor of 0.10 in the outer 10' band, and greater by 0.23 over the complete 4' area. The effect of increasing the outer diameter is less with a smaller spared area: the corresponding values with a 3' spared region are 0.33 (30' central region), 0.08 (10' outer band), and 0.15 (overall).

Reducing the outer diameter moderately also has fairly small effects. With a 6' rather than 7' outer diameter and 4' spared region, which reduces the illuminated area by nearly 40%, the spread light is less by factors of 0.25, 0.06 and 0.13 in the central 30', outer 10' band, and complete 4' spared area, respectively. With a 3' spared region, the corresponding values are 0.16, 0.04, and 0.08.

A fair summary is that the tabled values would change by no more than half* as the

*More precise correction factors can be specified for 6, 8, 9, and 10 outer diameters. The largest correction necessary for any value in Table 1 is reduction by a factor of 0.16 at 6', and increases by factors of 0.13, 0.24 or 0.33 at 8, 9 or 10', respectively; the only exceptions are values with a 4' spared area (bottom row in each part of Table 1), in which case the corresponding values are 0.25, 0.21, 0.39 and 0.54.
outer diameter varies from 6" to 10". Changing the outer diameter has a larger proportional effect at the center of the spared area than near the illuminated-spared border because, percentage-wise, additional spread light from the distant part of the surround is smaller close to the border where the effects of diffraction and the eye’s optics are dominant and relatively large.

**Illuminated disk with spared annular ring**

Another type of stimulus display is a large circular disk containing a thin spared ring. The ring, concentric with the center, is specified by its width and diameter (see Fig. 1, right). The width is defined here as half the difference between the inner and outer diameters of the spared ring; the diameter of the ring is defined as the mean of the ring’s inner diameter and outer diameter. As an example of these definitions, spared rings of diameter 2' and widths of 20', 40' or 1" are, equivalently, spared annular regions with inner and outer diameters of 1'40'-2'20', 1'20'-2'40', or 1'1'-3', respectively. Space-averaged spread light values were determined for ring diameters of 30', 40', 1", 1.5", 2", and 3", and widths of 10', 20', 30', 40', and 1". As before, the calculations assume the illuminated area has outer diameter 7".

Varying the diameter of a ring over a range from 30' to 3" has very little effect: the amount of spread light changes by less than 1%. The width of a ring, on the other hand, is an important factor: space-averaged spread light falling within a ring of width 10', 20', 30', 40' or 1" is, respectively, 18.5, 13, 10.85, or 6%. These values are accurate to within a few tenths of a percent for any ring diameter from 30' to 3".

**DISCUSSION**

The light-spread values presented here quantify the amount of light falling in regions of a spared area. They are not exactly accurate for every observer and visual display, of course, but like the light profile used to determine them they are “a useful description of ocular imagery for a standard observer (Vos et al., 1976, p. 218)”.

The results in Table 1 apply to illuminated areas with outer diameters from 6" to 10", bearing in mind an adjustment of up to half of the tabled value is required with outer diameters other than 7" (see also footnote on p. 607). Measurements of scatter from monochromatic lights suggest the table is valid for wavelengths throughout the visible spectrum, at least for distances of 0.5" or more (Vos, 1963; Wooten and Geri, 1987).

<table>
<thead>
<tr>
<th>Diameter of spared area</th>
<th>Central region within spared area (diameter)</th>
</tr>
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<tbody>
<tr>
<td>1&quot;</td>
<td>10&quot;</td>
</tr>
<tr>
<td>20'</td>
<td>30'</td>
</tr>
<tr>
<td>40'</td>
<td>1&quot;</td>
</tr>
<tr>
<td>1&quot;</td>
<td>1.5&quot;</td>
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<tr>
<td>2&quot;</td>
<td>2.5&quot;</td>
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<tr>
<td>3&quot;</td>
<td>3.5&quot;</td>
</tr>
<tr>
<td>4&quot;</td>
<td>4.5&quot;</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Diameter of spared area</th>
<th>Central region excluding outer 10' band</th>
</tr>
</thead>
<tbody>
<tr>
<td>10&quot;</td>
<td>19.9%b</td>
</tr>
<tr>
<td>20'</td>
<td>16.8%</td>
</tr>
<tr>
<td>40'</td>
<td>15.4%b</td>
</tr>
<tr>
<td>1&quot;</td>
<td>13.7%</td>
</tr>
<tr>
<td>2&quot;</td>
<td>12.2%</td>
</tr>
<tr>
<td>3&quot;</td>
<td>11.5%</td>
</tr>
<tr>
<td>4&quot;</td>
<td>10.9%</td>
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</tbody>
</table>

Table 1. Spread light falling in specific regions within the spared area of an annular illuminated surround (7' outer diameter)

<table>
<thead>
<tr>
<th>Diameter of spared area</th>
<th>Entire spared area excluding outer 10' band</th>
</tr>
</thead>
<tbody>
<tr>
<td>10&quot;</td>
<td>19.9%b</td>
</tr>
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<td>11.5%</td>
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<tr>
<td>4&quot;</td>
<td>10.9%</td>
</tr>
</tbody>
</table>

*Equivalent to inner diameter of illuminated area.

*bEntire spared area.
Previous calculations based on the Vos et al. light profile are the same as in Table 1, which is unsurprising but provides confidence in the accuracy of the present computations. Walraven (1973) reports 2% spread light in the center of a 3–7° (inner–outer diameter) annulus, which differs from 2.1% given in Table 1 only by rounding. The outer 10' band within the spared region of a 1.5–7° surround is estimated at “ca 12%” (Walraven, 1977), compared with the tabulated result of 12.2%.

Laboratory measurements of spread light at the center of a 3–8° annular surround are in reasonably good agreement with the calculated value, as Walraven (1973) observed. Rushton and Gubisch (1966) report 1.5% spread light, a result closely confirmed recently by Wooten and Geri (1987).

A width of 10' is the narrowest outer band within the spared area of a surround (Table 1) and the smallest width of a spared ring considered here. A lower bound of 10' was chosen on consideration of eye movements that accompany fixation of a stationary target. Drift of a few minutes of arc is typical (Hallett, 1986). Results with narrower widths would be meaningful only when the complete visual stimulus is presented very briefly.

Effects of spread light on vision

Light spread affects vision in ways predicted fairly easily because it causes real light to fall in an adjacent retinal area. Spread light can act as an adapting field, as when a surround field is in continuous view but the central patch is not. More commonly, however, central and surround are viewed at the same time (either briefly or steadily) so the spread light from the surround adds physically with light in the central stimulus field. In some cases the spread light may be insignificant compared to the level of the central-field stimulus, but this must be evaluated separately for each receptor type (consider, for example, a short-wavelength or broadband surround presented with a central field that does not appreciably stimulate short-wavelength-sensitive cones).

While the results here are not precisely accurate for every apparatus and observer, they are good quantitative guides to the amount of spread light falling in a “spared” area. They may be especially useful when a research design can be improved by acknowledging and estimating spread light rather than constraining experimental stimuli to avoid it.

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REFERENCES


