Is visual angle equal to retinal angle?

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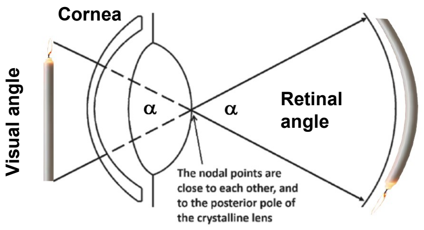
Introduction



We all know what the retinal image looks like – it's a doubly inverted (left/right & up/down) image of the outside world, its size given by the retinal angle, which is usually assumed to be **equal to the visual angle**. A typical textbook explanation is shown here, where lines from the endpoints of an object cross at the posterior surface of the crystalline lens, which just happens to be where the two nodal points of the eye are located very close together. Paraxial optics tells us that a ray directed to the first nodal point appears to leave the second nodal point at the same angle. This seems very reasonable for small angles but, clearly, the angle depicted in the sketch is far too large to be paraxial. So is this textbook graph "**fake news**"? Surprisingly, it is not. Indeed, it is valid up to very large angles.

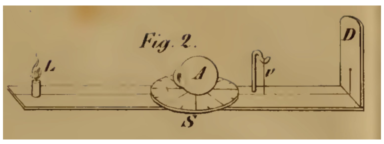
Volkmann's 1836 experiments

Alfred Wilhelm Volkmann from Leipzig in 1836 published a series of experiments, where he sought to determine the retinal location of an object. For this, he cleansed a rabbit's eye and mounted it on an apparatus that allowed rotating the eye around a predefined rotation point. He placed a **candle light** before the eye and observed, in the dark, the candle image's retinal location. He also used two candles in a line to see on which axis the two flame images would coincide.

The resulting lines Volkmann called **direction rays** or **direction lines**, and pointed out that these are not light rays (which would be refracted at the cornea and lens) but are hypothetical lines. They would not even need to pass through the pupil and could cross the sclera anywhere.

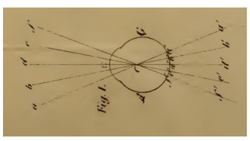
Volkmann did the experiments up to very large angles, more than 90°, and concluded the crossing point is behind the lens and near the eye's centre (p. 28).

Alfred Wilhelm Volkmann
1801–1877



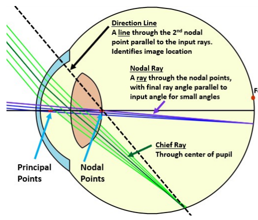
Volkmann's apparatus

light

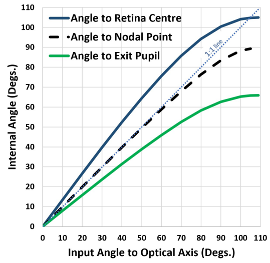


Volkmann's direction rays

Ray-tracing



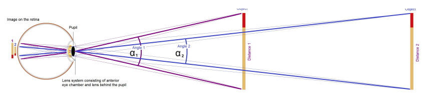
Terms



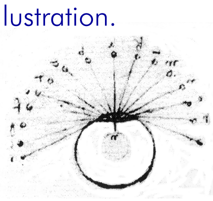
Modern ray-tracing software shows the path of light rays in a model eye and Volkmann's **direction lines** can thus be reconstructed from "actual" refracted rays. The **upper** graph shows a few basic concepts. Note how the direction line, that (by definition) is parallel to the rays entering the eye, arrives at the same retinal location but does not pass through the pupil. The dashed data line in the **lower** graph shows the retinal angle from the nodal point vs the visual angle. The two angles coincide nearly perfectly up to 70° (i.e. are on the main diagonal) and differ only slightly up to the maximal visual angle possible (~107°). When retinal angles are calculated from the **pupil** or the retinal **sphere centre** instead, there is also high angular linearity, but with a scale factor. This is a consequence of the optical design of the eye, with its small size, and high curvature of both the cornea and the retina. Distance along the retinal surface is proportional to angle.

Watch out

Popular drawings, for reasons of plausibility, often put the **crossing point** in the pupil or the lens. I.e. they mistake the lines for rays. The resulting retinal angles are then considerably too small, as the green line in the above data graph shows. Here, e.g., is Wikipedia's illustration.



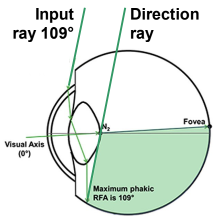
Wikipedia: Wrong crossing point



Leonardo, Manuscript D, ~1514*)

Seeing from behind

Remember that the **maximum angle** at which something can be seen is around 107°–109°, i.e. far exceeds 90°. Leonardo da Vinci already knew that as is evident from a drawing of his. The direction line will then pass through the sclera.



Seeing from behind

Conclusion

Volkmann's close-to-200-year old direction lines through the nodal point are still "the way to go" when estimating locations or image sizes on the retina, but you have to remember that although the lines look like rays, they aren't. And paraxial optics is not the reason for their validity.

References

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Volkmann, A.W. (1836). Neue Beiträge zur Physiologie des Gesichtssinnes. Breitkopf & Härtel, Leipzig.
*) Wade, N.J., personal communication.