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Journal
Topoi, 35(2)

ISSN
0167-7411

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Publication Date
2016-10-01

DOI
10.1007/s11245-014-9287-y

Peer reviewed

Idomenian Vision: The Empirical Basis of Thomas Reid's *Geometry of Visibles*

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Abstract Thomas Reid (1720-1796) claims to have learned of Idomenians, "an order of beings" in "sublunary regions" whose visual system is very much like ours except that they could detect only the direction of rays reaching their eyes, not the distance of origin. The properties of Idomenian vision are here examined in the light of the physiological optics of Reid's time and of the present. Increasing scientific knowledge has done nothing to invalidate the lessons drawn by Reid about the difference between "visible" and "tangible conception of things."

Keywords Visual space, Ocular optics, Geometry of ray bundles, Retinal local signs

1 Introduction

In pursuit of his inquiry into the difference between sensory data and object recognition, Thomas Reid (1710-1796) juxtaposed "tangible" and "visible" conceptions of things, the latter only partial and the former complete. To make the distinction more substantive, he proposed a reduced mode of vision in which the distance of objects from the eyes cannot be appreciated. Not that Reid denied that information about the three-dimensional disposition of objects is available through vision; rather he wanted to examine, by way of a *Gedankenexperiment*, the situation in which our visual clues were restricted to two dimensions, specifically the directions of rays entering the eye, decoupled from the position of origin along the rays. He called these *visibles* and devoted a section of his influential *Inquiry* (1764) to their geometry. Reid, a theologian by training , family background and early professional activities, serious as his philosophical disquisitions were, would nonetheless often be playful in his writings. Thus after an abstract analysis of the geometry of the visibles within a diminished visual system, he proceeds to the purported extract from a traveler who having "acquired the art of transporting himself to various sublunary regions ..

became acquainted with an order of beings" with exactly the reduced sensory capabilities that restrict their visual input to the visibles, unable to be supplemented by haptic cues. They are the Idomenians, the word, according to Breidert (1974) stemming from the Greek roots "seing" and "stay" or "remain," i.e., people with delimited vision.

Reid, as also Bishop Berkeley (1685-1756), his approximate contemporary and fellow student of vision, was well versed in the knowledge of ocular anatomy and optics of his day and frequently quotes the then recent and authoritative treatises of Porterfield (1759) and Robert Smith (1738). Thus while the Idomenians may have been the product of Reid's fancy, their physiological optics was not. In fact, with a few extensions, its principles remain valid today.

The fundamentals are laid out in two diagrams in Smith's *Compleat Opticks* of 1738. Fig. 1 is Smith's depiction of the manner by which three objects, *P*,*Q* and *R*, give rise for visual purposes to retinal images located at *r*, *p* and *q*, respectively, and how this process is represented by the ray from the targets to the center of the eye's entrance pupil. [1] This figure may be interpreted as still demanding object-image focus conjugacy, i.e., that *P* be imaged on *p*, *Q* on *q* and *R* on *r*. That this requirement can be relaxed is demonstrated in Fig.2, again taken from Smith and, incidentally, reproduced in Bishop Berkeley's 1754 *New Theory of Vision,* with the proviso that the in-focus image of a target and the center of the blur patch when it is no longer in focus equivalently define retinal image location. Then the direction of the ray from the target to the center of the entrance pupil, now called the *line of sight,* suffices as marker of the location of the target's retinal image. This was understood by Smith and the students of physiological optics of the middle of the 18th century and remains the teaching of today. The smaller an eye's actual pupil, the smaller the diameter of the blur patch and hence the larger the extent along the line of sight on which targets can be placed and be seen with adequate sharpness. With a small enough pupil, our eye can become a camera obscura (Crary, 1922) and targets equally focused anywhere along the line of sight.

Lines of sight, i.e., rays in object space directed to the center of the entrance pupil and hence unique correlates of retinal local signs, form a bundle having two angular dimensions, defining only direction; relationships between rays constituting the bundle can be analyzed without reference to distance from the eye.

What has been outlined above is the situation when the eye is held still. As Reid told his readers, vision is good only in the most central part of the retina, the fovea, and progressively deteriorates in acuity with eccentricity. There the depth of focus issue becomes less relevant and Idomenian vision more closely approximated. Reid seems never to have learned whether Idomenian eyes remained fixed in the orbit, but later in his exposition he addresses the question of the moving eye. It is here that the principles underlying Idomenian physiological optics would need extension, based on the fact that our eyes rotate about a point approximately 1 cm behind the center of the entrance pupil. The arguments developed so far also apply to the exploration of the object world with the foveal line of sight of the roving eye, provided the center of rotation is substituted for the center of the entrance pupil. The lack of coincidence of these two reference points would cause some minor dissonances in the hybrid situation of an Idomenian combining still-eye peripheral vision with foveal vision in rotated eye positions but they would be inconsequential for all but very close-up targets. A more serious issue arises from the laws of eye rotations, which will be dealt with later.

2 Geometry of Visibles.

Reid endowed his Idomenians with their particular type of reduced visual system for the purpose of highlighting the limitations of a spatial detecting device when it is capable of sensing only the directions of rays in a bundle passing through a single entry point in the eye. Elsewhere in chapter VI of his *Inquiry* he demonstrates that he was well aware of how we can actually pick up distance information by what are now called monocular cues derived from interpretation of the two-dimensional retinal image. His discourse on Idomenian vision seems in fact designed precisely to emphasize the task devolved on us in synthesizing knowledge of the three-dimensional disposition of objects were we to rely entirely on a monocular two-dimensional image.

Reid's approach, as so often, is cleverly didactic. We remain in the manifold of the two angular dimensions of a bundle of rays intersecting in a point, but instead of leaving the situation in that form, he chose to present it in the strictly equivalent form of the locus of the point on each ray that is at a fixed distance from the eye, that is a sphere centered on the center of the eye's entrance pupil. This an arbitrary but unproblematic step, fulfilling Reid's intent of representing the visible world, complete yet devoid of distance information, in a simple and easily visualizable way as if it were collapsed into the pattern of intersections of the rays with the sphere. Once Reid embarked on the artifice of representing the two dimensional world of visibles not as angles in a bundle of converging rays but in the fully equivalent form of traces on the surface of a (hypothetical!) sphere, he had to explain spherical geometry to his readers.

Two vertical sheets of rays through the reference point an angular separation in longitude apart, are marked on the sphere as two great circles that intersect at the poles (Fig. 3). Though by definition parallel (they each form a right angle with the horizontal plane) they eventually meet. The more overt step into non-Euclidean geometry was not taken until many decades later. But visibles, unquestionable then and now the direct spatial optical input to the eye, when examined as traces on the surface of a sphere have the uncomfortable property of two “parallel” lines meeting somewhere else than at infinity. The traces are, of course, only an aid to visualization of the situation. When the rays are extended to intersect a fronto-parallel plane, their traces, instead of marking an orange segment (technically *lune*), now become a pair of parallel straight lines. And on yet other surface, say an American football, they would be a set of curves. None of this is surprising, because Reid’s visibles are only indicators of the direction of rays and are allowed to have their origin anywhere. If outlined by the same set of rays, a rectangular grid on a fronto-parallel plane, a grid of great circles of longitude and elevations on a sphere, and a curvilinear grid on the surface of a football, would all be indistinguishable to an Idomenian.

The extensive discussion (see specifically Grandi, 2005, van Cleve, 2002, Yaffe, 2002) of whether Reid had anticipated non-Euclidean geometry does not relate to Idomenians going about their visual tasks. Their information of the spatial properties of configurations is derived solely from what we now call the visual angle. For them a 3-degree circular cone of rays remains a circular patch on the surface of the sphere, wherever it is swiveled to around the center of the entrance pupil. On a fronto-parallel plane, the same bundle outlines a circular disk when straight ahead but conic sections of different dimensions as it moves into the periphery. That is exactly Reid’s point: Idomenians can’t tell the difference, all they apprehend is the circular crossection of the bundle and its relative position within the large cone of all rays converging to the center of their entrance pupil.

3 The Moving Eye

The only kind of displacement that Reid’s visibles can undergo are rotations around their common point. Unlike vectors, rotations obey rules that are non-commutative, that is, the order in which two sequential operations are performed matters. For example, when a ray is said to be moved 20 degrees up and 30 degrees to the right of the straight-ahead, the position 20^o up (altitude or elevation) --> 30^o (azimuth) right is not the same as 30^o right (longitude) --> 20^o up (latitude). It gets worse. Suppose the different numbers associated with a given direction in the two coordinate systems had been identified and the ray brought from the straight-ahead into this direction separately via the two sequences. Even though the actual ray ends up in the identical direction, a pair of small sheets of rays, forming a horizontal/vertical cross attached to it, will not. A given configuration of visibles when moved around on Reid’s sphere, while remaining invariant is size and shape, will assume differing torsional stances in the same location depending on the sequence of rotations that brought it there (Fig. 4).

As mentioned, Reid never found out whether Idomenians move their eye. Suppose they do and suppose also they are subject to the same oculomotor laws as we are (Alpern, 1962). These, Donder's and Listing's laws, would give them the advantage that there would be only a single torsion associated with each eccentric fixation regardless of any previous eye rotation: a horizontal/vertical cross attached to the foveal line of sight of their roving eye would always be seen with a single torsional value for each eye position. True, the vertical limb may not be strictly vertical in the sense of a plumb bob, but as pointed out by Helmholtz (1867), the direction of an element of a long oblique line that is being traced into the periphery from the fovea would remain invariant.

4 Retinal Local Signs

The rays converging to the center of the entrance pupil, as Reid was well aware, are only the object-sided counterparts of an optical conjugacy. After refraction by the eye media, they form a bundle impinging on the retina (Fig. 1) and are therefore the correlates of the specific retinal location on which they impinge. Perceptually each location has a spatial value, called local sign since Lotze coined the term, in the ordered manifold that makes up an observer's visual space. We are here making the transition from the purely optical to the psychophysical. The disposition of rays in object space can be made as precise as one likes, and analyzed by mathematical formulations as rigorous as can be invented, but the responses they elicit, even in the simplest task of the apparent relative location of neighboring rays, belong to a different realm and their study cannot but involve the observer. Has not only the order but also the geometrical relationships within the physically-defined rays been preserved in psychophysical determinations of local signs?

If the retina were a sphere centered on the center of the eye's exit pupil, then the disposition of the visibles on the retina would indeed be that on Reid's hypothetical sphere and all his arguments about great circles, etc., would apply. But the center of the globe is about 1 cm removed from the point from which the rays diverge towards the retina. Other factors also enter, such as distortions due to the refractive components of the eye. In the end the mapping of the visibles on the retinal surfaces is unknown and the spatial structuring of retinal local signs in terms of the position within the bundle of their correlated incoming rays is an empirical question and the only approach is the psychophysical. When in any individual eye the lay-out of local signs reveals that a remapping has taken place away from Reid's scheme in which two parallel but diverging sheets of rays become two great circles, optical, anatomical and neural factors have already been confounded.

This was an acute question over 100 years ago (see Tschermak, 1931 for a detailed review) and was approached empirically by looking for the physical pattern in a fronto-parallel plane that appeared to observers as a square checkerboard (Fig. 5). It seems that the spherical-coordinate organization implicit in Reid's formulation has been largely compensated. The extent to which this is caused by passive optical and anatomical factors in the eye or by neural remapping remains open. And if it is neural, one would like to know, in line with Reid's kind of inquiry, whether it is inherent in the connectivity pattern laid down at birth, or whether there has been a gradual shift based on experience, away from the primitive visibles of beings who lack the facility of apprehending the third dimension, towards a spatial organization that takes for granted that our world is three-dimensional and plane section of rays through the center of the entrance pupil originate from Euclidean parallels in a fronto-parallel plane, and that great circle are merely constructs to support Reid's abstractions.

Idomenian vision, a not unreasonable caricature in that it condenses, sharpens and exaggerates, surely fulfills its role of lending substance to Reid's thesis of the deep distinction between visibles and tangibles.[2]

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Footnotes

[1] Smith was quite specific about using the center of the entrance pupil as the pivot point for the rays from the object to the eye. It is located in the eye's optical object space, i.e., in air, about 3 mm behind the cornea and has its image-sided correlate, from which the rays diverge to the retina, about 20 mm in front of the retina, i.e., a considerable distance from the center of the ocular globe, which is about 12mm from the retina. Many subsequent writers refer to the *center of the eye,* which is not what Smith and Reid meant. The difference is, however, not significant in the context of the discussions of *visibles.*

[2] The author is grateful to Hannes Matthiesson for making him aware of the eighteenth-century physiological optics of Thomas Reid, for providing references to contemporary discussion and for helpful discussion.

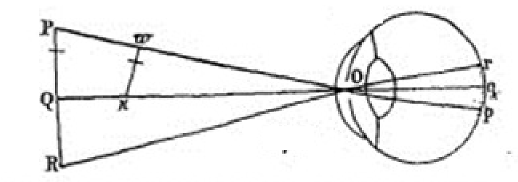


Fig. 1.   A figure in R. Smith *Compleat System of Opticks,* with which Reid was familiar, shows how the ray from an object to the center of the eye's entrance pupil defines the retinal image position associated with the object and how the bundle of these rays, now called lines of sight, can provide a representation of the world of visual targets.

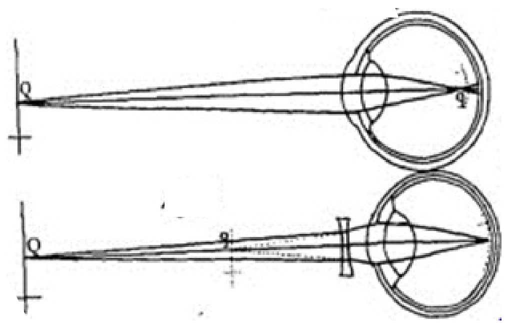
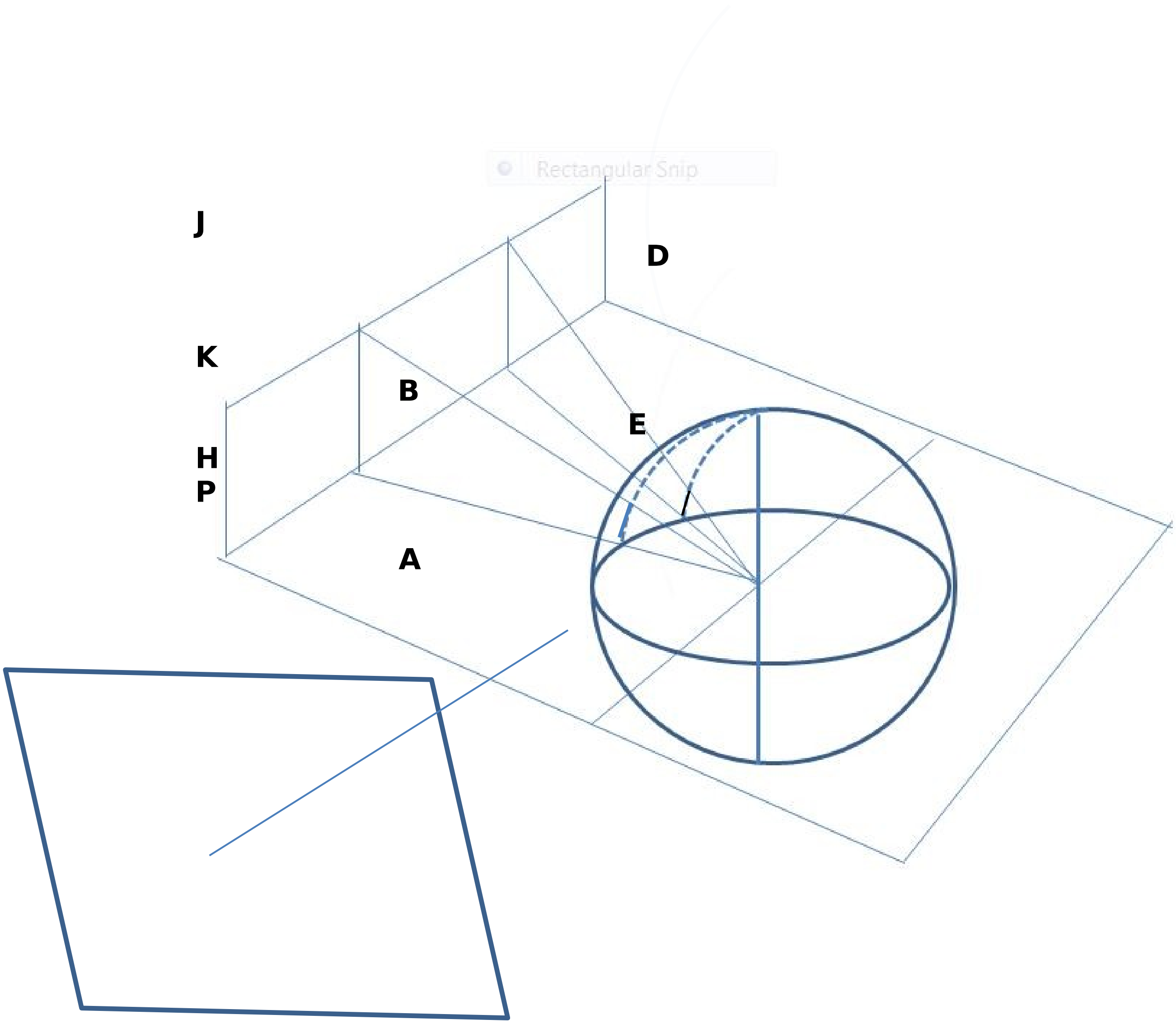


Fig. 2. A pair of diagrams from Smith’s *Compleat System of Opticks* illustrates how the ray from an object to the center of the eye’s entrance pupil defines retinal image location, whether by the center of the blur patch when out of focus (upper) or by a sharply focused image on the retina (lower).   If the center of the blur patch is a marker equivalent to a sharp image point, then the state of focus is immaterial and so is the target location along the incoming ray: by abstracting target distance and remaining entirely in the two-dimensional realm of direction of incidence of the bundle of rays directed to the center of the entrance pupil, Idomenian vision has been realized.



Fig, 3. Scheme showing how two vertical sheets of rays ABC, DEC converging to the center of a sphere C, intersect the surface of the sphere in two great circles meeting at the pole P   The two planes' intersection with a vertical plane GHJK normal to the straight-ahead, are a pair of parallel lines AB and DE.

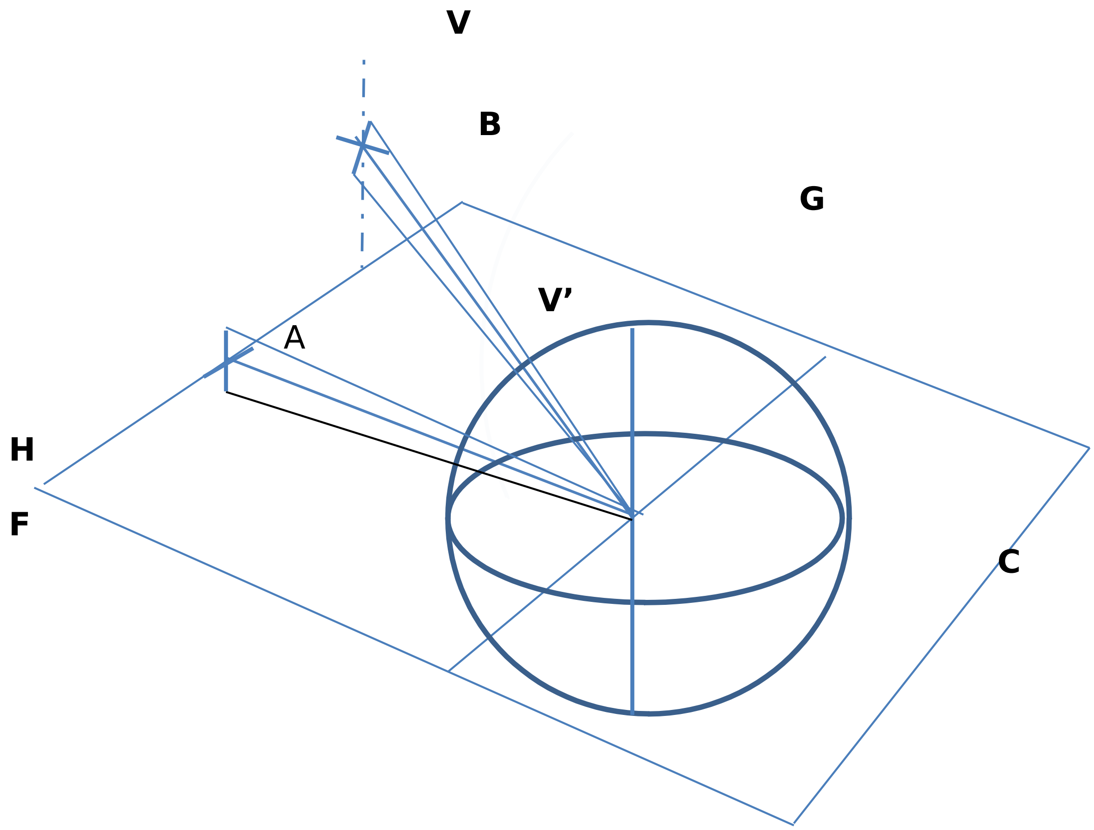


Fig. 4 A rectangular cross aligned with the horizontal plane EFGH through C, the center of the globe, is displaced into a location up and to the right. The orientation of the cross, that is its torsion around the line of sight, depends on the manner by which the fixation axis AC has been rotated around C to BC. Shown is the torsion exhibited in normal human eye movements when foveal fixation is shifted from A to B. The limb of the cross that had been vertical is no longer aligned with VV', the true vertical through the new fixation point.

Idomenian vision, which concerns itself only with the direction of lines of sight and not the points of their origin in object space, nevertheless is subject to torsional changes depending on the sequence of axes through C around which rotation from AC to BC occurs.

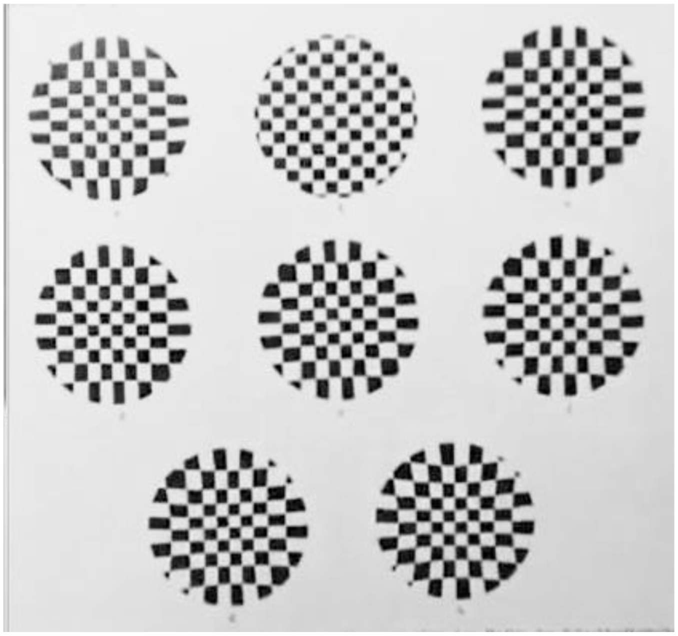


Fig. 5 Checkerboard patterns shown to the eye with very large angular subtense to determine whether the spatial organization of the human visual system has made allowance for the remapping that brings the intersection of converging parallel sheets of rays (Fig. 3) from great circles meeting at the poles of a sphere into a set of orthogonal parallel lines in a fronto-parallel plane (From Tschermak, 1931).