Supplementary Material S2

Methods, diagrammatic representations of visual fields, and dimensions of key comparative parameters

1. Methods

All of the visual fields discussed in this review have been determined using the same procedure; the ophthalmoscopic reflex technique. This determines the space around the head from which an animal’s retinas can be observed. It is based upon the assumption that if an observer can see the retina from a particular direction then the bird will be able to see objects which lie in the reverse of that direction. The technique makes no assumptions about resolution within the field of view, it estimates only the space around the head from which a birds could receive visual information at any one instant.

The procedure is used with alert birds which have their head held in a position that approximates the resting or characteristic position of the head when the bird is sitting or standing. Thus the head position adopted during measurements, and used in the presentation of the data, match those commonly adopted by birds when standing, presumably vigilant, for predators and conspecifics in their natural environment. Head position was defined by the angle that the eye-bill tip direction makes with the horizontal (figures 1 -3). Observations made in anaesthetised or dead birds are likely to be erroneous because eyes may rotate away from normal positions under these conditions.

Although the procedure used is non-invasive and not considered to fall within those requiring licence under the United Kingdom, Animals (Scientific Procedures) Act 1986, the ethical guidelines with respect to handling and restraining birds required for licensed procedures were followed in all of the studies. Birds used were either wild caught or obtained from collections. After measurements birds were returned to their aviaries or released close to their capture sites.

For a detailed description of the apparatus and methods see [1,2]. Briefly, each bird was hand held with the breast resting in a foam rubber cradle and the legs held out behind the body. The head was held in position at the centre of a visual perimeter (a device which permits the eyes to be examined from known positions about the head) by a specially manufactured steel and aluminium bill holder. Each holder had to be manufactured to hold the bill snugly and was based upon measurements taken from live birds and/or museum specimens. The surfaces of the holder were coated in cured silicone to provide a non-slip
cushioned surface. The bill was held in place by Micropore™ tape. The perimeter's coordinate system followed conventional latitude and longitude with the equator aligned vertically in the birds' median sagittal plane and this coordinate system is used for the presentation of visual field data (figures 1 & 2).

The eyes were examined using an ophthalmoscope mounted against the perimeter arm and its position read to ± 0.5°. Alignment of the birds’ heads in the perimeter was, such that the ophthalmoscope viewing aperture was, in effect, moved over the surface of a sphere centred on the mid-point of the line joining the centres of the pupils. This point was defined as the cyclopean projection centre, and the position of the visual fields are described by reference to it. The measured values of visual field features were corrected to those that would be determined a hypothetical infinite viewing distance [3]. To provide additional landmarks within the visual field in most of the species the projections of the edges of the pecten in each eye were recorded. The pecten produces a relatively large blind area within the visual field of each eye. It is a highly pigmented black structure that extends from the retinal surface into the posterior chamber of the eye. It provides nutrition to the retina and is situated above the point where the optic nerve exits and extends ventrally across the retina [4].

In all studies the aim was to measure limits of the visual field at 10° intervals of elevation in an arc from at least 20° below the horizontal directly behind the head, to above the head and then down to at least 60° below the horizontal in front of the head. In some species it was possible to measure to 90° below the horizontal in the frontal field. However, in some species at some elevations in the frontal field below the horizontal the bill holder intruded into the view of the eyes (this depended upon the size and shape of the bill). In such cases it was not possible to record visual field data at this elevation and binocular field width at this elevation was estimated as the mean value of the binocular field widths above and below these elevations. In some studies the direction of the optic axis of each eye was determined by recording the positions at which the 1st and 2nd Purkinje images (reflections from the cornea and from the lens anterior surface) of a discrete source of light held close to the line of sight on the perimeter arm were most closely aligned.
2. Diagrammatic representations of visual fields

From these combined data (corrected for viewing from a hypothetical viewing point placed at infinity) a summary of the visual field characteristics was determined and are presented diagrammatically in a number of ways, and in summaries of the dimensions of key parameters.

1. The angular separation of the retinal field margins of the two eyes as a function of elevation in the median sagittal plane of the head was produced (figure 1),
2. a topographical map of the visual field (figure 2 d,f,g) showing the boundaries of the retinal fields of the two eyes and the projection of the pectens, optical axes and the line of the bill,
3. a diagrammatic horizontal section through the visual fields in a horizontal plane (figure 2c) defined by elevation 270° - 90° (see figure 1),
4. a diagrammatic vertical section through the frontal binocular field in the median sagittal plane of the head.

3. Dimensions of key comparative parameters

The principal features of the entire field were determined for each species and their main dimensions summarised. These are shown collectively in Table S1 and their key features illustrated in figure 2. These key features are:

**Monocular field:** the width of the visual field of a single eye.

**Binocular field:** the area where monocular fields overlap, summarised by its maximum width, its width at the horizontal plane, its height in the median sagittal plane, and the direction of the maximum width with respect to the direction of the projection of the bill tip (this gives an indication of where maximum binocular field is centred with respect to the bill).

**Cyclopean field:** the width of the total visual field produced by the combination of both monocular fields.

**Blind Areas:** the widths of the blind areas directly above the head (perpendicular to the horizontal) and directly behind the head (in the horizontal plane).
4. Figures

Figure 1. Diagrammatic representation of a visual field. Data for two species of Gyps vultures [5]. This diagram shows the mean (±SE) angular separation of the retinal field margins as a function of elevation in the median sagittal plane. Positive values indicate overlap of the field margins (binocular vision), negative values indicate the width of the blind areas. The coordinate system is such that the horizontal plane is defined by the elevation 90° (in front of the head) and 0° lies directly above the head, the same co-ordinates are used in Fig. 2. These directions are indicated in the outline scaled drawing of the head of a griffon vulture. The projection of the eye–bill tip axis is also indicated. With these particular species the value of the binocular field width at elevation 110° could not be determined directly because of the intrusion of the bill holder into the view of the eye, and so the width of the binocular field at this elevation was interpolated from the mean of the recorded binocular field widths at elevations 100° and 120°. In these species the maximum width of the binocular field projects 20° above the direction of the bill (Table S1) and coincides with the horizontal when the head is held in the posture shown in the schematic drawing of the head.
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Figure 2. Diagrammatic representations of visual fields. Data for African white-backed vultures Gyps vultures [5], kori bustards Ardeotis kori [6] and cattle egrets Bulbulcus ibis [7]. The visual fields of the three species show marked and significant differences in all dimensions. These differences are readily apparent in the diagrams and are summarised in Table S1. The general functions of these kinds of differences are discussed in detail in the main review paper and in the specific references from which these data are drawn.
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The top row of the figure shows photographs of the head of a vulture from (a) along the horizontal (with reference to the head position shown in Fig. 1), (b) laterally and (c) from below at an angle of approximately 140°, which is at the lower limit of the binocular field. Note the prominent ridges above the eyes in all three photographs which are part of a "sunshade" structure and are linked with the wide blind area above the head (see main paper section 6). Also note that there is no blind area above the head in cattle egrets (d) Perspective views of orthographic projections of the boundaries of the retinal fields of the two eyes and the line of the eye-bill tip projection (indicated by a white triangle). The diagrams use conventional latitude and longitude coordinate systems with the equator aligned vertically in the median sagittal plane of the bird (grid at 20° intervals) and values in the sagittal plane correspond with those shown in figure 1. It should be imagined that the bird’s head is positioned at the centre of a transparent sphere with the bill tips and field boundaries projected onto the surface of the sphere with the heads in the orientations shown in (b). (e) Horizontal section through the visual fields in a horizontal plane. (f & g) Perspective views of orthographic projections of the visual fields in kori bustards and cattle egrets, respectively. (h-j) Vertical sections through the binocular fields in the median sagittal plane of the head in vulture, bustard and egret, respectively. Green areas, binocular sectors; pink areas, monocular sectors; blue areas, blind sectors; downward pointing black arrowheads in (e) indicates direction of the bill; white triangles indicates the direction of bill projections in (d, f & g).

References


