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A deep look into animated eyes

Animated movies have captivated audiences around the world since their first appearance in the early 20th Century. Since, unlike traditional live-action cinema, it does not require a physical set or filming location artists are only limited by their own imagination and graphical talents. Animation can tell fantastical stories that do not depend on the physical abilities of human actors. Characters like Mickey Mouse and Bugs Bunny became world-famous, and even the earliest cartoons in which they featured are still being watched today.

Aesthetically, the facial features of animated characters tend to be simplified, given that artwork had to be hand-drawn until relatively recently. This simplification, along with artistic design, necessitates an alternative visual language based on making exaggerated facial expressions to convey the same basic emotions that would have been easily portrayed by human actors. Eyes play a major role in these expressions, which consequently led artists to design their characters' eyes as very large and distinctive, but often in ways that are not physiologically accurate and may come at the expense of visual function. We, therefore, hypothesise that the visual function of the majority of cartoon characters is profoundly impaired.

In this work, we examine the ocular anatomy of well-known humanoid characters and assess the visual quality as well as potential disabilities that they experience, assuming that they are confined to the same restrictions as normal human physiology.

Phenotypes

Animated eyes come in a large anatomical variety that may be divided according to an increasing degree of abstraction. The design that is closest to actual human eyes, both physiologically and functionally, is the combination of a sclera, iris, and pupil (Figure 1a) found in most Disney characters, modern computer-animation, and in many Japanese anime. Further abstraction is a white sclera with a small, central black dot, which is by far the most popular design (e.g., Garfield, The Simpsons, South Park, Doraemon...; Figure 1b). Although these dots may depict the iris, they are often relatively small and may change size depending on emotional state, suggesting that the dot must be the pupil. Consequently, characters with this type of ocular anatomy are likely to have extremely light irises. Characters could also have very dark irises, micro-cornea, sub-total sclerocornea, wear white contact lenses or have received a corneal prosthesis in stories in which the central dot never changes size. The simplest eyes depict only the pupil (e.g., Tintin; Figure 1c). In humans, this situation is only found in highly pathological eyes, such as when the cornea is severely conjunctivalised, after an osteo-odonto-keratoprosthesis or type 2 Boston keratoprosthesis. Alternatively, this could mean that the eye is based on a pinhole, as can be seen in sea creatures like a nautilus. Finally, in masked characters the eyes are often shown as empty white, grey or black holes in the mask where the eyes would be (Figure 1d). When these holes are white, as seen in e.g., Batman, this may suggest conjunctivalization, sclerocornea. or stromal haze, resulting in blindness (not unexpected in a bat). It is more likely, however, that the eye holes in their masks are covered by a coloured, transparent material.

Bubble eyes

A cursory analysis of *100* randomly selected animated characters (*44* males, *56* females) of varying ethnic backgrounds (*56* Caucasian, *38* non-Caucasian, *1* god, *2* humanoid aliens, and *3* androids; data and calculations in Supplement), estimated using full frontal illustrations combined with body length estimates obtained from the Internet, showed that nearly every character has a head that is larger than expected based on normal proportions. Consequently, animated neck muscles ought to be stronger as well, especially since necks are often drawn thinner than reality as well. Meanwhile, most characters have pupil sizes and palpebral fissure lengths, used here as a measure for eye size, that are *2–3* times larger than normal reference values and the pupil sizes of female characters tend to be twice that of male characters.

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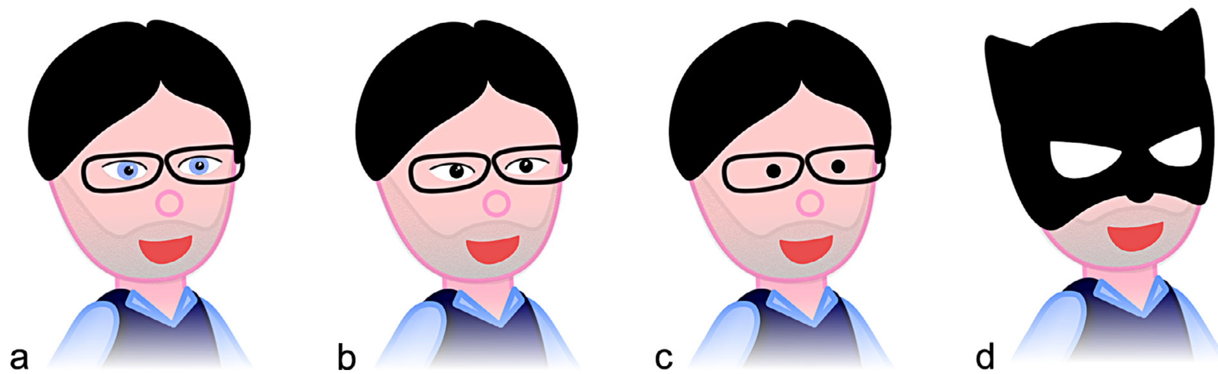

Figure 1 Different ocular animation styles: a) Realistic; b) sclera and black dot; c) dots; d) masked.

While generally considered to be attractive, large pupils are known to substantially reduce visual quality[1] due to the induction of higher order aberrations.[2] Animated women are, therefore, likely to have poorer vision than their male counterparts. Disney princesses, a group often targeted for their unrealistic depiction of young women, generally remain close to normal head sizes. While their eyes would be between *1.5* to *2.5* times larger than those of real humans, these dimensions still remain at the centre of what is normal in animated characters. Hence, as far as these young women's ocular anatomy is concerned, the criticism directed at them appears to be unfounded.

Case reports

Homer Simpson

The anatomy of Homer Simpson's eye may be studied in detail, given that he is one of the few characters for whom an MRI is available (Figure 2). At first glance, the eye appears to be structured differently from that of regular humans, given that it appears to be missing an anterior chamber or any direct connection to the brain. Instead, the eye seems entirely spherical, with a small, but bright, equiconvex lens that is in contact with the cornea. Using his reported body length as a yardstick, his axial length can be estimated at *104 mm*, corresponding with the eye size of a blue whale. Assuming the same refractive indices as those in real humans, Homer would have a myopia of -4.5 *D* (calculation in Supplement). Even so, he is never seen wearing any correction other than reading spectacles which, as a myope, he would not need. Apart from myopia, the lack of a visible anterior chamber suggests a serious anterior segment dysgenesis. It should also be noted, however, that the exterior position of his eyes (proptosis) is also found in most other residents of Springfield. Bilateral proptosis is most commonly associated with Graves' disease, which in turn has been associated with environmental exposure to radiation.[3] The combination of Homer's poor visual acuity and the possibility that there may be biologically significant exposure to nuclear radiation in the town of Springfield is a strong argument for replacing the current nuclear safety inspector.

Powerpuff girls

With their enormous eyes and pupils (Figure 3), the Powerpuff Girls are likely to encounter a host of ocular issues. These can be split into three categories: optics, physiological, and practical. Optically, their eyes would suffer from a large amount of wavefront aberrations. Although eyes may be scaled up and optimized for those particular dimensions, the rule that larger pupils suffer from a greater number of higher order aberrations would still apply. This is also seen in the eyes of a giant squid, coincidentally similar in size,[4] the eyes of which have evolved to such dimensions to maximally capture the scarce light found in the deep sea. Optical telescopes have very large apertures for similar reasons. This means that the Powerpuff girls should be extremely photophobic. Physiologically, maintaining the integrity of the cornea

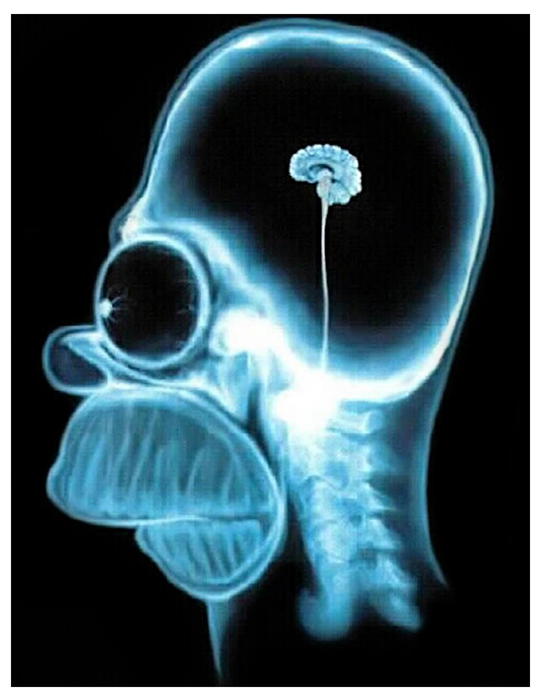

Figure 2 Sagittal T1 MRI of Homer Simpson's head, showing the ocular structure as well as a limited cerebral development. (artist unknown)

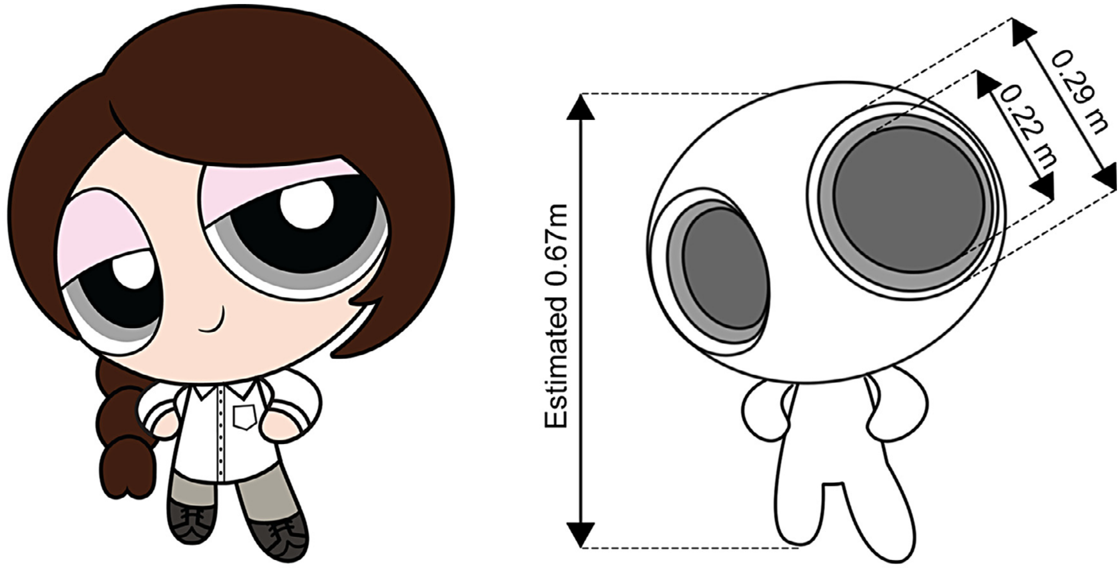

Figure 3 Powerpuffed pupils (Illustration produced with purpose-built online tool[10])

would also be a challenge. Enlarged tear glands would be required to make a tear film that is resilient enough to protect the corneal epithelium and to prevent severe dry eye. In humans, corneal epithelial cells are regularly shed and replaced by stem cells that are located in the peripheral limbus. In the case of the Powerpuff girls, epithelial defects could be quite bothersome as cells could take weeks to traverse from the limbus to the centre to close a wound. There is also the practical issue of flying at super speeds without protection, causing the girls to likely experience discomfort from a large number of insects hitting their eyes, while also forming a tempting target for

Figure 4 Qualitative simulation of the uncorrected visual acuity experienced by a) Normal reference; b) Homer Simpson; c) Powerpuff Girls; d) Asterix; e) Superman.

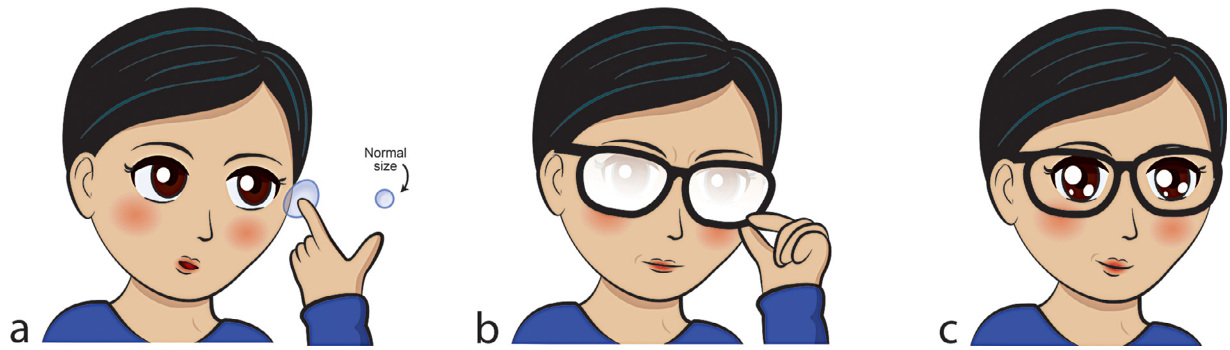

Figure 5 Ocular issues with Japanese anime: a) contact lenses 2–3 times the normal size; b) sudden, overpowering reflection on spectacles; c) excessive number of corneal reflections.

enemies. Well-fitting scleral contact lenses could help but would have to be the size of salad bowls.

Asterix

Some characters, like Asterix, have an elliptical sclera, iris, or pupil. These subjects are likely to experience a large corneal astigmatism that is proportional to the ellipticity of the corneal limbus. Assuming a white-to-white of *24 mm* and a maximal corneal elevation equal to a total anterior chamber depth of *7 mm* (both values being twice normal human size), Asterix has a vertical limbal size of *200%* of his WTW, producing a corneal astigmatism of *16.92 D* (See Supplement). Given the lack of availability of toric spectacles in the forests of ancient Gaul, he would have been severely handicapped and ought to be renamed to *Astigmatix*.

The poor visual quality expected of all these three characters is simulated in Figure 4 compared to normal vision and Superman's telescopic X-Ray vision.

Other ocular oddities

Although Japan is seeing a record high **myopia** prevalence,[5] this is not reflected in the animated world where glasses seem to be reserved for either intellectual or clumsy characters. Anime students must therefore either be emmetropic, have collectively undergone refractive surgery, or wear contact lenses that are larger even than scleral lenses, with a diameter of over *20 mm* (Figure 5a). Animated **spectacles** are generally very large, making them heavy for the wearer. Meanwhile, they are often flat in profile and their removal does not result in a change in apparent eye size. Consequently, the refraction of characters must be low, almost to the point where spectacles become a fashion statement or a clever disguise (e.g., Clark Kent). Specular reflections on anime spectacles can sometimes completely obscure the eyes, suggesting that anti-reflective coatings are not available (Figure 5b).

Some cartoons display bilateral transient **enlargement, deformation, or duplication** of the eye globes to express an acute state of surprise or shock. We have failed to reproduce this effect in real humans, even after careful observation of family members watching recent news broadcasts. This suggests that emotion-induced ocular duplication may represent an exaggeration on the part of the artists.

Female characters often display a large number of bright **corneal reflections** that may increase in states of extreme happiness or sadness (Figure 5c). As the number of reflections depends directly on the number of light sources present, this may point to corneal surface or tear film irregularities. Meanwhile, corneal reflections of a scene usually resemble flat mirror reflections, rather than that of a convex surface. This confirms that characters have very flat corneas to match their oversized eyes.

Conclusions

Artists who want to design a character must balance recognisability, practicality (e.g., amount of effort required to draw the character, ability to convey emotions, etc.) and the artist's own inspiration and creativity. These aspects almost automatically lead to depicting oversized heads and eyes; as such, characters are generally considered to be more attractive,[6] sympathetic,[7] and recognisable by audiences of any ages. They also convey a degree of cuteness, especially when combined with very large pupils (e.g., Puss in Boots). This can also have some real-life repercussions, given that exposure to large-eyed characters can shift observers' preferences towards people with larger eyes.[7] This cuteness almost invariably comes at the expense of good eyesight, however (Figure 4). This also depends on gender, as women likely experience worse visual quality due to their larger eyes, and animation style, as characters with realistically proportioned eyes are expected to have a visual quality close to that of real humans, whereas more cartoonesque characters likely have reduced visual acuity due to a range of pathologies.

While this is the first study addressing the ocular health of cartoon characters, to the best of our knowledge, it does have a limitation in that it was only able to perform an internal analysis in one single case. The fact that characters are not bothered by their presumed bad vision suggests that there may be corrective mechanisms in place. For example, should the refractive index of Homer's crystalline lens be lowered to slightly more than that of the cornea, then his eye would be emmetropic. The Powerpuff girls' photophobia could be reduced by assuming that their crystalline lenses are tinted like sunglasses. Higher order aberrations could also be reduced if the lens can adapt to compensate, something seen in humans.[8] Similarly, Asterix's astigmatism could be corrected by an equally (but opposite) lens astigmatism, as seen in young adults.[9] These examples suggest that their compensation mechanisms could be similar to those known to exist in real humans, even though they would function much more effectively.

Supplementary materials

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.optom.2022.02.001.

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