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Visual and Physiological Optics: where will the journey lead us in 10 years?

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"It's a dangerous business, Frodo, going out your door. (...) You step onto the road, and if you don't keep your feet, there's no knowing where you might be swept off to."

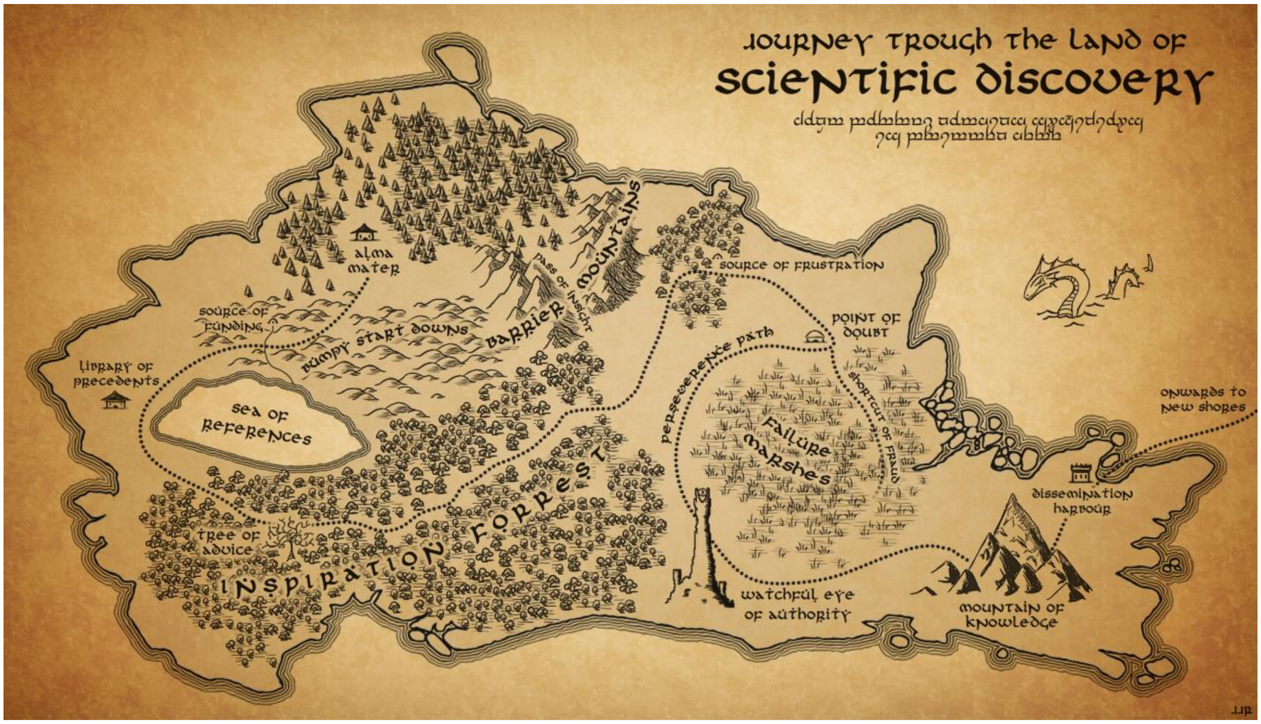
J.R.R. Tolkien, The Fellowship of the Ring

When setting off on a journey of discovery it often helps to have a sense of direction, a particular goal or a coveted treasure that makes all the hardships on the way to get there worthwhile. In science these treasures often come in the form of understanding, built up one tiny gold piece of insight at a time. But unlike the stories of Tolkien, the protagonists of a scientific journey cannot just set out blindly towards a vaguely-described goal without bothering about things such as finances. Instead, each step along the way must be considered carefully before it hits the ground, while thinking ahead two or three paces, as resources are scarce and funding agencies insist each step should have a reasonable chance of success. Each step may also turn out to be in the wrong direction, or, if you are very lucky, a leap straight for the gold. Consequently these journeys are often slow, with people dedicating an entire PhD to a single step. One can imagine that under these circumstances individual travellers may lose sight of the final goal ahead. But, luckily, in science we do not walk the entire journey by ourselves. As Bernard of Chartres and Isaac Newton both suggested, we are carried on the shoulders of our forebears until it is time to make our own steps, in the hope one of us will eventually reach the treasure of understanding. In that context it is good to stop sometimes and to look at the scenery of where we are now and all the places we may go.

Where are we now?

Looking at the current state of Visual and Physiological Optics, one can only say that it is blooming, with exciting new research is coming out at an unprecedented rate, in both old fields of research and in new fields that nobody had even heard of a decade ago. This can be seen in conferences around the world, such as the recent European Meeting on Visual and Physiological Optics (VPO 2016). During this meeting a relatively small group of international researchers presented their latest work, some of which is available in this special VPO 2016 issue of OPO.

The issue starts with an excellent invited review on corneal biomechanics by Kling & Hafezi.[1] Discussing the origins of the corneal stiffness, the influence of pathology, how to measure the biomechanical properties of the cornea, and methods to reinforce the corneal stiffness if needed, we can highly recommend this work to clinicians and researchers alike. Biomechanical analysis does not



remain limited to the cornea, however, as Boszczyk et al.[2] analysed how the eye globe responds as a whole to the mechanical force exerted by an air puff. They found that, besides corneal indentation and ocular retraction, the eye may also display a complex series of eye rotations, which may lead to a more detailed analysis of the mechanical response curves and more reliable measures for the corneal biomechanics. Meanwhile, Consejo et al.[3] tested with a corneal-scleral topographer how the scleral shape changes during forced accommodation and demonstrated a small inwards motion with increasing amounts of accommodation. This effect was found to be stronger in young myopes than in emmetropes and decreased with age. Another factor found to be different in myopes was retinal shape. While this in itself was already well-known, the results by Verkicharla et al.[4] suggest the mean shape of the retina varies between ethnicities, with steeper retinas found in East-Asians than in Caucasians. This, along with scleral factors, may play a role in myopization.

Several of the authors considered the optical quality of refractive error correction, such as Radhakrishnan & Charman[5] who compared the performances of commercially available Alvarez variable-power spectacle lenses. All designs tested seemed to offer an adequate range of correction, but should be tested in a formal clinical trial to determine how well they are accepted by patients. Similarly, Legras & Rio[6] compared current commercially bifocal contact lens designs with theoretically optimized designs and found the latter to perform better. If picked up by the industry, this result could lead to better bifocal corrections. But optical corrections also take place inside the eye itself, as investigated by Liu & Thibos,[7] who did a theoretical analysis of the sources of oblique astigmatism and found that the corneal contributions are partially compensated by those of the lens.

The meeting also saw many contributions in the field of wavefront aberrations, such as the work by Hastings et al.[8] that proposed using the visual Strehl visual quality metric to optimize the objective refraction. In myopic subjects these objective refractions led to visual acuities that were equivalent to those obtained by subjective refractions, but the subjects tended to prefer the objective refraction. Another contribution, by Molebny[9], considered a new way to objectively determine the visual axis of the eye using scanning laser beams and nanometre scale sensitivity. This method may be implemented in commercial aberrometers to improve the alignment of wavefront measurements.

Intraocular light scatter has been gaining interest in the literature. van den Berg[10] explored the reasons why retinal straylight affects visual acuity only weakly and explained that these aspects of visual quality are associated with different parts of the point spread function (PSF). These parts are each affected differently by aging. Christaras et al.[11] performed a Monte Carlo simulation of light diffusion in the fundus and analyzed its contribution to the spatial extent of the optical PSF. They found that light diffusion in the fundus and scattering at the level of the media have similar contributions to the PSF.

Finally, there were several theoretical works, such as the one by Harris et al.[12] describing the use of a 14-dimensional matrix method to analyse the optical characteristics of any type of linear optical system such as the eye. The same authors[13] established a set of relationships between the cardinal and anti-cardinal points of a Gaussian system, and illustrated these with extended Pascal's ring diagrams. The last paper[14] presents a stochastic of eye model for keratoconus in various stages of the disease. It describes the generation of an unlimited amount of synthetic biometry sets that may be used for developing and testing new optical correction methods.

While these papers represent only a tiny fraction of what has been accomplished in our field over the past two years, they cover diverse fields in visual and physiological optics.

Where could we go next?

In order to determine the most promising directions young researchers could follow, we asked the VPO 2016 delegates to suggest research problems which might deserve some extra attention and have a reasonable chance of being solved within *10* years from now. A discussion was led by Neil Charman, supported by panel members Larry Thibos, Ray Applegate, Barbara Pierscionek and Norberto Lopez-Gil. The discussion of the following list of *30* research problems can be found on YouTube (youtu.be/Om-sGEtdeW8).

Ocular growth and myopia

Given the large impact myopia is currently having around the world, this section was considered the most important challenge for visual and physiological optics today by the discussion panel. These questions are broad in nature and their answers are likely a combination of many different factors. Consequently many resources are already being dedicated to these problems:

1. How is ocular growth coupled to the central and peripheral visual images?
2. What is the origin of myopia?
3. Can the onset of myopia be predicted in a young child?
4. Are there solutions to avoid or reduce the progression of myopia?
5. Is eye growth influenced by nutrition?

Crystalline lens and presbyopia

The other major issue many people are confronted with is the loss of accommodation with age. Despite the large interest in finding practical solutions to deal with presbyopia, the underlying issues, or even the general crystalline lens properties, remain poorly understood. Any long-term solution to this problem would have to start from questions such as:

6. What is the origin of presbyopia?
7. Why does the amplitude of accommodation start to decline at an early age, reducing to half its peak value by the age of 20, when all other bodily functions are optimal?
8. Can one develop a practical solution to avoid presbyopia or reduce presbyopia progression?
9. Can one develop improved clinical devices to determine parameters such as lens radii of curvature, lens surface topography and gradient index of the lens?

Intraocular lenses (IOL) and refractive surgery

Nowadays most patients operated for cataract or a large ametropia demand to be spectacle–independent, both for distance and near vision. The industry has developed a variety of solutions to accomplish this goal, but these can at times fall short due to necessary trade-offs in the design. The questions that need to be asked here are:

10. Can one develop a (pseudo-)accommodating IOL without optical trade-offs?
11. How can IOLs be designed to avoid dysphotopsia or other entoptic phenomena?
12. What is the best possible axis by which to align a refractive surgery correction?
13. Can individualized eye models lead to improved clinical outcomes in cataract and refractive surgery?

Wavefront aberrations, straylight and image quality

These three phenomena result from many of the issues mentioned before. There seems to be a growing consensus that peripheral image quality is an important, but poorly understood driving factor in myopization. Developing new image quality metrics that include parameters beyond the on-axis wavefront may lead to interesting new ways to investigate refractive development. Here the specific issues include:

14. Can one define a metric to accurately predict the quality of sight based on wavefront aberrations, both for global and task-specific purposes?
15. Can one define peripheral refraction and peripheral image quality metrics?
16. Why is peripheral refraction very different in the horizontal and vertical visual fields?
17. How do the fast, continuous fluctuations in refraction due to accommodation, heartbeat, etc. influence visual quality?
18. Why is straylight largely independent from wavefront aberrations and visual acuity?
19. Can one define a single image quality metric that integrates contributions from both straylight and wavefront aberrations?

Ocular biomechanics

The material properties of the various ocular media determine how these media change shape under the forces and stress they experience every day. Changes in biomechanical properties may give early indications for pathologies and are associated with understanding presbyopia. Hence some of the issues here are:

20. What are the biomechanical properties of the various ocular structures (e.g. the cornea, sclera, lens, vitreous gel, etc.) in normal and pathological eyes?
21. How are the ciliary muscle and zonules on the one side, and the biomechanical structure of the lens associated with accommodation?
22. Can the optical and biomechanical response to an ocular treatment be reliably simulated by means of a virtual model prior to performing it in real eyes?

Virtual reality and augmented reality (VR/AR)

The recent introduction of technologies such as virtual reality into everyday life leads to new challenges, as they force users to use their visual and neural systems in a way that is disconnected from the other senses. This may provide opportunities to dynamically enhance visual quality in low vision patients. For this topic one may therefore wonder:

23. What is the neural response to VR/AR?
24. Is there a clinical use for VR/AR, for example in low vision and visual rehabilitation?

Retina

There are several unresolved issues at the level of the retina, most notably:

25. Why do photoreceptors have a directional sensitivity?
26. What is the role of the light-sensitive retinal ganglion cells?
27. Can advanced retinal imaging techniques assist in the earlier detection of retinal disease and help to stop the progression before any loss of visual function occurs?

Tear film

While the main function of the tear film lies in the hydration of the corneal surface, it is known to influence image quality as well. The issues one may consider for this topic are:

28. How can one dynamically measure tear film properties with non-invasive optical techniques across the surface of the cornea or a contact lens?
29. How does the tear film dynamically alter the optical properties of the eye and retinal image quality?
30. Can optical methods be used to diagnose dry eye syndrome and monitor treatments for this condition?

But while these are some of the goals that the discussion participants felt are the most pressing at this moment, the list is inevitably incomplete and new insights or instrumental developments may make other topics much more important as time goes by. We would therefore encourage young researchers to be inspired and wonder about the places they will visit along their scientific journey, to look at everything in a new light, and then wander off to new destinations. After all:

"Not all those who wander are lost."

J.R.R. Tolkien, The Fellowship of the Ring

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