European Science Foundation
Standing Committee for Physical and Engineering Sciences (PESC)

ESF PESC EXPLORATORY WORKSHOP

The New Optics of the Human Eye

Scientific Report

Heysel Expo Centre
Brussels, Belgium, 26-27 November 2004

Convened by:

Marie-José B. Tassignon and Frans Van de Velde

Department of Ophthalmology, University Hospital Antwerp

Co-sponsored by

The Schepens Retina Associates Foundation (Harvard)

Contents overview of the scientific report

The Scientific Report follows the outline of the Program that consisted of two parts: during the Morning Session, about 12 participants, part of the group of 23 individuals attending this exploratory workshop and which are world-renowned speakers in the field of biomedical optics, gave lectures that cover the intended spectrum of "The New Optics of the Human Eye" (see enclosed Program of Lectures and Abstracts of the material). A questionnaire about the contents of the meeting was circulated throughout the audience. This audience of more then 100 people consisted of residents in training in ophthalmology, assistants in ophthalmology, some ophthalmologist-practitioners attending the annual meeting of the Belgian Ophthalmological Society and interested faculty members of the departments of ophthalmology of Belgian Universities.

The data of this questionnaire served as the basis for Part Two in the afternoon, within the selected group of 23 participants of the Exploratory Workshop: a discussion mostly centered about educational needs and expectations of medical undergraduates, residents in training and ophthalmologists with regard to the novel ophthalmic diagnostic techniques that were presented during the morning session. A sample response of the Questionnaire is included. Statistical analysis of this data, courtesy of Dr. Tanja Coeckelbergh of the Department of Ophthalmology using SPSS version 12.0 is presented as well. The complete set of lectures will be published as a special feature issue of the Bulletin of the Belgian Ophthalmological Societies, a peer-reviewed and indexed journal (MEDLINE).

The meeting was dedicated to Oleg Pomerantzeff, Dipl. Eng. , a biomedical optics pioneer and world-citizen.

Abstract of the meeting with the main objectives

Significant developments during the last two decades in wave optics and photonics have led to novel applications in the field of ophthalmology. These include scanning laser ophthalmoscopy and polarimetry, laser Doppler velocimetry, optical coherence reflectometry and tomography, and the measurement of the optical quality of the eye using the method of Fourier optics and Zernike polynomial analysis descriptors of wave-front aberrations. Educational needs on the under-, graduate, and post-graduate level need to be reviewed at the European Community level.

The other goals of this ESF Exploratory Workshop are (1) the exchange of experiences between researchers from across Europe in the emerging field of applied photonics; (2) to establish new collaborative links between disciplines such as mathematics, physics, optics, and medical sciences; (3) to evaluate innovative ideas and develop these into collaborative research projects.

Discussion and Conclusions

The Morning Lecture Program

(Abstracts enclosed as Annex I)

This Exploratory Workshop was about the “New” or “Modern” optics of the human eye. During the last three decades we have witnessed an incredible progress both in fundamental optical science and its technical applications. At the same time, electrical engineering and computer science developed along, and both disciplines have merged into a field now called photonics. Landmark changes have for example been introduced by the advent of the laser, complex opto-electrical and opto-mechanical constructions, optic fibers and sensitive light detectors. Such devices often had a first use in telecommunication equipment and military operations, yet quickly found themselves a place in the ever growing array of diagnostic or therapeutic medical devices.

Particularly in ophthalmology, lasers became a part of the standard therapeutic possibilities early-on. This trend has not stopped. Today we can witness a range of diverse applications, from the established thermal coagulation treatment for retinal diseases to the selective laser ablation of the retinal pigment epithelium with a pulsed laser source, refractive surgery corneal ablations and the intra-corneal delineation of a lenticule with a femtosecond laser.

In this Workshop we discussed diagnostic ophthalmic applications that are closely related with regard to physical principles. We concentrated on those applications that have already been successfully introduced at the clinical level. These applications are scanning laser ophthalmoscopy, tomography and polarimetry, optical coherence reflectometry and tomography, laser Doppler velocimetry, and several new measurement techniques of the optical quality of the eye using Fourier optics or the Zernike polynomial analysis. There is a considerable amount of overlapping material in the basic principles of the techniques. The concept of waves and wave properties are a common and recurring theme. Hence our title could well have been “The Wave Optics of the Human Eye”. The choice of aforementioned established techniques has been deliberate because they are important enough to be an incentive for the medical student, vision researcher or clinician to know more about the background optical and physical sciences. And second, the basic science behind those techniques does cover a full range of important mathematical, optical, electrical and computer science concepts.

In scanning laser ophthalmoscopy (SLO) the retina is illuminated point by point in a raster-like fashion using a thin laser pencil. This happens through a small central optical entrance pupil serving as a pivot point for scanning, and larger surrounding optical exit pupil for collecting the light that is back-scattered from the retina. This light is captured by a photodiode and the resultant electrical video signal is used to modulate a synchronously moving electron beam on a TV monitor. Microperimetry, a technique to assess retinal function by modulation the scanning laser beam is an important derivate technology and has been developed by one of the co-convenors.
In optical coherence reflectometry or tomography (OCT) the intensity and timing of reflected low-coherence light from the retina is measured indirectly using a Michelson interferometer set-up with a variable length reference arm or vastly improved spectral techniques without moving parts. Applications include precise length measurements within the eye, biometry of extended areas such as the anterior surface of the ocular lens, polarization sensitive OCT for nerve fiber thickness analysis and Doppler sensitive OCT to measure blood flow within smaller retinal blood vessels at a precise depth.

The laser Doppler technique for measurement of blood flow is based on the well-known analogous Doppler effect in acoustics. Scattered laser light is shifted in frequency by an amount proportional to velocity. Several methods have been devised to exploit this phenomenon.

Global parameters of optical quality of an optical system, e.g. used in astronomy and optical metrology, are the point spread function and modulation transfer function. These concepts have recently been applied to the optical system of the eye. Diffraction and aberrations are the limiting factors for optical quality. Precise determination of complex aberrations can be obtained using either a laser ray tracing technique or the Hartmann-Schack method. The latter also been borrowed from astronomy. A generalized and extremely useful mathematical treatment of the optical aberrations is the Zernike polynomial analysis.

Instruments that perform the tasks mentioned above are commercially available for clinical use and FDA approved. All too often this advanced equipment is treated as a black box by the clinical ophthalmologist or vision researcher. There are many reasons for this. First, such approach is indeed often sufficient for clinical diagnosis and the making of sound therapeutic decisions. Second, the understanding of such topics is time demanding and difficult. No single source is readily available that treats this material comprehensively, starting with the basics. Existing reference or study books either assume too much about the basic knowledge level of the medical professional, or the material is oversimplified, an approach which does not work well in physical sciences. Third, as far as we know, no structured program in biological optics is offered at Institutes of higher learning in Europe.

The Questionnaire (Annex II)

The Questionnaire and its statistical analysis with comments can be found elsewhere in this report. Here we will comment on some aspects of this part. The reason for the Questionnaire was to have some (objective) idea whether biomedical optics is relevant to the ophthalmological community, whether at least a sub-set of ophthalmologists is attracted to this subject matter and what educational needs may be present.
The outcome does correspond to what we were thinking based on our personal experiences (the convenors of this meeting). There appears to be a subgroup of (mostly private practice) ophthalmologists who clearly indicate that biomedical optics is important and, moreover, this group desires more advanced instruction on this subject. It was difficult to find out how large this group of ophthalmologist actually is (in Belgium) because we did not control or account for the modalities under which participants could enter the auditorium. However, we believe from other information that this was a representative sample of specialists with a general broad interest in their discipline. The Questionnaire also does not reveal how many ophthalmologists want to dedicate most of their career professionally to vision research and biomedical optics, nor how many such ophthalmologists the academic society (or industry) actually needs.

Did the Exploratory Workshop and discussions meet our expectations?

The specific goals of this ESF Exploratory Workshop were (1) to initiate the exchange of knowledge and experiences between researchers from across Europe in the emerging field of applied photonics research; (2) to help establish new collaborative links between different disciplines (basic sciences such as mathematics, physics, optics, and medical sciences); (3) to evaluate innovative ideas on a peer level and develop potential collaborative research projects, (4) to evaluate educational needs at the undergraduate, graduate and postgraduate level (medical students, medical doctors, ophthalmologists).

We had ample opportunity to address all four points mentioned above. As for goals (1, 2, 3) the researchers involved are considered world-leaders in their respective fields and moreover from diverse backgrounds: physicists, optometrists and ophthalmologists. Already in the past we had the opportunity to get to know each other and to exchange experiences, and this meeting simply reinforced our bonds (important annual international meetings where such information is exchanged: ARVO, SPIE, OSA).

The educational needs (goal (4)) for various groups were addressed by our Workshop during the afternoon session. Pertinent conclusions are presented here. First, a distinction needs to be made between a basic amount of “knowledge of optics” and further advanced instruction in biomedical optics for certain groups. And the latter could still be divided into two subgroups: vision researchers/clinical researchers and some clinicians with advanced interests. It appears that the majority of ophthalmologists and residents-in-training do get enough opportunities (if they have the motivation and time to seize them), within our educational system, to obtain basic practical and useful knowledge (starting from high-school to post-graduate training). Quite recently though, the impact of refractive surgery has created a necessity to know (a lot) more about certain specific topics, e.g. Zernike polynomial analysis, wave front aberrations etc.

However, we may still need to define at the European Community level what is to be considered such basic understanding of optics for medical programs (e.g. how much linear algebra or Fourier analysis), and when certain mile-stones should be reached within which phase of education (including High School level). As a result we should also be able to better assign responsibilities for this education and assess the practical knowledge of students at a uniform European level.
It should be noted that in the US educational system, Medical School is typically only 4 years, but preceded by a “flexible” 4 year College education. And this gives US students a chance to pursue their own particular interests in the basic (pre-medical) sciences at a more advanced level. In Europe, we must make sure that at the end of High-School, important mathematical, physical and biological concepts have already been mastered by students because there is an unfortunate current trend in the usual 7 year European medical programs to curtail such basic sciences in the first couple of years. This may present a difficulty, and a re-thinking may be needed.

A deeper understanding of biomedical optics and physiological optics is obviously indispensable for a sub-set of vision-researchers and clinical researchers. Otherwise, and nearly as a matter of fact, clinical care would suffer in the long run because clinical translation of new concepts would no longer be made effectively. Expressed differently, society needs some ophthalmologists/researchers who are also well versed in biomedical optics. As for those advanced studies in biomedical optics, several options exist. Again we may want to standardize at the European level what constitutes such material. Specific courses could be added to the residency programs for those interested, and/or a more formal European degree granting program could be constructed (leading to a formal academic degree, e.g. master degree or doctor in biomedical sciences or doctor in medical sciences). This would again be similar to the MD, PhD combination in the United States.

Moreover, we believe that our model or plans for biomedical optics could also serve other directions in Medicine: e.g. molecular biology, immunology and genetics, which requires also a good amount of knowledge in more basic sciences such as various forms of chemistry.

What about the future, where to go from here?

Recently, we received information about the SOCRATES program of the European Union. SOCRATES seeks to enhance higher education at the European level by encouraging transnational cooperation between institutions. Practically, this program would give us the necessary support to construct within two years a formal “transnational” course, leading to an academic degree. We believe that this would be the right way to build upon the experiences of this Exploratory Workshop.

Scientific Programme (see overleaf)

The New Optics of the Human Eye
Scientific Programme
PREFACE

During my tenure at the European Society for Cataract and Refractive Surgery (ESCRS), I have come to realize how often we take the physical underpinnings of our instrumentation for granted: this is the black box approach, more by necessity than by choice. The reason for this is a lack in proper course material at the undergraduate, graduate and post-graduate medical education level. We are indebted to the European Science Foundation for their grant support to start an ongoing diversified program in Biomedical Optics at our University. This report is one of the first steps in the endeavor. Understandably, biomedical optics is only one specialty field within the wide spectrum of vision science, however it is an important one for clinicians and researchers alike. And, admittedly, the material is often difficult to understand without proper knowledge of the mathematical and physical principles; but we hope that this topical volume will serve as an anchor for those who wish to explore in greater depth.

Much inspiration for our approach comes from the Schepens Retina Associates Foundation at Harvard. We would like to acknowledge our co-sponsor for their intellectual and material support.

Marie-José B. Tassignon, MD, PhD
Antwerp, November 2, 2004

Chair, Department of Ophthalmology, University of Antwerp, Belgium
President of the Belgisch Oftalmologisch Gezelschap
President European Society for Cataract and Refractive Surgery (ESCRS)

I am grateful to the Belgian Ophthalmological Societies for giving me a chance to look back over a period of nearly 60 years. In 1945 I had the first opportunity to speak about the binocular indirect ophthalmoscope at the Society's annual meeting. It is equally very satisfying to see a significant number of our Institute's alumni and current or former faculty members contribute to this report on the New Optics of the Human Eye. Since its founding in 1950, the Schepens Eye Research Institute and later the Schepens Retina Associates Foundation have been a place for MD, OD, PHD, and Dipl. Eng. degree holders to interact and as a result make significant progress in vision science. Biomedical optics and ophthalmic clinical engineering are continuing to make great advances, in particular because of the tremendous impact of photonics in just about every domain of biological science. This report is a testimony of this trend in diagnostic ophthalmic imaging and minimally-invasive laser therapies for retinal disease. Last but not least, it is a pleasure to see this symposium dedicated to my life-long friend Oleg Pomerantzeff, Dipl. Eng., a true pioneer in the field of ophthalmic optical engineering.

Charles L. Schepens, MD
Boston, Mass., November 15, 2004

The Schepens Retina Associates Foundation, Boston MA, USA
Emeritus Clinical Professor of Ophthalmology – Harvard University
Founder and President Emeritus of the Schepens Eye Research Institute

EDITORIAL

During the Renaissance, political and economical circumstances happened to be right for the Patria Belgica – a.k.a. the Netherlands or the Low Countries – to become a particularly fertile ground for researchers in optical physics (continuing to this day). Those well-known people are portrayed on the front page of this report. I strongly encourage the readers to “google” all their names and spend some time to find out more about their exciting life stories and fundamental contributions to optics and vision science. Andreas Vesalius from Brussels pioneered modern anatomy and Simon Stevin from Brugge put the use of the decimal system with Arabic numerals on a firm footing. Both men broke the ground for the science of physiological optics, for which the year 1619 of Christopher Scheiner’s publication (see illustration and legend) can be regarded as a starting point.

Knowledge in optics and its application to vision science then increased rapidly over time with two facts worth mentioning. Some well-known physicists were also capable physicians contributing to eye optics, notably Thomas Young and Hermann von Helmholtz. And secondly, a remarkable interaction was continuing between the sciences of astronomy, optical physics and visual optics. Some of the persons who contributed to this fruitful exchange either directly or indirectly are Christopher Scheiner himself, Isaac Newton, George Bidell Airy (the Astronomer Royal who was the first person to correct his own astigmatism and publish this feat), then Christian Doppler, James Clerk Maxwell and Albert Michelson. At present, Zernike polynomial analysis, Hartmann-Schack technology and stellar interferometry are some of the modern astronomical techniques used by the authors of this report.

I conveniently end the “classical period” of ophthalmic optics around 1950-1960 for some reasons. By that time our Frits Zernike had received his Nobel prize in physics, the last award issued for work in traditional optics. Secondly, by the 50s, Allvar Gullstrand (Nobel laureate of 1911), Hans Goldmann, Charles Schepens and others had put their definitive marks on classical in-vivo imaging equipment of the different eye structures. Thirdly, the advent of the computer, laser and post-WWII progress in electrical engineering during the 50s and early 60s made our modern non-invasive diagnostic equipment possible. We want to report here on the basic science aspects of some related applications of modern wave optics that are clinically very relevant. The last decade has witnessed again further development concurrent with advances in photonics. This topical volume of the Bulletin of the Belgian Societies of Ophthalmology will therefore also serve as a snapshot of what has been accomplished in ophthalmic optics around the turn of our century.

Frans J. Van de Velde, MD
Boston, Mass., November 15, 2004

The Schepens Retina Associates Foundation, Boston MA, USA
The Schepens Eye Research Institute – Harvard University
The Department of Ophthalmology – University of Antwerp

THE NEW OPTICS OF THE HUMAN EYE

Prologue

08.25 – 08.30	**Marie-José Tassignon, MD, PhD,** Chair Department of Ophthalmology, University of Antwerp, Belgium

SCANNING LASER OPHTHALMOSCOPY, THERAPY, AND POLARIMETRY

08.30 – 08.45	**Frans J. Van de Velde, MD,** Department of Ophthalmology, University of Antwerp, Belgium and the Schepens Retina Associates Foundation,, Boston MA The relaxed confocal Scanning Laser Ophthalmoscope, development and applications
08.45 – 09.05	**Ralf Brinkmann, PhD,** Medizinisches Laserzentrum Lübeck, Germany Short pulse selective retinal photocoagulation – concept of relaxation time, anatomical effects and non-invasive retinal temperature measurements
09.05 – 09.20	**Xiang Run Huang, PhD,** Bascom Palmer Eye Institute, Miami, FL Birefringence of the nerve fiber layer with scanning laser polarimetry, origins, significance
09.20 – 09.35	**Qienyuan Zhou, PhD,** Laser Diagnostic Technologies, San Diego, CA Scanning Laser Polarimetry, corneal birefringence and a method for controlling this parameter

OPTICAL COHERENCE TOMOGRAPHY AND COMBINED DOPPLER, OCT, SLO

09.35 – 09.55	**Johannes de Boer, PhD,** Wellman Laboratories, Harvard University, Boston, MA: Spectral domain OCT
09.55 – 10.10	**Johannes de Boer, PhD,** Wellman Laboratories, Harvard University, Boston, MA Polarization – sensitive OCT of the Retina
10.10 – 10.25	**Adrian Podoleanu, PhD,** University of Kent Canterbury, United Kingdom Combining SLO and OCT technology
10.25 – 10.40	**Christoph Hitzenberger, PhD,** Department of Medical Physics, University of Vienna, Vienna, Austria Birefringence properties of the cornea measured with OCT

DOPPLER METROLOGY

10.40 – 11.00	**Gilbert Feke, PhD,** Schepens Retina Associates Foundation, Harvard University, Boston, MA Laser Doppler instrumentation for the measurement of blood flow: theory and practice
11.00 – 11.15	**Charles Riva, DSc,** Institut de Recherche en Ophtalmologie, Sion, Switzerland Measuring the choroidal blood flow in the foveal region

WAVEFRONT METROLOGY AND PHOTORECEPTOR OPTICS

11.15 – 11.35	**Susana Marcos, PhD,** Instituto de Óptica CSIC, Madrid, Spain Aberrometry: basic science and clinical applications, part I
11.35 – 11.45	**Susana Marcos, PhD,** Instituto de Óptica CSIC, Madrid, Spain Aberrometry: basic science and clinical applications, part II
11.45 – 12.00	**Jean-Marie Gorrand, PhD,** Faculté de Médecine et de Pharmacie, Clermont-Ferrand, France Origin and Measurement of the Stiles-Crawford effects, distribution of orientation in a population
12.00 – 12.15	**Austin Roorda, PhD,** College of Optometry, University of Houston, Houston, TX Adaptive optics, Hartmann-Shack technology and the photoreceptor mosaic

Epilogue

12.15 – 12.20	**Charles L. Schepens, MD,** the Schepens Retina Associates Foundation of Harvard University, Boston MA

Final list of participants of the ESF exploratory workshop meeting

The three tables below contain the full administrative information about all participants of the Exploratory Workshop, including the speakers. We have conveniently grouped the participants in three categories: a) from ESF contracting states, b) from Europe but non-ESF contracting states, and c) other. Dr. Charles Schepens, Professor Emeritus of Harvard University and founder of the Schepens Retina Associates Foundation and Schepens Eye Research Institute, was the guest of honor.

Participants from European countries with ESF affiliation:

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23.	Charles L. Schepens MD UNITED STATES	SERI-Harvard University Boston MA02114	T ++1-617-632-7777 F ++1-617-632-7770

Statistics on Participation

Gender Representation

F	2	M	21

Representation by country

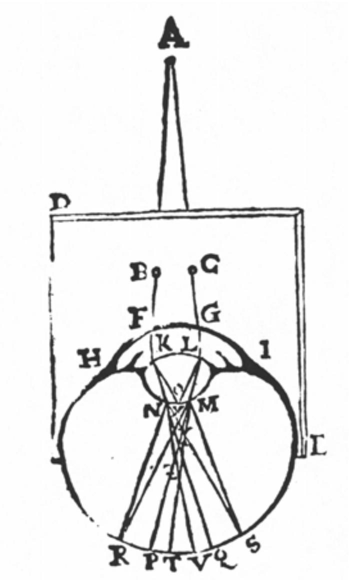
AT	1	DE	1
BE	4	CH	1
ES	1	FR	1
IT	1	NL	3
PL	1	SE	1
UA	1	UK	1
US	6		

We have all been much delighted by this ESF sponsored event. And we would like to thank the staff of the European Science Foundation, Exploratory Workshop Unit for its kind and professional attention to our work.

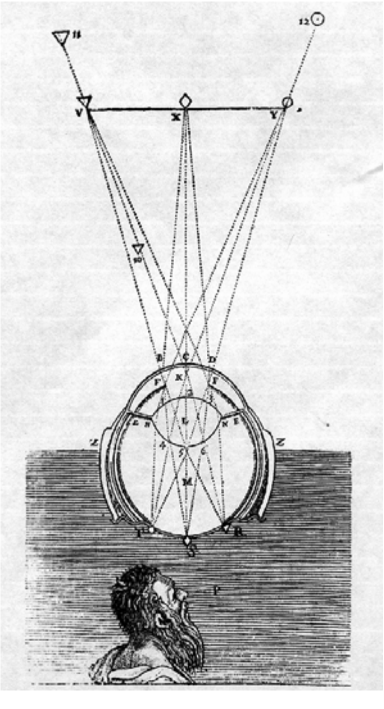
European Science Foundation Exploratory Workshop Annex I

The New Optics of the Human Eye

ABSTRACTS OF THE MORNING LECTURES



From Scheiner, C. Oculus, hoc est fundamentum opticum…, Agricola, Innsbruck, 1619
Scheiner’s principle (parallel rays entering the eye should end up on the same retinal location when emmetropia is present) is the basis for refractometers and laser ray tracing techniques.



Scheiner’s famous experiment of around 1610 (After a woodprint from a later work by Descartes). At this time Scheiner established that the retina was the seat of perception. The inverted image, a pseudo-problem, remained puzzling to Michelangelo.

THE RELAXED CONFOCAL SCANNING LASER OPHTHALMOSCOPE – HISTORICAL DEVELOPMENT AND APPLICATIONS

VAN DE VELDE, F.J.
The department of ophthalmology, University of Antwerp, Belgium and the Schepens Retina Associates Foundation, SERI-Harvard, Boston MA

SUMMARY

In 1950, at the ICO, Harold Ridley recounted the efforts of collaborators to construct an electronic ophthalmoscope using the flying spot principle from Young and Roberts' scanning light microscope. This endeavor failed for a principal reason that not enough light could be concentrated on a small enough spot on the retina. The presence of eye movements, limited numerical aperture and biological light toxicity requires a high speed scanning with high S/N ratio photo detection. In theory, this problem was solved in 1958 with the advent of the laser, but we had to wait till 1977 for Oleg Pomerantzeff to suggest the combination of three principles to obtain a successful Flying spot TV ophthalmoscope. Those three principles were a time resolved imaging through scanning with a laser beam, using the smaller central part of the pupil for illumination and the peripheral part for collection of light. Also around 1958, Marvin Minsky introduced the confocal principle in scanning light microscopy. It was first applied to scanning laser ophthalmoscopy by the team of Cohen-Sabban at the IOTA, Paris in 1983. This method of scanning the laser beam and de-scanning the backscattered light along the same optical pathway permits the suppression of stray light at a confocally placed pinhole before detection. This is a particularly effective strategy when deeply penetrating longer wavelengths are used. But this pinhole is rather large compared to the actual spot size of the focused laser beam on the retina, explaining the word relaxed. We can afford to do this because in ophthalmoscopy, fairly small beam entrance diameters are used resulting in a relatively large depth of focus within the retina. The ordinary confocal scanning laser ophthalmoscope is not intended to be a (highly) tomographic instrument unlike the confocal scanning light microscope. As a bonus a higher amount of light is returning to the detector, this in turn permitting faster scanning at true video-rates over larger areas. For the clinician, the single most important advantage is the capability of viewing retinal details in high contrast even with infra-red illumination. This is not possible with a regular fundus camera set-up.

Perhaps the single most important functional extension of this SLO is realized by modulating a visible laser beam (usually combined with the infra-red beam) with an acousto-optic modulator as these beams are focused together onto the retina. This modulation modality was implemented by Hughes and Webb in 1982 and was subsequently used by several teams to further develop Microperimetry, a technique that permits a high resolution study of visual fixation, acuity and sensitivity using the retina as an anatomical reference. In 1995 the author combined two-dimensional normalized gray-scale correlation with advanced optimized psychophysical strategies such as the 4 AFC for acuity testing and PEST for the accurate determination of absolute thresholds. Maxwellian view control and high-speed modulation have further increased precision.

Microperimetry is now important for low vision rehabilitation and planning or follow-up of various laser treatment modalities for age-related maculopathy.

SELECTIVE RETINA THERAPY (SRT) – A REVIEW ON METHODS, TECHNIQUES, PRECLINICAL AND FIRST CLINICAL RESULTS

BRINKMANN, R., ROIDER, J., BIRNGRUBER, R.*
*Medical Laser Center Lübeck, Germany, * University Eye Clinic Kiel, Germany*

SUMMARY

The selective retina therapy (SRT) is a new laser procedure targeting retinal diseases, which are thought to be associated with a degradation of the retinal pigment epithelium (RPE). Aim of the irradiation is to selectively damage the RPE without affecting the neural retina, the photoreceptors and the choroid. Goal of the treatment is to stimulate RPE cell migration and proliferation into the irradiated areas in order to improve the metabolism at the diseased retinal sites. In a pilot study more than 150 patients with soft drusen, retinopathia centralis serosa (RCS) and macular oedema were treated. The first 3-center international trial targets on diabetic macular oedema and branch vein occlusion.

In this review, selective RPE effects are motivated and two modalities to achieve selective RPE effects will be introduced: a pulsed and a continuous wave scanning mode. The mechanism behind selective RPE-effects will be discussed reviewing in vitro results and temperature calculations. So far clinical SRT is performed by applying trains of 30 µs-laser pulses from a Nd:YLF-Laser (527 nm, 100 Hz) to the diseased fundus areas. In the range of 450 - 800 mJ/cm^2 per pulse, RPE-defects in patients were proved angiographically by fluorescein or ICG-leakage. The selectivity with respect to surrounding highly sensitive tissue and the safety range of the treatment will be reviewed. With the laser parameters used neither bleeding nor scotoma, proved by microperimery, were observed thus demonstrating no adverse effects to the choroid and the photoreceptors, respectively.

During and after irradiation, it shows that the irradiated sides are ophthalmoscopically invisible, since the effects are very limited and confined to the RPE, thus a dosimetry control is demanded. We report on a non-invasive optoacoustic on-line technique to monitor successful RPE-irradiation and compare the data to those achieved with standard angiography one hour post treatment.

POLARIZATION PROPERTIES OF THE RETINAL NERVE FIBER LAYER

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SUMMARY

The retinal nerve fiber layer (RNFL) consists of the unmyelinated axons of retinal ganglion cells gathered into bundles lying just under the retinal surface. The RNFL is damaged in glaucoma and other optic nerve diseases. Clinical observation and red-free fundus photography provide qualitative assessment of the RNFL, and recently developed optical techniques provide quantitative structural measurements. Because structural damage often precedes detectable field loss, measurement of the RNFL has achieved an important role in the diagnosis and management of glaucoma. Understanding the optical properties of the RNFL is essential for a complete interpretation of the measurements.

Among the optical properties of the RNFL, its polarization properties are of particular interest because polarized light interacts with matter at the scale of the wavelength of light, meaning that measurement of RNFL polarization properties may reveal information about its microscopic structure.

In optical measurements of the RNFL, the eye acts as an “optical device” for passing light to and from the retina. The detected signals are related not only to the properties of the RNFL, but also to the optical properties of other ocular tissues. Because polarized light and polarization sensitive detectors are common in RNFL assessment instruments, polarization properties of the ocular media can act as a confounding variable. Thus, knowledge of the optical properties of other ocular tissues is also necessary for understanding the measured signals.

This paper will give a basic description of polarization, followed by a review of the polarization properties and relevant anatomy of the ocular tissues and a thorough discussion of the reflectance and polarization properties of the RNFL.

RETINAL SCANNING LASER POLARIMETRY AND METHODS TO COMPENSATE FOR CORNEAL BIREFRINGENCE

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SUMMARY

Diffuse and focal defects in the retinal nerve fiber layer (RNFL) are the earliest signs of glaucoma damage in the eye. Scanning laser polarimetry (SLP) was developed to provide objective assessment of RNFL, a birefringent tissue, by measuring the total retardation in the reflected light. SLP provides a tool for early detection of glaucoma and monitoring its progression. The birefringence of the anterior segment of the eye, mainly the cornea, is a confounding variable to SLP's clinical application. This paper reviews the principle of SLP and methods to measure and compensate for anterior segment birefringence as implemented in the commercial SLP system, GDx VCC (Laser Diagnostic Technologies, Inc., San Diego, CA). Clinical application of GDx VCC is also demonstrated.

The GDx VCC system is a confocal scanning laser ophthalmoscope integrated with an ellipsometer and a variable corneal compensator (VCC). Scan field size is 40º (Horizontally) by 20º (Vertically), covering both the peripapillary region and the macular region of the eye. The VCC module consists of two identical linear retarders; both the retardation magnitude and the axis can be adjusted. Anterior segment birefringence is measured from an SLP image of the Henle's fiber layer. Two methods for individualized anterior segment birefringence compensation were developed. One of the methods is to set the VCC to neutralize the anterior segment birefringence directly, and SLP directly measures the RNFL retardance. The other is to use VCC to introduce a large bias retarder in the measurement beam with approximately vertical slow axis, and SLP measures the total retardance of the bias retarder and the RNFL. The RNFL retardance is then extracted from the total retardance by mathematically removing the bias. GDx VCC provides quantitative RNFL assessment in addition to a visual image. Normative database and a machine learning classifier were established based on clinical data to assist glaucoma diagnosis.

GDx VCC output 4 images from each measurement: fundus reflectance image, retardation image, birefringence axis image, and depolarized light image. Anterior segment birefringence is measured from an SLP image of the Henle's fiber layer. Both the retardance and the birefringence axis of the anterior segment vary over a wide range among individuals, confirming the necessity of individualized anterior segment compensation. Anterior segment birefringence is effectively neutralized with both compensation methods, apparent from the uniform Henle's fiber layer retardance pattern in the final retardation images. The variability of RNFL assessment with SLP is significantly reduced in GDx VCC. Images acquired with the bias retarder demonstrate improved signal-to-noise ratio. The RNFL image allows ready identification of glaucomatous focal or diffuse RNFL damage. Quantitative RNFL measurement and an established normative database provide objective evaluation. GDx VCC retardation measurement often correlates with visual field sensitivity in

glaucoma patients. At times glaucoma-induced RNFL damage can be detected with GDx VCC prior to detectable visual field damage.

Individualized anterior segment compensation can be achieved with the described methods so that the measured retardation largely reflects the RNFL retardance. RNFL retardation is reduced in glaucomatous eyes. With the combination of a visual RNFL image and rapid, objective, and reproducible assessment of the RNFL, GDx VCC provides an attractive clinical tool in glaucoma management.

ULTRA-HIGH SPEED AND ULTRA-HIGH RESOLUTION SPECTRAL-DOMAIN OPTICAL COHERENCE TOMOGRAPHY AND OPTICAL DOPPLER TOMOGRAPHY IN OPHTHALMOLOGY

*CENSE, B., CHEN, T.C.**, *NASSIF, N., PIERCE, M.C., YUN, S., HYLE PARK, B., BOUMA, B.E., TEARNEY, G.J., DE BOER J.F.*
*Harvard Medical School and Wellman Laboratories of Photomedicine, Massachusetts General Hospital, Boston, Massachusetts 02114, * Massachusetts Eye and Ear Infirmary and Harvard Medical School, Boston, Massachusetts 02114*

SUMMARY

We present ultrahigh-resolution optical coherence tomography (OCT) structural intensity and optical Doppler tomography (ODT) flow velocity images of the human retina *in vivo*.

The ultra-high speed OCT system is based on Spectral Domain or Fourier Domain technology, which provides a sensitivity advantage over conventional OCT of more than 2 orders of magnitude.

This sensitivity improvement allows video rate OCT and ODT cross sectional imaging of retinal structures. Images are obtained with an axial resolution of six and 3.5 micron. We observed small features in the inner and outer plexiform layers, which are believed to be small blood vessels.

Flow velocity images are demonstrated that show pulsatile flow in retinal arteries and veins.

IN VIVO THICKNESS AND BIREFRINGENCE DETERMINATION OF THE HUMAN RETINAL NERVE FIBER LAYER USING POLARIZATION-SENSITIVE OPTICAL COHERENCE TOMOGRAPHY

CENSE, B., CHEN, T.C., DE BOER J.F.*
*Harvard Medical School and Wellman Laboratories of Photomedicine, Massachusetts General Hospital, Boston, Massachusetts 02114, * Massachusetts Eye and Ear Infirmary and Harvard Medical School, Boston, Massachusetts 02114*

SUMMARY

Thinning of the retinal nerve fiber layer and changes in retinal nerve fiber layer birefringence may both precede clinically detectable glaucomatous vision loss.

We present *in vivo* thickness and depth-resolved birefringence measurements of the human retinal nerve fiber layer (RNFL) by use of polarization-sensitive optical coherence tomography (PS-OCT). Using a fiber-based PS-OCT setup real-time images of the human retina *in vivo* were recorded, co-registered with retinal video images of the location of PS-OCT scans. PS-OCT scans around the optic nerve head (ONH) of two healthy young volunteers were made using 10 concentric circles of increasing radius. Both the mean retinal nerve fiber layer thickness and mean retinal nerve fiber birefringence for each of 48 sectors on a circle were determined.

The retinal nerve fiber layer thickness and birefringence varied as a function of sector around the ONH. Measured double pass phase retardation per unit depth values around the ONH range between 0.10 and 0.35 °/μm.

The retinal nerve fiber layer becomes thinner with increasing distance from the ONH. In contrast, the birefringence does not vary significantly as a function of radius.

COMBINING SLO AND OCT TECHNOLOGY

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SUMMARY

A review is presented of the research on high resolution imaging of the eye which can provide a dual display of images with different depth resolutions.

The presentation refers to the flying spot concept, widely exploited in the confocal scanning laser ophthalmoscope and recently extended to OCT imaging. For different reasons, imaging with two different depth resolutions is useful and this triggered the development of the dual *en-face* OCT – confocal imaging technology and of the OCT/Ophthalmoscope instrument. The dual acquisition can be performed in different versions such as simultaneously (practised in the OCT/Ophthalmoscope) or sequentially and each such version has specific applications. When the sequential switching is performed at the line rate of the frame acquisition, the display of the two images, OCT and confocal is quasi – simultaneous.

BIREFRINGENCE PROPERTIES OF THE HUMAN CORNEA MEASURED WITH POLARIZATION SENSITIVE OPTICAL COHERENCE TOMOGRAPHY

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SUMMARY

The purpose of our endeavor is threefold: to map the three-dimensional distribution of birefringence of the normal human cornea. To provide insight into structures and mechanisms causing corneal birefringence and to establish standard patterns of 3D birefringence distribution.

A polarization sensitive optical coherence tomography (PS-OCT) system was developed that allows measurement and imaging of three tissue parameters simultaneously: reflectivity, retardation, and slow optic axis orientation. This instrument was used to obtain 3D PS-OCT data sets of normal human corneas *in vitro*. From the 3D data sets, conventional cross sectional, as well as *en face* images of reflectivity, retardation, and optic axis orientation were derived. Preliminary results from a healthy cornea *in vivo* and a keratoconus cornea *in vitro* are also presented.

In transversal direction the retardation distribution of the normal cornea has a radially symmetric shape; retardation is lowest at the center of the cornea and increases towards the periphery. At peripheral regions, retardation also increases with depth. The distribution of the optic axis is not constant with the parallel illumination scheme used. Optic axis orientation is an approximately linear function of azimuth angle, however, if averaged over the entire cornea, a preferential optic axis orientation is observed. In a keratoconus cornea, the normal birefringence pattern is heavily distorted.

The results provide additional insight into corneal birefringence as compared to published work where corneal birefringence is usually averaged over a larger area. The results can be explained by a birefringence model based on stacked collagen fibril lamellae of different orientations. The observed birefringence patterns in normal corneas might be used as standard patterns for comparisons with pathologic changes.

LASER DOPPLER INSTRUMENTATION FOR THE MEASUREMENT OF RETINAL BLOOD FLOW: THEORY AND PRACTICE

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SUMMARY

Any discussion of the theory underlying the development of laser Doppler instrumentation for the measurement of retinal blood flow must be framed in terms of the confluence of three major events. First was the enunciation of the Doppler principle. Second was the invention of the laser. Third was the invention of the technique known as optical mixing spectroscopy that made the measurements possible.

Specific to the case of blood cells moving through blood vessels is the additional theoretical question of the description of the propagation and scattering of laser light in a dense suspension of “particles” that are large compared to the wavelength of the probing radiation.

Finally, specific to the case that the blood vessels are in the retina of a living human eye, are laser safety issues and, perhaps, the greatest engineering challenge of all, the need to overcome involuntary eye movements and maintain the incident laser beam on the exact center of the target blood vessel for a sufficient length of time to acquire data over several cardiac cycles.

SUB-FOVEAL CHOROIDAL BLOOD FLOW BY LDF: MEASUREMENT AND APPLICATION TO THE PHYSIOLOGY AND PATHOLOGY OF THE CHOROIDAL CIRCULATION

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SUMMARY

Laser Doppler flowmetry allows the measurement of relative choroidal blood flow in the sub-foveal region of the fundus (ChBF).

This technique has been applied to the investigation of the regulation of ChBF in response to a variety of physiological stimuli (breathing different gas mixtures of O_2 and CO_2, varying the systemic and ocular blood perfusion pressures, light-dark transition and zero gravity) in normal subjects.

Measurements in pathological conditions, such as diabetes, age-related macular degeneration and glaucoma appear to alter the response of ChBF to increased systemic blood pressure.

The data provide a better understanding of the regulation of the choroidal circulation in the normal and diseased eye.

ABERROMETRY: BASIC SCIENCE AND CLINICAL APPLICATIONS

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SUMMARY

The eye is an optical instrument that projects scenes of the visual world onto the retina. It has been known for many years that the eye is far from being a perfect optical system, in particular for large pupil diameters. Refractive anomalies (defocus or astigmatism) occur frequently in the eye.

In western countries myopia affects to about 30% of the population, although its prevalence is much higher (more than 80%) in certain Asian societies. But the eye suffers also from other optical imperfections (called *higher order aberrations*), which are not typically measured in the clinic and cannot be corrected by conventional means. Like defocus, optical aberrations blur the retinal image, reducing image contrast and limiting the range of spatial frequencies available to further stages of the visual processing. The contribution of aberrations to optical degradation is typically smaller than defocus or astigmatism.

The blurring effect of aberrations becomes more noticeable for large pupils. For small pupil sizes *diffraction* effects, associated to the limited aperture size, predominate over the aberrations.

Along with diffraction and aberrations, *scattering* also contributes to degradation of retinal image quality. Scattering occurs at the cornea, and particularly the lens. Although scattering is small in normal young eyes, it is well established that it increases with age (due to changes in the crystalline lens) and after PRK refractive surgery.

THE DIRECTIONALITY OF PHOTORECEPTORS IN THE HUMAN RETINA

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SUMMARY

The directional sensitivity of photoreceptors is a result of their structure that makes them act as optical fibers. Therefore the measurement of photoreceptor directionality is a tool for testing the physical properties of photoreceptors *in vivo*.

Clinical studies of photoreceptor directionality are limited by the fact that psychophysical methods for measuring the Stiles-Crawford effect are time consuming and require excellent co-operation from the subject. Thus different reflectometric techniques have been developed recently.

This paper describes these methods, that allow us to characterize the optical properties of photoreceptors, i.e. their orientation and directionality.

Mechanisms likely to explain the discrepancy between the directionality factor values given by these techniques are discussed. Finally the functional advantages of photoreceptor optics are considered.

WHAT CAN ADAPTIVE OPTICS DO FOR A SCANNING LASER OPHTHALMOSCOPE?

ROORDA, A., GARCIA, C.A., MARTIN, J.A.,POONJA, S., QUEENER, H., ROMERO, F., SEPULVEDA, R.*, VENKATESWARAN, K., ZHANG, Y.*
*University of Houston College of Optometry, Houston TX 77204, *University of Texas, Houston Health Science Center Ophthalmology and Visual Sciences, Houston, TX 77030*

SUMMARY

The invention of the scanning laser ophthalmoscope in 1980 represented one of the major developments in ophthalmoscopy in the 20 century (Webb, Hughes, & Pomerantzeff, 1980; Pomerantzeff & Webb, 1980). It has since enjoyed widespread use and application as a tool forbasic science as well as clinical research for more than two decades.

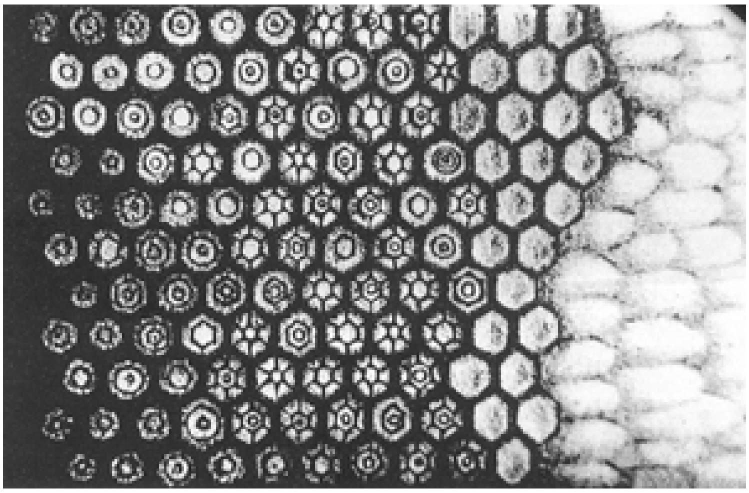
A scanning laser ophthalmoscope works in the following way: A small spot is focused on the retina and is scannd in a raster pattern. An image of the retina is constructed over time by recording the scattered light and synchronizing the detected intensity with the instantaneous location of the focused spot. There are many different ways to accomplish this, but the basic concept for all scanning laser ophthalmoscopes is the same. A scanning laser ophthalmoscope is essentially the same as a scanning laser microscope. The important difference is that, in a scanning laser ophthalmoscope, the optics of the eye serve as the objective lens, and the sample is always the retina.

While these differences may seem minor, they impose serious constraints on the imaging system. It is rare to see a system that serves as both a microscope and an ophthalmoscope (at least in the classic sense). The main constraint that the eye imposes is its limited numerical aperture. For that reason, a SLO will never achieve the same resolution as a scanning laser microscope. The maximum possible numerical aperture of the eye (which is a measure of the steepness of the cone of focusing light) is 0.23 with an 8 mm pupil. But this is not half the problem. The benefits of increased numerical aperture for any pupil sizes larger than 2-3 mm are defeated by the presence of aberrations, which blur the image. Studies have shown that the balance between diffraction which blurs the image for small pupils and aberrations is somewhere between 2 and 4 mm pupils, depending on the individual.

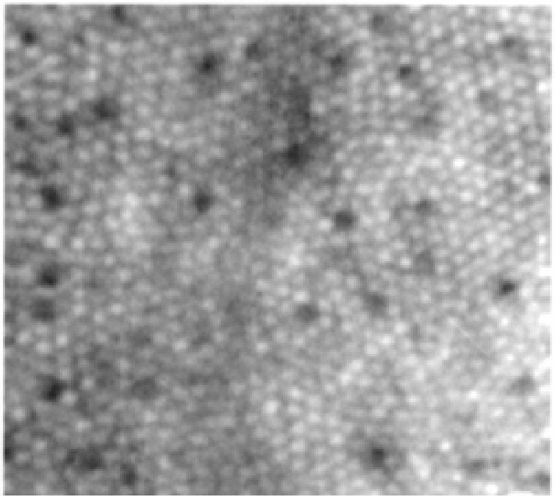
This limitation has been appreciated since the earliest SLO where a small entrance pupil less than 2 mm diameter was used to focus the scanning spot on the retina. Adaptive optics allows the use of much larger entrance pupils and consequently a higher resolution in the presence of aberrations.

The New Optics of the Human Eye

QUESTIONNAIRE RESULTS AND STATISTICAL ANALYSIS



Drawing of the frog's outer segments of photoreceptors, viewed end-on. This remarkable picture was obtained already in 1843 by Hannover (Hannover, A., Vid. Sel. Naturv. Og Math. Sk. X, 1843). Notice the remarkable resemblance of the pattern with the image of present day laser mode guides (misinterpreted in 1843 as internal structures). See also Enoch, J., Optical properties of the retinal receptors, JOSA, Vol. 53, pp 71-81, 1963.



From Roorda, A., Williams, D., The arrangement of the three cone classes in the living human eye. Nature, vol. 397, pp. 520-522, 1999.

This illustration shows the perifoveal photoreceptor mosaic and the sparse array of S cones, obtained in vivo using adaptive optics techniques. The mosaic puts an upper limit on the acuity resolution that can be obtained for any given pupil diameter (Sampling theorem of Shannon, Nyquist criterion). Such thinking was already present in the works of Bergmann in 1857. Bergmann, C. Anatomisches und Physiologisches uber die Netzhaut des Auges. Zeitschrift fur rationelle Medecin, Vol. 2, pp 83-108, 1857.

The European Science Foundation Exploratory Workshop
on the “New Optics of the Human Eye”
QUESTIONNAIRE

Please circle the appropriate answers and hand over to auditorium attendants when leaving

1. I am in an ophthalmology training program (1), I am a faculty member of a University Ophthalmology Department (2), in private practice (3), none of aforementioned apply (4)

(1) Trainee	(2) Faculty	(3) Private pract	(4) None apply	

2. I am not, a little, fairly, very interested in understanding the physical principles of diagnostic equipment I use, and physiological optics in general

(1) Not	(2) A little	(3) Fairly	(4) Very	(5) No answer

3. I have no, some, many, a lot of problems understanding spoken English during lectures

(1) No	(2) Some	(3) Many	(4) A lot of	(5) No answer

4. My native language is (1) Dutch, (2) French, (3) German, (4) English, (5) other

(1) Dutch	(2) French	(3) German	(4) English	(5) other

5. I think I have a (1) weak, (2) average, (3) good, (4) strong mathematical background

(1) weak	(2) average	(3) good	(4) strong	(5) No idea

6. My primary interest in ophthalmic research is elsewhere, e.g. (1) genetics and immunology, (2) pathology, (3) neuroscience, (4) unspecified, (5) not true

(1)	(2)	(3)	(4)	(5)

7. I wish we had had more elective opportunities to study math at high school or bachelor degree level (junior university level), disagree (1), possibly (2), agree (3), very much so (4)

(1) disagree	(2) possibly	(3) agree	(4) very much	

8. The lectures were easy for me to follow (1); were helpful to get an overview idea of the topics (2); were generally too difficult to grasp (3); I did not understand anything (4)

(1)	(2)	(3)	(4)	

9. I would like to, or, I wish I had had the opportunity to follow formal courses in depth in modern optics and biomedical optics at the university graduate or post-graduate level

(1) very much	(2) yes	(3) possibly	(4) unlikely	(5) no

10. I know what Fourier transforms are: a lot (1), somewhat (2), little (3) no idea (4)

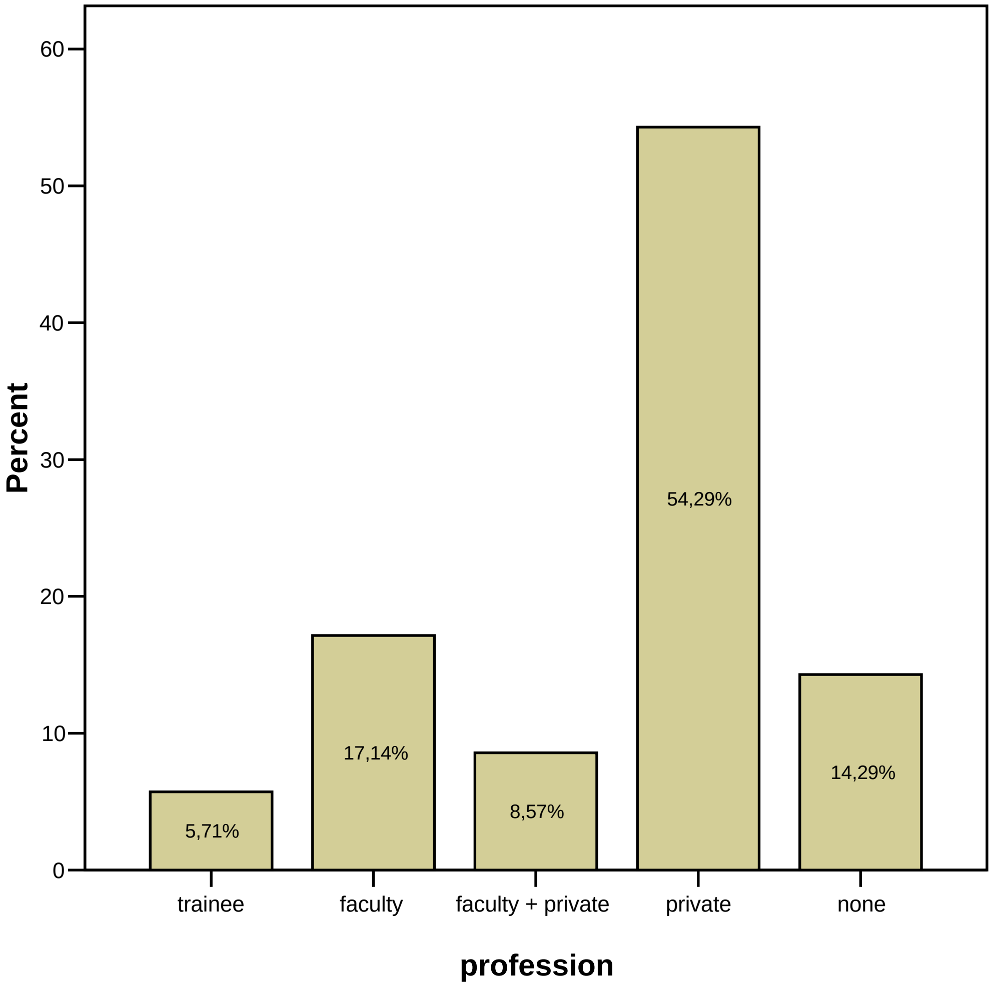
(1) a lot	(2) somewhat	(3) little	(4) no idea	

QUESTION 1

1. I am in an ophthalmology training program (1), I am a faculty member of a University Ophthalmology Department (2), in private practice (3), none of aforementioned apply (4)				
(1) Trainee	(2) Faculty	(3) Private pract	(4) None apply	

Observations and comments:

This question was asked to obtain an idea of the constitution of the audience for the lectures. About 800 ophthalmologists who are a member of the Belgian ophthalmological society are eligible to attend. Some outsiders and foreigners are allowed as well upon invitation. Also the circa 40 residents in ophthalmology in Belgium are strongly encouraged to attend. Door attendance registration for this plenary session of the Belgian Ophthalmological Society showed that 110 people entered the auditorium at any point. Thirty-five of them attended all lectures and also filled in the questionnaire.

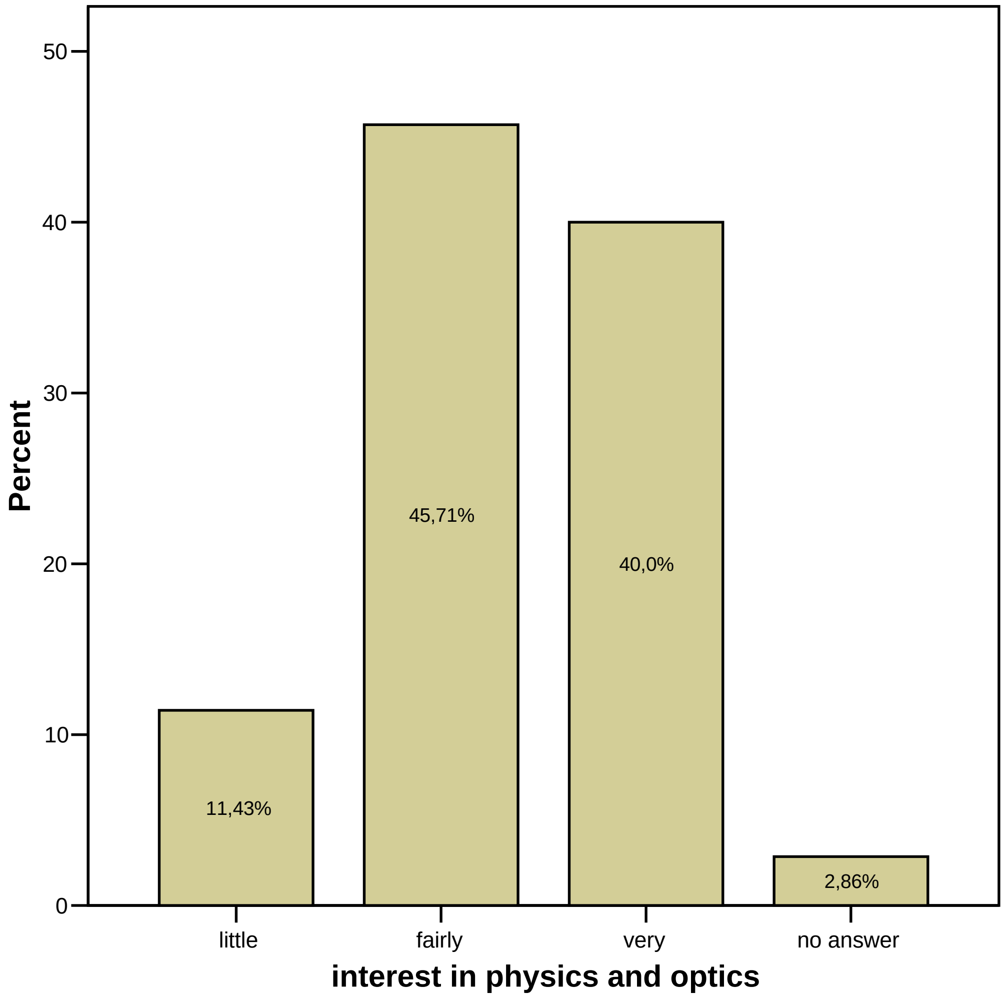


QUESTION 2

2. I am not, a little, fairly, very interested in understanding the physical principles of diagnostic equipment I use, and physiological optics in general				
(1) Not	(2) A little	(3) Fairly	(4) Very	(5) No answer

Observations and comments:

This question was asked to obtain an idea of the amount of interest in knowing the underlying principles of the equipment that is used daily by the ophthalmologist and the optics of the eye itself. We wanted to confirm that those people who attended and filled in the questionnaire did not do so for other reasons, for example to obtain accreditation credit points in postgraduate education. It appears that the majority of the participants had a genuine interest in the material that was present. On the other hand, there may have been a bias in the population of attendants since participation in this event was not compulsory.

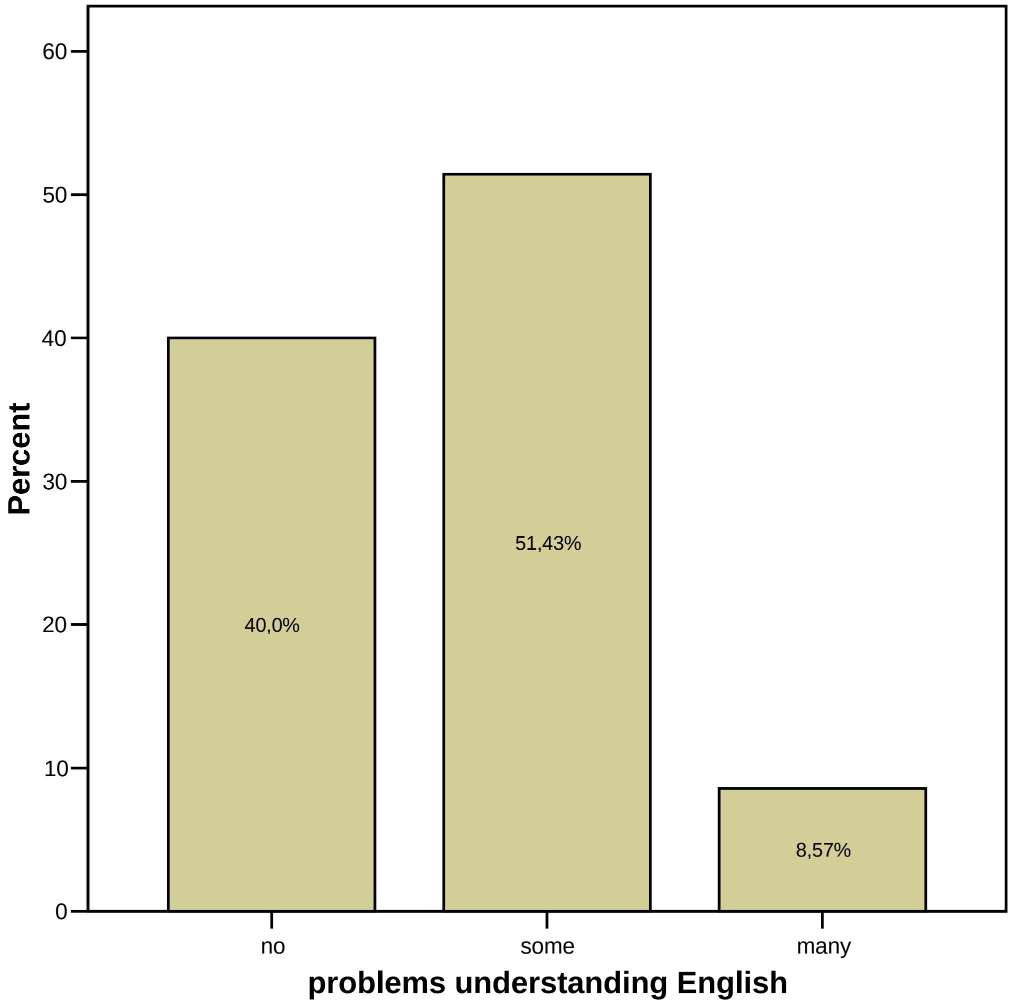


QUESTION 3

3. I have no, some, many, a lot of problems understanding spoken English during lectures				
(1) No	(2) Some	(3) Many	(4) A lot of	(5) No answer

Observations and comments:

This question was asked to obtain an idea of the amount of language proficiency of the audience. Several language groups exist in Belgium, and in fact, this is a characteristic of Europe. Feeling comfortable with spoken English is in our opinion very important for the exchange of scientific information between different language groups. There is probably still a difference depending on the native language of the listener. We elaborate on this in the cross-tabulations.

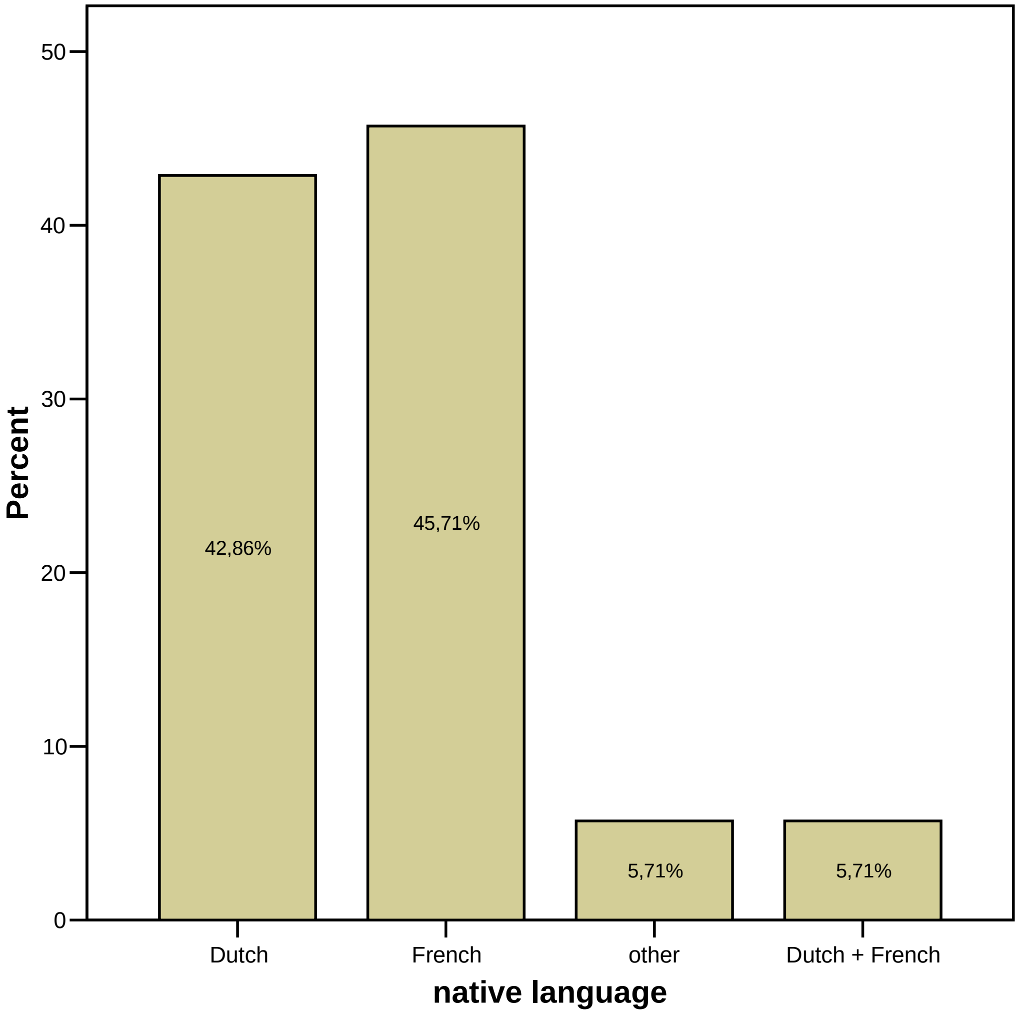


QUESTION 4

4. My native language is (1) Dutch, (2) French, (3) German, (4) English, (5) other				
(1) Dutch	(2) French	(3) German	(4) English	(5) other

Observations and comments:

This question was asked to obtain an idea of the amount of participation of specific language groups in Belgium. Somewhat surprising to us is the fact that some people indicated two native languages. This puzzling fact can be explained by the fact that in Belgium a number of people are truly bilingual, with mixed language parentage. As expected, about equal numbers of French and Dutch participants were present in the auditorium.

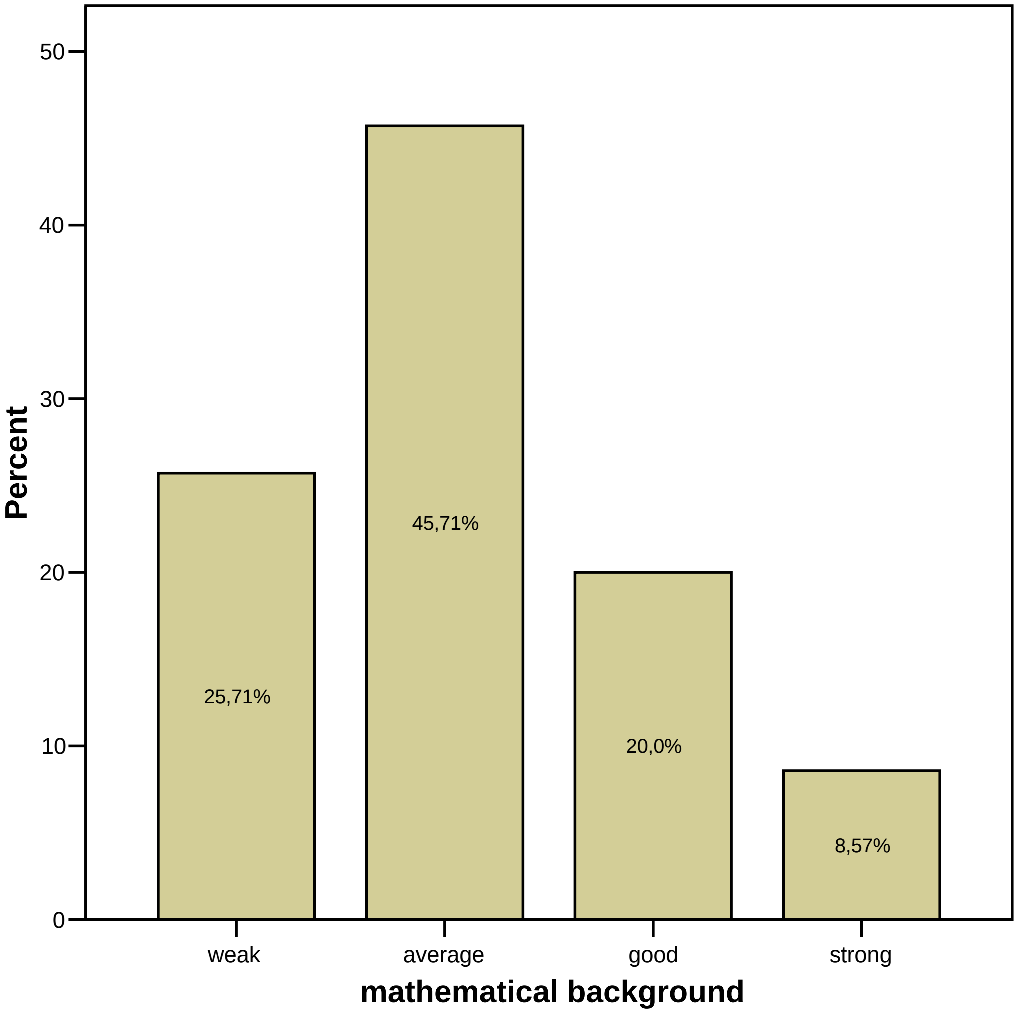


QUESTION 5

5. I think I have a (1) weak, (2) average, (3) good, (4) strong mathematical background				
(1) weak	(2) average	(3) good	(4) strong	(5) No idea

Observations and comments:

This question was asked to obtain an idea of the amount of mathematical proficiency the participants think they possess. Traditionally, Belgian secondary education (high-school level) is perceived to be fairly strong in the positive sciences. Thus students enter the undergraduate university programs with a fairly adequate background (except perhaps for those who put most emphasis on the classic languages, Greek and Latin, in High School). We believe that the statistics below reflect this situation.

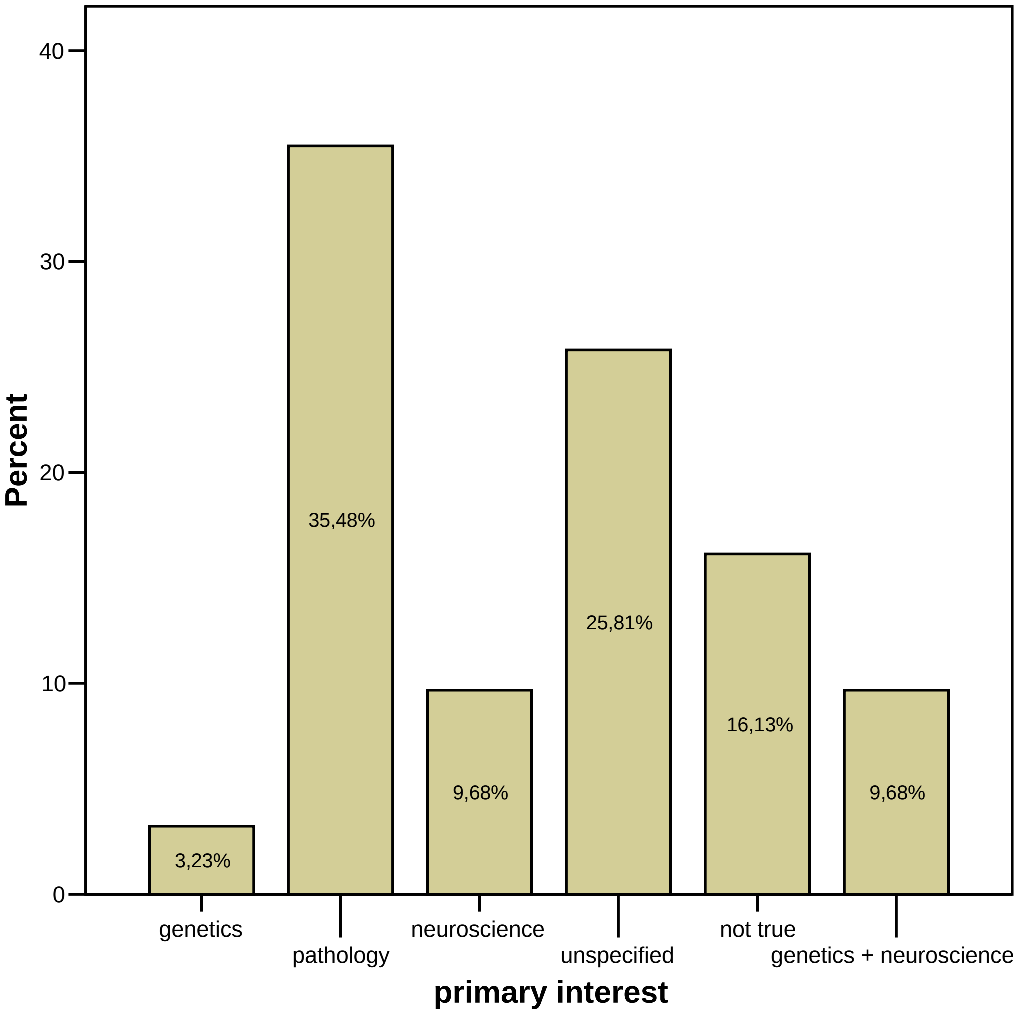


QUESTION 6

6. My primary interest in ophthalmic research is elsewhere, e.g. (1) genetics and immunology, (2) pathology, (3) neuroscience, (4) unspecified, (5) not true				
(1)	(2)	(3)	(4)	(5)

Observations and comments:

This question was asked to obtain an idea of the main interest are of the attendants. In retrospect, we might have dropped the word “research” in this question, and also replaced the “not true” option with “optics”. However, the results seem to be consistent with the fact that the majority of the participants are active clinicians, interested in the broad spectrum of sub disciplines within ophthalmology, some of them particularly interested in refractive surgery.

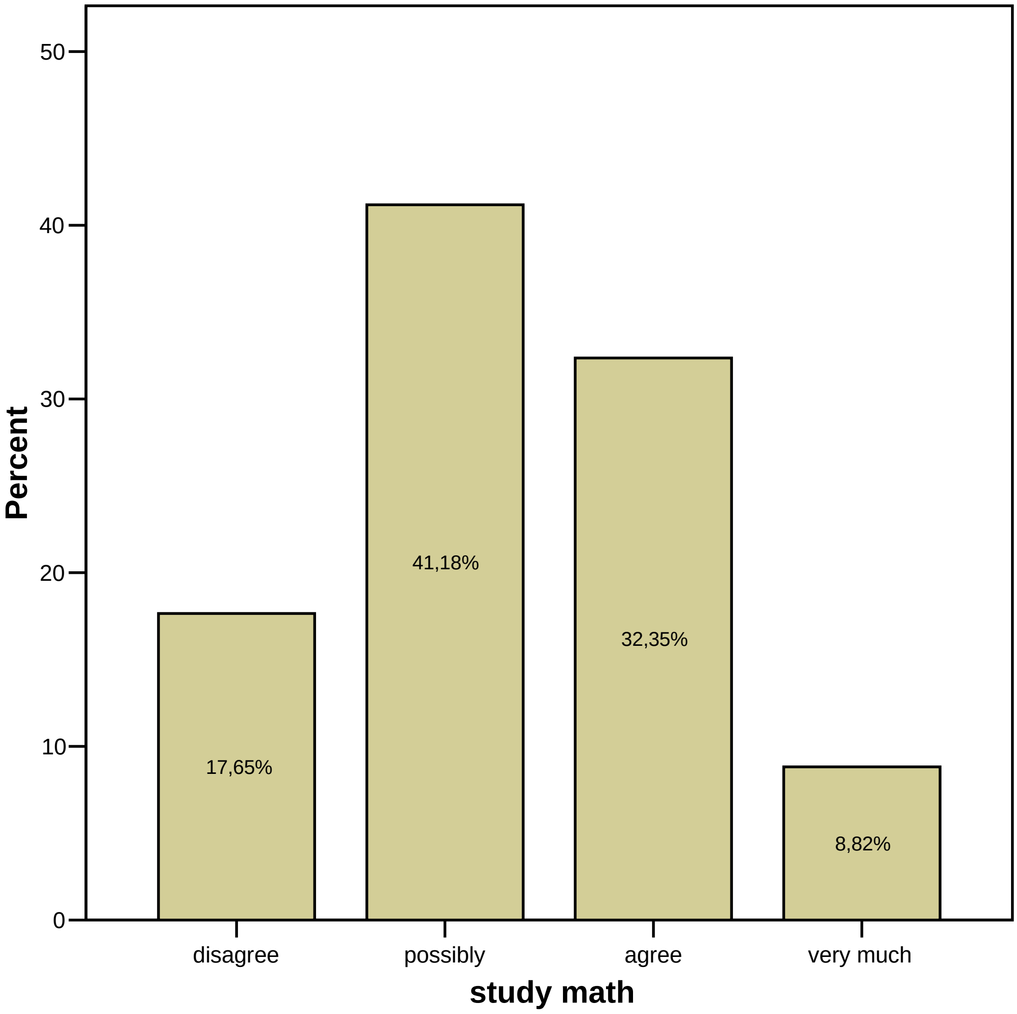


QUESTION 7

7. I wish we had had more elective opportunities to study math at high school or bachelor degree level (junior university level), disagree (1), possibly (2), agree (3), very much so (4)				
(1) disagree	(2) possibly	(3) agree	(4) very much	

Observations and comments:

This question was asked to find out if the participants wanted more mathematical instruction before entering medical school. This question is related to question 5 and both taken together seem to indicate that (1) participants consider a good mathematical background important and (2) a (still) somewhat more intensive preparation is useful.

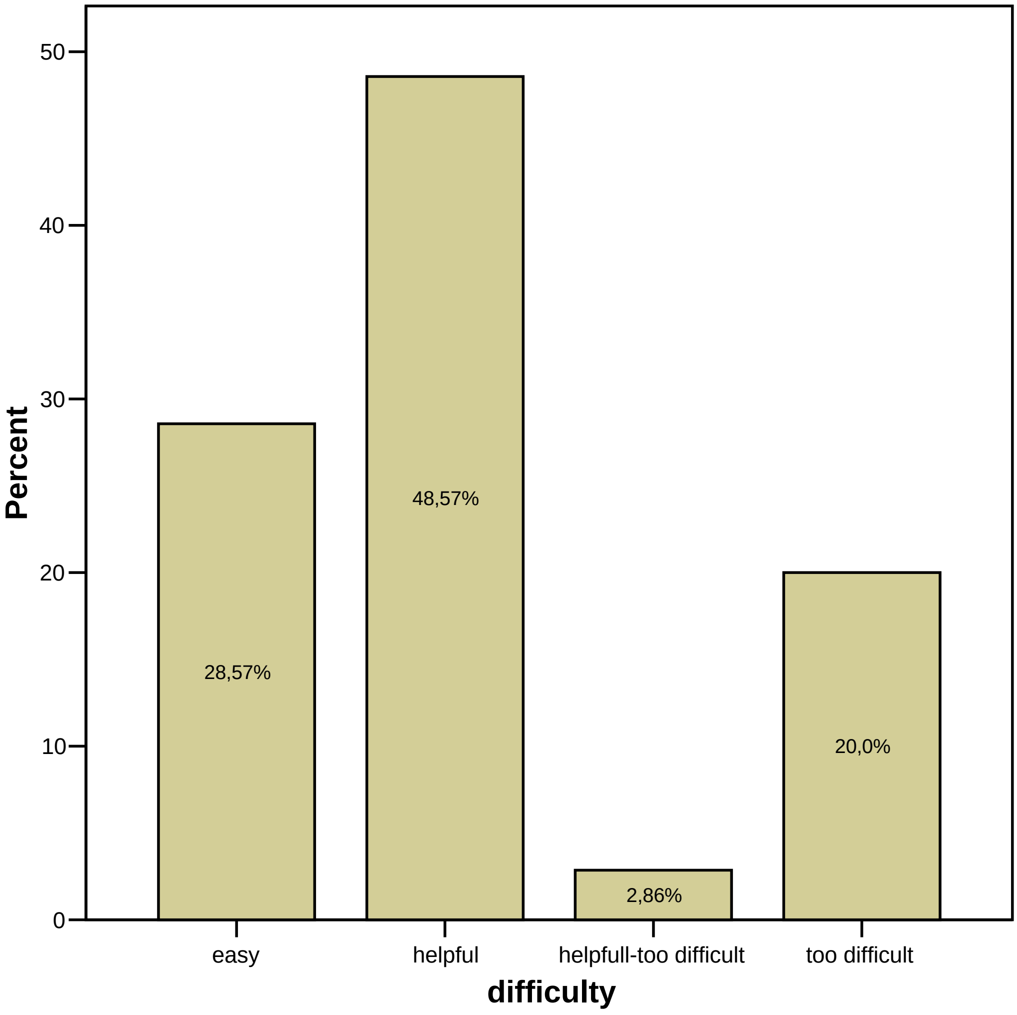


QUESTION 8

8. The lectures were easy for me to follow (1); were helpful to get an overview idea of the topics (2); were generally too difficult to grasp (3); I did not understand anything (4)				
(1)	(2)	(3)	(4)	

Observations and comments:

This question was asked to find out if the participants understood what was being presented in the lectures Somewhat surprisingly, about one-third found the lectures easy to follow. The presenters had been instructed to position their content to some extent at the level of clinical ophthalmologists. The statistics below may indicate that they succeeded in doing so.

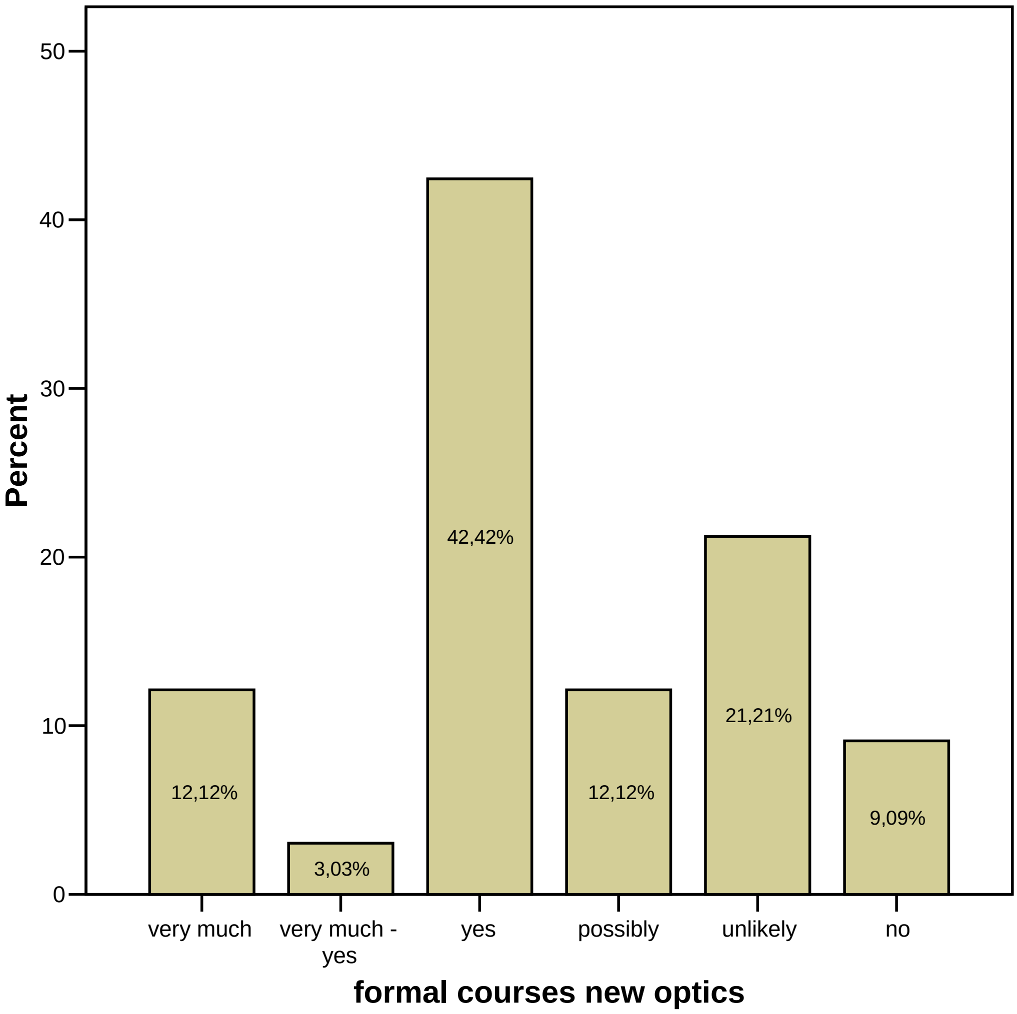


QUESTION 9

9. I would like to, or, I wish I had had the opportunity to follow formal courses in depth in modern optics and biomedical optics at the university graduate or post-graduate level				
(1) very much	(2) yes	(3) possibly	(4) unlikely	(5) no

Observations and comments:

This question was asked to find out if the participants wanted more education to be available specifically dealing with biomedical optics. More than half of the audience indicated that this was true. This result is generally in line with the responses to other questions.

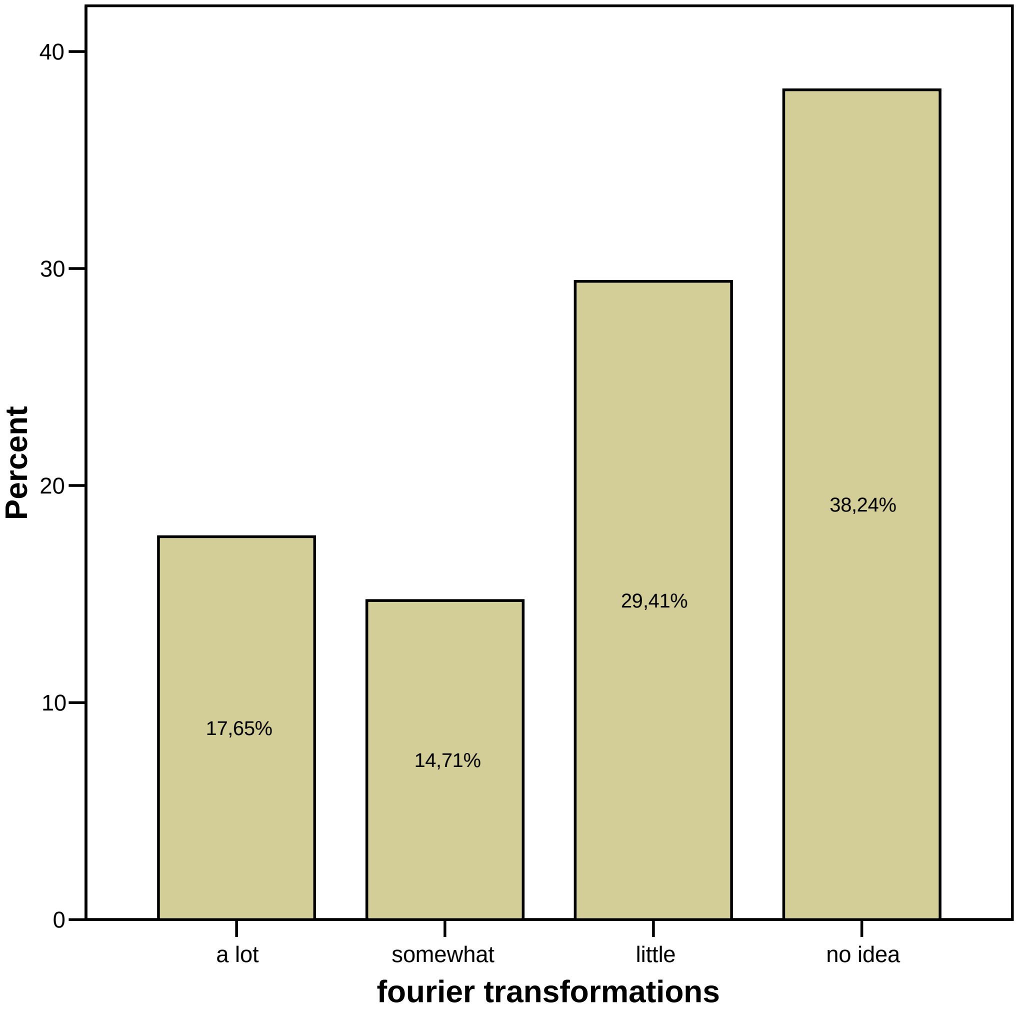


QUESTION 10

10. I know what Fourier transforms are: a lot (1), somewhat (2), little (3) no idea (4)				
(1) a lot	(2) somewhat	(3) little	(4) no idea	

Observations and comments:

This question was asked to find out if the participants knew about a mathematical technique that is currently crucial for understanding (advanced) medical optics. Not surprisingly more than half of the listeners did not. In fact, many of the audience may not even be aware that Fourier transforms are a major tool in current biomedical engineering.



CROSS-CORRELATION BETWEEN Q4 AND Q3 (all subjects)

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
native language * problems understanding English	35	100,0%	0	,0%	35	100,0%

		problems understanding English			Total
		no	some	many	
native language	Dutch	10	4	1	15
	French	3	11	2	16
	other	1	1	0	2
	Dutch + French	0	2	0	2
Total		14	18	3	35

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	9,657(a)	6	,140
Likelihood Ratio	10,859	6	,093
Linear-by-Linear Association	1,206	1	,272
N of Valid Cases	35		

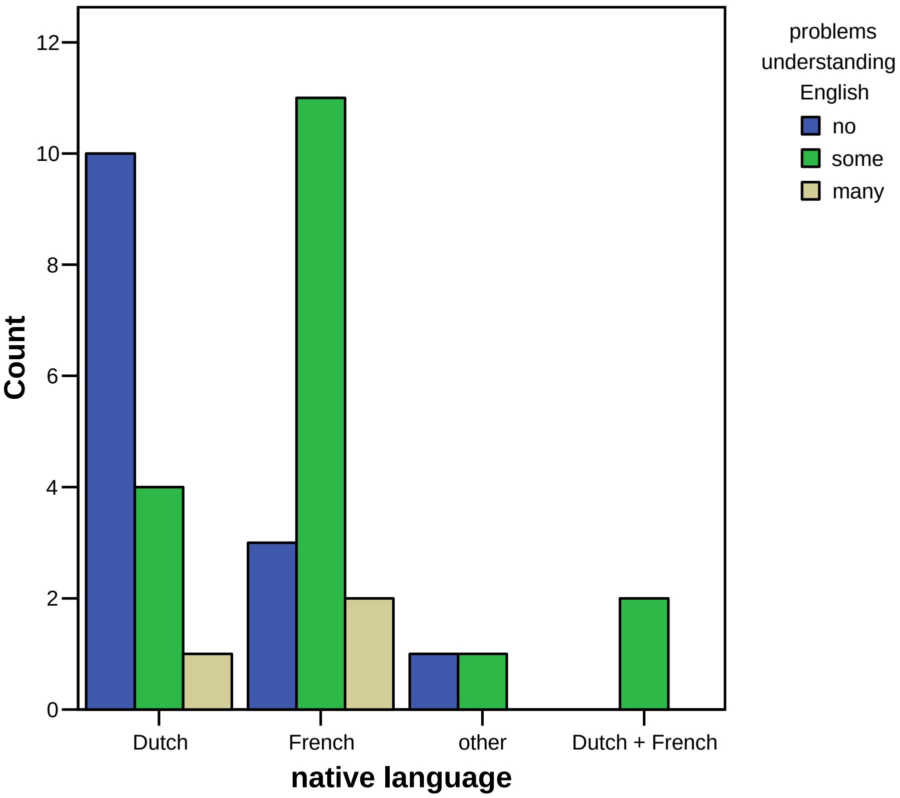
Observations and comments:

This cross correlation addresses the question whether a statistically significant difference exists between the ease of understanding the spoken language of the lectures (English) and the native language of the audience.

It appears that there is just about no difference when all language groups are concerned. However see next cross-correlation for the difference between Dutch and French native speakers only.

Graph: see next page

Bar Chart


Count
0
2
4
6
8
10
12
Dutch
French
other
Dutch + French
native language
problems understanding English
no
some
many

CROSS-CORRELATION BETWEEN Q4 AND Q3 (French and Dutch only)

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
native language * problems understanding English	31	100,0%	0	,0%	31	100,0%

		problems understanding English			Total
		no	some	many	
native language	Dutch	10	4	1	15
	French	3	11	2	16
Total		13	15	3	31

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	7,345(a)	2	,025
Likelihood Ratio	7,681	2	,021
Linear-by-Linear Association	5,253	1	,022
N of Valid Cases	31		

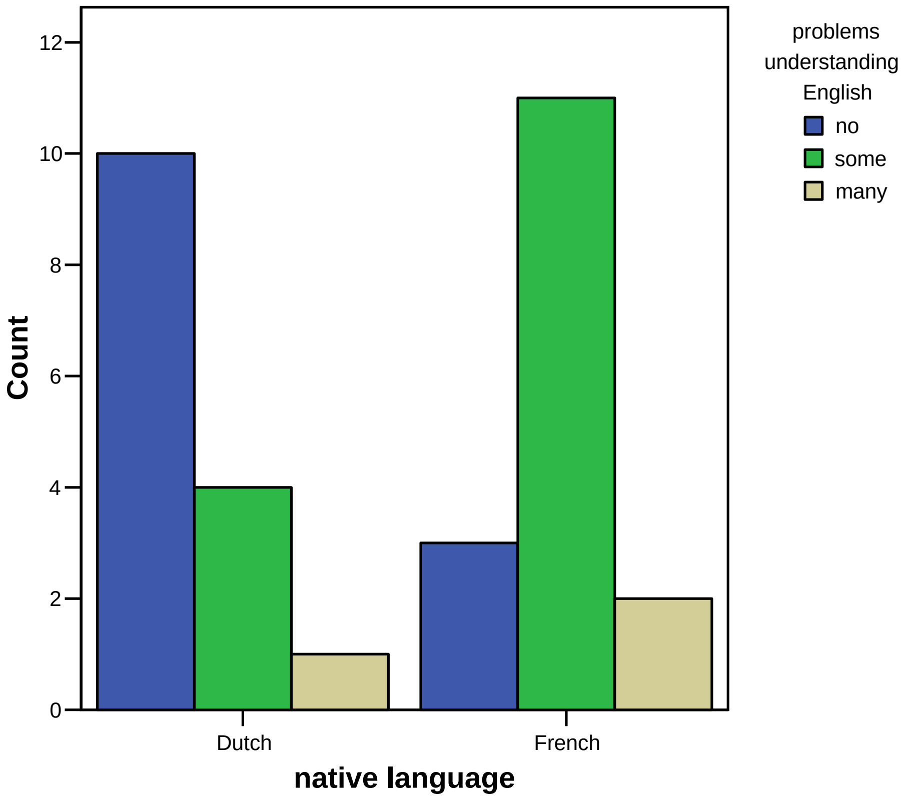
Observations and comments:

This cross correlation addresses the question whether a statistically significant difference exists between the ease of understanding the spoken language of the lectures (English) and the native language of the audience, Dutch versus French only.

It appears that there is a difference when only the Dutch and French groups are concerned. However, this difference is not outspoken but probably still corroborates to some extent the public opinion that language instruction in English may lag behind in the French speaking part of Belgium.

Graph: see next page

Bar Chart


Count
12
10
8
6
4
2
0
Dutch
French
native language
problems understanding English
no
some
many

CROSS-CORRELATION BETWEEN Q4 AND Q5 (Dutch and French only)

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
native language * mathematical background	31	100,0%	0	,0%	31	100,0%

		mathematical background				Total
		weak	average	good	strong	
native language	Dutch	4	6	2	3	15
	French	2	9	5	0	16
Total		6	15	7	3	31

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	5,526(a)	3	,137
Likelihood Ratio	6,739	3	,081
Linear-by-Linear Association	,062	1	,803
N of Valid Cases	31		

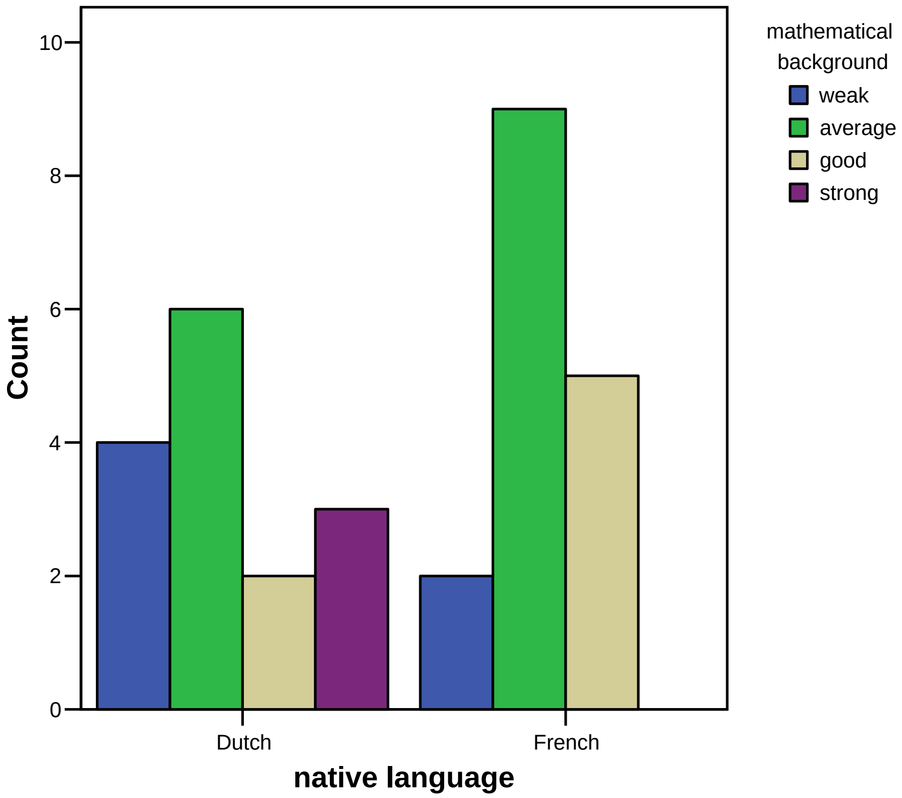
Observations and comments:

This cross correlation addresses the question whether a statistically significant difference exists between the self-perceived mathematical background of the audience and the native language of the audience (Dutch or French).

As expected, we do not see a statistically significant difference in this sample.

Graph: see next page

Bar Chart


mathematical background
weak
average
good
strong
Count
0
2
4
6
8
10
Dutch
French
native language

CROSS-CORRELATION BETWEEN Q4 AND Q9 (Dutch and French natives)

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
native language * formal courses new optics	30	96,8%	1	3,2%	31	100,0%

Count

		formal courses new optics						Total
		very much	very much-yes	yes	possibly	unlikely	no	
native	Dutch	3	1	5	2	3	0	14
	French	1	0	9	2	2	2	16
Total		4	1	14	4	5	2	30

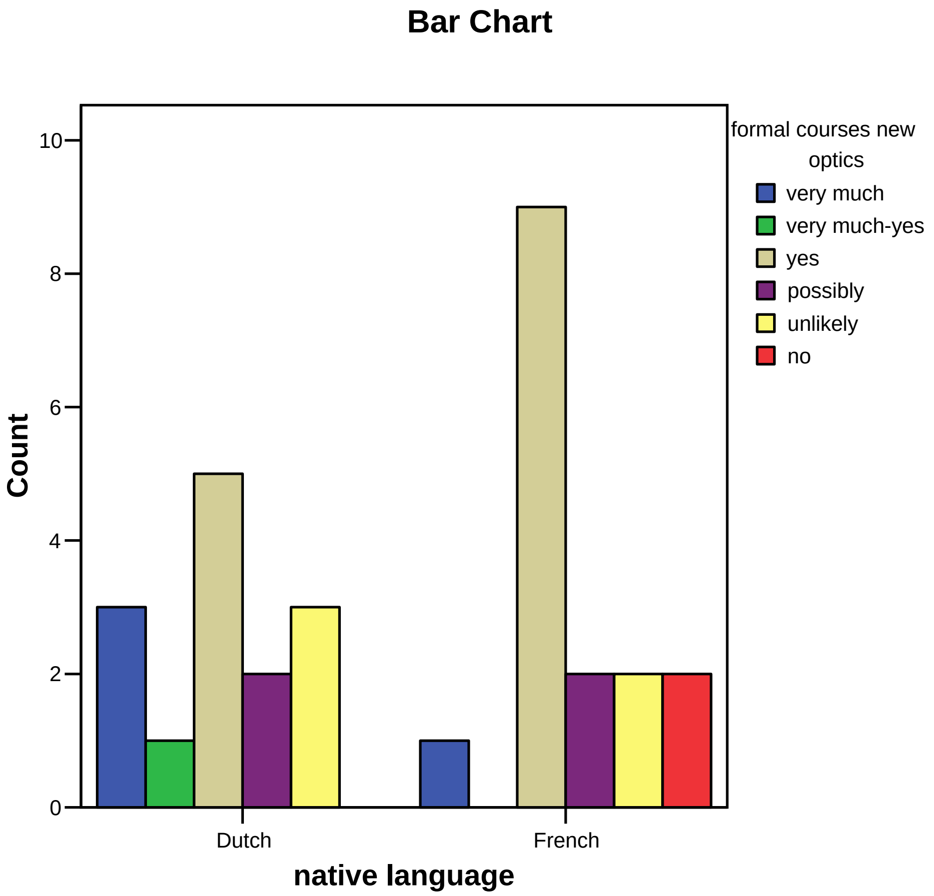
	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	5,233(a)	5	,388
Likelihood Ratio	6,432	5	,266
Linear-by-Linear Association	,759	1	,384
N of Valid Cases	30		

Observations and comments:

This cross correlation addresses the question whether a statistically significant difference exists between the desire to receive formal courses in optics and the native language of the audience (Dutch or French).

Like previous cross-correlation this comparison serves as some form of double check on our statistics in general: we did not expect a significant difference and we didn’t calculate a significant difference.

Graph: see next page


Bar Chart
Count
10
8
6
4
2
0
Dutch
French
native language
formal courses new optics
very much
very much-yes
yes
possibly
unlikely
no

CROSS-CORRELATION BETWEEN Q5 AND Q1 (All language groups)

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
profession * mathematical background	35	100,0%	0	,0%	35	100,0%

		mathematical background				Total
		weak	average	good	strong	
profession	trainee	1	1	0	0	2
	faculty	1	3	1	1	6
	private	4	10	5	0	19
	none	2	1	0	2	5
	faculty + private	1	1	1	0	3
Total		9	16	7	3	35

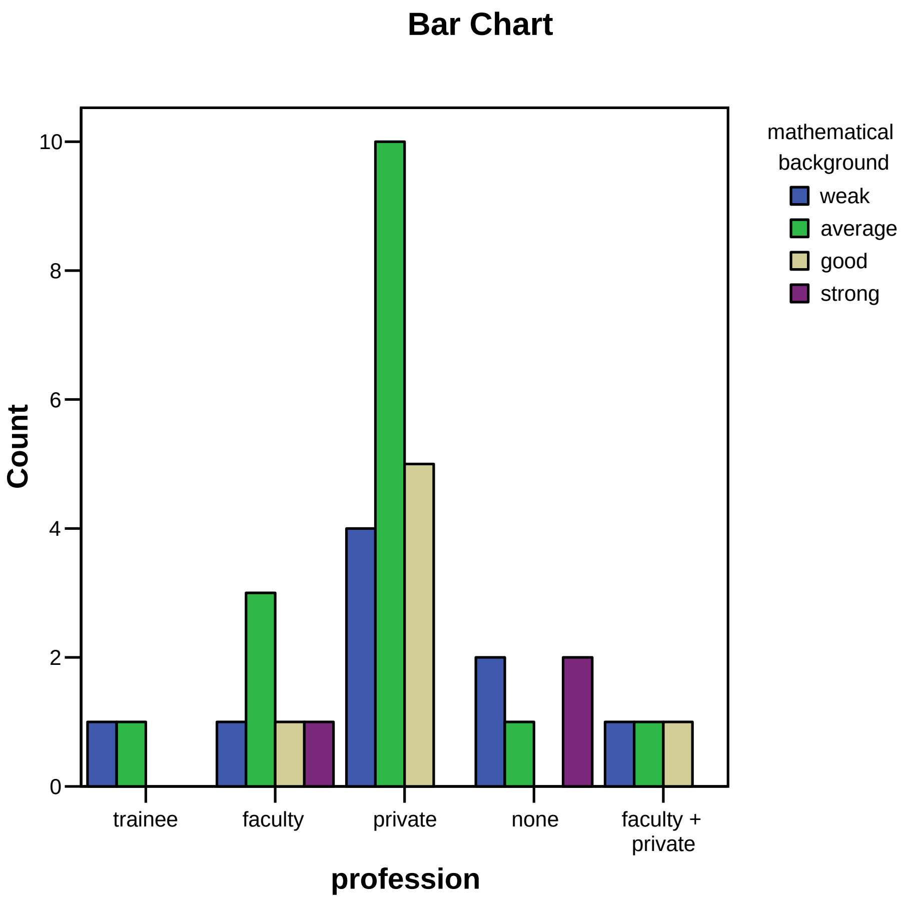
	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	12,686(a)	12	,392
Likelihood Ratio	13,292	12	,348
Linear-by-Linear Association	,027	1	,869
N of Valid Cases	35		

Observations and comments:

This cross correlation addresses the question whether a statistically significant difference exists between the professional category of participants and their self perceived mathematical background.

No statistically significant difference can be seen, however some cells did not contain enough data to make this a solid derivation

Graph: see next page


Bar Chart
Count
0
2
4
6
8
10
trainee
faculty
private
none
faculty + private
profession
mathematical background
weak
average
good
strong

CROSS-CORRELATION BETWEEN Q9 AND Q1 (All language groups)

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
profession * formal courses new optics	33	94,3%	2	5,7%	35	100,0%

		formal courses new optics						Total
		very much	very much-yes	yes	possibly	unlikely	no	
profession	trainee	0	0	0	0	2	0	2
	faculty	2	0	2	0	2	0	6
	private	1	0	10	3	2	3	19
	none	1	1	0	1	0	0	3
	faculty + private	0	0	2	0	1	0	3
Total		4	1	14	4	7	3	33

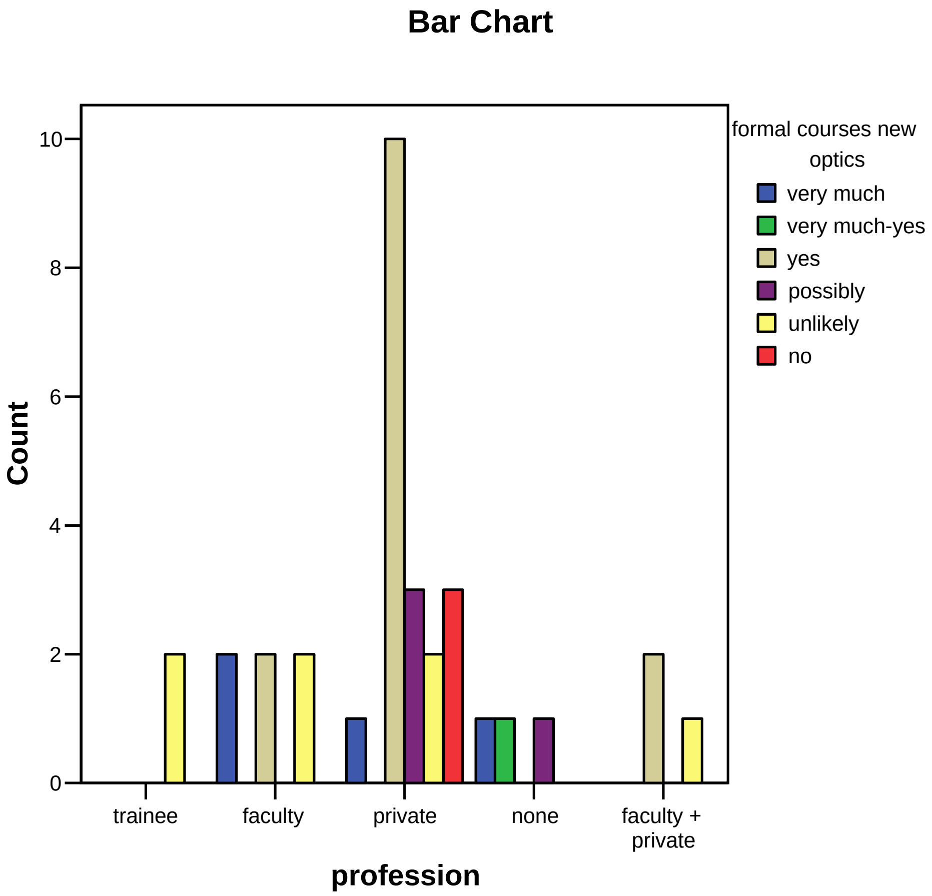
	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	30,808(a)	20	,058
Likelihood Ratio	27,386	20	,125
Linear-by-Linear Association	,363	1	,547
N of Valid Cases	33		

Observations and comments:

This cross correlation addresses the question whether a statistically significant difference exists between the professional category of participants (in particular more research oriented versus more clinically oriented) and their wish to receive formal course in biomedical optics.

No statistically significant difference can be seen, however we did not obtain enough expects counts for some cells to have reliable results

Graph: see next page


Bar Chart
Count
0
2
4
6
8
10
trainee
faculty
private
none
faculty + private
profession
formal courses new optics
very much
very much-yes
yes
possibly
unlikely
no

CROSS-CORRELATION BETWEEN Q8 AND Q9 (All language groups)

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
difficulty * formal courses new optics	33	94,3%	2	5,7%	35	100,0%

		formal courses new optics						Total
		very much	very much-yes	yes	possibly	unlikely	no	
difficulty	easy	1	0	3	2	3	1	10
	helpful	3	0	7	2	2	1	15
	too difficult	0	0	4	0	2	1	7
	helpful-too difficult	0	1	0	0	0	0	1
Total		4	1	14	4	7	3	33

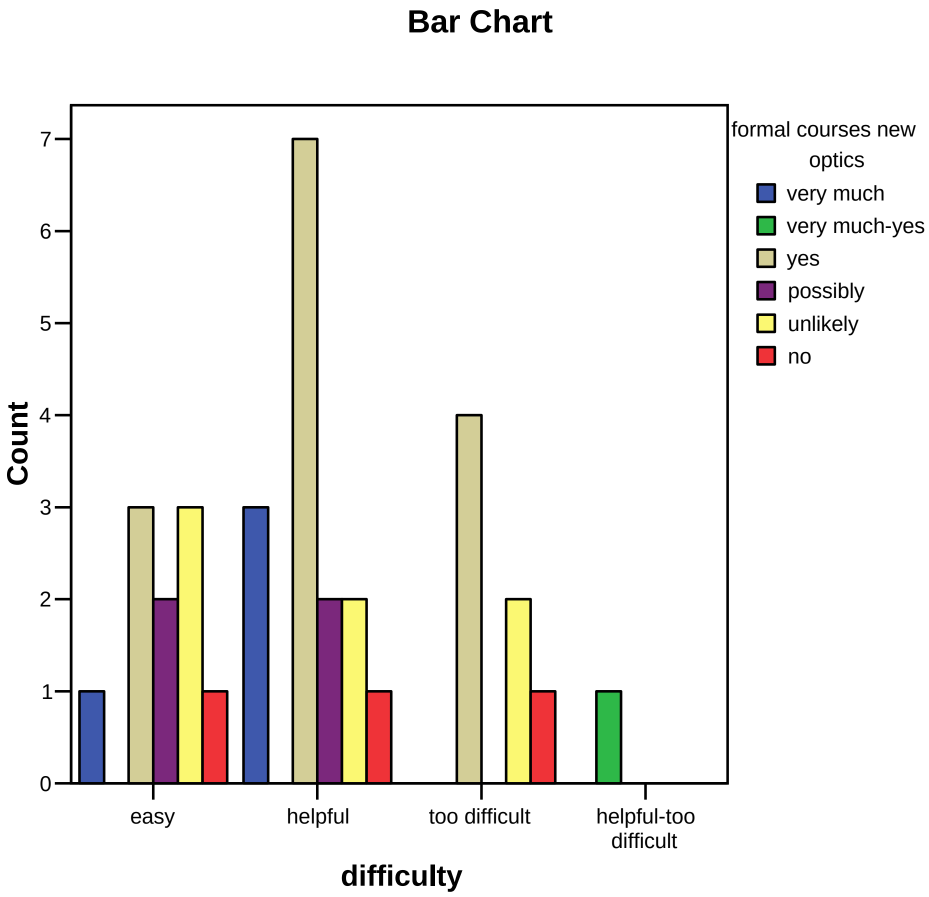
	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	38,083(a)	15	,001
Likelihood Ratio	15,523	15	,414
Linear-by-Linear Association	,751	1	,386
N of Valid Cases	33		

Observations and comments:

This cross correlation addresses the question whether a statistically significant correlation exists between the perceived difficulty of the lectures (English) and the request for formal courses in biomedical optics.

This correlation appears to be significant, although again some cells do not have a sufficient expected count in the statistics.

Graph: see next page


Bar Chart
Count
7
6
5
4
3
2
1
0
easy
helpful
too difficult
helpful-too difficult
difficulty
formal courses new optics
very much
very much-yes
yes
possibly
unlikely
no