Accommodation, refraction and cycloplegia: a review

Rafael Iribarren[a], Abel Szeps[b], Leonardo Fernández Irigaray[c], Carlos Kotlik[d], María Marta Galán[e]

[a] *Consultorio Dres. Iribarren, Buenos Aires, Argentina.*

[b] *Hospital Posadas, El Palomar, provincia de Buenos Aires, Argentina.*

[c] *Consultorio Dr. Fernández Irigaray, Buenos Aires, Argentina.*

[d] *Hospital Pediátrico Dr. Humberto Notti, Mendoza, Argentina.*

[e] *Exjefe del Departamento de Oftalmología del Hospital de Niños, La Plata, Argentina.*

Received: April 1st, 2023.
Approved: May 19th, 2023.

Corresponsal author
Dr. Rafael Iribarren
Arenales 981
Buenos Aires, Argentina.
rafairibarren@gmail.com

Oftalmol Clin Exp (ISSNe 1851-2658)
2023; 16(2): e109-e114.

Abstract

Accommodation is a type of reflex mediated by many cells and is thus called synkinesis. It is involuntary and produced by the fact that the retina is able to detect the plane of the image by computing the contrast sensitivity of the different wavelengths of the cones for red and blue. Since this involuntary synkinesia is associated with the triad *accommodation + convergence + myosis*, it is always present when refracting subjectively (or when performing retinoscopy or automatic autorrefractometry), and must be taken into account by performing cycloplegia after all the subjective tests of spectacles and phoria have been tried, both monocularly and binocularly, before prescribing glasses, drops or surgery, according to the best medical criteria to benefit the patient. In this paper we review current concepts on the subject and point out their importance in the context of medical care of visual health, both in school children and in adults, whether myopic or hyperopic. All these aspects show us that refractive problems are now currently considered conditions for medical treatment.

Key words: accommodation, refraction, cycloplegia, myopia, hyperopia, presbyopia

Algunas notas sobre la acomodación, la refracción y la cicloplejía

Resumen

La acomodación es una forma de reflejo que, al ser mediado por muchas células, se llama sincinesia. Es involuntaria y producida por el hecho de que la retina es capaz de detectar el plano de la imagen sobre ella a partir de computar la sensibilidad al contraste de las diferentes longitudes de onda de los conos para el rojo y el azul. Ya que esta sincinesia involuntaria se asocia a la triada *acomodación + convergencia + miosis*, ella está siempre presente al refraccionar subjetivamente (o al hacer retinoscopía o realizar autorrefractometrías automáticas), y es importante tenerla en cuenta realizando una cicloplejía luego de hacer todas las pruebas subjetivas de anteojos y foria, tanto monoculares como binoculares, antes de prescribir artesanalmente anteojos, gotas o cirugía, según el mejor criterio médico en beneficio para el paciente. En este trabajo realizamos una revisión sobre conceptos actuales del tema y señalamos la importancia que tienen en el contexto del cuidado médico de la salud visual, tanto en población escolar como en los adultos, ya sean miopes o hipermétropes. Todos estos aspectos realzan el concepto de que los problemas refractivos se consideran actualmente condiciones pasibles de tratamiento médico.

Palabras clave: acomodación, refracción, cicloplejía, miopía, hipermetropía, presbicia.

Algumas notas sobre acomodação, refração e cicloplegia

Resumo

A acomodação é uma forma de reflexo que, sendo mediada por muitas células, é denominada sincinese. É não intencional e produzido pelo fato de que a retina é capaz de detectar o plano da imagem sobre ela, calculando a sensibilidade ao contraste dos diferentes comprimentos de onda dos cones vermelho e azul. Como esta sincinesia involuntária está associada à tríade *acomodação + convergência + miose*, ela está sempre presente na refração subjetiva (ou na retinoscopia ou na autorrefratometria automática), e é importante levá-la em consideração realizando uma cicloplegia após fazer os testes subjetivos de óculos e foria, monoculares e binoculares, antes de prescrever óculos artesanais, colírios ou cirurgia, de acordo com o melhor critério médico para benefício do paciente. Neste trabalho fazemos uma revisão dos conceitos atuais sobre o tema e apontamos a importância que têm no âmbito dos cuidados médicos para a saúde visual, tanto na população escolar como em adultos, sejam eles míopes ou hipermétropes. Todos esses aspectos reforçam o conceito de que os problemas refrativos são atualmente considerados condições passíveis de tratamento médico.

Palavras-chave: acomodação, refração, cicloplegia, miopia, hipermetropia, presbiopia.

Introduction

In this paper we will review important aspects of the accommodative process and its impact on refractive error measurement, both in school children and in adults, considering the new research that allows us to understand why refractive problems are considered a condition to be treated from a medical approach. For this reason, we will describe general aspects of accommodation, convergence, refraction, and the role of the retina in accommodation on one hand and in the elongation of the eye on the other. We will also discuss the importance of cycloplegia, without neglecting what happens with physiological hyperopia, which seems to be overshadowed by the increased information we have in recent times about the epidemic of myopia.

Accommodation

Accommodation is the process of adapting vision to the different distances of the objects we are looking at, and its main actors are the crystalline lens with changes in curvature and position caused by the ciliary muscle. We now know that this process is part of a much larger complex system of accommodation that also includes small changes in corneal curvature, choroidal thickness and axial length, as well as internal changes in the refractive index gradient of the lens[1-3]. This

mechanism would be mediated by the postulated Perlia nucleus in the midbrain, in close proximity to the Edinger-Westphal nucleus. This mechanism of accommodation is found in children and young adults until middle age. Accommodation also allows good vision when there are hypermetropic refractive errors at these ages, which are partly the cause of asthenopia due to their insufficiency. This accommodation is altered over time by precipitation and oxidation of crystalline alpha, beta and gamma proteins, leading to presbyopia basically due to hardening of the crystalline lens[4].

It is known that accommodation is not part of a voluntary act because the ciliary is smooth muscle with muscarinic receptors for acetylcholine. But… "how is that, we don't focus at will?" someone approaching the subject would say. We can indeed move our eyes at will with voluntary extra ocular muscles innervated with acetylcholine also, but with nicotinic receptors. We can fixate on an object binocularly through extra ocular muscles, but bilateral accommodation, usually symmetrical, is done alone, involuntarily, reflexively. This is because the para-macular retina detects within milliseconds whether the image is falling into focus[5]. Then, via the parasympathetic reflex arc of the 3rd cranial nerve, the brainstem nuclei send the signals necessary for proper accommodation to the ciliary nerves[1]. All this occurs away from the cortex, our voluntary zone.

Accommodation and convergence

Accommodation and convergence (to see near objects) are partly linked by a triad (synkinesis): accommodation, convergence and myosis[1]. Yet this triad can be decoupled, as when we look closely in divergence at the beautiful 3D images that form in optical illusion games. The system is so dynamic that when a child or young person with good accommodation looks into an ordinary autorrefractometry unit with one eye into the apparatus and the other into the housing, they tend to accommodate and converge automatically without realizing that they are seeing double. Thus, without cycloplegia, myopes appear more myopic to the machine, and hyperopes less hyperopic, because of this reflex accommodative error.

Refractive error and accommodation

It is necessary to avoid these accommodative reflexes that also occur when refracting subjectively by putting a test frame on and covering one eye. As soon as the eye is covered, binocularity disappears, and a covered eye can go into a slight convergence thus accommodating the tested eye, so that the subjective refraction at a distance is wrongly tested. That is why, when refracting young people and children, the first thing to do is to perform static retinoscopy with both eyes open and looking into the distance, to detect binocularly if the eyes are myopic, hyperopic or astigmatic. And once in the presence of a myopic or hypermetropic patient, it is advisable to alternate binocular and monocular tests. We are all familiar with monocular tests. In these tests, we always try to give the highest positive addition, or the least negative addition, which provides the best possible acuity of vision without blurring and seeing red and green evenly in the duochrome test, precisely to avoid this reflex accommodation.

The lesser known binocular tests are simple. Looking into the distance, three meters away, with the subjective refraction already tested, add +0.50 or -0.50 in one eye without covering the other, to see how the patient sees better and how he/she feels more comfortable. Then the same can be done in the other eye. You can also then place two +0.50 probes, one with each hand, with both eyes of the subject looking at far, to see if he/she is still accommodating unnecessarily. In binocularity, looking far away, the accommodation linked to convergence is cancelled out. There are of course more complex tests that are beyond the scope of this analysis.

The retina, accommodation and axial elongation

We said earlier that the retina detects whether the image is falling into focus in milliseconds. But

how does it do this? We have the answer in part to Frank Schaeffel who spent 35 years researching this area in Germany, after discovering that chickens became myopic if they were fitted with negative lenses (and hyperopic with positive lenses)[6]. He has spent a lifetime unravelling this mysterious mechanism, and has just discovered that the retina detects the blur sign by comparing the contrast sensitivity of the S (blue) cones and the L (red) cones[7-8]. This is because the wavelength of blue falls in front of the retina when red and green are in the plane of the photoreceptors. There is almost a diopter difference (or approximately 300 microns of distance) between the focus of blue and red light in a 24 mm eye. And each group of cones has its own receptive fields and its own contrast sensitivity. So the retina in milliseconds computes the red and blue contrast sensitivity and knows if the image falls in focus. From there it sends at least two messages, one for accommodation through the optic nerve and the brainstem, and a much slower and local one in children and young people, to elongate the eye further if it has not yet finished growing for its best focal length (emmetropization)[9]. Frank Schaeffel discovered this in elegant experiments with young subjects watching films where the pixilation of red or blue had been alternately blurred out of focus with software developed in C++, showing that the retina moves closer or further away from the focus within a few minutes by moving 10 to 20 microns (measured with Lenstar)[7-8]. His experiments are all described in his lectures which can be viewed on the internet[8].

Cicloplegia

Despite all the efforts we make with fogging, binocular tests alternating with monocular tests and wide-field binocular auto-refractometry at one meter —as with the Plusoptix or the 2WIN (designed after the old photoscreener that took polaroid photos and a prototype presented at ARVO at the end of the last century also by Frank Schaeffel)[10-11]— involuntary accommodation can cause us to miss the right refractive error measurement, so cycloplegia becomes necessary for a correct prescription. Two drops of the cycloplegic agent after one drop of anesthesia, and waiting 40 minutes until the pupil does not respond, help us to know what the refraction is without accommodation[12].

Then the prescription of total cycloplegia or a partial refraction that respects accommodative tone and physiological hyperopia is another, more delicate question, especially in hyperopic children and young adults[13]. For this we have to take into account whether they are strabismic, endophoric or exophoric. Phoria and convergence are very important when prescribing. We often receive adults in their 50s who are unhappy with their +2.00 prescription for presbyopia and who have undetected near exophoria with poor convergence, who will do well with orthoptic treatment. Presbyopia is also a medical condition that affects the entire adult population, as today it can be treated with glasses, contact lenses, drops or surgery and the correct prescription depends on the ophthalmologist[14-16].

Today refractive errors are considered medical conditions

In addition to the accommodative phenomenon we have described, we now know about "retinal autonomy", a capacity of the para-macular retina which is strongly influenced by paraxial rays of the glasses we usually prescribe, in a positive or negative way. Ophthalmic optics is intrinsically associated with biochemistry, biology and physiology. What do we mean by this? Can a spectacle lens influence the progression of refractive pathology?

In children and young people it certainly can[17]. We are not talking now about correcting a refractive error, but about treating a medical condition which as such requires the exclusive action of the ophthalmologist. Refraction is therefore a medical act because, with drops or glasses, among many other things, its evolution over time can be modified and it is now considered a disease and not an error or defect[18]. There are already glasses that control the progression of myopia[19] and soon we will have those that control hyperopia[20], mak-

ing it disappear faster in growing children. As mentioned above, these designs are based on modulating the image falling around the fovea with defocusing or filtering.

Physiological hyperopia

Finally, we would like to explain what physiological hyperopia and normal accommodative tone are. From the age of one year, and during infancy, normal healthy children have an average cycloplegic refraction of +1.25 dioptres which decreases to +0.75 and then to +0.50 during adolescence until reaching near emmetropia in young adulthood in many cases[9]. These subjects function as emmetropes because of normal accommodative tone. But, isn't it that when we look into a vacuum the ciliary relaxes and the lens is focused at infinity as with cycloplegia? No, again it is not. In the complete darkness of the moonless night sky and seeing nothing but stars in the black space, emmetropic pilots generally show blurred vision as the accommodative tone without visual stimuli puts them between 0.75 and one diopter myopic[21]. This has been known for a long time and became very evident since the 1940s when night flights in the war time began. It was tested with open-field autorrefractometry by putting subjects in the dark for a while before measuring them and comparing with their refraction under cycloplegia[22]. This night myopia or empty field myopia is, as the name suggests, a transient myopia in the dark. Nowadays, in times of night driving, we have to be more aware of it. Many patients need negative glasses only at night or for driving: they are emmetropic during the day and myopic at night.

Thus the normal accommodative tone of young people compensates for physiological hyperopia. The mechanism of emmetropization has led us to study one of the most beautiful phenomena in nature[9, 23]. So knowing all this, to refract people under the age of 50, it is always advisable to do all the subjective tests described here, but after this it is also advisable to do cycloplegia to confirm the findings by paralyzing accommodation, and then to prepare the prescription for glasses to be bougth in the optician's office, so that in due course the optician can choose the frame that is easiest to center for each patient.

Conclusions

Accommodation is a complex physiological phenomenon, and despite the advances being made in neuroscience, there are still many mysteries for research. But the factors we know today allow us to understand the importance of aspects such as convergence, cycloplegia, the role of the retina and the effect of adequate refraction, since appropriate and integrative treatment can modify the development of a disease or even prevent its onset. The aspects discussed emphasize the role of vision in general health and its relationship with the central nervous system. All these aspects highlight the importance of the proper prescription of optical correction in order to achieve good binocular vision, which is why refraction is considered a medical pathology that must be treated as such.

References

1. Barraquer R. Mecanismos de acomodación del ojo humano. In: Arias Puente A (ed.). *Cirugía de la presbicia.* Madrid: Sociedad Española de Cirugía Ocular Implanto-Refractiva (SECOIR), 2010.

2. Maceo BM, Manns F, Borja D *et al*. Contribution of the crystalline lens gradient refractive index to the accommodation amplitude in non-human primates: in vitro studies. *J Vis* 2011; 11: 23.

3. Iribarren R. Crystalline lens and refractive development. *Prog Retin Eye Res* 2015; 47: 86-106.

4. Truscott RJ. Presbyopia: emerging from a blur towards an understanding of the molecular basis for this most common eye condition. *Exp Eye Res* 2009; 88: 241-247.

5. Panorgias A, Aigbe S, Jeong E *et al*. Retinal responses to simulated optical blur using a novel dead leaves ERG stimulus. *Invest Ophthalmol Vis Sci* 2021; 62: 1.

6. Schaeffel F, Glasser A, Howland HC. Accommodation, refractive error and eye growth in chickens. *Vision Res* 1988; 28: 639-657.
7. Swiatczak B, Schaeffel F. Emmetropic, but not myopic human eyes distinguish positive defocus from calculated blur. *Invest Ophthalmol Vis Sci* 2021; 62: 14.
8. Schaeffel F. Functional changes in the myopic retina interfere with emmetropization. In: Ohio State University. College of Optometry. Richard and Leonora Hill Lecture Series, 2023. Available at: https://www.youtube.com/watch?-v=OY5aYOzPmPc
9. Rozema J, Dankert S, Iribarren R. Emmetropization and non-myopic eye growth. *Surv Ophthalmol* 2023; *in press*.
10. Schaeffel F, Weiss S, Seidel J. How good is the match between the plane of the text and the plane of focus during reading? *Ophthalmic Physiol Opt* 1999; 19: 180-192.
11. Seidemann A, Schaeffel F. An evaluation of the lag of accommodation using photorefraction. *Vision Res* 2003; 43: 419-430.
12. Morgan IG, Iribarren R, Fotouhi A, Grzybowski A. Cycloplegic refraction is the gold standard for epidemiological studies. *Acta Ophthalmol* 2015; 93: 581-585.
13. Jacobs DS, Afshari NA, Bishop RJ *et al*. *Refractive errors*. San Francisco: American Academy of Ophthalmology, 2022. (Preferred practice pattern).
14. Renna A, Alió JL, Vejarano LF. Pharmacological treatments of presbyopia: a review of modern perspectives. *Eye Vis (Lond)* 2017; 4: 3.
15. Orman B, Benozzi G. Pharmacological treatments for presbyopia. *Drugs Aging* 2023; 40: 105-116.
16. Vejarano, F, Alió J, Iribarren R. Review of pharmacological treatments for presbyopia. *Curr Ophthalmol Rep* 2023; 11: 13-19.
17. Charman WN, Radhakrishnan H. Peripheral refraction and the development of refractive error: a review. *Ophthalmic Physiol Opt* 2010; 30: 321-238.
18. Holden BA, Fricke TR, Wilson DA *et al*. Global prevalence of myopia and high myopia and temporal trends from 2000 through 2050. *Ophthalmology* 2016; 123: 1036-1042.
19. De Tomas M, Kotlik C, Szeps A *et al*. Nuevos anteojos para control de la miopía. *Oftalmol Clin Exp* 2022; 15: e240-e243.
20. Beasley IG, Davies LN, Logan NS. The effect of peripheral defocus on axial growth and modulation of refractive error in hyperopes. *Ophthalmic Physiol Opt* 2022; 42: 534-544.
21. Bouman MA, Van Den Brink G. On night myopia. *Ophthalmologica* 1952; 123: 100-113.
22. Leibowitz HW, Owens DA. Night myopia and the intermediate dark focus of accommodation. *J Opt Soc Am* 1975; 65: 1121-1128.
23. Swiatczak B, Schaeffel F. Myopia: why the retina stops inhibiting eye growth. *Sci Rep* 2022; 12: 21704.