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Optical factors influencing the amplitude of accommodation

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ABSTRACT

The purpose of this work was to find plausible predictors among optical parameters that may explain the inter-individual differences in subjective amplitude of accommodation not explained by age. An exploratory multivariable regression analysis was carried out retrospectively on a dataset with 180 eyes from 97 subjects (ages ranged from 20 to 58 years). Subjective amplitudes of accommodation were recorded with the use of a custom-made Badal system. A commercial aberrometer was used to obtain each eye's wavefront during the full range of accommodation. The plausible predictors under study were pupil diameter in the unaccommodated eye, its reduction with accommodation; fourth- and six-order Zernike spherical aberration, their reduction with accommodation, and subjective refraction. At a significance level of 0.05, only fourth- and sixth-order Zernike spherical aberration were found to be predictors of subjective amplitude of accommodation not explained by age, each explaining on their own less than 5% of the variance, and about 9% together. All other optical parameters explained less than 2%. Spherical aberration did not explain the greater variability for younger eyes than for older eyes. The remainder variability in amplitude of accommodation not explained by age or spherical aberration was about ±2.6 D for 20 year-old subjects, ±1.5 D for 40 year-old subjects, and about ±0.6 D for 55 year-old subjects. Optical factors do not seem to account for much of the inter-individual differences in subjective amplitude of accommodation. Most of the variability not explained by age must be due to anatomical differences and physiological, psychological, or other factors.

1. Introduction

Although the reduction in the ability to accommodate is an irreversible consequence of visual function senescence, there are very large inter-individual differences in the maximum accommodation capacity for subjects of the same age. Fig. 1 is a reprint of a figure from Duane (Duane, 1922; Duane, 1909; Duane, 1912) showing the decrease in subjective amplitude of accommodation (AA) with age. The inter-individual differences are evident. For instance, for subjects of age 20, there are some subjects who accommodate more than 6 D more than others. Even for presbyopes older than 52 years, differences in AA can be as large as 2 D.

Duane's AA data may have been considerably influenced by axial refraction (Bernal-Molina, Vargas-Martín, Thibos, & López-Gil, 2016), as it was measured to the spectacle plane (Duane, 1909). Although he did not report specific refraction values of the subjects, this may explain the large variability of AA for any given age as seen in Fig. 1. In contrast, mean values of the data obtained by Jackson (solid blue curve superimposed on Duane's graph in Fig. 1), who used a more appropriate plane of reference placed 2 mm behind the corneal vertex (Xu, Bradley, Lopez Gil, & Thibos, 2015), show lower subjective AA values, especially for non-presbyopic eyes. Jackson's data also exhibited larger inter-individual differences, even for subjects with age beyond 52 years (Fig. 1). The large variability in the AA found by these two researchers has also been found in more recent studies using subjective and objective measurements (Ostrin & Glasser, 2004; Wold, Hu, Chen, & Glasser, 2003).

The different methodology used by these two researchers may explain their differences in the mean AA value and illustrates that, in general, special care should be taken when comparing values of subjective AA obtained in different studies. In addition to differences in calculations, instructions given to subjects (Stark & Atchison, 1994), stimulus (Stark & Atchison, 1994), object luminance (Johnson, 1976; Lara, Bernal-Molina, Fernandez-Sanchez, & Lopez-Gil, 2014), and object chromaticity (Drew, Borsting, Stark, & Chase, 2012); refractive errors, amblyopia and biometric parameters (Maheshwari et al., 2011), and letter size (Heath, 1956; Lopez-Gil et al., 2013) have been shown to play an important role in the outcome of subjective AA. However, none of those studies, or

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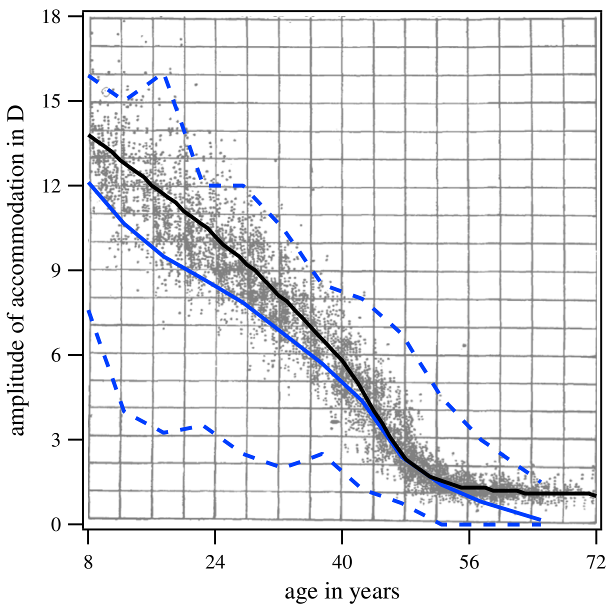

Fig. 1. Change in amplitude of accommodation with age. Original data from Duane (Duane, 1922), reprinted from American Journal of Ophthalmology, 5, Duane A, Studies in monocular and binocular accommodation with their clinical applications, 865–77, 1922, with permission from Elsevier. The solid black curve represents the mean AA and its change with age from Duane data. The solid blue curve represents the mean AA and its change with age from Jackson (Jackson, 1907) data. Maximum and minimum at each age (dashed blue curves) are also shown.

any other published so far, have provided a explanation of the large variability of the AA between subjects with similar biological parameters using similar methodological procedures (Duane, 1912; Jackson, 1907; Wold et al., 2003). Large variability in the AA may be due to inter-individual differences in ciliary muscle function or lens properties, optical factors other than physiological power change (ametropia, pupil size, HOA,...), or psychological factors, such as variability in blur criterion among individuals (Woods, Colvin, Vera-Diaz, & Peli, 2010) or between different trials of the same individual. Other experimental errors also add to variability.

It is well known that high-order aberrations (HOA) differ considerably between subjects (Salmon & van de Pol, 2006; Thibos, Hong, Bradley, & Cheng, 2002) and that they affect the eye's depth of focus (DoF) (Benard, Lopez-Gil, & Legras, 2010; Rocha, Vabre, Chateau, & Krueger, 2009), as well as the accommodative response (Lopez-Gil & Fernandez-Sanchez, 2010). Nevertheless, since each eye of the same subject has slightly different HOA (Castejon-Mochon, Lopez-Gil, Benito, & Artal, 2002), their subjective AA should be different, which is not usually the case (Sabesan, Zheleznyak, & Yoon, 2012). One might argue that the reason they are not different is that the differences in HOA between eyes is not large enough to produce a measurable difference in DoF between eyes, or because DoF is mainly affected by those HOA that present similar magnitudes in most eyes (Castejon-Mochon et al., 2002; Porter, Guirao, Cox, & Williams, 2001). However, it has been shown that LASIK does not seem to change AA greatly, even though it does significantly change HOA.

Several studies have been performed so far regarding the variations of the aberration during accommodation (Duane, 1912; Jackson, 1907), its dependence with age (Castejon-Mochon et al., 2002; Ostrin & Glasser, 2004; Radhakrishnan & Charman, 2007; Sabesan et al., 2012), different ocular parameters (Abraham et al., 2010); and the variability of the AA measurements (Antona, Barra, Barrio, Gonzalez, & Sanchez, 2009). Nevertheless, no optical explanations have yet been given to the large variation found among the normal population.

The purpose of this work was to estimate how much optical factors such as pupil diameter, spherical aberrations (SA) and their variation with accommodation, and uncorrected spherical equivalent explain inter-individual differences in subjective AA not explained by aging. A non-linear model was fitted to the subjective AA and residuals, i.e., the part in AA not explained by age, extracted. In an exploratory analysis, simple and multiple linear regression fits were obtained for the residual AA over one or more covariates and the most statistically plausible model selected.

2. Methods

2.1. Subjects

This was a retrospective study with data extracted from a dataset of 180 eyes from 97 subjects (López-Gil, Fernández-Sánchez, Thibos, & Montés-Micó, 2009). All subjects in the study had a visual acuity of 20/20 or better in the eye analyzed. Exclusion criteria included eyes with glaucoma, conjunctivitis, keratitis, cataracts, dry eye syndrome, and amblyopia eyes. Eyes were discarded from young subjects that reported accommodative insufficiency or for which that insufficiency was evident during an initial clinical evaluation. After that evaluation none of the eyes involved in this study presented any factor that could interfere with general or ocular health, including accommodation and visual function. The study was conducted following the tenets of the Declaration of Helsinki. Written informed consent was obtained from each participant before testing and after explaining the procedure and goals of the experiment.

2.2. Subjective measurement of the amplitude of accommodation

The amplitude of accommodation was obtained subjectively with a custom-made Badal optometer. The stimulus used was a Bailey-Lovie chart (with a luminance of 100 cd/m^2) located 6 m (20 feet) from the subject's eye. Optical details of the Badal optometer and measurement procedures have been described elsewhere (López-Gil et al., 2009). The origin of vergences used was the entrance pupil plane of the eye. The instrumental precision was ±0.1 D. The subject's head was fixed using a chin rest and astigmatism corrected with a trial lens placed 12 mm in front of the eye. To avoid diplopia, the contralateral eye was covered. Changes in the equivalent sphere caused by astigmatism correction, as well as the distance between the target and the moving lens, were taken into account using Gaussian optics in the computation of the near and far point. The subject's task was to find the two extreme positions of the lens where the 20/25 line of letters was maintained clear without any perceptible blur. The same trained optometrist performed all subjective measurements. Mean and standard deviation of 5 repeated measurements for both subjective far and near points were obtained. When left and right eyes were measured, it was made randomly and without taking into account the potential difference between dominant and non-dominant eye. A high contrast letter chart with 20/25 letters was used as stimulus since it stimulus contains high spatial frequencies and so blur can be more easily detected when it is out of focus. The Badal system assured that the spatial frequency content in terms of cycles per degree stayed constant at any vergence.

2.3. Measurements of wavefront aberrations at different accommodative states

Wavefront aberrations of each eye were recorded during accommodation with a commercial aberrometer (irx3 Imagine Eyes, France). This device has a Shack-Hartmann wavefront sensor

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