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Myopia and visual acuity impairment: a comparative study of Greek and Bulgarian school children

Sotiris Plainis[1], Joanna Moschandreas[2], Panagoula Nikolitsa[1], Eleani Plevridi[1], Trisevgeni Giannakopoulou[1], Vania Vitanova[3], Paraskevi Tzatzala[1], Ioannis G. Pallikaris[1,3] and Miltiadis K. Tsilimbaris[1,3]

[1]Institute of Vision and Optics (IVO), School of Health Sciences, University of Crete, PO Box 2208, 71003 Heraklion, Crete, [2]Department of Social Medicine, University of Crete, Crete, and [3]Department of Ophthalmology, University Hospital of Crete, Crete, Greece

Abstract

Purpose: To compare the proportions of school children with myopia and impaired visual acuity in Greece and Bulgaria.

Methods: A sample of 898 children, aged 10–15 years, was selected from two primary and two secondary schools in a Greek city (Heraklion), and one primary and secondary school in a Bulgarian city (Stara Zagora). Five hundred and eighty eight children were Greek (65.5%, mean age 12.5 ± 0.08 years) and 310 Bulgarian (34.5%, age 12.4 ± 0.07 years). VA was assessed with the habitual refractive correction. Refractive error was measured in the absence of cycloplegia using an auto-refractor.

Results: The percentage of children, tested with their habitual refractive correction, with decimal VA <0.5 in at least one eye was 11.7% (95% CI 9.1–14.3%) for Greek and 5.2% (95% CI 2.7–7.6%) for Bulgarian pupils. The percentage of myopic children also differed between the two countries with the proportion with myopic refractive error ≤–0.75 D and decimal VA <0.8 at primary school level being 14.1% and 28.9% in Stara Zagora and Heraklion respectively and 13.0% and 46.9% (95% CI 18.2–29.2%, $p < 0.0001$) at secondary school level. Among the myopic pupils only 35.8% used corrective spectacles in Stara Zagora, compared to 70.7% of the children in Heraklion. Finally, myopia appeared more prevalent in female adolescents with the effect being statistically significant only for Greek children (55% vs 40% of males, $p = 0.015$).

Conclusions: The increased proportion of myopic children in Heraklion, compared to Stara Zagora, may arise from a number of environmental and socio-economic factors, which need to be further investigated in order to understand the differences observed among European populations.

Keywords: astigmatism, myopia, refractive error, school children, visual acuity

Introduction

Twenty years ago, a report by a working group on the prevalence and progression of myopia (Adams *et al.*, 1989) concluded that among Caucasian schoolchildren there have been no major changes in the distribution of refractive errors in the last 100 years, with the exception of severe myopia which appeared to be less prevalent at all ages. On the other hand, myopia prevalence increased significantly in non-Caucasian ethnic groups, especially in East Asian (Wilson and Woo, 1989; Saw, 2003) and Eskimo (Young *et al.*, 1969; Morgan and Munro, 1973; Alward *et al.*, 1985) populations. In the last two decades, many studies have confirmed the rising figures in prevalence rates in Asia, which have today reached almost epidemic proportions in urban commu-

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Correspondence and reprint requests to: Sotiris Plainis.
Tel.: +0030 2810 394807; Fax: +0030 2810 394653.
E-mail address: plainis@med.uoc.gr

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nities, such as Hong Kong, Taiwan and Singapore (see Saw, 2003 for review). For example, Lin *et al.* (2004) found that the prevalence of myopia in 12-year old school children in Taiwan increased from 36.7% in 1983 to 61% in 2000. Moreover, in a study involving Chinese school children in Hong Kong, Wu and Edwards (1999) documented a 50% increase in the prevalence of myopia in the offspring of non-myopic parents over two generations. They attributed the increase in myopia to environmental influence.

It is well established that a number of limitations and inconsistencies in technical and statistical procedures (i.e. myopia definition, mode of determining refractive error, use of cycloplegia, participation criteria) impede direct comparisons between various studies since no standardization has been introduced (Weale, 2003). Comparisons of prevalence rates within populations become even more difficult because myopia prevalence and progression varies also with age, country, sex, race, occupation, environment, and socio-economic factors (Adams *et al.*, 1989; Negrel *et al.*, 2000; Gilmartin, 2004; Konstantopoulos *et al.*, 2008).

However, there is evidence that in recent years the prevalence of myopia in young adolescent eyes has also increased in the industrialised societies of the West (Grosvenor, 2003; Gilmartin, 2004). This is consistent with a recent compilation of studies on Scandinavian school children. Villarreal *et al.* (2000) examined 1045 Swedish children between ages 12 and 13 and found a prevalence of myopia of about 49.7%; greatly increased compared to values of 6.0% reported in Danish children of the same age in the 1960s (Goldschmidt, 1968) and of 7.2% (Laatikainen and Erkkila, 1980) and 14%(Mantyjarvi, 1983) reported on Finnish children in the 1980s. Similarly, in a longitudinal study in U.S between 1989 and 1993, Zadnik (1997) reported a myopia (≤−0.50) frequency of 28% for 13 year old children. This value is significantly increased compared to the 12% myopia prevalence found for 13 year old children in the same community in a previous study between 1954 and 1956 (Blum *et al.*, 1959), although there is a possibility of changes in the ethnic demographics of the population over the intervening period. For example, in a large city with a strong ethnic mix, such as Sydney, myopia prevalence may vary between districts, depending on the ethnnicity of the residents. As a result, myopia prevalence for 12 year–old children in Eastern suburbs, with 42.9% being immigrants from Eastern Europe, was found to be 8.3% (Junghans and Crewther, 2003), whereas a study across all suburbs (Rose *et al.*, 2008) reported average rates of 12.8%, with only 5.1% of European Caucasians being myopic. The low rates for Caucasians in Eastern European countries were confirmed by a recent study of Polish 12–13 year-old school children of the same age-group, showing that 13% of students were myopic (Czepita *et al.*, 2007), with the rates being constant for the last 35 years (Orlikowska, 1971). Therefore, the suggestion of the tendency towards myopisation among Caucasian populations is not confirmed across all European ethnicities.

Although myopia is the most commonly encountered visual problem among school-aged children (Resnikoff *et al.*, 2008; World Health Organisation (WHO) (2000), Maul *et al.*, 2000; Villarreal *et al.*, 2003, 2000; Saw, 2003; Laatikainen and Erkkila, 1980), with significant economic and educational consequences (Powell *et al.*, 2005; Resnikoff *et al.*, 2008), to date only a few studies have been carried out to estimate myopia prevalence in European school-children. The main purpose of the study is to compare the proportions of children with impaired visual acuity and myopia in Greece and Bulgaria. Moreover, visual acuity with habitual refractive correction at school is assessed in order to evaluate the extent to which optimal refractive error corrections are being met in school-aged children in a Greek and a Bulgarian city.

Methods

Study participants

A sample of two primary schools and two secondary schools were selected in the Greek city of Heraklion on the island of Crete, and one primary and secondary school housed in the same building were selected in Stara Zagora, Bulgaria. One primary and one secondary school in Crete were independently funded, whilst all other schools were state schools. Stara Zagora and Heraklion have a similar population size, each having approximately 180 000 residents. The schools were located in the centre of the two cities. All pupils in primary grades five to six and secondary school grades one to three were invited to participate. The study was conducted in two periods: Greek children were examined in March and April 2006 and May 2007, and Bulgarian children in May 2007. All pupils at school on the day of examination were tested apart from two Greek secondary school pupils (0.73%) who did not wish to participate.

Of the 932 pupils who initially agreed to participate in the study, 34 did not participate in all vision screening tests, thus 898 children (96.4%) were included in final analysis. Five hundred and eighty eight children were Greek (65.5%) and 310 children were Bulgarian (34.5%).

Written informed consent was obtained from at least one of the parents and the regional department of primary and secondary education (Ministry of Education) in both countries. The study design was observational and therefore no interventional procedures, such as cycloplegic drugs, were incorporated. Verbal consent was obtained from each child before examination. The research conformed to the tenets of the Declaration of Helsinki and followed a protocol approved by the University of Crete Research Board.

Experimental procedure

Visual acuity (VA) was assessed with the habitual refractive correction (if any), by two examiners (working in parallel), using the UoC European-wide (Plainis *et al*., 2007) logMAR chart 1 and chart 2 for RE and LE, respectively. A back-illuminated slim stand (Cat No. 392; Sussex Vision Ltd., Rustington, West Sussex, UK), at 4 m distance, held the acuity charts. Luminance values were within the recommendations for standardising the measurement of VA (160 cd m^{-2}) (Ferris and Sperduto, 1982). All subjects were asked to identify each letter one by one in each line starting from the upper left-hand letter, and to proceed by row until they could no longer name correctly at least one letter in a line. They were instructed to read slowly and guess the letters when they were unsure. The termination rule for stopping was four or five mistakes on a line (Carkeet, 2001). The experimenter scored correct responses on specially designed data forms. Visual acuity was derived from the calculation of missed letters up to the last readable line.

Sphero-cylidrical refractive error was measured using an auto-refractor (Potec PRK-5000; Potec Ltd., Daejeon, Korea). Children with strabismus ($n = 8$), identified using a cover test, were excluded from the study. Automated refraction was performed without using any cycloplegic drugs. Spectacle use was ascertained by children's verbal responses and was classified into three categories: no use of prescription spectacles, use of spectacles at all times, use of spectacles only at home.

Children with decimal VA < 0.8 (corresponding to logMAR acuity > 0.1) in at least one eye were characterised as having 'minimal visual impairment', whereas children with decimal VA < 0.5 (corresponding to logMAR acuity > 0.3) were characterised as having 'mild visual impairment', caused by uncorrected or inadequately corrected refractive error, according to World Health Organisation (WHO) standards [World Health Organisation (WHO), 2003], needing referral for visual screening [World Health Organisation (WHO), 2000]. Myopia proportions were calculated by the use of spectacles, the score of decimal VA and the measured refractive error. VA score was included in the definition of myopia to reduce the possibility of overestimating the proportion of myopic children, since cycloplegia was not applied beforehand. Myopia was defined using the following criteria: (1) spherical equivalent (mean of the two principal meridians) refractive error ≤−0.75 D in at least one eye and myopic spectacle use at school or (2) uncorrected decimal VA < 0.8 with spherical equivalent refractive error ≤−0.75 D in at least one eye. Astigmatism was defined as a difference between the two principal meridians > 0.75 D in at least one eye.

Statistical analysis

Comparisons between categorical variables were made using the chi-squared test of independence. 95% confidence intervals for proportions and differences between proportions were calculated using the normal approximation to the binomial distribution. The independent samples Z test was used to compare the average ages of the children examined in each country at each of the two educational levels. Cochran's test was used to study the possible effect of educational level on decreased VA (VA < 0.5), accounting for country differences. Unconditional logistic regression models were fitted to compare the estimated odds of myopia in the two groups of children (Stara Zagora and Heraklion), adjusted for the possible effects of sex and age. Second order interaction terms were also considered. The significance level was set to 5%. The statistical package SPSS 15.0 (SPSS Inc., Chicago, IL, USA) was used throughout.

Results

A summary of the characteristics of the 310 Bulgarian and 588 Greek pupils, and comparisons between the two countries for the two age groups considered, are presented in *Tables 1 and 2*. The total number of male participants was 313 (53.2%) in Crete and 151 (48.7%) in Stara Zagora ($p = 0.197$). The mean age of pupils was not found to differ to a statistically significant extent (mean age 12.5 years, S.E. 0.08, and 12.4, S.E. 0.07, in Stara Zagora and Crete respectively, $p = 0.630$).

The proportions of Greek and Bulgarian pupils wearing spectacles at school were found to be 23.3% (with 95% CI from 19.9% to 26.7%) and 8.7% (with 95% CI from 5.6% to 11.9%), respectively ($p < 0.0001$, the 95% CI for the difference being between 10 percentage units and 19 percentage units). It was found that 17.8% (95% CI 13.6–22.0%) of the Greek 5th–6th grade primary school pupils wore spectacles for the correction of myopia or hyperopia as contrasted with 9.4% (95% CI 4.7–14.1%) of the corresponding Bulgarian pupils $p < 0.0001$, the 95% CI for the difference being from 2.1 to 14.7 percentage units). For pupils in grades 1–3 of secondary school, the percentage of spectacle wearers in Crete was 40.7% compared to 14.3% in Stara Zagora.

The percentage of children, tested with their habitual refractive correction, with decimal VA < 0.8 in at least

Table 1. Comparisons of characteristics of children between 10 years and 15 years of age in Bulgaria and Greece ($n = 898$)

	Stara Zagora ($n = 310$)	Heraklion ($n = 588$)	
Characteristics	***n* (%)**	***n* (%)**	***p*-value**
Mean age in years (S.E.)	12.5 (0.08)	12.4 (0.07)	0.630
Sex	–	–	0.197
Male	151 (48.7)	313 (53.2)	–
Female	159 (51.3)	275 (46.8)	–
VA < 0.5[a]	16 (5.2)	69 (11.7)	0.001
Spectacle use	–	–	0.165[b]
At all times	4 (25)	16 (23)	–
Only at home	1 (6)	21 (30)	–
No spectacles	11 (69)	32 (46)	–
VA < 0.8[a]	68 (21.9)	192 (32.7)	0.001
Myopia prevalence	42 (13.5)	219 (37.2)	<0.001
Spectacle use	–	–	<0.001
At all times	13 (31.0)	128 (58.4)	–
Only at home	2 (4.8)	27 (12.3)	–
No spectacles	27 (64.3)	64 (29.2)	–
Sex	–	–	0.032
Male	19 (12.6)	104 (32.2)	–
Female	23 (14.5)	115 (41.2)	–
Astigmatism prevalence	30 (9.7)	101 (17.2)	0.002

[a]In at least one eye, measured with the currently available (if any) refractive correction.
[b]Comparisons were made of spectacle use vs no spectacles (due to the small expected frequencies), using Fisher's exact test.

one eye was 29.5% (95% CI 24.5–34.6%) for Greek compared to 20.8% (95% CI 14.3–27.8%) for Bulgarian children, the 95% CI for the difference in percentages between the two countries being 0.5–16.9 percentage units. When the visual impairment criterion was set to VA <0.5 in at least one eye the corresponding percentages were 11.7% (95% Cl 9.1–14.3%) for Greek and 5.2% (95% Cl 2.7–7.6%) for Bulgarian students, again a statistically significant difference ($\chi^2 = 10.24$ on 1 df, $p = 0.001$). A trend in decreased VA was observed, with a higher proportion of children in secondary education having VA <0.5 (5.6% vs 4.7% vs in Stara Zagora and 13.2% vs 10.5% in Crete), although the result was not statistically significant (Cochran's chi-squared statistic 0.82 on 1 df, $p = 0.365$) (see *Figure 1*). Whilst 53.6% (37 out of 69 pupils) of the Greek children with VA <0.5 have been prescribed with spectacles, the percentage for Bulgarian children was significantly lower (31.3%, chi-squared 16.59 on 2 df, $p < 0.0001$).

Regarding the myopia rates, 37.2% (95% CI 33.3–41.5%) of Greek children vs only 13.5% (95% CI 9.7–17.4%) of Bulgarian children showed myopic refractive error ≤-0.75 D and decimal VA <0.8. The 95% confidence interval for the difference between the two proportions is from 18.2 to 29.2 percentage units ($p < 0.0001$). *Figure 2a* also shows that myopia rates

Table 2. Characteristics of children for two age groups: (1) between 10 years and 12 years attending primary school ($n = 464$) and (2) between 13 years and 15 years attending secondary school in Bulgaria or Greece ($n = 434$)

	Primary school			Secondary school		
	Stara Zagora ($n = 149$)	Heraklion ($n = 315$)		Stara Zagora ($n = 161$)	Heraklion ($n = 273$)	
Characteristics	***n* (%)**	***n* (%)**	***p***	***n* (%)**	***n* (%)**	***p***
Mean age in years (S.E.)	11.3 (0.04)	11.3 (0.04)	0.712	13.7 (0.06)	14.1 (0.05)	<0.001
Sex	–	–	0.316	–	–	0.428
Male	73 (49)	170 (54)	–	78 (48.4	143 (52.4)	–
Female	76 (51)	145 (46)	–	83 (51.6)	130 (47.6)	–
VA < 0.5[a]	7 (4.7)	33 (10.5)	0.038	9 (5.6)	36 (13.2)	0.012
Spectacle use	–	–	–	–	–	0.024[b]
At all times	3 (43)	8 (24)	–	1 (11)	8 (22)	–
Only at home	0	5 (15)	–	1 (11)	16 (44)	–
No spectacles	4 (57)	20 (61)	–	7 (78)	12 (33)	–
VA < 0.8[a]	31 (20.8)	93 (29.5)	0.048	37 (23.0)	99 (36.3)	0.004
Myopia	21 (14.1)	91 (28.9)	0.001	21 (13.0)	128 (46.9)	<0.001
Spectacle use	–	–	0.165	–	–	<0.001
At all times	8 (38)	49 (54)	–	5 (24)	79 (62)	–
Only at home	1 (5)	10 (11)	–	1 (5)	17 (13)	–
No spectacles	12 (57)	32 (35)	–	15 (71)	32 (25)	–
Sex	–	–	–	–	–	–
Male	12 (16.4)	44 (27.6)	–	7 (9)	57 (39.9)	–
Female	9 (11.8)	47 (30.3)	–	14 (16.9)	71 (54.4)	–
Astigmatism	9 (6)	52 (16.5)	0.002	21 (13)	49 (17.9)	0.180

[a]In at least one eye, measured with the currently available (if any) refractive correction.
[b]Comparisons were made of spectacle use vs no spectacles (due to the small expected frequencies), using Fisher's exact test.

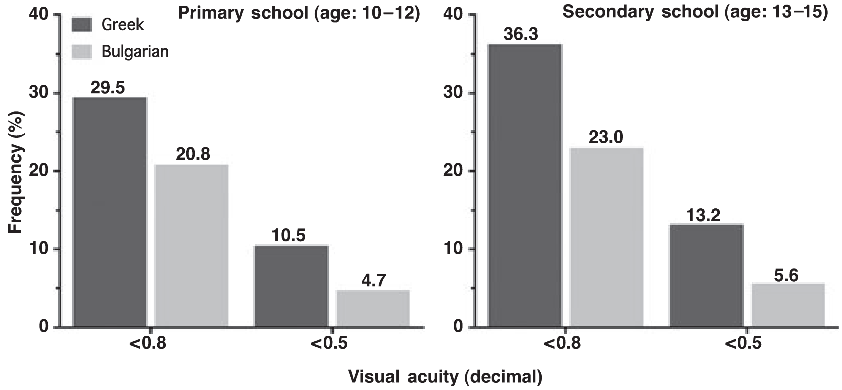

Figure 1. Plots of percentage frequency of primary (left) and secondary (right) school children in Greece and Bulgaria showing reduced visual acuity (<0.8 or <0.5) at school. Children were tested with their habitual refractive correction.

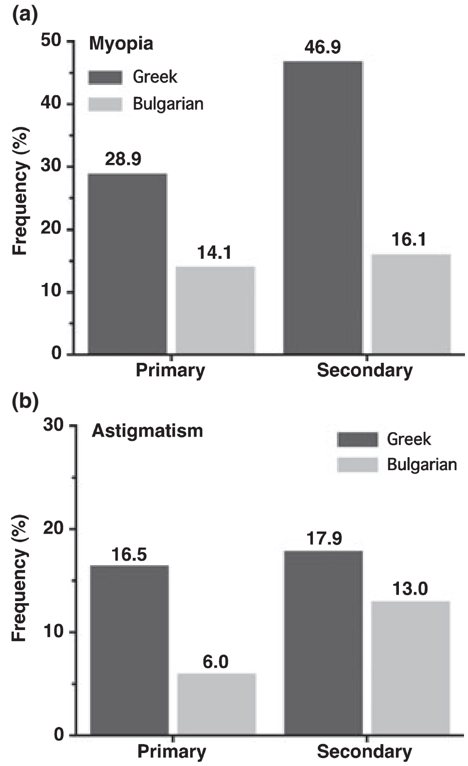

Figure 2. Plots of (a) myopia and (b) astigmatism rates (%) for Greek and Bulgarian children attending primary and secondary schools.

differ between primary (28.9%) and secondary (46.9%) school children in Greece ($p < 0.0001$), although no statistically significant difference was found from the Bulgarian children (14.1% in primary school children, 13.0% in secondary school children, $p = 0.787$) (see *Figure 2a*). Note, that 70.7% of Greek myopic pupils wear spectacles, and 58.4% of Greek myopic children wear spectacles at all times. In contrast, only 35.8% of Bulgarian children with myopia wear spectacles (either at all times or at home). This difference between the two countries is statistically significant ($\chi^2 = 19.2$ on 2 df, $p < 0.0001$).

Figure 2b displays the rates of astigmatism (cyl ≤ −0.75D), which also shows statistically significant differences ($\chi^2 = 8.5$ on 1 df, $p = 0.004$) between the two countries (16.8% in Greece vs 9.7% in Bulgaria).

Finally, as depicted in *Figure 3*, the percentage of girls with myopia appeared somewhat higher than that of boys in both countries, although the difference was statistically significant in the Greek (33.2% of boys, 41.2% of girls, $p = 0.032$) and not in the Bulgarian children (12.6% and 14.5%, $p = 0.628$). For secondary educational level the difference in myopia proportions was significant in both Greek (39.9% of boys vs 54.6% of girls) and Bulgarian children (9.0% of boys vs. 16.9% of girls). No statistically significant gender differences in myopia prevalence were detected at primary school level in either country although in Bulgaria the proportion of girls with myopia was lower than that of boys (Bulgaria: 16.4% boys vs 11.8% of girls; Greece: 27.6% of boys vs 30.3% of girls).

Using a logistic regression model, it was found that the odds of myopia in Greek primary school children were 2.5 times those for Bulgarian children (the 95% CI for the OR being 1.5–4.2), after adjusting for age group (OR 0.91, 95% CI 0.66–1.24) and sex (OR 0.98, 95% CI 0.63–1.51). No evidence was found of an interaction between sex and country. The odds of myopia in Greek secondary school children were found to be 5.9 times those for Bulgarian children (the 95% CI for the OR being 3.5–10.0), after adjusting for sex (the odds of myopia in males being 0.5 times those for females, 95% CI 0.3–0.8) and year of age (OR 1.2, 95% CI 0.9–1.5). Again, there was no evidence of a second order interaction.

Discussion

The present comparative vision screening study is the first to have been undertaken in Greek and Bulgarian

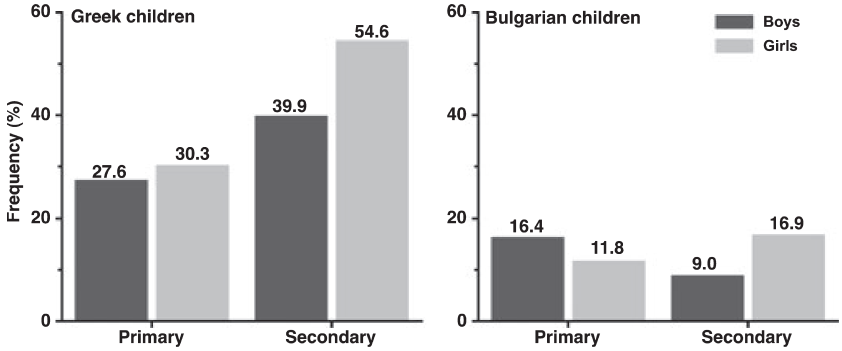

Figure 3. Plots of myopia rates (%) as a function of sex for Greek (left) and Bulgarian (right) primary and secondary school children.

school children. Only two previous published studies, conducted on older age groups than in the current study, present findings from young Greek populations, one reporting myopia prevalence in 15–18 year-old students, based on self-reported data (Mavracanas *et al*., 2000) and a recent one investigating factors associated with myopia in young men undertaking their military service (Konstantopoulos *et al*., 2008). The results indicate that a high proportion of children in both countries (21.9% of Bulgarian vs 32.7% of Greek) attend school lessons with ''minimal visual acuity impairment'' (VA < 0.8), as a result of uncorrected or inadequately corrected refractive error or limited use of spectacles at home. When the criterion of reduced acuity is set to VA <0.5, affecting visual performance to a level needing correction [World Health Organisation (WHO), 2000], the percentage of children is markedly lower: 5.2% in Stara Zagora and 11.7% in Heraklion. Among the children with VA <0.5, 46.4% of Greek and 68.8% of Bulgarian children do not use spectacles at all. In addition, 23% of Greek and 25% of Bulgarian children wear spectacles at school with inadequate (non-optimal) correction, resulting in decreased VA. Moreover, the percentage of pupils with visual acuity <0.5 is found to be higher for children attending secondary education, and this may be a result of the lack of frequent screening.

In the current study an impressive difference in myopia rates, averaged across age, was found between Greek and Bulgarian school children, i.e. 37.2% of Greek vs 13.5% for Bulgarian. The high estimated proportion of children in Heraklion with myopia is similar to that reported in recent studies in Swedish (Villarreal *et al*., 2000) and Mexican (Villarreal *et al*., 2003) children aged 12–13, but slightly higher than the prevalence rates reported by Zadnik for 12-year-old US children (Zadnik, 1997). On the other hand, the low percentages for the Bulgarian children matches the myopia prevalence rate (SEq ≤ -0.50 D under cycloplegia) reported for Polish children (Czepita *et al*., 2007) and European Caucasian children outside Europe (Kleinstein *et al*., 2003; Rose *et al*., 2008). A previous study on a Greek student population (15–18 years of age) (Mavracanas *et al*., 2000) postulated a 36.8% prevalence of myopia. However, no direct comparison with the present study can be made, since refractive error data was collected from self-reported questionnaires, while myopia was defined as a spherical error <-0.25 D.

It is also evident that there is a significant difference in the proportion of myopic pupils between the two age groups. This is not surprising, since the majority of refractive error studies have highlighted a shift towards increasing myopia with age, resulting in about a 5–8 times increase in prevalence rates between 6 year and 12 year-old children, with the rate being higher for East Asians (Hirsch, 1952; Edwards, 1999; Lin *et al*., 1999; Maul *et al*., 2000; Rose *et al*., 2008). However, when the results between primary and secondary schools from the two countries are compared, the higher percentages for the older group are only evident for Greek children (46.9% in secondary compared to 28.9% in primary education level). In contrast, myopia rates are similar for primary (14.1%) and secondary (13.0%) Bulgarian school children. This again agrees with Czepita *et al*.'s study (Czepita *et al*., 2007) reporting 13.1% and 14.7% myopia prevalence rates, for 11–12 and 13–15 year-old Polish children respectively.

It is of interest in determining the potential factors that differentially influence school-aged myopia between the two examined populations. High rates for myopic refractive error were also found in British 50%, Logan *et al*., (2005), Danish 50%, Fledelius (2000), and 37%, Jacobsen *et al*., (2008) and Norwegian 50.3%, (Midelfart *et al*., 1992) university students, but these are independently associated with educational level. Extensive near-work activity (Zadnik, 1997; Mutti *et al*., 2002; Saw, 2003; Gilmartin, 2004; Konstantopoulos *et al*., 2008) and reduced sports and/or outdoor activity (Mutti *et al*., 2002; Jacobsen *et al*., 2008; Rose *et al*., 2008) have also been linked with increased myopia rates, but there are no reasons to suggest that Greek pupils spend less time outdoors. However, the city of Stara Zagora is not as built-up as Heraklion and even in the city centre of Stara Zagora there are parks and lots of open field space, allowing children to spend more time on outdoor activities. There are other factors that have been positively related to prevalence rates, such as family income, level of education of parents, refractive status of parents, and scholastic success (Zadnik *et al*., 1994; Ip *et al*., 2007; Kurtz *et al*., 2007; Konstantopoulos *et al*., 2008). There is a suggestion that the higher proportions of myopic children in Greece may arise from the increasingly stressful education system, which 'forces' children to attend 4–6 h daily private tuition in addition to school teaching classes. These private classes usually start as early as the first grade of secondary education. Primary school children, on the other hand, often attend private foreign language courses from the second grade. Furthermore, parents encourage pupils to study hard in order to succeed in their entry exams for tertiary education in Greek Universities (Ierodiakonou, 1988). It is postulated that a high percentage of secondary school children give up sports and other activities to concentrate on this task.

The observed gender differences, with higher percentages of girls showing myopia in both countries at secondary school level, agrees with previous findings irrespective of the degree of myopia prevalence and the ethnicity of the population studied (Krause *et al*., 1982; Villarreal *et al*., 2003; Morgan *et al*., 2006; Jacobsen *et al*., 2008; Rose *et al*., 2008). Interestingly, it has been reported that boys spend more time outside each day than girls (Parssinen and Lyyra, 1993; Rose *et al*., 2008).

The percentages for astigmatism were also found to differ between the pupils in Heraklion (17.2%) and Stara Zagora (9.7%). A wide range of prevalences of astigmatism has been reported, varying from approximately 5% in 6 year-old Australians (Huynh *et al*., 2006), 7% in India (Murthy *et al*., 2002), 19% in Chile (Maul *et al*., 2000) to 26.4% for Caucasians and 33.6% for Asians reported in a US-based population study (Kleinstein *et al*., 2003). It is also well established that the prevalence of astigmatism increases with age (Katz *et al*., 1997).

Finally, although the proportion of children with myopia in Stara Zagora is low compared to Heraklion, only 35.8% of the myopic pupils wear corrective spectacles, half of the corresponding proportion (70.7%) of the children in Heraklion. The difference between the countries is more pronounced for secondary school children, with 75% of Greek vs 29% of Bulgarian children wearing spectacles. Visual impairment due to uncorrected refractive error may lead to significant educational consequences, including poor academic performance and reduced scholastic and social participation (Negrel *et al*., 2000; Powell *et al*., 2009). The compliance rates for Greek children are high, since it has been observed that, among several surveyed populations, only one third or less of children with visual impairment due to refractive error are wearing corrective spectacles (Preslan and Novak, 1998; Villarreal *et al*., 2003; He *et al*., 2004; Castanon Holguin *et al*., 2006). Low rates of compliance may be due to lack of affordability for refractive corrections and private health insurance, and less education (Vitale *et al*., 2006), whereas in economically advanced societies with structured health care programs, the factors mainly contributiong to the high risk of non-compliance are male gender, younger age and low myopic refractive error (Khader *et al*., 2006).

Limitations of the present study should be acknowledged. Due to the design of the present study, and given that examinations were limited to children in a single town in each country, it is not possible to draw any conclusions regarding myopia prevalence (in the 11–15 year age group) at a national level. In fact, the findings should be considered as being only indicative of myopia prevalence in the study population, given that estimates were not obtained using random (probability-based) sampling techniques. It could be hypothesized that the relatively high proportions of secondary school children with myopia in the Greek city reflect the family socioeconomic status of the children in the selected schools, given that one of the two was a fee-paying school (21% of the children measured). Comparisons made between the two Greek secondary schools, however, do not bear out this hypothesis, the proportions of pupils with myopia being 46.6% and 47.0% in the independent and state schools, respectively ($p = 0.928$).

Moreover, myopia was defined on refractive error recordings taken with an autorefractor in the absence of cycloplegia. It was decided at the design stage of the study that cycloplegia would not used, in order to minimize the discomfort of the children and potential parent dissatisfaction. The effect of cycloplegia on children's distance myopic error by autorefraction has been reported to range from about 0.20D (Mutti *et al*., 1994; Hofmeister *et al*., 2005; Powell *et al*., 2009) to 0.50D (Zhao *et al*., 2004), reducing also measurement variability (Mutti *et al*., 1994). In order to reduce the possibility of overestimating the proportion of myopic children, myopic spectacle use or uncorrected visual acuity < 0.8 formed prerequisites in myopia definition.

In conclusion, it should be emphasised that, since a central research question is whether myopia prevalence in Europe and generally in Western societies will increase to the levels observed in East Asian countries, there is a need to identify the factors contributing to the differences observed among populations of the same ethnicity.

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References

Adams, A., Baldwin, W. and Biederman, I., *et al.*. (1989) *Myopia: Prevalence and Progression, Commission on Behavioral and Social Sciences and Education*. National Academy Press, Washington DC.

Alward, W. L., Bender, T. R., Demske, J. A. and Hall, D. B. (1985) High prevalence of myopia among young adult Yupik Eskimos. *Can. J. Ophthalmol.* **20,** 241–245.

Blum, H. L., Peters, H. B., Bettman, J. W., Fellows, V. Jr and Johnson, F. (1959) Design and evaluation of a vision screening program for elementary school children. *Am. J. Public Health Nations Health* **49,** 1670–1681.

Carkeet, A. (2001) Modeling logMAR visual acuity scores: effects of termination rules and alternative forced-choice options. *Optom. Vis. Sci.* **78,** 529–538.

Castanon Holguin, A. M., Congdon, N., Patel, N., Ratcliffe, A., Esteso, P., Toledo Flores, S., Gilbert, D., Pereyra Rito, M. A. and Munoz, B. (2006) Factors associated with spectacle-wear compliance in school-aged Mexican children. *Invest. Ophthalmol. Vis. Sci.* **47,** 925–928.

Czepita, D., Zejmo, M. and Mojsa, A. (2007) Prevalence of myopia and hyperopia in a population of Polish schoolchildren. *Ophthalmic Physiol. Opt.* **27,** 60–65.

Edwards, M. H. (1999) The development of myopia in Hong Kong children between the ages of 7 and 12 years: a five-year longitudinal study. *Ophthalmic Physiol. Opt.* **19,** 286–294.

Ferris, F. L. III and Sperduto, R. D. (1982) Standardized illumination for visual acuity testing in clinical research. *Am. J. Ophthalmol.* **94,** 97–98.

Fledelius, H. C. (2000) Myopia profile in Copenhagen medical students 1996–98. Refractive stability over a century is suggested. *Acta Ophthalmol. Scand.* **78,** 501–505.

Gilmartin, B. (2004) Myopia: precedents for research in the twenty-first century. *Clin. Experiment. Ophthalmol.* **32,** 305–324.

Goldschmidt, E. (1968) [On the etiology of myopia. An epidemiological study]. *Acta Ophthalmol. (Copenh)* **98** (Suppl.), 91.

Grosvenor, T. (2003) Why is there an epidemic of myopia? *Clin. Exp. Optom.* **86,** 273–275.

He, M., Zeng, J., Liu, Y., Xu, J., Pokharel, G. P. and Ellwein, L. B. (2004) Refractive error and visual impairment in urban children in southern china. *Invest. Ophthalmol. Vis. Sci.* **45,** 793–799.

Hirsch, M. J. (1952) The changes in refraction between the ages of 5 and 14; theoretical and practical considerations. *Am. J. Optom. Arch. Am. Acad. Optom.* **29,** 445–459.

Hofmeister, E. M., Kaupp, S. E. and Schallhorn, S. C. (2005) Comparison of tropicamide and cyclopentolate for cycloplegic refractions in myopic adult refractive surgery patients. *J. Cataract Refract. Surg.* **31,** 694–700.

Huynh, S. C., Kifley, A., Rose, K. A., Morgan, I., Heller, G. Z. and Mitchell, P. (2006) Astigmatism and its components in 6-year-old children. *Invest. Ophthalmol. Vis. Sci.* **47,** 55–64.

Ierodiakonou, C. S. (1988) Adolescents' mental health and the Greek family: preventive aspects. *J. Adolesc.* **11,** 11–19.

Ip, J. M., Huynh, S. C., Robaei, D., Rose, K. A., Morgan, I. G., Smith, W., Kifley, A. and Mitchell, P. (2007) Ethnic differences in the impact of parental myopia: findings from a population-based study of 12-year-old Australian children. *Invest. Ophthalmol. Vis. Sci.* **48,** 2520–2528.

Jacobsen, N., Jensen, H. and Goldschmidt, E. (2008) Does the level of physical activity in university students influence development and progression of myopia?–a 2-year prospective cohort study. *Invest. Ophthalmol. Vis. Sci.* **49,** 1322–1327.

Junghans, B. M. and Crewther, S. G. (2003) Prevalence of myopia among primary school children in eastern Sydney. *Clin. Exp. Optom.* **86,** 339–345.

Katz, J., Tielsch, J. M. and Sommer, A. (1997) Prevalence and risk factors for refractive errors in an adult inner city population. *Invest. Ophthalmol. Vis. Sci.* **38,** 334–340.

Khader, Y. S., Batayha, W. Q., Abdul-Aziz, S. M. and Al-Shiekh-Khalil, M. I. (2006) Prevalence and risk indicators of myopia among schoolchildren in Amman, Jordan. *East. Mediterr. Health. J.* **12,** 434–439.

Kleinstein, R. N., Jones, L. A., Hullett, S., Kwon, S., Lee, R. J., Friedman, N. E., Manny, R. E., Mutti, D. O., Yu, J. A. and Zadnik, K. (2003) Refractive error and ethnicity in children. *Arch. Ophthalmol.* **121,** 1141–1147.

Konstantopoulos, A., Yadegarfar, G. and Elgohary, M. (2008) Near work, education, family history, and myopia in Greek conscripts. *Eye* **22,** 542–546.

Krause, U., Krause, K. and Rantakallio, P. (1982) Sex differences in refraction errors up to the age of 15. *Acta Ophthalmol. (Copenh)* **60,** 917–926.

Kurtz, D., Hyman, L., Gwiazda, J. E., Manny, R., Dong, L. M., Wang, Y. and Scheiman, M. (2007) Role of parental myopia in the progression of myopia and its interaction with treatment in COMET children. *Invest. Ophthalmol. Vis. Sci.* **48,** 562–570.

Laatikainen, L. and Erkkila, H. (1980) Visual screening of school children. *Acta Ophthalmol. (Copenh)* **58,** 137–143.

Lin, L. L., Shih, Y. F., Tsai, C. B., Chen, C. J., Lee, L. A., Hung, P. T. and Hou, P. K. (1999) Epidemiologic study of ocular refraction among schoolchildren in Taiwan in 1995. *Optom. Vis. Sci.* **76,** 275–281.

Lin, L. L., Shih, Y. F., Hsiao, C. K. and Chen, C. J. (2004) Prevalence of myopia in Taiwanese schoolchildren: 1983–2000. *Ann. Acad. Med. Singapore* **33,** 27–33.

Logan, N. S., Davies, L. N., Mallen, E. A. and Gilmartin, B. (2005) Ametropia and ocular biometry in a U.K. university student population. *Optom. Vis. Sci.* **82,** 261–266.

Mantyjarvi, M. (1983) Incidence of myopia in a population of Finnish school children. *Acta Ophthalmol. (Copenh)* **61,** 417–423.

Maul, E., Barroso, S., Munoz, S. R., Sperduto, R. D. and Ellwein, L. B. (2000) Refractive Error Study in Children: results from La Florida, Chile. *Am. J. Ophthalmol.* **129,** 445–454.

Mavracanas, T. A., Mandalos, A., Peios, D., Golias, V., Megalou, K., Gregoriadou, A., Delidou, K. and Katsougiannopoulos, B. (2000) Prevalence of myopia in a sample of Greek students. *Acta Ophthalmol. Scand.* **78,** 656–659.

Midelfart, A., Aamo, B., Sjohaug, K. A. and Dysthe, B. E. (1992) Myopia among medical students in Norway. *Acta Ophthalmol. (Copenh)* **70,** 317–322.

Morgan, R. W. and Munro, M. (1973) Refractive problems in Northern natives. *Can. J. Ophthalmol.* **8,** 226–228.

Morgan, A., Young, R., Narankhand, B., Chen, S., Cottriall, C. and Hosking, S. (2006) Prevalence rate of myopia in schoolchildren in rural Mongolia. *Optom. Vis. Sci.* **83,** 53–56.

Murthy, G. V., Gupta, S. K., Ellwein, L. B., Munoz, S. R., Pokharel, G. P., Sanga, L. and Bachani, D. (2002) Refractive error in children in an urban population in New Delhi. *Invest. Ophthalmol. Vis. Sci.* **43,** 623–631.

Mutti, D. O., Zadnik, K., Egashira, S., Kish, L., Twelker, J. D. and Adams, A. J. (1994) The effect of cycloplegia on measurement of the ocular components. *Invest. Ophthalmol. Vis. Sci.* **35,** 515–527.

Mutti, D. O., Mitchell, G. L., Moeschberger, M. L., Jones, L. A. and Zadnik, K. (2002) Parental myopia, near work, school achievement, and children's refractive error. *Invest. Ophthalmol. Vis. Sci.* **43,** 3633–3640.

Negrel, A. D., Maul, E., Pokharel, G. P., Zhao, J. and Ellwein, L. B. (2000) Refractive Error Study in Children: sampling and measurement methods for a multi-country survey. *Am. J. Ophthalmol.* **129,** 421–426.

Orlikowska, A. (1971) Ocular refraction in school children in the lower grades of primary schools. *Klin. Oczna* **41,** 427–429.

Parssinen, O. and Lyyra, A. L. (1993) Myopia and myopic progression among schoolchildren: a three-year follow-up study. *Invest. Ophthalmol. Vis. Sci.* **34,** 2794–2802.

Plainis, S., Tzatzala, P., Orphanos, Y. and Tsilimbaris, M. K. (2007) A modified ETDRS visual acuity chart for European-wide use. *Optom. Vis. Sci.* **84,** 647–653.

Powell, C., Wedner, S. and Richardson, S. (2009) Vison screening for correctable visual acuity deficits in school-age children and adolescents. *Cochrane Database Syst. Rev.* 2004, CD005023.

Preslan, M. W. and Novak, A. (1998) Baltimore Vision Screening Project. Phase 2. *Ophthalmology* **105,** 150–153.

Resnikoff, S., Pascolini, D., Mariotti, S. P. and Pokharel, G. P. (2008) Global magnitude of visual impairment caused by uncorrected refractive errors in 2004. *Bull. World Health Organ.* **86,** 63–70.

Rose, K. A., Morgau, I. G., Ip, J., Kifley, A., Huynh, S., Smith, W. and Mitchell, P. (2008) Outdoor activity reduces the prevalence of myopia in children. *Ophthalmology* **115,** 1279–1285.

Saw, S. M. (2003) A synopsis of the prevalence rates and environmental risk factors for myopia. *Clin. Exp. Optom.* **86,** 289–294.

Villarreal, M. G., Ohlsson, J., Abrahamsson, M., Sjostrom, A. and Sjostrand, J. (2000) Myopisation: the refractive tendency in teenagers. Prevalence of myopia among young teenagers in Sweden. *Acta Ophthalmol. Scand.* **78,** 177–181.

Villarreal, G. M., Ohlsson, J., Cavazos, H., Abrahamsson, M. and Mohamed, J. H. (2003) Prevalence of myopia among 12- to 13-year-old schoolchildren in northern Mexico. *Optom. Vis. Sci.* **80,** 369–373.

Vitale, S., Cotch, M. F. and Sperduto, R. D. (2006) Prevalence of visual impairment in the United States. *JAMA* **295,** 2158–2163.

Weale, R. A. (2003) Epidemiology of refractive errors and presbyopia. *Surv. Ophthalmol.* **48,** 515–543.

Wilson, A. and Woo, G. (1989) A review of the prevalence and causes of myopia. *Singapore Med. J.* **30,** 479–484.

World Health Organisation (WHO) (2000) *Elimination of Avoidable Visual Disability due to Refractive Errors*. World Health Organisation, Geneva.

World Health Organisation (WHO) (2003) *Consultation on development of standards for characterization of vision loss and visual functioning*. World Health Organisation, Prevention of Blindness & Deafness, Geneva.

Wu, M. M. and Edwards, M. H. (1999) The effect of having myopic parents: an analysis of myopia in three generations. *Optom. Vis. Sci.* **76,** 387–392.

Young, F. A., Leary, G. A., Baldwin, W. R., West, D. C., Box, R. A., Harris, E. and Johnson, C. (1969) The transmission of refractive errors within Eskimo families. *Am. J. Optom. Arch. Am. Acad. Optom.* **46,** 676–685.

Zadnik, K.. (1997) The Glenn A. Fry Award Lecture (1995). Myopia development in childhood. *Optom. Vis. Sci.* **74,** 603–608.

Zadnik, K., Satariano, W. A., Mutti, D. O., Sholtz, R. I. and Adams, A. J. (1994) The effect of parental history of myopia on children's eye size. *JAMA* **271,** 1323–1327.

Zhao, J., Mao, J., Luo, R., Li, F., Pokharel, G. P. and Ellwein, L. B. (2004) Accuracy of noncycloplegic autorefraction in school-age children in China. *Optom. Vis. Sci.* **81,** 49–55.