Myopia and natural lighting extremes: risk factors in Finnish army conscripts

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ABSTRACT.
Purpose: **To establish whether features of environmental lighting in far northern latitudes might be associated with prevalence of myopia.**
Methods: **Using both questionnaires and military medical examinations, this cross-sectional survey of Finnish conscripts assessed both light exposure and conventional risk factors for myopia.**
Results: **While myopia was not associated with the month of birth, there was a trend towards a higher prevalence of myopia among conscripts living above the Arctic Circle, consistent with the hypothesis that ambient lighting might influence refractive development. Other novel associations with myopia were decreased sunglasses use and brown iris colour. As indicated by other reports, myopia was found to be associated with family history, education and nearwork.**
Conclusion: **Although constraints inherent in surveying this military population may have limited our ability to detect associations, the positive findings suggest that studying northern populations may prove useful in clarifying any potential role of the light/dark cycle in refractive development.**

Key words: arctic regions – cross-sectional study – Finland – light – myopia – risk factors – photoperiod – refraction

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Introduction

Notwithstanding the high prevalence of myopia and its sight-damaging complications, any meaningful understanding of its aetiology has remained elusive despite longheld hypotheses invoking genetic and/or environmental factors (Saw et al. 1996). Certainly, the increased prevalence of myopia in Western societies during the 19th century and in Asian societies during the last half-century argue for prominent environmental influences. Epidemiological studies typically survey parameters long hypothesized to relate to myopia, such as family history, education and reading, but they have neither identified the underlying mechanisms nor led to clinically acceptable therapies that meaningfully reduce the incidence or progression of myopia (Saw et al. 2002a).

Basic laboratory research has generated several novel ideas for myopia pathogenesis, including the notion that the daily light/dark cycle might influence refractive development. Diurnal fluctuations of the retinal neurotransmitter dopamine influence both the state of retinal light–dark adaptation and the relation of endogenous retinal rhythms to the daily light/dark cycle (Rodieck 1998). In chicks and monkeys, diurnal dopamine rhythms in the retina of myopic eyes are disrupted and dopamine drugs can block myopia, suggesting that dopaminergic amacrine cells participate in the mechanism modulating eye growth (Iuvone et al. 1989; Stone et al. 1989; Iuvone et al. 1991; Stone 1997). More recently described, the eye's dimensions undergo diurnal oscillations in chicks (Nickla et al. 1998; Weiss & Schaeffel 1993; Papastergiou et al. 1998), rabbits (Liu & Farid 1998), marmosets (Nickla et al. 2002) and humans (Stone et al. 2003). Studied so far only in chicks, daily oscillations in eye length are disrupted in eyes that are becoming myopic (Weiss & Schaeffel 1993; Nickla et al. 1998; Papastergiou et al. 1998). An altered photoperiod affects postnatal refractive development profoundly in chicks (Stone et al. 1995) and to a considerably lesser extent in monkeys (Smith et al. 2001), a fact which also implicates the light/dark cycle.

The initial extension of this laboratory work to children with a high proportion of early onset myopia in a US hospital clinic found increased myopia among subjects whose parents reported using artificial bedroom lighting at night during infancy (Quinn et al. 1999). Similar surveys assessing infant night-time light exposure by parental questionnaire in more generalized populations of older US children and in a UK university student sample did not corroborate this association (Gwiazda et al. 2000; Zadnik et al. 2000; Guggenheim et al. 2003). In children from Singapore and China (Saw et al. 2002b), no clear association was found between refraction and infant night-time light exposure; but children with a history of infant night-time light exposure had longer eyeballs as measured by ultrasound, consistent with the possibility of a light-related growth effect. Law students with less night-time exposure to darkness experienced increased myopia progression, also suggesting an influence of the daily light/dark cycle on refraction in a specialized but older population (Loman et al. 2002). A coherent theory reconciling these disparate reports is yet to emerge.

Because of marked seasonal variation in the hours of naturally occurring daylight and darkness in countries of high northern latitude, the Finnish population offers an opportunity to study whether ambient lighting influences refractive development without relying on questionnaires to determine light and dark exposures. Our primary hypothesis was that, if the light/dark cycle exerts a particularly robust influence on refractive development during early infancy, refractive error might be associated with birth date. A secondary hypothesis was that refraction patterns might vary with latitude even within Finland because seasonal variations in light exposure are particularly extreme above the Arctic Circle.

Material and Methods

Study population

Finnish males (aged 17–30 years) join the Finnish Defence Forces in either January or July for mandatory military service. We studied two conscript cohorts, with approval from the Finnish Defence Forces Health Care Ethics Committee and the Institutional Review Board of the University of Pennsylvania; subjects provided informed consent prior to participation. During the entry medical examination, 30–100 conscripts form groups based on the alphabetical listing of names, and every fourth conscript in each grouping from 10 of Finland's 35 military garrisons was randomly selected. Subjects in the July 1999 cohort comprised 1799 conscripts; those in the July 2000 cohort comprised another 1752 conscripts. Both cohorts came from the same garrisons. The conscripts completed a written questionnaire concerning their vision and various risk factors. Questionnaire responses could be linked to uncorrected visual acuities obtained at the entry medical examinations for the 1999 cohort, but not for the 2000 cohort.

Questionnaires

The questionnaires assessed the presence of myopia and its risk factors, including demographic characteristics, various habits, health status and questions about the conscripts' families. The 1999 questionnaire was more comprehensive than the 2000 questionnaire, as described below.

Definition of myopia

As refractions were not available, myopia was defined by questionnaire responses, using terminology likely to be understood by the lay Finnish population. Conscripts indicated whether they wore spectacles and/or contact lenses. Those who gave a positive response were then asked whether they wore 'minus' or 'plus' glasses, a designation well known among the Finnish public. Myopia was defined as self-reported wearing of 'minus' glasses. For the 1999 cohort, for which objective, uncorrected visual acuity (VA) data were available, myopia defined by this self-reporting agreed highly with uncorrected VA of worse than 20/40 in at least one eye (kappa = 0.81, $p < 0.0001$; agreement = 94%). Agreement between self-reported wearing of 'minus' glasses and uncorrected VA was virtually identical when the 1999 subjects were stratified by the four geographic regions described below.

Risk factors

The questionnaires assessed both conventional risk factors and parameters that might relate to natural light exposure as a novel risk factor. Conventional risk factors examined in both the 1999 and 2000 cohorts included: age, conscript education, height, weight, body mass index (BMI), premature birth and parental myopia. Body mass index was calculated as $(\text{weight})/(\text{height})^2$ in kg/m^2.

Due to questionnaire differences between the 2 years, the following risk factor data were available only for the 1999 cohort: current nearwork activities, parental education and sibling myopia. Total daily hours of nearwork were estimated in two ways:

(1) an unweighted total, comprising the sum of average daily hours devoted to studying, reading (e.g. magazines and books), personal computer work, playing computer games and watching television, and
(2) a weighted total that adjusted nearwork hours in proportion to task proximity and accommodative demand, calculated in diopter-hours as [3 × (studying + reading) + 2 × (personal computer work + computer games) + (television watching)] (Zadnik et al. 1994).

Educational attainment was stratified as two levels: lower (basic, vocational or higher school) and advanced (college or advanced academic degree). For sibling myopia, the conscripts indicated their total number of siblings and how many wore spectacles and/or contact lenses. The myopic sibling percentage was calculated as (number of optically corrected siblings)/(total sibling number) × 100.

Light exposure

As risk factors potentially associated with natural lighting, conscripts in both cohorts provided information on their birth date, eye colour, sunglasses wearing habits and community of current residence. To analyse geographic differences in light exposure, Finland's provinces were grouped by latitude into four regions: Lappi (northernmost province), Oulu (second most northern province), central region (Keski-Suomi, Vaasa, Kuopio, Pohjois-Karjala, and Mikkeli provinces), and southern region (Turku, Pori, Häme, Kymi and Uusimaa provinces). Lappi includes all Finnish territory above the Arctic Circle and comprises some 30% of the country's land area; 80% of Lappi lies north of the Arctic Circle. Based on this province grouping and the more detailed 1999 questionnaire, 89.9% of conscripts currently lived in the same region of Finland where they had been born, 90.6% had lived most of their lives in their region of birth, and 96.1% had lived most of their lives in the region of current residence. Accordingly, we used the current region of residence to estimate north/south differences in natural light exposure. The number of conscripts for each region was as follows: Lappi ($n = 154$), Oulu ($n = 451$), central ($n = 1032$), south ($n = 1838$) and unknown ($n = 49$). Two indices were used to assess seasonal variations in natural light exposure:

(1) daily hours of darkness in each month for each region, and
(2) daily global irradiance (in KJ/m^2), a parameter that incorporates both daily hours of sunshine and angle of sunlight incidence to the earth's surface.

Average daily hours of darkness in each month were calculated for each region from sunrise and sunset times available in astronomical tables (http://aa.usno.navy.mil/data/docs/RS_OneYear.html) using 1980, the year in which the largest proportion of the conscript population was born. The daily global irradiance per month (as total irradiance for light in the 305–2800 nm wavelength range) was collected by the Finnish Meteorological Institute from seven observatories in different locations in Finland during 1977–83 and allowed average daily global irradiance to be assigned for each of the above four latitudinal regions of Finland.

Statistical analysis

Continuous variables were analysed both as continuous and categorized by quartile. The associations of risk factors with myopia were first examined by univariate analysis using the Chi-square test and simple logistic regression. Then multivariate logistic regression models were fitted to adjust for possible confounding factors. Those risk factors with $p \leq 0.20$ from the univariate model were included in the multiple logistic regression models. Due to missing values in some risk factors, only 3354 of 3524 conscripts were included in the multivariate model (multivariate model 1), and only 1658 of 1793 conscripts were included in the multivariate model with risk factors specific to the 1999 cohort (multivariate model 2). The odds ratio (OR) and corresponding 95% confidence intervals from logistic regression models were used to assess the strength of association of risk factors with myopia. All data analyses were performed in SAS Version 8.2 (SAS Institute, Inc., Cary, North Carolina, USA).

Results

A total of 3551 conscripts answered the questionnaire, 1799 in the 1999 cohort and 1752 in the 2000 cohort. A total of 27 (0.8%) conscripts (six in the 1999 cohort and 21 in the 2000 cohort) did not answer the questions about their vision and thus were excluded from analysis. The mean (±SD) age of the 3524 conscripts used for analysis was 19.2 ± 1.2 years. As evidence of age homogeneity, 92.4% were born in 1979–82, with the largest proportion (36.8%) being born in 1980. Because of this narrow distribution, age was not analysed as an independent factor. A total of 98.7% of subjects were male and 5.5% reported a history of premature birth. The mean daily hours of darkness and irradiance in the birth month were 11.3 hours (range 0–23 hours) and 3.7 log KJ/m^2 (range 1.1–4.3 log KJ/m^2). For birth month, the hours of darkness and irradiance level were highly correlated (Spearman correlation $r = -0.98$, $p < 0.0001$).

The overall prevalence of myopia was 22.2%. Among myopes, glasses were first worn at a mean (±SD) age of 13.3 ± 3.3 years (range 4–28 years). The age of initial spectacle wear did not vary by geographic region within Finland (data not shown).

In assessing a potential role of perinatal light exposure relevant to far northern latitudes (Table 1), we found no association of myopia prevalence with birth month, global irradiance at birth month or daily hours of darkness during the birth month. We extended these factors to assess natural light/darkness exposures during the first 3 months and first 6 months of life; similarly, no association with myopia emerged (data not shown). Myopia risk was not associated with current light exposure (data not shown). Among myopes, onset of spectacle wear at earlier ages was also not associated with birth month (data not shown).

Table 1. Light exposure at birth month and the risk of myopia.

Risk factors	Total conscripts conscripts ($n = 3524$)	Conscripts with myopia (%)	p-value
Birth month			0.59
Feb, March, April	898	210(23.4)	
May, June, July	930	193(20.8)	
August, Sept, Oct	820	185(22.6)	
Nov, Dec, Jan	833	185(22.2)	
Unknown	43	8(18.6)	
Global irradiance in birth month*			0.35†
1st quartile (lowest)	870	196(22.5)	
2nd quartile	902	209(23.2)	
3rd quartile	820	183(22.3)	
4th quartile (highest)	850	177(20.8)	
Unknown	82	16(19.5)	
Hours of darkness in birth month*			0.51†
1st quartile (lowest)	918	192(20.9)	
2nd quartile	740	172(23.2)	
3rd quartile	914	206(22.5)	
4th quartile (highest)	870	195(22.4)	
Unknown	82	16(19.5)	
Region			0.09
Lappi	154	46(29.9)	
Oulu	451	94(20.8)	
Middle	1032	234(22.7)	
South	1838	395(21.5)	
Unknown	49	12(24.5)	

* Incorporates both region and birth month.
† From the trend test.

Table 2. Comparisons of characteristics of conscripts from Lappi with those from other regions.

Characteristics		Lappi	Other regions*	p-value
Years of education	Mean (SE)	12.4 (0.10)	12.2 (0.02)	0.12
Height (cm)	Mean (SE)	177.0 (0.53)	178.6 (0.11)	0.003
Eye colour	Blue	51.6%	59.5%	0.0009
	Green	22.9%	26.0%	
	Brown	25.5%	14.4%	
Parental myopia	Yes	54.6%	53.1%	0.72
% of myopic siblings	No sibling	5.6%	10.0%	0.33
	0	46.5%	51.7%	
	1–50	21.1%	18.0%	
	50 +	26.8%	20.3%	
Wear sunglasses in bright weather	Yes	53.0%	55.0%	0.62
Education level	Below high school	53.6%	46.0%	0.07
Prematurely born	Yes	8.4%	5.3%	0.10
Nearwork activities (in 1999 cohort)				
Weighted nearwork (diopter hours/day)	Mean (SE)	13.6 (0.95)	13.1 (0.21)	0.63
Unweighted nearwork (hours/day)	Mean (SE)	6.9 (0.37)	6.1 (0.08)	0.12

* Includes Oulu, central and southern Finland.

Table 3. Distribution of risk factors and their associations with myopia.

Risk factors	Total conscripts ($n = 3524$)	Conscripts with myopia	(%)*	p-value†
Parental history of myopia				<0.0001
Both myopic	470	159	(33.8)	
Only father myopic	499	137	(27.5)	
Only mother myopic	879	250	(28.4)	
Neither myopic	1625	225	(13.9)	
Unknown	51	10	(19.6)	
Education level of conscript				<0.0001
Below high school	1623	209	(12.9)	
High school or above	1773	544	(30.7)	
Other	109	23	(21.1)	
Unknown	19	5	(26.3)	
Wears sunglasses in bright weather/very bright sunlight				<0.0001
No	1003	266	(26.5)	
Yes	2494	506	(20.3)	
Unknown	27	9	(33.3)	
Height (cm)				0.06
<180	2238	471	(21.1)	
≥180	1248	298	(23.9)	
Body mass index (BMI; kg/m^2)				0.04‡
≤21	922	221	(24.0)	
21–24	1360	303	(22.3)	
24 +	1194	242	(20.3)	
Unknown	48	15	(31.3)	
Eye colour				0.15
Blue	2060	439	(21.3)	
Green	906	201	(22.2)	
Brown	526	133	(25.3)	
Unknown	32	8	(25.0)	
Prematurely born				0.82
No	3290	727	(22.1)	
Yes	193	44	(22.8)	
Unknown	41	10	(24.4)	

Conscripts from Lappi had the highest prevalence of myopia, but not to a statistically significant degree ($p = 0.09$) (Table 1). Among subjects from Lappi, there was no association of myopia prevalence by birth month (data not shown). There was a higher proportion of subjects with brown eyes, a somewhat lower overall educational level and shorter height among Lappi conscripts than among those from the three other regions but all were similar in other characteristics (Table 2).

From data on more conventional risk factors available in both cohorts (Table 3), conscript myopia was associated positively with educational attainment and parental myopia. Myopic conscripts were less likely to wear sunglasses in bright light conditions. Despite no statistical association with body weight (data not shown), there was a trend towards a higher prevalence of myopia among taller conscripts and among conscripts with a lower BMI. Although myopia was somewhat more frequent among conscripts with brown eyes compared to those with green or blue eyes, the association was not statistically significant ($p = 0.15$) for both cohorts combined; this association did reach statistical significance in the 1999 cohort alone ($p = 0.04$, data not shown). No association was found between sunglasses wearing habits and eye colour (data not shown). Myopia prevalence was not associated with premature birth.

From data available only in the 1999 cohort (Table 3), myopia was associated with sibling myopia. Myopia was also associated positively with nearwork activities for both unweighted (hours/day) and weighted (diopter-hours/day) indices. Years of education positively correlated, but weakly, with amount of nearwork (Spearman correlation $r = 0.12$, $p < 0.0001$). Myopia associated positively with the education of the mother but not with that of the father. Myopia did not correlate with daily hours of sports activities.

Univariate logistic regression models (Table 4) provided OR estimates for the data in Tables 1 and 3. Two multivariate logistic regression models were applied (Table 4). Model 1 used both conscript cohorts with the risk factor data available for both. Simultaneously adjusting for these risk factors had little effect on the

Table 3. Continued.

Risk factors only in 1999 cohort ($n = 1793$)			
Percent of myopic siblings			<0.0001‡
0	911	129(14.2)	
1–50	320	81(25.3)	
>50	367	127(34.6)	
No siblings	176	39(22.2)	
Unweighted total nearwork (hours/day)			0.0004‡
<4.0	403	64(15.9)	
4.0–5.5	496	102(20.6)	
5.6–8.4	438	98(22.4)	
>8.5	436	112(25.7)	
Unknown	20	3(15.0)	
Weighted nearwork (diopter hours/day)			<0.0001‡
0–7	457	67(14.7)	
8–12	558	115(20.6)	
13–18	338	79(23.4)	
19 +	359	103(28.7)	
Education of mother			0.0002
Below college	940	164(17.5)	
College or above	585	154(26.3)	
Other	213	49(23.0)	
Unknown	55	12(21.8)	
Education of father			0.11
Below college	1086	214(19.7)	
College or above	536	130(24.3)	
Other	115	24(20.9)	
Unknown	56	11(19.6)	
Hours of doing sport/day			1.00
≤1.0	1059	226(21.3)	
>1.0	689	147(21.3)	
Unknown	45	6(13.3)	

* Myopia defined as: wearing minus spectacles or minus contact lenses.
† For the test of independence (with unknown category excluded).
‡ From the trend test.

estimated ORs and their associated p-values, although the p-value associated with region decreased from 0.10 to 0.04. Model 2 used only the 1999 cohort, with its more extensive risk factor data. Under model 2, the associations of parental myopia, conscript education, BMI and sunglasses wearing with myopia weakened slightly compared to the univariate model that included both cohorts because the estimated ORs generally shifted modestly towards 1.0 and, for sunglasses use especially, the p-value increased. Although still statistically significant, the associations of percent myopic siblings, unweighted nearwork and weighted nearwork became weaker under the multivariate model 2 compared to the univariate model for these factors that included only the 1999 cohort. There were marked differences between the models in some of the other factors. In model 2, region of origin was not associated with conscript myopia, with no apparent increased risk of myopia for conscripts from Lappi; the OR for the mother's education decreased and was not statistically significant; the association with the father's education changed from a non-significant positive association to a non-significant negative association. These differences between models were also present when only the 1999 cohort was used in model 1. Increased myopia among conscripts with brown eyes was statistically significant ($p = 0.04$) in model 2, as it was in model 1 restricted to the 1999 cohort.

Discussion

In this study, the prevalence of myopia was estimated by survey responses. It is likely that myopia and myopic astigmatism comprise the principal diagnoses accounting for reported spectacles use and decreased uncorrected vision among conscripts. Despite a reasonable agreement between self-reported myopia with uncorrected VA measurements of less than 20/40 in the 1999 cohort, it is

Table 4. The association of myopia risk factors from univariate and multivariate logistic regression models.

Risk factors	Univariate model		Multivariate model 1†		Multivariate model 2‡	
	Crude OR (95% CI)	p-value	Adjusted OR (95% CI)	p-value	Adjusted OR (95% CI)	p-value
Parental history of myopia						
Neither myopic	1.0	<0.0001*	1.0	<0.0001*	1.0	<0.0001*
Only father myopic	2.4(1.9–3.0)	<0.0001	2.1(1.7–2.8)	<0.0001	2.0(1.4–3.0)	0.0006
Only mother myopic	2.5(2.0–3.0)	<0.0001	2.3(1.9–2.9)	<0.0001	2.1(1.5–2.9)	<0.0001
Both myopic	3.2(2.5–4.0)	<0.0001	3.0(2.4–3.9)	<0.0001	2.4(1.7–3.6)	<0.0001
Conscript's education						
Below high school	1.0	<0.0001*	1.0	<0.0001*	1.0	<0.0001*
High school or above	3.0(2.5–3.6)	<0.0001	2.8(2.3–3.3)	<0.0001	2.6(1.9–3.5)	<0.0001
Other	1.8(1.1–2.9)	0.02	2.0(1.2–3.2)	0.008	1.7(0.8–3.7)	0.20
Eye colour						
Blue	1.0	0.15*	1.0	0.17*	1.0	0.04*
Green	1.1(0.9–1.3)	0.59	1.0(0.8–1.2)	0.90	0.9(0.7–1.3)	0.62
Brown	1.3(1.0–1.6)	0.05	1.3(1.0–1.6)	0.06	1.5(1.1–2.1)	0.02
Body mass index						
≤ 21.0	1.0	0.12*	1.0	0.28*	1.0	0.73*

Table 4. Continued.

Risk factors	Univariate model		Multivariate model 1†		Multivariate model 2‡	
	Crude OR (95% CI)	p-value	Adjusted OR (95% CI)	p-value	Adjusted OR (95% CI)	p-value
21.1–24.0	0.9(0.8–1.1)	0.35	0.9(0.7–1.1)	0.27	1.0(0.8–1.4)	0.86
>24.0	0.8(0.7–1.0)	0.04	0.8(0.7–1.1)	0.12	0.9(0.7–1.3)	0.58
Wears sunglasses in bright weather/sunlight						
No	1.0		1.0		1.0	
Yes	0.7(0.6–0.8)	<0.0001	0.7(0.5–0.8)	<0.0001	0.8(0.7–1.0)	0.06
Region						
South Finland	1.0	0.10*	1.0	0.04*	1.0	0.53*
Middle Finland	1.1(0.9-1.3)	0.46	1.1(0.9-1.3)	0.35	0.9(0.64-1.2)	0.37
Oulu	1.0(0.8–1.2)	0.76	1.0(0.8–1.3)	0.94	1.2(0.8–1.8)	0.36
Lappi	1.6(1.1–2.2)	0.02	1.8(1.2–2.6)	0.005	1.0(0.5–2.0)	0.91
Percent of myopic siblings§						
0	1.0	<0.0001*			1.0	<0.0001*
1–50	2.1(1.5–2.8)	<0.0001			1.8(1.3–2.6)	0.0007
>50	3.2(2.4–4.3)	<0.0001			2.7(2.0–3.7)	<0.0001
No siblings	1.7(1.2–2.6)	0.008			1.6(1.0–2.5)	0.04
Mother's education§						
Below college	1.0	0.0002*			1.0	0.39*
College or above	1.7(1.3–2.2)	<0.0001			1.2(0.9–1.7)	0.22
Other	1.4(1.0–2.0)	0.06			1.2(0.8–1.9)	0.35
Father's education§						
Below college	1.0	0.11*			1.0	0.12*
College or above	1.3(1.0–1.7)	0.04			0.7(0.5–1.0)	0.04
Other	1.1(0.7–1.7)	0.77			0.8(0.4–1.4)	0.42
Unweighted nearwork (hours/day)§						
As continuous	1.1(1.0–1.1)	<0.0001			1.0(1.0–1.1)	0.03
<4.0	1.0	0.006*			1.0	0.44*
4.0–5.5	1.4(1.0–1.9)	0.07			1.2(0.8–1.8)	0.31
5.6–8.4	1.5(1.1–2.2)	0.02			1.3(0.9–1.9)	0.23
>8.5	1.8(1.3–2.6)	0.0005			1.4(0.9–2.0)	0.11
Weighted nearwork (diopter-hours/day)§						
As continuous	1.03(1.02–1.05)	<0.0001			1.02(1.00–1.03)	0.02
0–7	1.0	<0.0001*			1.0	0.10*
8–12	1.5(1.1–2.1)	<0.0001			1.3(0.9–1.9)	0.17
13–18	1.8(1.2–2.6)	<0.0001			1.3(0.9–1.9)	0.21
19+	2.3(1.7–3.3)	<0.0001			1.6(1.1–2.4)	0.01

* For the overall difference.
† Risk factors in model 1 include parental myopia, conscript's education, eye colour, BMI, sunglasses wearing and region (four levels). Due to missing data on risk factors, only 3354 of 3524 conscripts were included in model 1.
‡ Risk factors in model 2 include the risk factors in model 1 and percent of myopic siblings, mother's education, father's education and weighted nearwork. Estimates for unweighted nearwork were computed by replacing weighted nearwork by unweighted nearwork in the model. Due to missing data on risk factors, only 1658 of 1793 conscripts were included in model 2.
§ Risk factors available only for 1999 cohort.

likely that the resulting prevalences are underestimates of the actual prevalence of myopia, particularly for low myopia. Depending on pupil size and magnitude of astigmatism, VA of 20/40 is potentially compatible with up to 1 or 2 diopters of myopia (Holladay et al. 1991) and may not be sufficiently symptomatic in all individuals to warrant spectacle correction. While self-reporting was the only practical means for myopia classification in the combined conscript groups, this definition is clearly not as precise as objective refraction, limits accurate subject classification and qualifies the associations found.

The population surveyed here is relatively homogeneous in terms of race and genetic background as well as age and gender. The Finnish population has remained comparatively isolated from other European and northern populations, presumably because of language and geographical restrictions, and demonstrates less genetic diversity than other European groups. The Saami people (Lapps) comprise a distinct minority group in northern Finland and are even more isolated genetically (Lahermo et al. 1996; Zerjal et al. 1997; Peltonen et al. 1999; Kere 2001).

Among the risk factors associated with light exposure, our results did not substantiate our primary hypothesis that myopia prevalence might correlate with birth date. The lack of an association of myopia with birth month in this population suggests that the critical period for an influence of the light/dark cycle on refractive development (Quinn et al. 1999), if it exists at all, is not of a duration measured in months. A longer critical period would mean that exposure averaging throughout the year and over several annual cycles would obscure any birth date effect. The lack of a short critical period for light effects is also consistent with the association between reduced dark exposure and myopia progression among young adults in law school (Loman et al. 2002). Alternatively, Finnish males may be resistant to an influence on refractive development of a perturbed light/dark cycle during the neonatal period because of genetics or because of a confounding factor not assessed here.

A tendency toward a higher myopia rate among conscripts from Lappi, the only Finnish province north of the Arctic Circle (Table 1), is consistent with our second hypothesis that refraction might be influenced by light exposure extremes. This trend in the univariate analysis strengthened in multivariate model 1, but the association was not present in model 2 (Table 4). The difference between regions in models 1 and 2 does not appear to be a cohort effect because restricting both the univariate model and model 1 to only the 1999 cohort provided estimates similar to those in Table 4. Because the 1999 cohort included only 71 conscripts from Lappi, it is difficult to determine whether the lack of association of myopia with the Lappi region in multivariate model 2 is attributable to additional confounding or to an unreliable estimate of the OR for the Lappi region in model 2 due to trying to estimate too many effects (10 other covariates) from too few observations (i.e. the comparatively small sample size).

Genetic admixing between Lapps and Finns in the Arctic does not easily explain the increased trend towards myopia in the Lappi garrison. Some 99% of conscripts from the Lappi garrison identified themselves as Finns, not Lapps, and available, although limited, data imply low myopia rates for genetic Lapps. A 1966 survey of Skolt Lapps found myopia in 3.7% of males and 8.8% of females (Forsius et al. 1999), and another survey of Lapps in northern Finland found an overall rate of myopia prevalence of 11.5% (Forsius & Pestriakov 1986).

While the association of myopia with conscripts from Lappi is weak, it suggests some alternative mechanisms that might be explored more effectively in the future using objective refractions with larger sample sizes from Arctic regions. The combination of prolonged natural light during the warmer months and the use of artificial lighting during the colder months may provide insufficient annual total exposure to darkness for optimum emmetropization, as suggested in some available studies (Quinn et al. 1999; Loman et al. 2002; Saw et al. 2002b). The eye's longitudinal chromatic aberration may influence emmetropization because it shifts the focal position of red light behind that of shorter wavelengths (Kroger & Binder 2000; Siedemann & Schaeffel 2002) and thus may optically predispose to eye lengthening. While many factors influence natural lighting quality, twilight and the night sky typically tend towards red light compared to a clear daytime sky (Lythgoe 1972). Coupled with the red enrichment of incandescent lighting, light exposures in the Arctic may permit an influence of chromatic aberration on emmetropization, which is not seen in less extreme environments. In addition to any influence of extreme light conditions, other parameters such as weather or diet cannot be excluded as possibly contributing to the trend towards more myopia among Lappi conscripts.

Two other novel associations with myopia found here are a lower rate of use of sunglasses and brown eye colour. Because the higher cost of prescription sunglasses may account for their reduced use in myopic subjects, the association alone cannot determine whether the reduced use of sunglasses comprises a risk factor for or a consequence of myopia. The higher myopia prevalence among subjects with brown eyes in the univariate model persisted in both multivariate models, suggesting an association independent of the higher prevalence of myopia in conscripts from Lappi. While we suspect that an association of myopia with such an obvious parameter as iris colour has been sought previously, we were unable to find such a reference. Perhaps a relationship emerged because the relative genetic homogeneity of the present population limited any potential confounding by other variables. Any possible relationship between ocular pigmentation and refraction would seem to merit further exploration.

Among conventional risk factors, myopia prevalence was positively associated with years of conscripts' education, with both parental and sibling history of myopia, and with the mother's educational attainment. Whether familial associations reflect shared genes and/or shared environment is indeterminate from such survey data. Frequently assessed, the relationships of refractive errors with height, weight and BMI are complex, with varied results between reports (Wong et al. 2001). In Finnish conscripts, the association of myopia with lower BMI and the trend towards an association with greater height is consistent with prior data for Finnish males (Pärssinen et al. 1985; Teikari 1987). It is hypothesized that a risk factor such as socioeconomic status might influence both refraction and body growth (Wong et al. 2001).

Myopia was associated with both unweighted and weighted nearwork in univariate analysis. While an association of myopia with nearwork persisted in the multivariate logistic model, its statistical strength greatly diminished. This reduced statistical association of myopia with nearwork is quite typical in applying regression models to myopia epidemiology and highlights the difficulty in deciding whether nearwork *per se* comprises an independent risk factor or whether it reflects more primary influences of education, socioeconomic status or other characteristics (Rosenfield & Gilmartin 1998).

To our knowledge, the present report is the first epidemiological study designed to establish whether features of environmental lighting in far northern regions might provide insights into the pathogenesis of myopia. It is limited by the use of questionnaire responses for refraction classification. The results did not support our primary hypothesis of a possible association of myopia with birth date, but the possibility that ambient lighting might influence refractive development is consistent with the trend toward higher rates of myopia prevalence among conscripts originating from above the Arctic Circle. As suggested independently (Midelfart 2002), studying refractive development in northern populations might introduce new research approaches to understanding myopia pathogenesis, using or modifying the light exposure methods applied here. New high precision eye measurement methods, such as partial coherence interferometry (Stone et al. 2003), might be particularly useful for assessing possible seasonal effects. Given the evolving laboratory and clinical evidence for diurnal influences on refractive development, study of populations living in areas with extreme natural lighting may help to clarify the role, if any, of the daily light/dark cycle in myopia pathogenesis.

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