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REVIEW ARTICLE

Reappraisal of the historical myopia epidemic in native Arctic communities

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Abstract

Purpose: This study was developed to explain the extraordinary rise in myopia prevalence beginning after 1950 in Indigenous Arctic communities considering recent findings about the risk factors for school myopia development. Myopia prevalence changed drastically from a historical low of less than 3% to more than 50% in new generations of young adults following the Second World War. At that time, this increase was attributed to concurrent alterations in the environment and way of life which occurred in an aggressive programme of de-culturalization and re-acculturation through residential school programmes that introduced mental, emotional and physical stressors. However, the predominant idea that myopia was genetic in nature won the discussion of the day, and research in the area of environmental changes was dismissed. There may have also been an association between myopia progression and the introduction of extreme mental, emotional and physical stressors at the time.

Recent findings: Since 1978, animal models of myopia have demonstrated that myopiagenesis has a strong environmental component. Furthermore, multiple studies in human populations have shown since 2005 how myopia could be produced by a combination of limited exposure to the outdoors and heavy emphasis on academic subjects associated with intense reading habits. This new knowledge was applied in the present study to unravel the causes of the historical myopia epidemics in Inuit communities.

Summary: After reviewing the available published data on myopia prevalence in circumpolar Inuit populations in the 20th century, the most likely causes for the Inuit myopia epidemic were the combination of increased near work (from almost none to daily reading) and the move from a mostly outdoor to a much more indoor way of life, exacerbated by fewer hours of sunshine during waking hours, the lower illuminance in the Arctic and the extreme psychophysical stress due to the conditions in the Residential Schools.

KEYWORDS
education, illumination, Inuit, myopia, myopiagenesis, residential schools

INTRODUCTION

The Inuit are a group of 150,000 First Nations people living in the circumpolar regions of Northern Canada, Alaska, Siberia and Greenland.[1] During the 1,000 years they have lived in this harsh, icy environment they have developed a unique culture and hunter-gatherer skills to make the most of the limited resources available. Since their first contact with Europeans, their way of life has been changing through a relentless acculturation process,[2] in part voluntarily and in part imposed by governmental regulations. One of these regulations, mandatory schooling, triggered a well-documented myopia epidemic[3] in the Inuit during the 1950s and 1960s, which is often cited as cautionary proof that education is strongly associated with myopia development. However, with the scientific progress that has occurred since the original reports were first published, it became clear that education is only one, albeit a key, co-factor in myopia.[4] Therefore, to fully understand what transpired during the onset of the so-called Inuit myopia epidemic, we reappraised the historical data with the benefit of recent insight, by assessing the influence of other parameters such as indoor illumination, as well as the discriminatory historical circumstances during which this rise in myopia prevalence occurred.

Key points

- Inuit children have suffered a massive increase in myopia prevalence since the 1950s, concurrent with mandatory formal education in residential schools.
- Children were forced to leave their families in favour of European education, leading to a permanent alienation from their original culture.
- This prevalence increase is likely associated with intense reading demands and poor lighting conditions.

HISTORICAL CONTEXT

To better appreciate the massive changes that the Inuit societies have undergone in the past few centuries, we begin with a brief overview of their history as a starting point for the investigation into the myopia epidemic.

In the 1,000 years before encountering Europeans, the Inuit lived as nomads along the Arctic Ocean shores of the Northwest Territories and Nunavut, as they named their land. As part of their cultural heritage, Inuit were well-versed in fishing, hunting and living in the open air. They lived in snow houses (igloos) or tents made of animal skin, and wore clothes made of animal skin and fur, as recorded in early documentaries[5] and reports (*Figure 1*). Sled dogs were central to their community. During the 18th century, these rural communities encountered the first European whale hunters and fishermen who came to Hudson Bay. These early interactions consisted mostly of trade, but Inuit families were also hired as guides and hunters, as well as for daily chores such as sewing and tanning. In time, the overexploitation of resources, primarily by European whalers and fur traders, depleted populations of key species, making the Inuit increasingly dependent on the Europeans for trade, food and employment.[2]

Acculturation

In the late 19th century, the influence of the Western governments, along with religious institutions, reached the remote Arctic regions. These included the North West Mounted Police of Canada and Christian missionaries, who began establishing churches, schools and hospitals. At this time whaling had already declined in the region, leading to massive unemployment and starvation among the Inuit since consumer goods were prohibitively expensive due to their long-distance transport by ship. Consequently, these native people, who had persisted for more than a thousand years in some of the harshest environments, became heavily dependent on charity and government aid. In Canada, this prompted the federal government to initiate relief programmes, later replaced by nationwide social, healthcare and education programmes, and determined that the Inuit had to abandon their traditional ways. Instead, they were to receive formal education so that the Inuit could be a workforce to mine the abundant mineral resources. The authorities ensured a reliable food supply, pensions, a family allowance, fixed housing, economic development, healthcare, formal education and rights equal to those of all other Canadian citizens. But while economically beneficial, these programmes ultimately led to the Inuit's assimilation into European-Canadian society, thus significantly affecting their cultural identity.

The most impactful change on Inuit life, as well as on the later myopia epidemic, was the implementation of a compulsory education system based entirely on Eurocentric ideas and classroom instruction. Originally, Inuit children were educated mainly outdoors by the adults in their community through oral traditions, food sharing, spirituality, community values and many Inuit traditional games that were often both physically and mentally demanding. Reading was not part of their culture until missionaries began teaching them French or English using the Bible. From 1870 onward, formal education was provided by residential schools and hostels run by religious orders sponsored by the federal government. Initially, these institutions infamously aimed to "kill the Indian within the child".[6] Children 5 years and older were forcibly removed from their homes, often at the hands of armed police, to live entire academic years inside large wooden buildings far from their families and forbidden to speak their own language or practice their traditions. They studied from English and French books, with their inherent social, academic, cultural and Christian biases (for example, books would show cornfields and car traffic, which were entirely unfamiliar to

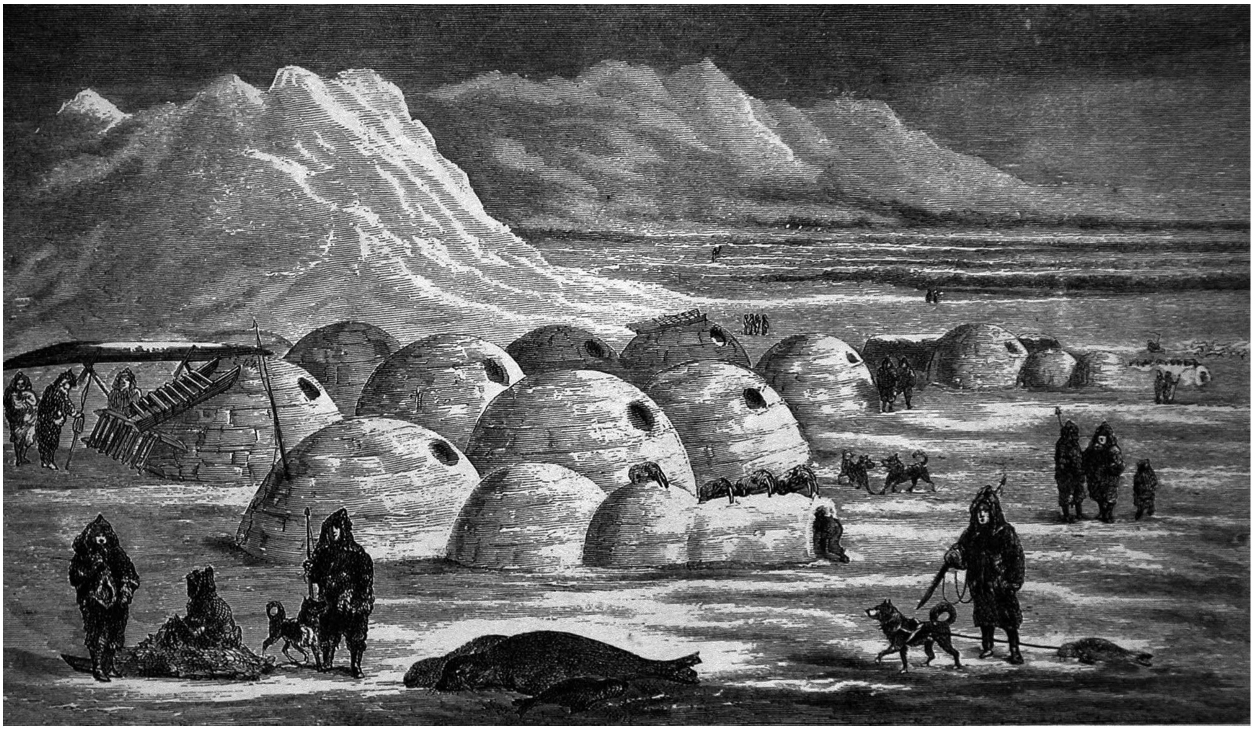

FIGURE 1 Oopungnewing, Inuit village on Baffin Island (ca. 1861)[96]

them). Fundamental pillars of Inuit culture, such as sharing food and stories among community members, were replaced by a value system based on individual achievement, self-discipline, punishment and penance in the hope of future rewards. In the end, when the children were finally permitted to return to their families for the summer, they would find themselves culturally alienated from their parents.[7] To make matters worse, residential schools were known to subject their students to a broad array of neglect, shame and deprivation, along with physical, mental and sexual abuse, or non-consensual medical experimentation.[8] This was the fate of over 150,000 Canadian Inuit and First Nation children between the ages of 6 and 15 years,[9] and the legacy of residential schools continues to affect generations of survivors and their families. While residential schools were not unique to Canada, with the indigenous populations of Alaska[10] and Greenland[11] facing many of the same social and cultural consequences, their impact was far larger in Canada than in other Arctic regions.

THE MYOPIA EPIDEMIC

Literature overview

The first known reports on the ocular refraction of the Inuit were those by Tweedle[12] and Bind,[13] both of whom sailed three-month voyages on the RMS Nascopie in 1945–1947 to bring ophthalmic care to remote Northern communities (*Figure 2*). In his report, Tweedle[12] mentions refracting 183 Inuit and 40 Europeans, of whom a total 20 (or 9%) needed a myopic correction. Meanwhile, Bind found myopia in only 4 of the 250 Inuit he investigated (or 1.6%), none of whom were children, noting that the Inuit refractive condition was "particularly good with very few of the younger ones actually needing lens corrections".[13] A few years later, Skeller reported seeing negative refractions in 39% of Greenland Inuit aged 20–24 years, but none were more negative than −1.25D.[14] Meanwhile in Canada, reports of myopia in Inuit populations were still rare,[15] with Cass asserting at first that myopia would occur in Inuit only if they had European ancestry.[16] Later, however, she noted that among people living in the settlements or attending the residential schools, almost all developed myopia,[17,18] with an increase in prevalence from 6.5% in 1958 to 65% in 1970.[16] Around this time Young *et al*.[19,20] noticed rapidly increasing myopia in children, with a prevalence of 87.8% in 21–25 year-olds and an average refraction of −2.08D. Meanwhile, the Canadian government and universities organized the Arctic Ophthalmological Survey in 1970–1971, followed by a whole series of studies[21-31] spread over three countries (*Figure 2*), each confirming the Arctic myopia epidemic. This epidemic continues to this day, with young Inuit still having very high myopia rates of around 45%,[30,31] comparable to those of young people in Western cities.[32]

Combined analysis

Distilling a global picture from these historical studies is not straightforward because of differences in methodology (cycloplegia, techniques, testing environment, definition

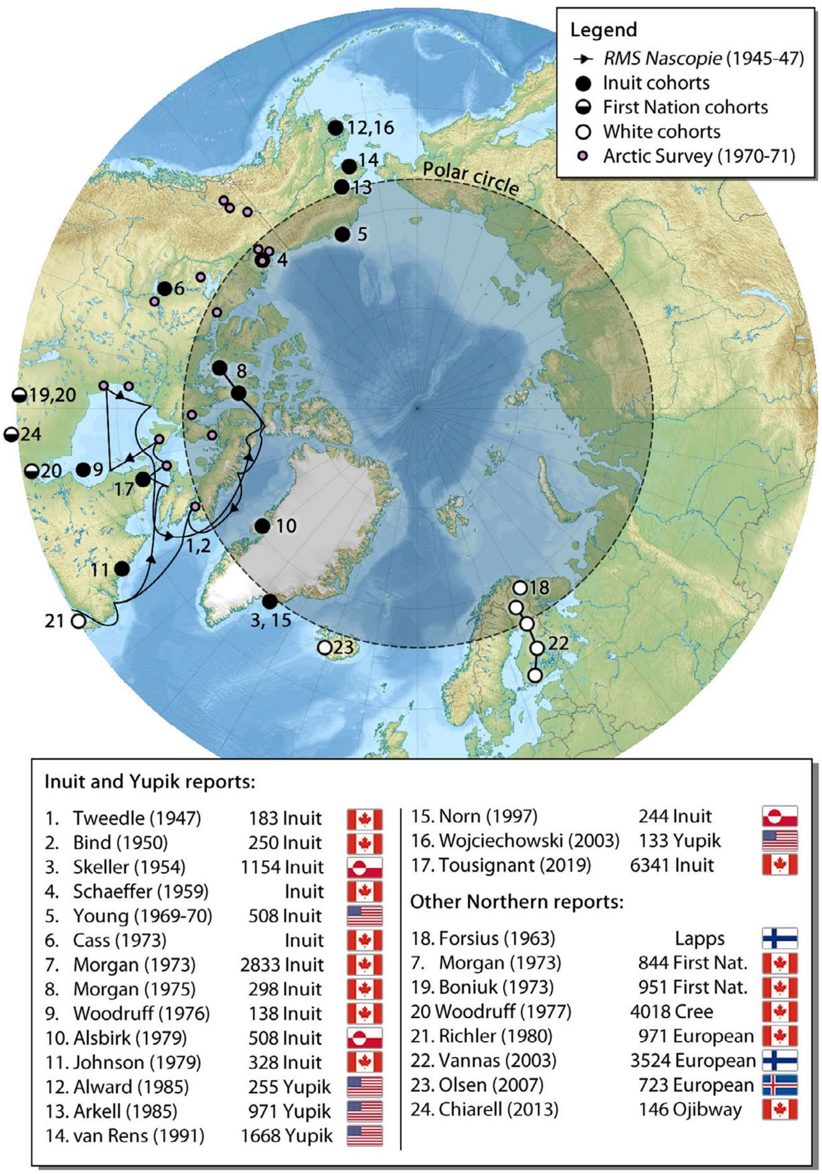

FIGURE 2 Overview of reports on refraction in the Arctic. Study no. 7 is the Arctic Survey of 1970–1971, indicated by small purple markers. (map: Wikimedia Commons)

of myopia), population sizes, geographical latitude, natural illumination and historical background of the countries involved. Furthermore, some studies could not be used due to technical issues, such as reporting errors[26] or insufficient information,[12,13,31] and one was a revisit of Skeller's study cohort 44 years later.[29] This left 9 studies[14,19,21,22,23,24,25,27,28,30] that provide either mean refraction or myopia prevalence as a function of age in ancestral Inuit or Yupik in Alaska, Canada and Greenland, using a definition of myopia as having a refraction of either ≤ −0.25D or < −0.25D. The details of these studies are provided in Supplement A. Since each of these studies was cross-sectional, changes reported as a function of age are associated not only with the gradual societal changes that led to the myopia epidemic, but also with ageing and normal eye growth. Hence, we averaged the data by decade of measurement. Clearly, conclusions herein are based on general historical trends of reasonably acceptable data, and there may always be problems with reproducibility and verification in situations such as this. Nevertheless, even after the removal of some supporting data, this combined analysis clearly illustrates the increase in myopia prevalence: while in the 1950s the mean refraction was still mildly hypermetropic in adults 20–40 years old, it became very myopic (–2.31D) in the 1980s and later (*Figure 3a*). This corresponds with a change of about −0.83D per 10 years from the 1950s onward. Similarly, the myopia prevalence increased at a rate of 10.7% per 10 years in the same period (*Figure 3b*). Several authors noted that women were often more myopic than men,[23,25,27,28] but the opposite was also reported.[22,26] These trends were not unique to Inuit, however, as similar trends have been reported in contemporary Métis,[16] First Nation,[16,24,33,34,35,36] Lapps[37]

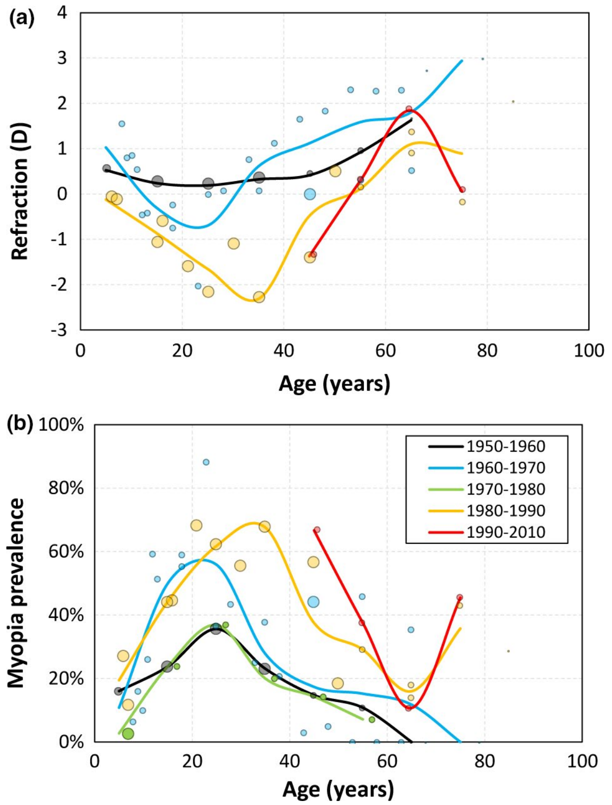

FIGURE 3 Overview of (a) mean refraction and (b) myopia prevalence in the Arctic per decade, derived from the available literature. Bubble size corresponds with cohort size. Note that the last set of studies (in red) considered a period of 20 years, rather than 10, and the figure legend applies to both figures 3a and 3b.

and Northern European people[38] as well as Indigenous Australians.[39]

Causes

Many potential causes were discussed at the time, including environmental factors such as education,[2,3,16,19,20,21,23,25] increased near work,[3,19,20] bad illumination,[3,19] housing[3,16,19,20,21,25] and dietary changes,[3,16,19,20,23,25,40] while genetics was at most seen as a contributing factor.[19,21,22,23,25,26] Meanwhile, the gender difference was attributed to men doing more outdoor activities (hunting) and women doing more activities indoors (cooking, sewing)[23,41] or having more regular attendance at school.[23] There is also reasonable cause to implicate psychophysical stress, given the extreme treatment suffered by the majority of the subject populations, and the fact that not all populations living in similar physical environments suffer the same levels of myopia prevalence.

In the following sections, we will revisit these factors using current understanding to propose a possible model for what happened during the period of transition to traditional formal education. We will focus on the increase in time spent indoors and the pervasively weak indoor illumination, both of which are known to be associated with myopia.[42–44]

EDUCATION AND NEAR WORK

After classroom education became mandatory in the Canadian Arctic, Inuit school attendance quickly increased from 15% to 75% between 1955 and 1964,[9] corresponding almost perfectly with the start of the myopia epidemic.[16,19,20,21,22,23,24,25,26,27,28,29,30,31] While we are unaware of any studies specifically correlating the years of school attendance with myopia in the Inuit, this was established in a nearby European population,[41] as well as many other studies.[4,43,44] Education and near work will therefore not be discussed further here.

HEALTHCARE, STRESS, AND NUTRITION

One of the causes for the Inuit myopization considered by authors in the 1960s–1970s was the change in diet. With the move to permanent settlements and the rapid acculturation of the Inuit, diets changed substantially from the meat of fish, seal, walrus, caribou and whale (rich in vitamins, minerals and omega-3 fatty acids) to a diet high in refined sugar and carbohydrates. This brought an epidemic of obesity, metabolic syndrome and diabetes that became famous in the history of medicine[45] – along with dental caries, anaemia, heart disease and cancers, which were rare among the Inuit prior to this dietary shift. While it may have seemed reasonable at the time, diet has long since been accepted as inconsequential in myopia development,[46,47] although it does play a role in overall eye size.[48]

Health programmes, including transportation to hospitals, were developed further by government after 1970 and are still underway, this time with new approaches that include health education programmes and employ indigenous personnel.[2] Regardless, the level of healthcare of the Inuit still remains below that of European-Canadians today.[49,50]

Psychophysical stress

During their stay at the residential schools, Inuit children endured extreme psychophysical stress from the physical, emotional and often sexual abuse at the hands of authorities as well as classmates, either directly or indirectly by witnessing violence committed against others or the need to bury classmates. These experiences were accompanied by feelings of isolation due to being separated from their families and culture or being discriminated against. Even after graduation, the psychophysical stress would continue as the destruction of the social fabric led to rampant social problems such as alcoholism, drugs, crime, chronic unemployment, poverty, physical and sexual abuse, depression and high suicide rates.[51] Consequently, the violence in schools was reflected in the homes, then transported to the schools where it was reinforced, and finally returned to the homes in a cycle of ever increasing stress.

Although a possible link between stress and myopia was proposed more than 30 years ago,[52] this topic has not been studied further. It therefore remains unclear whether the retinal metabolism and signalling mechanisms involved in myopiagenesis could be affected by the systemic hormonal environment. For example, men and taller subjects tend to have larger eyes with flatter corneas and less powerful crystalline lenses, resulting in unchanged refractive errors. This shows that although the systemic hormonal environment affects eye growth, the normal regulation of refractive development is able to control the refractive error, provided these changes occur at an early age.[53] Meanwhile, sudden hormonal changes at a later age due to extreme stress could theoretically offset the balance between axial growth and the corneal and lenticular ability to compensate, leading to rapidly increasing myopia.

ILLUMINATION

One underappreciated factor in the Inuit myopia epidemic was the low ambient light level in the environment where the children spent their time (*Figure 4*). In the past 15 years it has been clearly established that spending many hours outdoors each day is associated with a decreased risk of developing myopia,[42,44,54] leading to a general recommendation that schoolchildren should spend two hours in outdoor daylight each day.[55-57] From what is known about the residential schools, it is likely that this daily minimum would often not be reached in the North – because of the cold weather, the varying length and intensity of daylight, or the intense demands of the school programmes.

It is impossible to quantify the illuminance inside the classrooms of that era. At the time no measurements were taken as far as we know, and photographs are unreliable for this purpose because of differences in aperture and exposure. To the best of our knowledge, Young *et al.*[19] were the only ones to mention that Inuit houses were often illuminated by a single 40 W lightbulb, leading to an illuminance that they estimated at 4 footcandles (ca. 43 lux). Typically, people would spend 8 waking hours or longer in these circumstances per day.[19]

The following will attempt to verify whether the estimates by Young *et al.*[19] would also be realistic inside the class- and hostel rooms of the residential schools where the Inuit schoolchildren spent most of their days. In the absence of real measurements, it is theoretically possible to use dedicated software to estimate the illuminance inside a classroom, provided the layout and orientation of the room are known in great detail.[58] However, as such details are unavailable, we will instead use a number of simplifying assumptions to obtain an order-of-magnitude estimate of the classroom illuminance derived from the amount of natural outdoor light and window sizes.

Natural light

Other than the freezing temperatures, the biggest difference between the Arctic and more Equatorial regions is the lower irradiance received from the Sun, as the same sunlight is spread over a much larger area there than in the

FIGURE 4 Views inside classrooms and hostels with Inuit and First Nation children (Images courtesy of the General Synod Archives, Anglican Church of Canada and National Film Board of Canada)

tropics. Consequently, if one considers the hourly Global Horizontal Illuminance, i.e. the illuminance produced by the visible part of the direct solar radiation on a horizontal surface, averaged over a year, the Arctic sees values of about 11,000 lux. These are far lower values than those found in, for example, New York (18,847 lux), Honolulu (25,054 lux) or Singapore (21,659 lux), as recorded in open access weather reports.[59,60] Regardless, the environment might appear brighter in the Arctic as the snow that covers it for a large part of the year is far more reflective (60%–90%) than the typical scenes found elsewhere in the world, potentially leading to excessive glare and snow blindness. This would be a nuisance to the Inuit's daily activities, so they would use goggles to reduce snow glare to an acceptable level. Since this makes it practically impossible to estimate the resulting levels of illuminance at the eye, the following will disregard the influence of glare and only consider the illuminance from direct sunlight.

One peculiarity of the Arctic is the Polar Circle, located at a latitude of 66.5°, where, depending on the latitude, the sun will not rise above the horizon for 3–11 weeks on end during winter during the 'polar night'. Meanwhile in summertime an equally long 'polar day' occurs during which the sun does not set. Contrarily to what the name suggests, the polar night is not always dark near the polar circle, as sunlight will still scatter in the atmosphere and reflect onto the snowy ground. This causes a few hours of 'polar dusk' around mid-day, when the sky is coloured in a deep blue light that can still reach illuminances of 1,000 lux (measured in Kiruna, Sweden (67.86°N); Arne Lowden, personal communication, 20 December, 2020).

Plotting the highest adult myopia prevalence in each Inuit study as a function of the latitude at which it was performed, a significant correlation is seen, with the highest values being found in the most Northern regions (*Figure 5a*). Similarly, plotting the highest prevalence as a function of the mean global horizontal illuminance reveals a similar correlation, with lower illuminances corresponding with a higher myopia prevalence (*Figure 5b*). It is important to note, however, that these correlations decrease considerably if European and First Nation studies are also considered (red markers in *Figure 5*). Even so, these results are similar to those of a Finnish study by Vannas *et al*.[61] – that army recruits from more Northern regions tend to have more self-reported myopia than those from the South.

Overall, these observations suggest that outdoor light levels in the Arctic are 30%–50% of those in tropical regions, and that there might be a significant relationship between light levels and myopia development. However, the outdoor light levels probably did not change much between 1940 and 1970, and there is little evidence for high myopia prevalence in the Arctic prior to 1960. Outdoor illuminance therefore probably played only a minor role in myopiagenesis in this case. It might become important, however, in conjunction with other factors such as indoor activities and indoor lighting.

HOUSING AND INDOOR ILLUMINANCE

As the Inuit began giving up their traditional igloos and animal skin tents in favour of wooden houses during the first half of the 20th Century, their way of life also changed from nomadic open-air activities to sedentary indoor living. Originally, these houses consisted of a single room, but from 1960 onward thousands of prefabricated two- or three-bedroom units were built by the government, providing the amenities of a 1960s' European lifestyle. Typically, these houses were compact, with small windows to preserve the heat and two doors to avoid being locked in by snow. Inuit would rent these through a government programme that also included furniture, fuel and electricity from a communal oil-fuelled generator, but there were not enough houses, and many Inuit had limited financial means. As a result, these houses often had to be shared

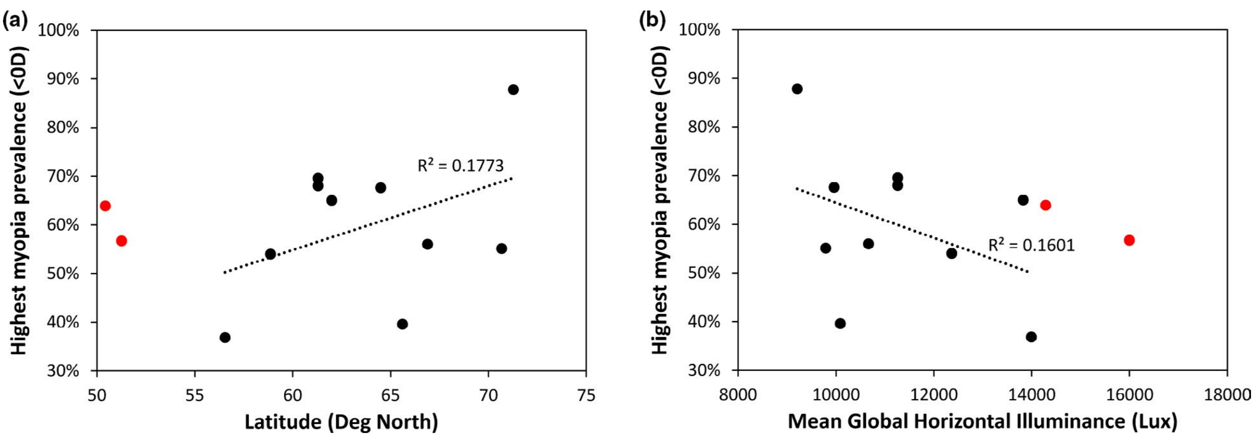

FIGURE 5 Highest adult myopia prevalence as a function of: (a) latitude and (b) mean global horizontal illuminance (averaged over a year), in the location where the study was performed; black markers indicate Inuit studies, red markers represent one White study and one First Nation study

with other families, sometimes making them crammed to the point where residents had to sleep in shifts because of the lack of beds (GVR, personal observation). By the end of the 1970s most Inuit were living permanently in such overcrowded settlements.[2]

The highest amount of natural light entering a room is directly related to the size of the windows. To this end, images of 6 residential schools and hostels known to house Inuit children during the 1950s were analysed, using ImageJ (V1.8.0.172; imagej.nih.gov) to estimate the window-to-wall ratio (WWR) of these buildings (*Figure 6*). This ratio, calculated by dividing the total window surface by the total wall surface, was 15.9 ± 3.9%, meaning that, on average, only a maximum of 15.9% of the total available sunlight per external surface unit may have entered the Arctic classrooms. These WWR values are considerably lower than the 22% currently found in student buildings in the USA,[62] as well as the current construction standards of 25%–30% that are needed for a balance between good illumination and low heat loss.[63] Meanwhile, in the Arctic temperature control was achieved by use of heavy curtains covering the windows.

To get a very rough estimate of the lighting in an Arctic classroom, let's assume three hypothetical learning environments. The first is the traditional outdoors education in the Alaskan town of Kotzebue,[27] the town with the Global Horizontal Illuminance (GHI) that was the median of all Inuit study locations, the second is a 1960's classroom with a WWR of 15.9% in Kotzebue and the third is a modern classroom with the American average WWR of 22% in New York City, illuminated according to all current standards for classroom illumination. Assuming clean, unobstructed windows, the historical Alaskan classroom would have received an estimated 35.4% of the daylight in the current New York classroom, and only 15.9% of the traditional outdoor education (*Table 1*). Once inside, the actual natural illuminance at any school desk will depend greatly on the position inside the room with respect to the windows and the reflectance of the walls, floors and ceilings.[64] Hence, current school buildings tend to have bright walls to maximize the propagation of daylight. In contrast, the weaker natural light in the Arctic school would enter a crowded classroom with many dark surfaces (*Figure 4*), causing the daylight to be less effective and leading to relatively dark rooms. Furthermore, in practice, Arctic classrooms were likely to be still more weakly illuminated, as curtains would often be closed to preserve heat or keep out the glare of direct sunlight and light reflected by the snow. This meant that almost no natural light would enter the classroom, especially for long periods in wintertime. Another aspect of importance may be the change in spectral composition

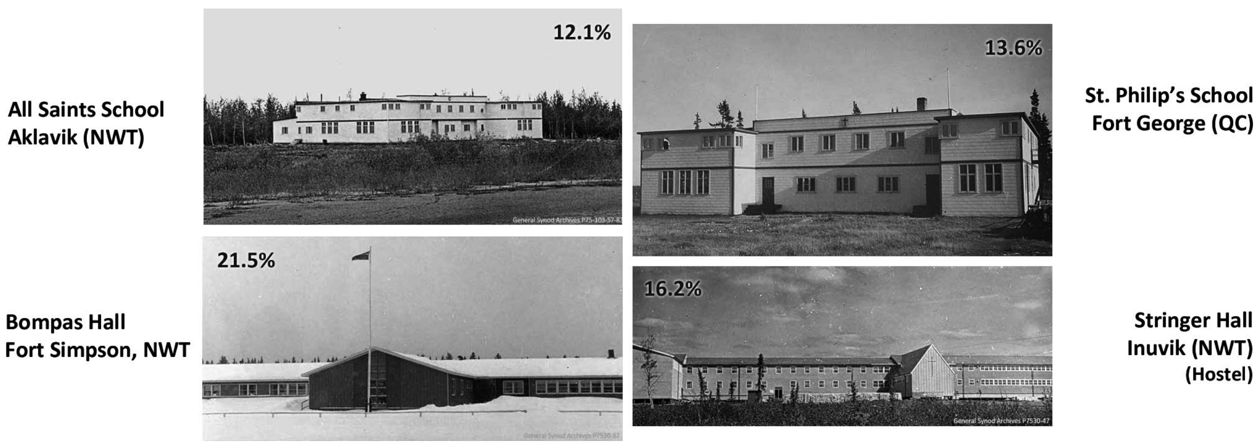

FIGURE 6 Photographs of schools attended by Inuit children in the 1950s, which were used for determining the window-to-wall area ratio (Added as percentages; Images courtesy of the General Synod Archives, Anglican Church of Canada; two images not shown due to copyright issues)

TABLE 1 Comparison between estimated natural illuminance entering in three hypothetical classroom situations in Kotzebue (Alaska) and New York City

	Global Horizontal Illuminance (GHI)*	Window to Wall Ratio (WWR)	Natural illuminance entering classroom*
Kotzebue (outdoors)	22,513 lux	100.0%	22,513 lux
Kotzebue (1960's school)	22,513 lux	15.9%	3,579 lux
New York City (Current)	45,953 lux	22.0%	10,109 lux
Relative differences			84.1% less than traditional outdoor education 64.6% less than New York City school

*Hourly mean during school hours (09:00–17:00), averaged over a year.

of the light experienced by the children, from outdoor light with a strong blue component, known in animal studies to drive hypermetropic growth,[65] to indoor light (candles and light bulbs) with a strong red component, known to drive myopic growth.[65]

In the absence of natural light, the modern New York classroom would typically be illuminated by large fluorescent lights that bring the illuminance at the school desk to a recommended ISO standard of 500 lux.[66] The lighting in the 1960s' Arctic school, on the other hand, would be far sparser, consisting of several lightbulbs spread around the classroom (*Figure 4*). Not much is known about the type of lights being used or the lampshades in which they were placed. Following the descriptions of Young *et al.*,[19] if one were to place a 40 W incandescent lightbulb in a 90° lampshade 2 m above a table, then the table would have an estimated illuminance of about 48 lux, which agrees with their report (43 lux). But this is rather low, and not realistic in a classroom setting. The leftmost pictures in *Figure 4* seem to suggest a much larger lampshade angle. If this angle is assumed to be 120° and the lamp is 2 m above the desks, then a 100 W incandescent lamp would give an illuminance of about 40 lux, whereas a more efficient 100W mercury vapour lamp would provide about 135 lux. These estimates are for students directly underneath the lamps; those further away would experience even lower illuminance. Note that the lights in *Figure 4* are covered in frosted glass – which, along with reflections on the walls, would improve the spread of the light and thus distribute the illumination more evenly. Either way, these illuminances would have remained far below today's recommended standards of 500 lux.

In this context, it is interesting to note that current day office workers in Kiruna (Sweden) experience a mean indoor illuminance at noon (11:00–14:00) of around 1,000 lux during the polar day in summer, but only around 100 lux at midday (7:00–14:00) during the polar night in wintertime.[67] Similarly, office workers further south in Denmark experience mean indoor illumination levels of 308–472 lux during winter workdays and 755–2,428 lux during summer workdays (06:00–18:00).[68] These values are far superior to those of the 1960s' Arctic schools, as modern construction materials (e.g., insulation, double glass) allow for larger windows, and cheap, energy-efficient lighting has become available. Even so, current illumination levels in everyday situations do not always reach recommended standards (see Supplement B).

DISCUSSION

In the previous sections we have clearly illustrated how myopia in native Arctic communities went from almost non-existent to close to ubiquitous in a single generation, and have analysed the most likely contributing factors. A special focus was placed on illumination, which had only been considered cursorily before in this context, as well as the possible influence of extreme psychophysical stress suffered at the residential schools.

Not much is known about how human eyes develop under predominantly low levels of indoor illumination. The best analogue available in the literature is an experiment in which chicks were reared in a 50 lux environment for three months, resulting in average myopia of −2.41D; this amount of myopic refractive error is relatively small, probably because chronic rearing under low-intensity light caused not only excessive axial elongation, but also flattening of the cornea and thinning of the lens, and probably also involved disturbance of growth mechanisms affected by circadian rhythms.[69] In agreement with many other studies in animal models of myopia, these authors observed that the amount of refractive change was closely correlated with the rate of dopamine release from the retina; this is of interest because dopamine has been implicated as an intrinsic retinal inhibitor of myopia development and progression.[70] Consistent with findings in these animal models, a recent human epidemiological study of the refractive errors in over 1200 4-year-old kindergarteners in 30 Israeli schools suggests that variations in indoor illuminance affect refractive development in children.[71] Although the mean refractive error was hypermetropic in all cases, as is common in young children, those spending their days in low-illuminance schools (at around 300 lux) were significantly less hypermetropic (mean refraction +0.50D) than those spending their schooldays under high illuminance (near 800 lux; mean refraction +1.00D). Moreover, low-luminance experiments in monkeys reared in less than 50 lux produced an increase in hypermetropia, rather than myopia, leading the researchers to conclude that for monkey a low-light environment by itself is insufficient to develop myopia, but that it can affect emmetropization and form deprivation myopia.[72] Together, these observations suggest that indoor illuminance levels play a role in refractive development.

The well-known connection between education and myopia was first suggested in 1813 by Ware, who observed that myopia was very rare in British army recruits, but that those affected were often better educated and of higher social standing.[73] Tscherning later expanded on that by looking at refractive development in people of many different professions and levels of education, finding that the level of education and amount of near work were indeed important risk factors for myopia.[74] One later example is Sweden, where education became compulsory in 1930. When Stromberg[75] investigated refraction in army recruits in 1934–1935, only 8.8% were myopic, but ten years later Stenström[76] reported considerably more myopia (27.5%) in a similar cohort. In neighbouring Denmark, school became mandatory in the 19th Century, but the myopia rate in army recruits was stable between 1882 and 2004.[77] But education by itself does not necessarily cause myopia either, as exemplified by the very low myopia rate in young adults (2.7% with refraction <0D) found by Sorsby *et al.*,[78] despite education being compulsory in the UK since 1880. This could be associated with children spending longer outside after class to work or play at that time.

These examples show that bad lighting or several years of schooling by themselves do not unavoidably lead to myopia, but that the combination of both might be detrimental. This was the case in middle- and upper-class children in late 19th Century European cities, who were often more highly educated and would spend more time indoors under poor lighting (candles and oil lamps). Ultimately, these children suffered a largely forgotten but well-documented[79] myopia epidemic that is reminiscent of what the Inuit experienced in the 1950s and '60s (*Figure 7*). A detailed comparison of both myopia epidemics might therefore be interesting – albeit challenging, as many of the original references are very difficult to obtain today. Regardless, both cases seem to have resulted from a "perfect storm" of near work and bad illumination, probably along with reduced time spent outdoors. Loman *et al.*,[80] Jorge *et al.*,[81] Lin *et al.*,[82] and many others have shown the link between advanced academic studies and the progression of myopia even well past puberty. In a sense, these myopiagenic circumstances are now common worldwide, even more so during the global lockdowns of the COVID-19 pandemic that forced children to stay indoors much more than usual and engage much more with digital interfaces while adopting a more sedentary lifestyle. Although the full impact of current events will only become apparent in a few years, there are already indications of a major increase in myopia concurrent with the COVID-19 pandemic in young Chinese schoolchildren.[83]

Inuit

Despite the similarities with the 19th Century epidemic, the Inuit myopia prevalence seems to remain on the higher end of the European values, suggesting that other causes remain to be considered and identified. Obvious differences between the environments of these two populations include the cold climate, the low outdoor illuminance and the extreme variations in daylight in the Arctic. But, as mentioned before, these did not lead to myopia in the Inuit before the 1960s because of their outdoor way of life, and therefore cannot be directly responsible for the myopia epidemic. Indirectly, however, these circumstances probably played an aggravating role when the Inuit children began receiving formal education in poorly lit school rooms with far less natural light due to small windows (*Table 1*), curtains (for thermal insulation) and poor electric lighting. The total time Inuit children were permitted outside exposed to natural light for sports and play would have been severely reduced and restricted for much of the year compared to the pre-acculturation era, with additional restrictions due to inclement weather, extreme cold and a heavy schedule of academics, prayers and chores. This is reminiscent of the observation that in Finland myopia prevalence increases with latitude,[61] which may be associated with spending more time indoors as it becomes darker and colder further North.

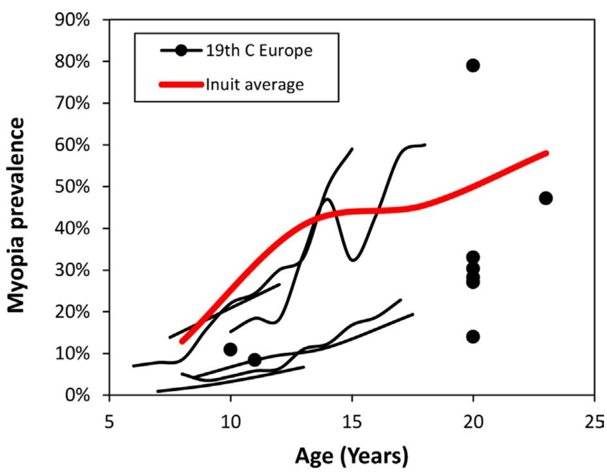

FIGURE 7 Comparison of the mean increase in myopia prevalence in 1950s–1960s Inuit, and in European city schools and universities in the late 19th Century (data from Steiger[2])

Several reports[12,35,84] also mention compliance issues with the wearing of spectacles by Inuit and First Nations children. This was associated with the fact that before the 1990's it was difficult to obtain a prescription, as one had to either travel great distances or wait for a traveling optometrist. Furthermore, eyeglasses were prohibitively expensive for most Inuit families because of their low incomes, and the glasses caused serious discomfort in the extreme cold. Government-issued glasses were widely available, but these were primarily a heavier black zylonite construction that carried a strong social stigma in communities where bullying was common. Frame breakage, metal frames burning the skin due to the cold and continuously fogging lenses all hampered daily outdoors activities.[28] Consequently, many Inuit would have been routinely uncorrected or under-corrected, which is associated with an acceleration of myopia progression.[85,86] Even today, limited access to basic eye care and refractive correction remains a major obstacle to health and prosperity among most Indigenous populations (CB, personal observations).

Importance of classroom design

The Arctic classrooms in the 1950s and '60s and those of 19th Century Europeans are clear examples of how poor classroom design and dim lighting led to a myopia epidemic. Although the importance of large classroom windows was already known in the mid-19th Century,[87] the current illumination at the level of the blackboards or the desks of rural schools in China can still be as low as 75 lux,[88] and some schools even see illuminance levels that are known to lead to spontaneous myopia development in chicks within 3 months.[70,89] Another study from India showed that certified schools can have 90 lux at the desktops 5 m from the windows and 1200 lux near the windows.[90] This shows that indoor illumination can vary substantially, ranging between very inadequate levels and levels considered safe. More research is needed, however, to determine the minimal level of illumination and total exposure time required to prevent myopia development in students. In this context the work of Cohen *et al*.[71] (ARVO 2021) is of great importance, as it directly links variations in illuminance inside kindergartens to levels of hypermetropia, keeping in mind that lower levels of hypermetropia are a risk factor for later myopia.[91] Consequently, the international standard of bringing the illuminance of indoor workplaces and classrooms to 300–500 lux should be promoted more, or even raised to 800–1,000 lux, in an effort to control the myopia epidemic[92] and to reduce physical disorders and loss of productivity due to alterations in the circadian rhythm,[66] as well as seasonal and industrial light-related affective and cognitive disorders.

Observations such as these have inspired the introduction of novel classroom designs that incorporate large windows for a high natural illuminance, and studies on the efficacy of these designs to prevent or arrest myopia development in students are currently ongoing.[93] Meanwhile, a prospective, year-long study – in which schools increased the artificial light levels in their classrooms – demonstrated reduced myopia progression in children in the modified classrooms compared to those in control schools.[88] This, again, underlines the importance of classroom illumination.

It is interesting to note that not all historical schools had poor illumination. For example, the Granaderos de San Martin School in Buenos Aires (Argentina) was built in 1929 according to the construction standards of the time, with large classrooms, high ceilings, and big windows (*Figure 8*). The large windows had a calculated WWR of 52.81%, producing an illuminance of about 1,100 lux inside the classroom, as well as very good ventilation to avoid the heat. It is conceivable that this historical building design prevented significant myopia in the children that attended in early 20th century.[94]

Limitations

It is important to mention the limitations of the analysis, which are mostly related to large methodological variations among old scientific studies. For example, several of these papers[12,13,16,17,24] are not population studies, but rather clinical reports without much statistics. Most papers also do not mention cycloplegia, so one must assume that it was not applied. Near retinoscopy without cycloplegia tends to induce a myopic response, so that the myopia rates presented are upper-limit estimates rather than actual prevalence. With many children to examine in close quarters in a short time, we must assume a wide margin of error in all historical data reports. Another issue is that the definition of myopia varies between studies, ranging from "any negative refraction" to "refractions of −1D and below". To ensure that this would not affect the results in *Figure 3* by too large a margin, studies using the latter definition were not used to calculate the average curves. It is noteworthy that some population studies rely on spherical equivalent; this can inflate myopia figures when there is a high prevalence of hypermetropic astigmatism, as is common among some First Nations populations (CB, personal clinical experience).[36,95] Future studies of ametropia prevalence should rely primarily on distinct measures of

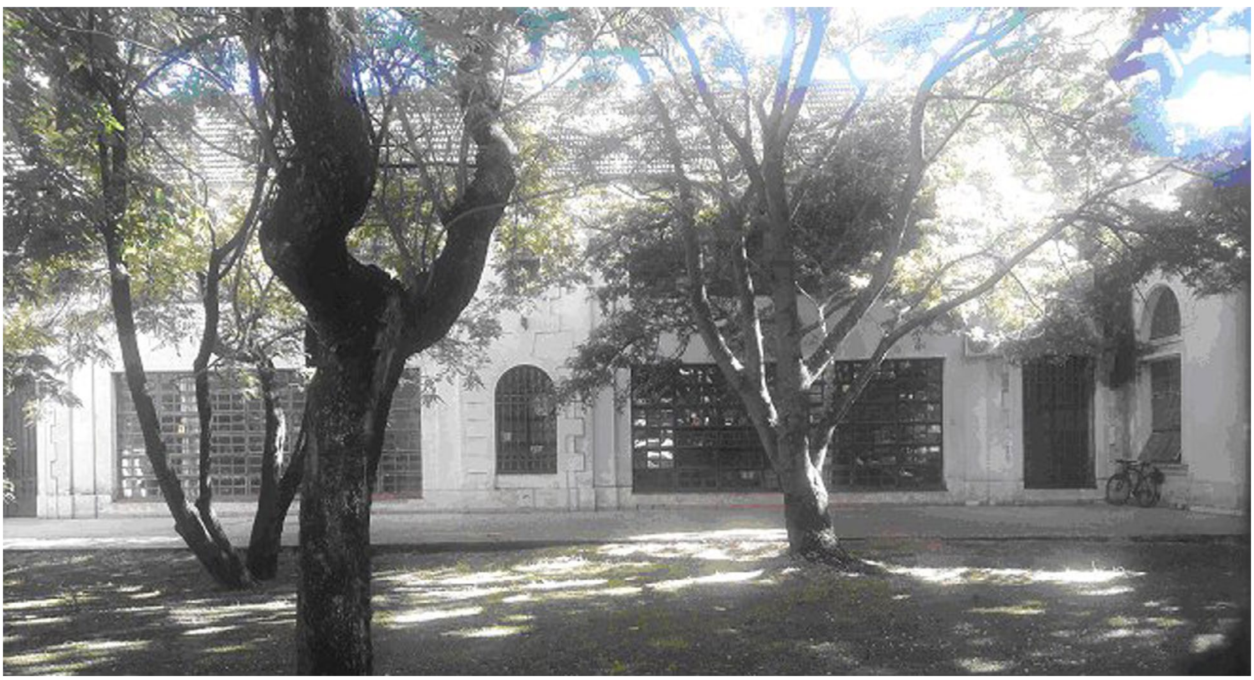

FIGURE 8 Granaderos de San Martin School (1929), Buenos Aires, Argentina

spherical values, with separate reporting of astigmatism and spherical equivalent.

Finally, it is important to note when interpreting the results of this paper that the luminous environment of the Arctic throughout the year is very much unlike anything to which people in more Southern regions are accustomed. Also, rather large environmental and cultural differences exist among the Arctic communities discussed here. Some communities would see snow all year round, while others experience relatively mild summers with fields of green grass and flowers. Some live far above the polar circle and will experience the long polar days and nights, while others will experience a day/night cycle that resembles that of Scotland or Denmark. These results therefore represent general trends and may therefore not apply equally to all Arctic communities.

Conclusions

The most likely causes for the Inuit myopia epidemic were the combination of increased near work (from almost none to daily reading) and the move from a mostly outdoor to a much more indoor way of life, exacerbated by fewer hours of sunshine during waking hours, the lower illuminance in the Arctic and the extreme psychophysical stress due to the conditions in the Residential Schools. The observations on classroom illuminance support a strong argument for controlling and perhaps raising the existing illuminance standards for any room being used by children, and to incorporate more exposure to outdoor daylight as part of instruction time, in an effort to contain the spread of myopia. More research in this area is needed to determine whether current international recommendations for industrial lighting in schools should be revised.

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CONFLICT OF INTERESTS

None.

AUTHOR CONTRIBUTION

Jos Rozema: Conceptualization (equal); Data curation (equal); Formal analysis (equal); Investigation (equal); Methodology (equal); Resources (lead); Validation (lead); Visualization (lead); Writing-original draft (equal); Writing-review & editing (equal). **Charles Boulet:** Conceptualization (equal); Supervision (equal); Writing-review & editing (equal). **Yuval Cohen:** Data curation (supporting); Supervision (supporting); Writing-review & editing (supporting). **Bill Stell:** Conceptualization (equal); Supervision (equal); Writing-review & editing (equal). **Luciano Iribarren:** Conceptualization (supporting); Supervision (supporting); Validation (supporting); Writing-review & editing (supporting). **Ger Van Rens:** Conceptualization (equal); Investigation (equal); Supervision (equal); Validation (equal); Writing-review & editing (equal). **Rafael Iribarren:** Conceptualization (equal); Formal analysis (equal); Investigation (equal); Methodology (equal); Writing-original draft (equal); Writing-review & editing (equal).

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REFERENCES

1. Young TK, Bjerregaard P. Towards estimating the indigenous population in circumpolar regions. *Int J Circumpolar Health*. 2019;78:1653749. doi.org/10.1080/22423982.2019.1653749
2. Bonesteel S. Canada's relationship with Inuit. A history of policy and program development. Anderson E, editor. Minister of Indian Affairs and Northern Development and Federal Interlocutor for Métis and Non-Status Indians; 2006.
3. Johnson GJ. Myopia in arctic regions: a survey. *Acta Ophthalmol*. 1988;66:13–18.
4. Morgan IG, Wu P-C, Ostrin LA, *et al*. IMI risk factors for myopia. *Invest Ophthalmol Vis Sci*. 2021;62:1–20.
5. Flaherty R. Nanook of the North, distributed by Pathé Exchange. 1922.
6. Truth and Reconciliation Commission of Canada (TRC). Honouring the truth, reconciling for the future: Summary of the final report of the truth and reconciliation commission of Canada. Truth and Reconciliation Commission of Canada; 2015. p. 130.
7. Hobart CW. Report on Canadian Arctic Eskimos: some consequences of residential schooling. *J Am Indian Educ*. 1968;7:13–17.
8. Canadian Broadcasting Corporation. Inuit sue federal government over medical experiments that included skin grafts. Canadian Broadcasting Corporation. 2019 www.cbc.ca/news/canada/north/inuit-experiments-skin-grafts-lawsuit-1.5185181.
9. King D. A Brief Report of the Federal Government of Canada's Residential School System for Inuit. Aboriginal Healing Foundation, Ottawa; 2006.
10. Barnhardt C. A history of schooling for Alaska Native people. *J Am Indian Educ*. 2001;40:1–30.
11. Bryld T. I den bedste mening [With the best intentions]. Gyldendal, Copenhagen; 2010.
12. Tweedle AH. Visual survey of East Canadian Arctic Eskimos. *Opt J Rev Optom*. 1947;84:36–39.
13. Bind E. Carrying optometrical service to the Eskimos of the eastern Arctic. *Am J Optom Arch Am Acad Optom*. 1950;27:24–31.
14. Skeller E. Anthropological and ophthalmological studies on the Angmagssalik Eskimos. CA Reitzel, Copenhagen; 1954.

15. Schaefer O. Medical observations and problems in the Canadian Arctic: Part II. *Can Med Assoc J*. 1959;81:386–393.
16. Cass E. A decade of northern ophthalmology. *Can J Ophthalmol*. 1973;8:210–217.
17. Cass E, editor. Ocular conditions amongst the Canadian western arctic Eskimo. *Int Congr Ophthalmol*; 1966; Excerpta Medica Congress Series, Munich: 1041–1053.
18. Cass E. The effects of civilization on the visual acuity of the Eskimo. In: Malaurie J, editor. The Eskimo people today and tomorrow. Mouton, Paris; 1969. p. 243–257.
19. Young FA, Leary GA, Baldwin WR, *et al*. The transmission of refractive errors within eskimo families. *Am J Optom Arch Am Acad Optom*. 1969;46:676–685.
20. Young FA. Refractive errrors, reading performance, and school achievement among Eskimo children. *Am J Optom Arch Am Acad Optom*. 1970;47:384–390.
21. Alward W, Bender T, Demske J, Hall D. High prevalence of myopia among young adult Yupik Eskimos. *Can J Ophthalmol*. 1985;20:241–245.
22. Alsbirk P. Refraction in adult West Greenland Eskimos: a population study of spherical refractive errors, including oculometric and familial correlations. *Acta Ophthalmol*. 1979;57:84–95.
23. Morgan RW, Speakman JS, Grimshaw SE. Inuit myopia: an environmentally induced "epidemic"? *Can Med Assoc J*. 1975;112:575–577.
24. Morgan RW, Munro M. Refractive problems in Northern natives. *Can J Ophthalmol*. 1973;8:226–228.
25. Johnson GJ, Matthews A, Perkins ES. Survey of ophthalmic conditions in a Labrador community. I. Refractive errors. *Br J Ophthalmol*. 1979;63:440–448.
26. Woodruff ME, Samek MJ. The refractive status of Belcher Island Eskimos. *Can J Public Health*, Revue canadienne de sante publique. 1976;67:314–320.
27. Arkell S, Lightman DA. Alaska eye survey I: The Maniilaq region. State of Alaska, Juneau 1985. p. 1–79.
28. Van Rens G. Ophthalmologic findings among Alaskan Eskimos of the Norton sound and Bering Straits region, Catholic University of Nijmegen, Nijmegen. 1988.
29. Norn M. Myopia among the Inuit population of East Greenland: Longitudinal Study 1950–1994. *Acta Ophthalmol*. 1997;75: 723–725.
30. Wojciechowski R, Congdon N, Anninger W, Broman AT. Age, gender, biometry, refractive error, and the anterior chamber angle among Alaskan Eskimos. *Ophthalmology*. 2003;110:365–375.
31. Tousignant B, Brûlé J. Eye health services and refractive error among Nunavik Inuit. *Opt Vis Sci* 2019;96:E-abstract 195357.
32. Hashemi H, Fotouhi A, Yekta A, *et al*. Global and regional estimates of prevalence of refractive errors: systematic review and meta-analysis. *J Curr Ophthalmol*. 2018;30:3–22.
33. Boniuk V. Refractive problems in native peoples (the Sioux Lookout Project). *Canada J Ophthalmol*. 1973;8:229–233.
34. Woodruff M, Samek M. A study of the prevalence of spherical equivalent refractive states and anisometropia in Amerind populations in Ontario. *Can J Publ Health*. 1977;68:414–424.
35. Chiarelli C, Chris A. Visual status of first nations children: The Sagamok First Nation vision care project. *Canada J Optom*. 2013;75:6–10.
36. Twelker JD, Miller JM, Sherrill DL, Harvey EM. Astigmatism and myopia in Tohono O'odham Native American children. *Optom Vis Sci*. 2013;90:1267–1273.
37. Forsius H, Eriksson A. Die Frequenz von Pinguecula und Pterygium bei Innen-und Aussenarbeitern. *Klin Mbl Augenheilk*. 1963;142:1021–1030.
38. Richler A, Bear JC. The distribution of refraction in three isolated communities in Western Newfoundland. *Am J Optom Physiol Opt*. 1980;57:861–871.
39. Taylor HR, Robin T, Lansingh V, Weih L, Keeffe J. A myopic shift in Australian Aboriginals: 1977–2000. *Trans Am Ophthalmol Soc*. 2003;101:107–110.
40. Young FA. Transmission of refractive errors within Eskimo families. *Am J Optom Arch Am Acad Optom*. 1970;47:246–249.
41. Richler A, Bear JC. Refraction, nearwork and education: a population study in Newfoundland. *Acta Ophthalmol*. 1980;58:468–478.
42. Morgan IG, Rose KA. Myopia: is the nature-nurture debate finally over? *Clin Exp Optom*. 2019;102:3–17.
43. Morgan IG, French AN, Rose KA. Intense schooling linked to myopia. *BMJ*. 2018;361:k2248. doi.org/10.1136/bmj.k2248
44. Morgan IG, French AN, Ashby RS, *et al*. The epidemics of myopia: Aetiology and prevention. *Progr Retin Eye Res*. 2018;62:134–149.
45. Young T, Reading J, Elias B, O'Neil J. Type 2 diabetes mellitus in Canada's First Nations: status of an epidemicin progress. *CAMJ*. 2000;163:561–566.
46. Grzybowski A, Kanclerz P, Tsubota K, Lanca C, Saw SM. A review on the epidemiology of myopia in school children worldwide. *BMC ophthalmology*. 2020;20:27. doi.org/10.1186/s12886-019-1220-0
47. Modjtahedi BS, Abbott RL, Fong DS, Lum F, Tan D. Reducing the global burden of myopia by delaying the onset of myopia and reducing myopic progression in children: the academy's task force on myopia. *Ophthalmology*. 2020;128:816–826.
48. Rozema JJ, Sun W, Wu JF, *et al*. Differences in ocular biometry between urban and rural children matched by refractive error: the Shandong Children Eye Study. *Ophthalmic Physiol Opt*. 2019;39:451–458.
49. Statistics Canada. Aboriginal peoples in Canada: First Nations people, Métis and Inuit: National Household Survey Ottawa: Government of Canada; 2013.
50. Greenwood M, de Leeuw S, Lindsay N. Challenges in health equity for Indigenous peoples in Canada. *Lancet*. 2018;391:1645–1648.
51. Kielland N, Simeone T. Current issues in mental health in Canada: the mental health of First Nations and Inuit communities. Library of Parliament, Ottawa; 2014.
52. Bowan MD. Stress & eye: New speculations on refractive error. *J Behavior Optom*. 1996;7:115–122.
53. Iribarren R, Morgan IG, Hashemi H, *et al*. Lens power in a population-based cross-sectional sample of adults aged 40 to 64 years in the Shahroud Eye Study. *Invest Ophthalmol Vis Sci*. 2014;55:1031–1039.
54. Morgan IG. Myopia prevention and outdoor light intensity in a school-based cluster randomized trial. *Ophthalmology*. 2018;125:1251–1252.
55. Wildsoet CF, Chia A, Cho P, *et al*. IMI - interventions myopia institute: interventions for controlling myopia onset and progression report. *Invest Ophthalmol Vis Sci*. 2019;60:M106–M131.
56. Wolffsohn JS, Flitcroft DI, Gifford KL, *et al*. IMI - myopia control reports overview and introduction. *Invest Ophthalmol Vis Sci*. 2019;60:M1–M19.
57. Ho CL, Wu WF, Liou YM. Dose-response relationship of outdoor exposure and myopia indicators: a systematic review and meta-analysis of various research methods. *Int J Environ Res Public Health*. 2019;16:2595. doi.org/10.3390/ijerph16142595
58. İnan T. An investigation on daylighting performance in educational institutions. *Struct Surv*. 2013;31:121–138.
59. Ladybug Tools LLC. EPWmap. 2021; Available from: ladybug.tools/epwmap/. Accessed 2 May, 2021.
60. Climate One Building. Repository of free climate data for building performance simulation. 2019; Available from: climate.onebuilding.org/. Accessed 2 May, 2021.
61. Vannas AE, Ying GS, Stone RA, *et al*. Myopia and natural lighting extremes: risk factors in Finnish army conscripts. *Acta Ophthalmol*. 2003;81:588–595.
62. Winiarski DW, Halverson MA, Jiang W. Analysis of building envelope construction in 2003 CBECS. Pacific Northwest National Lab.(PNNL), Richland, WA (United States); 2007.
63. American Society of Heating RaA-CE. Energy Standard for Buildings Except Low-Rise Residential Buildings. American Society of Heating, Refrigerating and Air Conditioning Engineers, Atlanta, GA 2019.
64. Illumination Engineering Society of North America. The IESNA Lighting Handbook, 9th edn. IESNA; 2000.

65. Seidemann A, Schaeffel F. Effects of longitudinal chromatic aberration on accommodation and emmetropization. *Vis Res*. 2002;42:2409–2417.
66. Preto SGC. Lighting in the Workplace: Recommended Illuminance (lux) at Workplace Environs. In: Advances in Design for Inclusion. Springer, editor. Bucchianico, G, 2019. p. 180-191.
67. Lowden A, Lemos NAM, Goncalves BSB, *et al*. Delayed sleep in winter related to natural daylight exposure among Arctic day workers. *Clocks Sleep*. 2019;1:105–116.
68. Daugaard S, Markvart J, Bonde JP, *et al*. Light exposure during days with night, outdoor, and indoor work. *Ann Work Exposures Health*. 2019;63:651–665.
69. Cohen Y, Belkin M, Yehezkel O, Solomon AS, Polat U. Dependency between light intensity and refractive development under light-dark cycles. *Exp Eye Res*. 2011;92:40–46.
70. Cohen Y, Peleg E, Belkin M, Polat U, Solomon AS. Ambient illuminance, retinal dopamine release and refractive development in chicks. *Exp Eye Res*. 2012;103:33–40.
71. Cohen Y, Iribarren R, Massarwa A, *et al*. The ambient light in nursery school and children's refraction. *Invest Ophthalmol Vis Sci*. 2021;62. ARVO E-abstract 1391.
72. She Z, Hung LF, Arumugam B, Beach KM, Smith EL 3rd. Effects of low intensity ambient lighting on refractive development in infant rhesus monkeys (Macaca mulatta). *Vis Res*. 2020;176:48–59.
73. Ware J IV. Observations relative to the near and distant sight of different persons. *Phil Trans Roy Soc London*. 1813;103:31–50.
74. Tscherning M. Studien über die Aetiologie der Myopie. *Graefes Arch Clin Exp Ophthalmol*. 1883;29:201–272.
75. Strömberg E. Über Refraktion und Achschenlange des Menschlichem Auges (Vorläufige Mitteilung). *Acta Ophthalmol*. 1936;14:281–297.
76. Stenström S. Variations and correlations of the optical components of the eye. Butterworth & Co., London; 1948. p. 87–102.
77. Jacobsen N, Jensen H, Goldschmidt E. Prevalence of myopia in Danish conscripts. *Acta Ophthalmol*. 2007;85:165–170.
78. Sorsby A, Sheridan M, Leary GA, Benjamin B. Vision, visual acuity, and ocular refraction of young men. *Br Med J*. 1960;1:1394–1398.
79. Steiger A. Die Entstehung der sphärischen Refraktionen des menschlichen Auges: Übersichtigkeit, Normalsichtigkeit, Kurzsichtigkeit. Karger; 1913.
80. Loman J, Quinn GE, Kamoun L, *et al*. Darkness and near work: myopia and its progression in third-year law students. *Ophthalmology*. 2002;109:1032–1038.
81. Jorge J, de Almeida JB, Parafita MA. Binocular vision changes in university students: a 3-year longitudinal study. *Optom Vis Sci*. 2008;85:E999–E1006.
82. Lin L, Shih Y-F, Lee Y-C, Hung P-T, Hou P-K. Changes in ocular refraction and its components among medical students–a 5-year longitudinal study. *Optom Vis Sci*. 1996;73:495–498.
83. Wang J, Li Y, Musch DC, *et al*. Progression of myopia in school-aged children after COVID-19 home confinement. *JAMA Ophthalmol*. 2021;139:293–300.
84. Chris AP, Young NL, Belanger K, Greasley L. Results of an environmental scan to determine the level of uncorrected refractive error in First Nations elementary school children in Ontario. *Can J Optom*. 2017;79:7–19.
85. Adler D, Millodot M. The possible effect of undercorrection on myopic progression in children. *Clin Exp Optom*. 2006;89:315–321.
86. Chung K, Mohidin N, O'Leary DJ. Undercorrection of myopia enhances rather than inhibits myopia progression. *Vis Res*. 2002;42:2555–2559.
87. Cohn H. Untersuchungen der Augen von 10060 Schulkindern, nebst Vorschlägen zur Verbesserung der den Augen nachtheiligen Schuleinrichtungen: Eine ätiologische Studie. Mit 1 Figurentafel u. zwei Druckbeilagen. Fleischer; 1867.
88. Hua WJ, Jin JX, Wu XY, *et al*. Elevated light levels in schools have a protective effect on myopia. *Ophthalmic Physiol Opt*. 2015;35:252–262.
89. Stone RA, Cohen Y, McGlinn AM, *et al*. Development of experimental myopia in chicks in a natural environment. *Invest Ophthalmol Vis Sci*. 2016;57:4779–4789.
90. Singh PAR. Classroom illuminance: Its impact on students' health exposure & concentration performance. International Ergonomics Conference HWWE. 2014. Guwahati, Assam, India
91. Gwiazda J, Thorn F, Bauer J, Held R. Emmetropization and the progression of manifest refraction in children followed from infancy to puberty. *Clin Vis Sci*. 1993;8:337–344.
92. Németh J, Tapasztó B, Aclimandos WA, *et al*. Update and guidance on management of myopia. European Society of Ophthalmology in cooperation with International Myopia Institute. *Eu J Ophthalmol*. 2021;65:18. doi.org/10.1177/1120672121998960
93. Zhou Z, Chen T, Wang M, *et al*. Pilot study of a novel classroom designed to prevent myopia by increasing children's exposure to outdoor light. *PLoS One*. 2017;12:e0181772.
94. Hobday R. Myopia and daylight in schools: a neglected aspect of public health? *Perspect Public Health*. 2016;136:50–55.
95. Harvey EM, McGrath ER, Miller JM, *et al*. A preliminary study of astigmatism and early childhood development. *J AAPOS*. 2018;22:294–298.
96. Hall CF. Arctic Researches and Life Among the Esquimaux: Being the Narrative of an Expedition in Search of Sir John Franklin in the Years 1860, 1861, and 1862. Harper and Brothers, New York; 1865.

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