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 – through the lens of, and taking into consideration, recent findings about the risk factors for school myopia development. Myopia prevalence changed drastically from an 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 simultaneous alterations in environment and lifestyle that occurred simultaneously, but 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.

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

Summary: After reviewing available published data on myopia prevalence in circumpolar Inuit populations in the *20*th century, and taking into account the social and environmental changes that took place during this epoch, the authors conclude that the myopia epidemics in these communities were mainly induced by the implementation of Residential Schools with their attendant intense reading demands and low environmental illumination.

Keywords: Myopia, Education, Illumination, Inuit, Myopiagenesis, Residential Schools

The Inuit are a group of *500,000* First Nations people living in the circumpolar regions of Northern Canada, Alaska, Siberia and Greenland.[3] During the thousand years when they lived in this harsh, icy environment they had developed a unique culture and hunter-gatherer skills to make the most of the limited resources available. Since their first contact with Europeans, their lifestyle has been changing through a relentless acculturation process,[4] in part voluntarily and in part imposed by governmental regulations. One of these regulations, mandatory schooling, triggered a well-known myopia epidemic[5] in Inuit during the *1950*s and '*60*s that is often cited as cautionary proof that education is strongly associated with myopia development. But with the scientific progress that has occurred since the original reports were first published, it became clear that education is only one, albeit key, aspect of myopia. 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 education and illumination as well as the discriminatory historical circumstances during which this rise in myopia prevalence occurred.

1. History of the Inuit

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 thousand 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[6] and reports (Figure 1). Sled dogs were central to their community. During the *18*th century, these rural communities encountered the first European whale hunters and fishermen that came to Hudson Bay. These early interactions consisted mostly of trade, wherein Europeans offered access to metal knives and needles, rifles, tobacco, cloth, or food in exchange for dogs and their traditional subsistence goods. Inuit families were hired as guides and hunters to maintain the

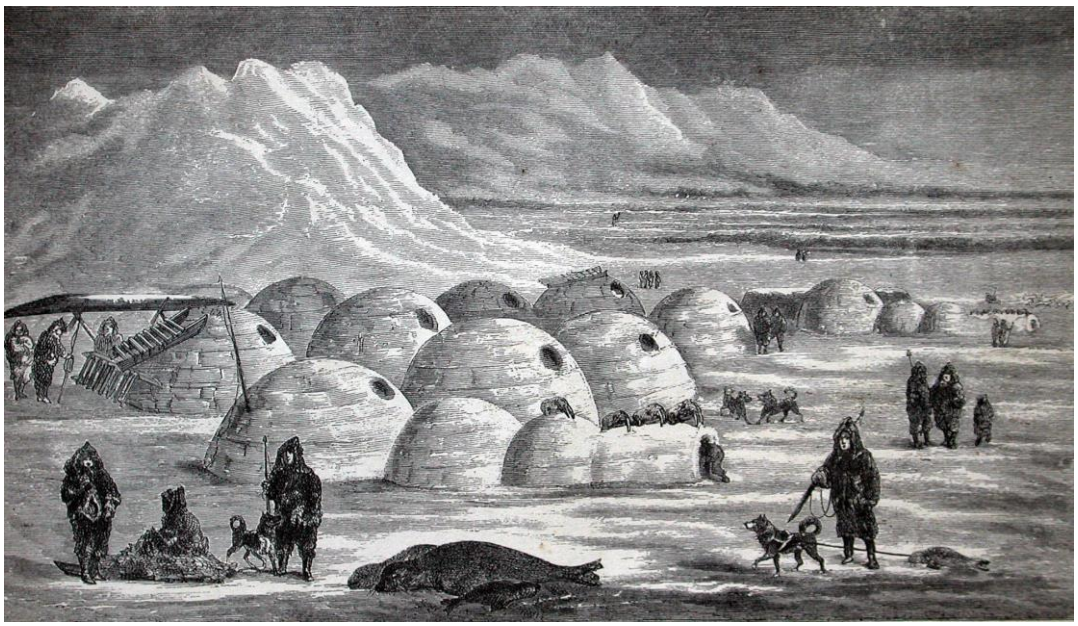


Figure 1: Oopungnewing, Inuit village on Baffin Island (ca. 1861).[1]

meat supplies for the whaling ships' crews, or for sewing, laundry and tanning. In time, the overexploitation of resources, primarily by European whalers and fur traders, depleted populations of key species. With this, the Inuit became increasingly dependent on the Europeans for trade, food and employment.[4]

Acculturation

In the late *19*th Century, the influence of the US, Canadian and Danish governments, along with religious institutions, reached the remote Arctic regions. For example, the North West Mounted Police of Canada made their way North in the *1890*s, while Christian missionaries began establishing churches, schools, and hospitals. At this time whaling had already declined in the region, leading to massive unemployment among the Inuit. Consequently, these native people, who had persisted for more than a thousand years in some of the harshest environments on Earth, became entirely dependent on the charity of missionaries and the police within the span of a century. For a while, Inuit hunted foxes for the very profitable fur trade, but this ended quickly in *1930* as a result of excessive trapping, falling prices, and legislation to protect Arctic wildlife.[4] This again led to massive unemployment, as well as starvation, since consumer goods were prohibitively expensive because of the long-distance transport by ship.

In Canada, this dire situation led the federal government to initiate relief programmes, which were later replaced by nation-wide comprehensive social, healthcare and education programmes. Since many Inuit were starving near abandoned whaling settlements, the federal authorities determined that they had to abandon their traditional ways. Instead, the politicians thought that, with education and development, the Inuit could be a workforce to mine the mineral resources. The authorities ensured that Inuit had a reliable food supply, pensions, a family allowance, fixed housing, economic development, healthcare, education, and rights equal to those of all other Canadian citizens. While economically beneficial, these programmes ultimately led to the Inuit's assimilation into European-Canadian society and a loss of their cultural identity.

The change having by far the most impact on Inuit life, as well as the later myopia epidemic, was the implementation of a compulsory education system based entirely on Eurocentric ideas and classroom instructional models. Originally, Inuit children were taught all their cultural practices and knowledge by adults in the community. This education involved oral traditions, food sharing, spirituality, community values, and many Inuit traditional games that were often both physically and mentally demanding. Reading books was not part of Inuit culture until missionaries began teaching them to read and speak French or English using the Bible. Formal education was extended by the introduction of residential schools or hostels run by religious orders in collaboration with the federal government, from *1870* onward. Initially, these institutions infamously aimed to *"kill the Indian within the child"*,[7] forcing children *5* years and older to live entire academic years in large wooden buildings far from their families, and allowing them to return only to see their parents for two months in summertime. Separated from their families and forbidden to speak their own language or practice their traditions, these children studied from English and French books, with their inherent social, academic, cultural, and Christian biases. The educational material would, for example, show cornfields and car traffic, which were entirely unfamiliar to them. Thus, instead of sharing food and stories among community members, a pillar of Inuit culture, these schools imposed a value system based on individual achievement and self-discipline, punishment, and penance, in the hope of future rewards. This created a permanent cultural alienation between Inuit parents and their children.[8] In addition, these children would have under normal circumstances been taught by more tactile and oral means – that is, by in-

structional methodology much less reliant upon the fine visual acuity and oculomotor control required for reading linear text. Since formal education became compulsory in the Canadian Arctic in *1950*, over *150,000* children between *6* and *15* years old were forced to attend co-called residential schools.[9] These children experienced a broad array of significant neglect, shame, and deprivation, along with physical, mental, and sexual abuse, and where some were also subjected to non-consensual medical experimentation.[10] The legacy of the residential schools continues to affect generations of survivors, their families, and communities. Concurrently, similar myopiagenic epochs occurred among Indigenous populations in Alaska[11] and Greenland,[12] in association with many of the same social and cultural consequences for those affected. Note that, while residential schools were not unique to Canada, their extent was far larger than in the other countries inhabited by the Inuit. Hence, in the following review we will focus mainly on the Inuit experience with the European-Canadian education system.

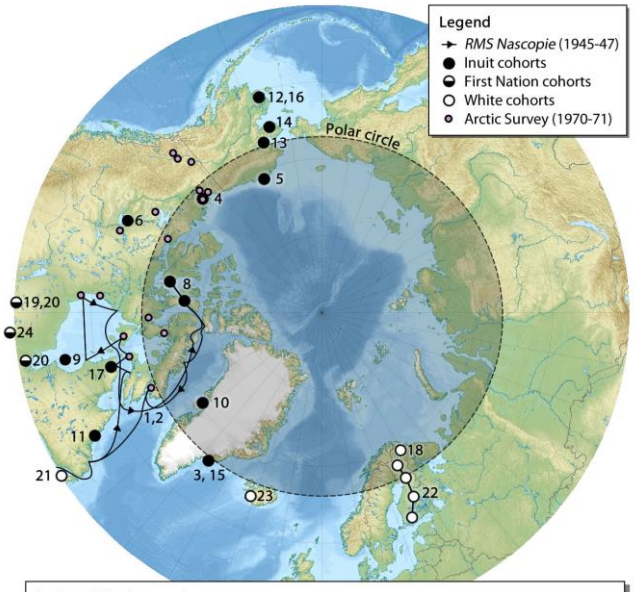
The first formal acknowledgement of these injustices in Canada appeared in the *1970*s, when books and teachers in the Inuit language (Inuktitut) became available, along with parental participation in schools.[4] The last residential school closed in *1996*. Ever since then, the First Nations and the Canadian government have been slowly coming to terms with the cultural damage inflicted by the residential schools. In *2008*, the Government of Canada issued a Statement of Apology to former students, and the Indian Residential Schools Truth and Reconciliation Commission was established, and work continues towards repairing the social and cultural damage done. The US issued a written apology to American natives in *2009*, while Denmark apologized very recently (*2020*).

2. The myopia epidemic

Literature overview

We obtained access to *23* publications reporting on the refractions of indigenous peoples in the far North. The locations of the populations studied are shown in Figure 2.

The first known reports on the ocular refraction of the Inuit were the reports by Tweedle[13] and Bind[14], both of whom sailed *3*-month voyages on the *RMS Nascopie* in *1945-47* to bring ophthalmic care to remote Northern communities. In his report, Tweedle[13] 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 whom were children, noting that the Inuit refractive condition was *"particularly*



Inuit and Yupik reports:

1.	Tweedle (1947)	183 Inuit	15.	Norn (1997)	244 Inuit
2.	Bind (1950)	250 Inuit	16.	Wojciechowski (2003)	133 Yupik
3.	Skeller (1954)	1154 Inuit	17.	Tousignant (2019)	6341 Inuit
4.	Schaeffer (1959)	Inuit			
5.	Young (1969-70)	508 Inuit	Other Northern reports:		
6.	Cass (1973)	Inuit	18.	Forsius (1963)	Lapps
7.	Morgan (1973)	2833 Inuit	7.	Morgan (1973)	844 First Nat.
8.	Morgan (1975)	298 Inuit	19.	Boniuk (1973)	951 First Nat.
9.	Woodruff (1976)	138 Inuit	20	Woodruff (1977)	4018 Cree
10.	Alsbirk (1979)	508 Inuit	21.	Richler (1980)	971 European
11.	Johnson (1979)	328 Inuit	22.	Vannas (2003)	3524 European
12.	Alward (1985)	255 Yupik	23.	Olsen (2007)	723 European
13.	Arkell (1985)	971 Yupik	24.	Chiarell (2013)	146 Ojibway
14.	van Rens (1991)	1668 Yupik			

Figure 2: Overview of reports on refraction in the Arctic (map: Wikimedia Commons).

good with very few of the younger ones actually needing lens corrections".[14] The tone of both reports was rather colonial and paternalistic,[15] with Bind spending far more time discussing the difficulties during the voyage and performing their work, than presenting the results of his examinations.

A few years later, Skeller reported seeing negative refractions in *39%* of Greenland Inuit age *20-24* years, but none were more negative than *–1.25D*.[16] Meanwhile in Canada myopia was still rare,[17] with Cass asserting at first that myopia would occur in Inuit only if they had European ancestry.[18] Later, however, she noted that people living in the settlements or attending the residential schools all developed myopia,[19, 20] with an increase in prevalence from *6.5%* in *1958* to *65%* in *1970*.[18] Around this time Young et al.[21, 22] 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 *1970-71*, followed by a whole series of studies[23-33] spread over three countries (Figure 2), each confirming the existence of a myopia epidemic in the far North. This epidemic continues until this day, with young Inuit still having very high myopia rates of around *45%*,[32, 33] comparable to those of young people in Western cities.[34]

Combined analysis

Distilling a global picture from these historical studies is not straightforward, however, because of differences in methodology (cycloplegia, definition of myopia), population sizes, geographical latitude, natural illumination, and historical background of the countries involved. Meanwhile, some studies could not be used due to technical issues, such as reporting errors[28] or insufficient information,[13, 14, 33] and one was a revisit of Skeller's study cohort *44* years later.[31] This left *9* studies[16, 21, 23-27, 29, 30, 32] 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*. It is also important to note that all these studies are cross-sectional. Consequently, changes as a function of age are not only associated 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. This combined analysis clearly illustrates the increase in myopia prevalence: while in the *1950*'s the mean refraction was still mildly hypermetropic in adults *20–40* years old, it became very myopic (*–2.31D*) in the *1980*'s and later (Figure 3a). This corresponds with about *–0.83D/10* years from the *1950*'s onward. Similarly, the myopia prevalence increased at a rate of *10.7%/10* years in the same period (Figure 3b). Several authors noted that women were often more myopic than men,[25, 27, 29, 30] but the opposite was also reported.[24, 28] These trends were not unique to Inuit, however, as similar

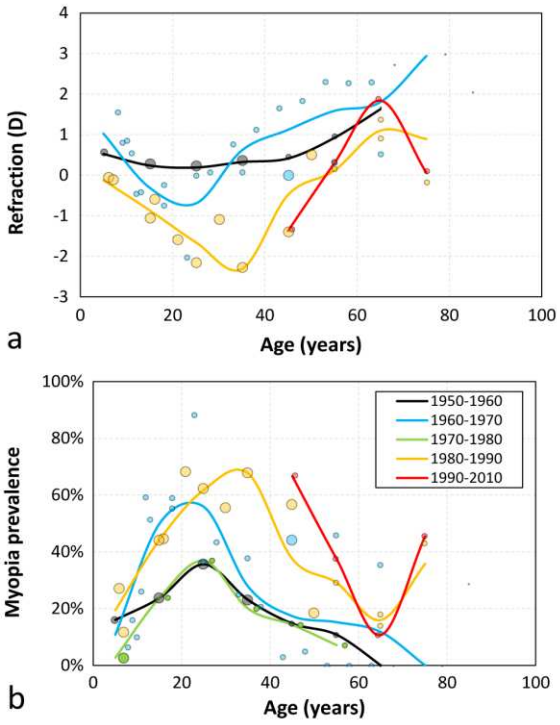


Figure 3: overview of (a) mean refraction and (b) myopia prevalence in the Arctic per decade, derived from the available literature.

trends have been reported in contemporary Métis,[18] First Nation,[18, 26, 35-38] Lapps,[39] and Northern European people,[40] as well as Australian Aboriginals.[41]

Causes

Many potential causes were discussed at the time, including environmental factors such as education,[4, 5, 18, 21-23, 25, 27] increased near work,[5, 21, 22] bad illumination,[5, 21] housing,[5, 18, 21-23, 27] and dietary changes,[5, 18, 21, 22, 25, 27, 42] while genetics was at most seen a contributing factor.[21, 23-25, 27, 28] Meanwhile, the difference between the sexes was attributed to men doing more outdoor activities (hunting) and women doing more activities indoors (cooking, sewing)[25, 43] or having a more regular attendance at school.[25]

In the following, 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, with a focus on the increased time spent indoors, intense text-based education, and pervasively weak illumination, all of which are known to be associated with myopia.[44-46]

3. Education

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.[18, 21-33] While we are unaware of any studies specifically correlating the years of school attendance with myopia in Inuit, this was established in a nearby European population,[43] as well as many other studies,[45, 46] and will therefore not be discussed further.

4. Healthcare and nutrition

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[47] – along with dental caries, anaemia, heart disease and cancers, which were rare among the Inuit prior to this dietary shift. The confined, indoors life in residential schools also led to a preventable epidemic of tuberculosis,[48] which became a leading cause of death among children. In other latitudes, open-air schools were built to avoid the spread of the disease.[49-51] The destruction of the social fabric also led to rampant social problems, such as alcoholism, drug abuse (including solvents and inhalants), chronic unemployment, physical and sexual abuse, depression, and high suicide rates.[52] Health programs, including transportation to hospitals, were developed further by government after *1970* and are still underway, this time with new approaches that include health education programs and employ indigenous personnel.[4] Regardless, the healthcare situation of the Inuit still remains below that of European-Canadians today.[53, 54]

While there is no clear link between nutrition and myopia,[55, 56] there are indications that the high-calorie diet in cities lead to taller individuals with larger eye sizes than the low-calorie diets in the countryside.[57] But larger eyes in the urban environment have flatter corneas and possibly lower lens powers so it seems that the growing eye manages to remain in focus without developing myopia, unless other aetiological known factors like low outdoor exposure and reading are involved.[57]

Figure 4: Views inside classrooms and hostels with Inuit and First Nations children (Images courtesy of the Anglican Church of Canada).

5. Illumination

One underappreciated factor in the Inuit myopia epidemic was the low ambient light environment in which the children spent their time, as confirmed by photographs taken at the time from inside the classrooms and hostel buildings (Figure 4). In the past *15* years it has been clearly established that spending many hours daily outdoors is associated with decreased risks of the incidence and progression of myopia,[44, 46, 58] leading to a general recommendation that schoolchildren should spend two hours outdoors every day.[59-61] 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 of daylight, or the intense demands of the school programmes.

It is impossible now to quantify the illuminance inside the classrooms of those times, as no measurements were taken at the time as far as we know, and photos are unreliable for this purpose because of differences in aperture and exposure. To the best of our knowledge, Young et al.[21] were the only ones to mention that rooms in Inuit houses were often illuminated by a single *40 W* lightbulb, leading to an illuminance that they estimated at about *4 footcandles* (ca. *43 lux*). Typically, people would spend *8* waking hours or longer in these circumstances per day.[21]

The following will attempt to verify whether the estimates by Young et al.[21] would also be realistic inside the class- and hostel rooms 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 is known in great detail.[62] But as such details are unavailable, we will use a number of simplifying assumptions instead 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 tropics. Consequently, if one considers the

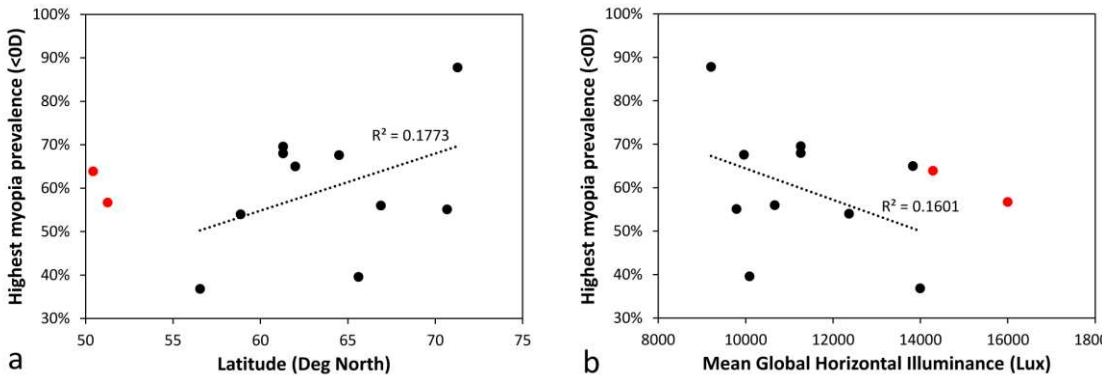


Figure 5: Highest adult myopia prevalence as a function of (a) latitude and (b) mean global horizontal illuminance (averaged over a year) of where the study was performed; black markers indicate Inuit studies, red markers two European and First Nation studies.

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 found in open access weather reports.[63, 64]

One peculiarity of the Arctic is the Arctic Circle, located at a latitude of *66.5°*, where the Sun will not rise above the horizon for weeks on end during winter. Depending on the latitude, this polar night can last between *3 – 11* weeks. 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 very dark in the regions just north of the polar circle, as sunlight will still scatter in the atmosphere and reflect onto the snowy ground, creating a 'polar dusk'. For example, in Kiruna (*67.86°N*, Sweden), noon during the polar night can still see a diffuse illuminance of *1,000 lux* (Arne Lowden, personal communication, 20/12/2020).

Plotting the highest adult myopia prevalence in each Inuit study as a function of the latitude of where the study 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.[65] – 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 with myopia development. But as 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 light exposure *per se* probably plays only a minor role in emmetropization and myopiagenesis; 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 igloo houses and animal skin tents in favour of wooden houses, during the first half of the *20*th Century, their lifestyle also changed from nomadic open-air activities to sedentary indoor living. Originally, these houses consisted of

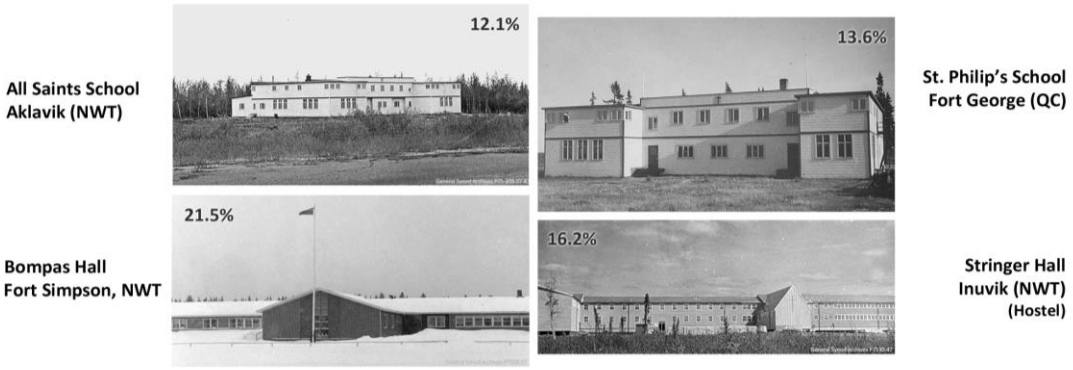


Figure 6: Photos of schools attended by Inuit children in the 1950's used to determine the window-to-wall area ratio (Added as percentages; Images courtesy of the Anglican Church of Canada).

a single room, but from *1960* onward thousands of prefabricated two- or three-bedroom units were built, having the amenities of a *1960*s' European lifestyle. Typically, these houses were small, with small windows to preserve the heat and two doors to avoid being locked in by snow. Inuit would rent these through a government program that also included furniture, fuel, and electricity from a communal oil-fuelled generator. But as there were not enough houses, and many Inuit had limited financial means, families began sharing their houses with other families, sometimes making the houses 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 *1970*s most Inuit were living permanently in such overcrowded settlements.[4]

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 *1950*s (Figure 6) were analysed, using ImageJ (*V1.8.0.172*; https://imagej.nih.gov) to estimate the window-to-wall ratio (*WWR*) of these buildings. 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 enter the classroom. These *WWR* values are considerably lower than the *22%* currently found in student buildings in the US,[66] as well as the current construction standards suggesting that values of *25-30%* are needed for a balance between good illumination and low heat loss.[67]

To get a very rough estimate of the lighting situation in an Arctic classroom, let's assume two hypothetical classrooms. The first is a *1960*'s classroom with a WWR of *15.9%* in the Alaskan town of Kotzebue,[29] the place with the Global Horizontal Illuminance (*GHI*) that was the median of all Inuit study locations. The second is a modern classroom with the US average *WWR* of *22%* in New York City, illuminated according to all current standards for classroom illumination. Assuming clean, unobstructed windows, the historical Alaskan school would have received only an estimated *35.4%* of the daylight of the current New York school (Table 1). Once inside, the actual natural illuminance at any school desk will depend greatly the position inside the room with respect to the windows and the reflectance of the walls, floors, ceilings, etc.[68] Hence, current school buildings tend to have bright walls to maximize the propagation of daylight. Meanwhile, 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, leading to relatively dark rooms. In practice, however, 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 reflections by the snow.

Especially for long periods around wintertime, this meant that practically no natural light would enter the classroom.

Table 1: Comparison between estimated natural illuminance entering in two hypothetical classrooms in Kotzebue (Alaska) and New York City

	Global Horizontal Illuminance (GHI)*	Window to Wall Ratio (WWR)	Natural illuminance entering classroom*
Kotzebue (1960's)	*22,513 lux*	*15.9%*	*3,579 lux*
New York City (Current)	*45,953 lux*	*22.0%*	*10,109 lux*
Relative difference			*35.4%*

**Hourly mean during school hours (9:00 – 17:00), averaged over a year*

In the absence of natural light, the modern New York classroom would typically be illuminated by large fluorescent lights that bring the illuminance to a recommended ISO standard of *500 lux.*[69] 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.,[21] if one were to place a *40W* incandescent lightbulb in a *90°* lampshade *2m* above a table, 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 at *120°* and the lamp is *2m* above the desks, a *100W* incandescent lamp would give an illuminance of about *40 lux*, while 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 more 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* between at midday (*7:00-14:00)* during the polar night in wintertime.[70] 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 (*6:00-18:00*).[71] These values are far superior to those in the *1960s*' Arctic schools, as modern construction materials (e.g. insulation, double glass windows) 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 (supplementary material available).

6. Discussion

In the previous sections we have illustrated clearly how myopia in native Arctic communities went from almost non-existent to almost 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.

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 that chicks 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 un-

der low-intensity light caused not only excessive axial elongation, but also flattening of the cornea and thinning of the lens.[72] In agreement with many other studies in animal models of myopia, these authors observed that the amount of hyperopic shift in refraction was closely correlated with rate of dopamine release from the retina; this is of interest because dopamine has been implicated as an intrinsic inhibitor of myopia development and progression.[73] Consistently with the results in animal models, a recent human epidemiological study, based on the refractive errors of over *1,200* four-year-old kindergarteners in *30* schools, suggests that variations in indoor illuminance affect refractive development in children (Cohen et al., ARVO 2021). Although the mean refractive error was hypermetropic in all cases, as is often the case in young children, those spending *8* hours a day 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*). Finally, low-luminance experiments in which monkeys were reared under less than *50 lux* led to more hypermetropia, rather than myopia, leading the researchers to conclude that a low-light environment by itself is insufficient to develop myopia in monkeys but can affect emmetropization and form deprivation myopia.[74] Even in that case the effect on emmetropization of 50 lux may be different than the influence of lights between *250* and *750 lux* that affected refractive development of Israeli kindergarten children. Together, these observations suggest that indoors illuminance levels play a role in refractive development, but do not of themselves immediately lead to myopia.

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 of higher social standing and better educated.[75] 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.[76] 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.,[77] despite education being compulsory in the UK since *1880*. This could be associated with children back then spending more time outside after class to work or play. An example to the contrary is Sweden, where education became compulsory in *1930*. When Stromberg[78] investigated refraction in army recruits in *1934–1935*, only *8.8%* were myopic, but ten years later Stenström[79] reported considerably more myopia (*27.5%*) in a similar cohort. Meanwhile, in neighbouring Denmark, where school became mandatory in the *19*th Century, the myopia rate in army recruits was found to be rather stable between *1882* and *2004*.[80] We must be aware that, in all population studies, students with significant non-myopic ametropia (hypermetropia, astigmatism, very high myopia) might be excluded by their absence from the cohorts of students that comprised the study populations.

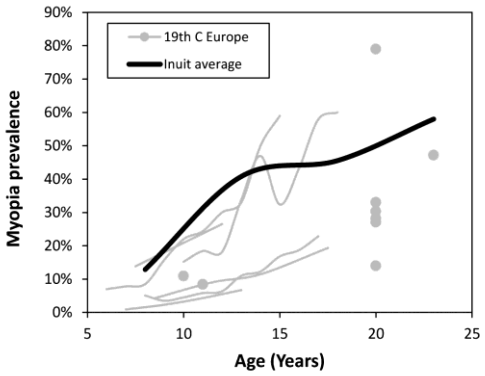


Figure 7: Comparison of the mean increase in myopia prevalence in 1950-60's Inuit and in European city schools and universities in the late 19th Century (data via Steiger[2])

While bad lighting or several years of schooling by themselves do not unavoidably lead to myopia, it seems that the combination of both is especially detrimental. This was the case in middle- and upper-class children in late *19*th 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[2] myopia

epidemic that is reminiscent of what the Inuit experienced in the *1950*s and '*60*s (Figure 7). At the time, this sudden rise in myopia caused much concern among ophthalmologists, prompting one of them to say in *1874* that *"if the school is able to make one in 4 children short-sighted, compulsory schooling ought to be completely illegal."*[2] 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 a reduction in time spent outdoors. Loman et al., Jorge et al., Lin et al., and many others have shown the link between advanced academic studies and the progression of myopia even well past puberty.[81-83] In a sense, these myopiagenic circumstances are now common worldwide, even more so during the worldwide lockdowns of the COVID-19 pandemic that forced children to stay indoors much more than usual and engage much more with digital interfaces while remaining immobile 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.[84]

Inuit

Despite the similarities with the *19*th 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 and the low outdoor illuminance of the Inuit. However, as mentioned before, it appears these did not lead to myopia in the Inuit before the *1960*s and so cannot on their own be directly responsible for the observations available. It is worth noting that during the time prior to formal education, there was ample opportunity to balance out the effects of the extremes of winter darkness and summer light. This natural balancing over the annual cycle of ambient (outdoor) illumination was partly eliminated with the advent of poorly lit school rooms with window coverings. Several reports[13, 37, 85] also mention compliance issues with wearing 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 in deep cold, and continuously fogging lenses all hampered daily activities outdoors.[30] Consequently, many Inuit would have been routinely under-corrected (that is, uncorrected), and this is associated with acceleration of myopia progression.[86, 87] Limited access to even basic eye care and refractive correction remains a major obstacle to health and prosperity among most Indigenous populations (CB, personal observations).

Another aspect is the observation that in Finland myopia prevalence increases with latitude,[65] even though the calculations above show that during winter at high latitudes there is sufficient outdoor illumination to avoid myopia development. Although it is not immediately clear why myopia prevalence would increase with latitude, it may be associated with spending more time indoors as it becomes darker and colder further North.

Importance of classroom design

The Arctic classrooms in the *1950*s and '*60*s and those of *19*th Century Europeans are clear examples of how poor design and dim lighting led to a myopia epidemic. But even today, the 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 three months.[89, 90] Another study from India showed that certified schools can have *90 lux* at the desktops *5m* from the windows and *1,200 lux* near the windows.[91] 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. (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.[92] 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 *800-1000 lux*, in an effort to control the myopia epidemics[93] and to reduce physical disorders and loss of productivity due to alterations in the circadian rhythm[69], 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.[94] 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.[95]

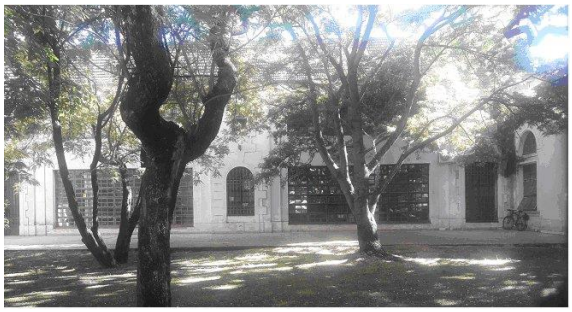


Figure 8: Granaderos de San Martin School (1929) Buenos Aires, Argentina.

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[13, 14, 18, 19, 26] 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 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 much, 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).[38, 96] Future studies of ametropia prevalence should rely primarily on distinct measures of spherical values, with separate reporting of astigmatism and spherical equivalent.

Conclusions

Although education level and low indoor illumination are both well-known myopia risk factors, the combination of both appears especially detrimental, as clearly demonstrated by the myopia epidemics in the Arctic in the *1950*s and '*60*s and late *19*th Century Europe. These epidemics support a strong argument for controlling and perhaps raising the existing illuminance standards for any room being used by children, and to incorporate more outdoor daylight time as part of instruction, 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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Figure legends

Figure 1: Oopungnewing, Inuit village on Baffin Island (ca. 1861).[1]

Figure 2: Overview of reports on refraction in the Arctic (map: Wikimedia Commons).

Figure 3: Overview of (a) mean refraction and (b) myopia prevalence in the Arctic per decade, derived from the available literature.

Figure 4: Views inside classrooms and hostels with Inuit and First Nation children (Images courtesy of the Anglican Church of Canada).

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 two White and First Nation studies.

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 Anglican Church of Canada).

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])

Figure 8: Granaderos de San Martin School (1929), Buenos Aires, Argentina.

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