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Myopia rates among Hadza hunter-gatherers are low but not exceptional

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Abstract

Objectives: Myopia rates are increasing globally. This epidemic is linked to increased school participation, decreased outdoor activity and the proliferation of near-work occupations. The Tanzanian Hadza have traditionally subsisted as hunter-gatherers. School participation has historically been low and near-work otherwise minimal. Previous studies have reported exceptionally low myopia rates among hunter-gatherers, though such studies are few. The present study aims to expand this dataset. We report Hadza myopia rates and compare them to those from other economic/subsistence niches. We look for temporal changes in eyesight, in line with changing Hadza subsistence. Further, we assess the impact two known myopia risk factors, gender and educational participation, on Hadza eyesight.

Materials and Methods: We measured visual acuity among 182 bush-living Hadza aged 10–75 using a non-Latin optotype. From these measures, we estimate age-specific myopia prevalences.

Results: We find age-specific myopia prevalences between 5% and 10% for individuals under 40, increasing thereafter. This is low compared to industrialized populations, although not atypical for rural and non-industrialized populations. Unlike previous studies of hunter-gatherers, myopia was not exceptionally rare. We find that Hadza men have better distance vision than Hadza women. Though the Hadza have experienced subsistence change, we find no statistical evidence of associated decreases in visual acuity between 2006 and 2013/14 after controlling for gender imbalances. Finally, we find no support for our prediction that schooling participation reduces visual acuity, though so few attended school (13 of 58) that this analysis lacked statistical power and probably represents a false negative.

KEYWORDS
Hadza, hunter-gatherers, myopia, visual acuity

1 | INTRODUCTION

Myopia, or short-/near-sightedness, now affects more than 23% of the world's population, and is projected to continue increasing (Holden et al., 2016). The annual global economic impact of uncorrected refractive errors is estimated at above $250 billion (Smith et al., 2009). In many industrialized populations, myopia prevalences have increased substantially over the past century. The most rapid increases are reported in east Asian populations (e.g., Lee et al., 2013; Lin et al., 2004). In Hong Kong, Singapore, Taiwan, and South Korea, myopia prevalences among 20-year-olds have increased from <20% between 1950 and 1970 to >80% today (Morgan, French, Ashby, et al., 2018). Substantial, though less extreme temporal age-specific increases have been observed in many other industrialized populations, including Iceland (Sveinsson, 1982), Denmark (Fledelius, 1983; Jacobsen et al., 2007), Australia (French et al., 2013), Northern Ireland (Mccullough et al., 2016), England (Williams et al., 2013), and the United States (Vitale et al., 2009).

The etiology of myopia is mutifaceted and complex. But, while a small number of genetic myopia risk factors have been identified (Morgan & Rose, 2019; Nallasamy et al., 2007; Verhoeven et al., 2013), the present consensus view is that environmental variables are predominantly responsible for the recent global epidemic (Goldschmidt & Jacobsen, 2014; Morgan et al., 2017; Morgan & Rose, 2005, 2019). These include near work (French et al., 2013; Grzybowski et al., 2020), exposure to LED light (Pan et al., 2018, but see Morgan, French, Ashby, et al., 2018), and lack of time spent outdoors (Ashby et al., 2009; Morgan et al., 2017; Rose et al., 2008). Gender plays a role also, and myopia is often higher among women (Courtright & Lewallen, 2009). Some have suggested a role of diet in myopia, including exposure to increasingly carbohydrate heavy diets (Cordain et al., 2002; Goldschmidt & Jacobsen, 2014), although these theories are contested (see Chua et al., 2018; Edwards, 1996; Goldschmidt & Jacobsen, 2014).

Myopia occurs at disproportionately greater rates in industrialized, wealthy societies (see Apicella et al., 2020; Henrich et al., 2010) with high rates of education (Ku et al., 2019). It also tracks socioeconomic status (Saxena et al., 2015), and the rural/urban divide (Grzybowski et al., 2020). Education, especially, has a pronounced impact on myopia risk (Jacobsen et al., 2007; Morgan et al., 2017; Morgan, French, & Rose, 2018; Mountjoy et al., 2018), as it combines multiple independent risk factors (e.g., outdoor time and near work), and typically occurs while the eye is still developing.

Certain authors, most notably Cordain et al. (2002), drawing on the logic of "discordance" (see Gluckman et al., 2016) have proposed that research into hunter-gatherer eyesight may improve our understanding of the myopia epidemic. In fact, today's foragers are "ecologically and culturally diverse contemporary populations with their own geopolitical and social histories" (see Crittenden & Schnorr, 2017, p. 99). The uncritical use of hunter-gatherers as models for past environments has drawn criticism (see Singh & Glowacki, 2022; Solway et al., 1990) as has the notion that all ancestral environments were alike (Irons, 1998). Despite this, many hunter-gatherers score low relative to urban and industrialized populations on many myopia risk factors, and frequently have low rates of educational participation. Additionally, a small number of authors (Barnicot & Woodburn, 1975; Cordain et al., 2002) have considered the more contentious (see Morgan & Rose, 2019) notion that hunting and gathering subsistence may create positive selection for acute vision.

Although relatively few hunter-gatherer populations have been surveyed, myopia prevalences in existing studies are indeed extraordinarily low compared to industrialized populations. One of few review articles on the topic concludes that moderate or worse myopia among foragers "is either non-existent or occurs in about one person out of a thousand" (Cordain et al., 2002, p. 50). Several studies support this claim. In a study of refractive errors among 2364 Gabonese hunter-gatherers (aged 20–65 years), only 0.4% of 3624 eyes measured were myopic (Holm, 1937). A study of refractive errors among 508 aboriginal Alaskans showed that, while myopia rates were high among young people, among the 131 participants aged >41 who had grown up in isolated communities, only 1.5% of eyes measured were myopic (Young et al., 1969).

However, studies of myopia among foragers are few in number and biased towards north American groups. Most key studies are over 50 years old (e.g., Holm, 1937; Young et al., 1969). There is clear need to expand the available dataset and to further test the prediction that foragers have exceptionally low myopia rates. It would be further enlightening to assess whether recent subsistence changes, and known myopia risk factors (e.g., engagement with education) have a measurable impact on vision. We do just this.

Here we report visual acuity measures for the Hadza, a population in northern Tanzania who have traditionally subsisted as hunters and gatherers. The aims of this research are four-fold. First, we report visual acuity and age-specific myopia prevalence estimates and assess how Hadza myopia rates compare other populations from a range of economic/subsistence niches. Second, as gender is a myopia risk factor elsewhere (Courtright & Lewallen, 2009), we assess the influence of gender on Hadza myopia risk. Third, as school participation is a key myopia risk factor globally (Morgan, French, & Rose, 2018), we assess the impact of participation in formal education on myopia rates in the subset of cases where such data are available (58 participants, 22% of whom had some schooling). Fourth and finally, as Hadza subsistence has changed substantially over the last decades, we explore whether there have been any age-controlled decreases in visual acuity between by 2006 and 2013–14.

2 | MATERIALS AND METHODS

2.1 | Study population

The Hadza are an ethnolinguistic group from the Eyasi region of northern Tanzania who have traditionally subsisted through hunting and gathering. There is a division foraging labour by gender and men and women pursue different sets of resources (Crittenden et al., 2013; Marlowe, 2010; Stibbard-Hawkes et al., 2022). Most Hadza move between camps/settlements several times a year. As consequence, comprehensive census data are difficult to collect, though it is estimated that there are around 1000 Hadza-speakers (Blurton Jones, 2016). Today some Hadza practice horticulture. Many more participate in the tourist trade, using cash proceeds to augment their diet with grain. While data are not available for the whole population, a recent study of two bush camps and two village camps found that while "village camps had access to substantially more domesticated foods" (p. 2) all camps surveyed had some proportion of foraged food in their diet (see Pollom et al., 2021). Many, especially those in bush camps, where most study data were collected, continue to rely predominantly on foraged foods.

Many proposed risk factors for myopia are low among the Hadza relative to urban industrialized populations.

Except for battery flashlights (torches), which are used minimally and predominantly as hunting tools, most people have little exposure to LED light. Instead, in hours of darkness, people habitually use moonlight and firelight as sources of illumination.

Moreover, most Hadza spend the great majority of their waking hours outdoors. Although people make grass dwellings in the rainy season, in the dry season most individuals sleep outside (Marlowe, 2010). Even in the wet season, time spend inside dwellings is predominantly restricted to hours of darkness or when needed as shelter. Most people leave their dwellings at first light to go foraging and will socialize, eat, rest and play outdoors.

Similarly, compared to industrialized populations, most adults participate in relatively little near-work. Mobile phone ownership is low and few habitual economic activities involve looking at a screen, page or other close object for an extended period. The key exception is tool and ornament manufacture. Men periodically whittle new pipes and hunting bows, and produce arrows, arrowheads and poisons, while women periodically string beads. While precise daily averages are not available, from personal observation we estimate that individuals in bush camps average no more than an hour a day in such activities, probably less.

The only other notable exception is schooling. Until recently, schooling was inaccessible to many. Pre-2010 data showed that only 20% of Hadza under 60 years old had some schooling; 40% of those under 30. Where individuals had attended school, it was usually no more than 1–2 years (see Marlowe, 2010). In the last few years, there is evidence that school attendance has increased among younger Hadza. In 2017 estimates, 12 of 32 Hadza children (37.5%) reported attending school (Pollom et al., 2020), substantially higher than the 1/32 in a 2005 sample. With assistance from the recently implemented Olanakwe community fund school transport programme (see https://www.olanakwe.org/projects), we expect school access will continue increasing.

However, in the 2013–2014 data analyzed in the current study, the proportion of adult participants who had attended school was low, at 22% (13/58). Of these, six individuals had completed a full seven years of primary education, one had completed six years, three had completed four years, one had completed three years and two had only completed one year. Schooling engagement statistics were not available for our 2006 dataset though, based on other reports from a similar time period (Marlowe, 2010), rates are likely to be comparable.

Though many risks are low, there are several risks faced by the Hadza which are less commonplace in other subsistence environments. First, many Hadza frequently report eye irritation caused by smoke from hearths, which are used daily as a source of light, warmth and as a means of cooking food. Moreover, rates of accident and injury from foraging work are high and, for example six of 72 individuals in the 2013/14 dataset were blind in one eye due to an injury. From anecdotal observation, bacterial eye-infection is not uncommon. Moreover, while access to medical provision including antibiotics is improving, traditionally it has been very limited.

2.2 | Field trips, demographics and sample size

Study data were collected over four field trips, the first conducted by Dr Apicella in 2006, the second three conducted by Dr Stibbard-Hawkes between 2013 and 2014. The total sample size across trips was 182 (Table 1), 110 from 2006, 72 from 2013–14. Ages ranged from 10–70 in the 2006 and 17–75 in the 2013–14 dataset respectively. All data were collected in bush camps, far from markets. Though the distinction between market and bush camps has become blurred in recent years, it was a meaningful and measurably important distinction at the time data were collected (e.g., see Stagnaro et al., 2022 and the village/bush camp distinction continues to be situationally important (see Pollom et al., 2021). While, today, Hadza subsistence is rapidly changing, almost all participants in this study were full-time foragers.

2.3 | Study ethics, remuneration, and data availability

At the beginning of each camp visit, research methods and aims were explained in clear, layman's Swahili and permission to conduct research was attained at the camp level. Each individual also provided verbal consent, and all were free to drop out at any time. The 2006 study was approved by Harvard University's Committee on the use of Human Subjects and the 2013–14 study by the Cambridge Human Biology Research Ethics Committee. Both were approved by the Tanzanian Commission for Science and Technology. Participants were remunerated with gifts, including good-quality clothing (shawls, blankets, and shoes), tools, and other useful items difficult to attain in the bush (crockery, soap, utensils etc.). All data were stripped of individual identifiers including names and locations. Anonymized study data alongside code for statistical analyses (Stibbard-Hawkes & Apicella, 2022) are openly available online at the following url: https://github.com/DStibbardHawkes/HadzaEyesight

2.4 | Visual acuity measurement and myopia estimates

Visual acuity data in the study were collated from two sets of measurements, the first collected in 2006, the second between 2013 and 14. Both used an optotype, where participants indicate the orientation of a series of identical symbols organized in rows.

TABLE 1 Participant demographics by study year

	Combined sample	2006 sample	2014 sample
Total *N*	182	110	72
Total age range	10–75	10–70	17–75
Total med. age	35	33.5	38
Provided education data	58	0	58
Had some schooling	13	NA	13
Years in school, range	0–7	NA	0–7
Men *N*	123	51	72
Men age range	10–75	10–68	17–75
Men med. age	35	33	38
Women *N*	59	59	0
Women age range	12–70	12–70	NA
Women med. age	35	35	NA

The 2006 study used a tumbling E optotype at 20 feet, and the 2013–14 study used a Landolt C optotype at 10 feet. Both charts are designed to require no knowledge of any alphabet (see Keeffe et al., 1996). Both study measurements were functionally identical and were otherwise conducted identically. The chart was positioned at eye-level on a stationary object perpendicular to the ground, either the trunk of a tree or, where none were in the vicinity, the side of a field vehicle.

As there were no suitable indoor spaces, all tests were conducted outdoors. Tests were conducted between 9 am and 4 pm when light was at its highest, and hourly average solar intensities at the nearest weather station (Narok, Kenya, 466 km away) were no lower than 225 Wh/m^2 (EnergyPlus, 2022), equivalent to light levels of approximately 31,110 lx (see Michael et al., 2020). Although it was impossible to completely standardize lighting conditions, the chart was always positioned such that the sun was behind the participant to prevent glare. We also ensured that the chart was clearly illuminated but free from reflections.

Participants indicated the facing of the symbol (the direction of the gaps in the E or C) with their hands: up, down, left or right. Optionally, participants clarified the direction in either Swahili or the Hadza language. Participants performed the test one eye at a time, with the unused eye covered by their other hand. When participants misidentified or were unable to identify three or more of the rings on a particular row, they attempted the previous row again, then attempted that row again from the beginning. If they misidentified 3 or more rings a second time, we recorded their visual acuity as the Snellen fraction associated with the preceding row.

Visual acuity is normally represented by a fraction (known as the *Snellen fraction*) where the numerator indicates the distance at which a person with clinically "normal" vision (i.e., 20/20 vision) could read a given symbol. For example, 20/10 vision indicates that a person could read a line at 20 feet away that a person with normal vision could only read at 10. The preferred measurement for analysis is given by LogMAR, which is the negative of the logarithm of a Snellen fraction. We converted our measurements into LogMAR scores using the following equation:

$$\mathrm{LogMAR}(i,j) = -\log\left(y_i/x_j\right), \tag{1}$$

where $y_i (i = 1, 2)$ is the numerator of the Snellen fraction corresponding to the baseline distances of the two eye-charts we used (i.e., 10 and 20 feet) and x_j is the denominator of the Snellen fraction for the visual acuity of each eye measured $(j = 1, \ldots n)$. As such, "normal" 20/20 or 10/10 vision correspond to a LogMAR score of 0, while negative logMAR scores indicate better than normal vision and positive scores indicate worse than normal vision.

We also used our visual acuity measure to estimate myopia prevalence, creating a binary variable for myopia, which took the value 1 where myopia was present and 0 when it was absent. Here, we defined myopia as a better-eye LogMAR score of 0.3 or higher. This is normally equivalent to refractive error measurements of −0.5 dioptres (e.g., Luo et al., 2006), though there is variation in preferred cuttoffs (e.g., Tong et al., 2004). Present myopia estimates are workable proxies, but are not perfectly comparable to refractive measures, especially for individuals over 40, as they do not account for the possible influence of eye-disease on vision, (e.g., cataracts, retinal degeneration) independent of refractive error (see Methodological Limitations).

2.5 | Age estimation

Many Hadza under the age of 50 know their age and can provide an exact year. Almost no participants keep any documentation and ages could not be so verified. Moreover, as among many small-scale populations (e.g., Hill & Hurtado, 1996; Howell, 1979) many older Hadza do not know their exact ages. Anthropologists have been collecting demographic data from the Hadza for over 40 years (Blurton Jones, 2016; Marlowe, 2010) and have collected age estimates throughout this period. Where available, we verified ages in our dataset with those given by Marlowe/Blurton Jones in prior decades.

Where participants did not know their age, or in cases of substantial disagreement, we used these ages. In those few cases where participants did not know their ages and there was no existing record, we estimated ages visually, using within-camp relative ages to set upper and lower bounds.

2.6 | Methodological limitations

Given the remoteness of the field site and the lack of indoor spaces, we were subject to several key limitations.

First we measured visual acuity without cycloplegia using an optotype (Landolt C/Tumbling E). This was portable, straightforward and suitable for non-literate participants and participants who are unaccustomed to medical apparatus. The majority of myopia studies employ autorefraction measures of spherical equivalent refraction (SER), defining myopia as SER <−0.50 dioptres. By contrast, optotype-derived measures provide no direct information about refractive errors, and cannot distinguish between refractive error and either participant error or non-refractive visual pathologies. In other words, results approximate but do not directly measure axial myopia, and may be influenced by, for example, retinal degeneration, visual processing impairment or cataracts.

The study population is residentially mobile, and most live in small, ephemeral camps. All equipment must be transported between camps and research conducted outdoors, without chairs or flat surfaces. Under these conditions, autorefraction tests would be difficult to implement, and we believe present methods were appropriate. However, it should be noted that optotype derived myopia measures systematically yield higher myopia prevalence estimates than autorefraction measures (Tong et al., 2004).

Second, although we did exclude eye injuries from analysis, we conducted no cataract checks. UV exposure outdoors is a risk factor in cataract formation (Yam & Kwok, 2014). As the Hadza have high UV exposure, cataracts are likely to occur at higher-than-typical prevalences. This factor may also cause present prevalence statistics to further overestimate myopia, especially for individuals over 40 years old.

Third, although due care was taken to keep the optotype chart free from glare, and to avoid reflection and otherwise reduce inter-test variation, it was impossible to wholly standardize lighting conditions.

TABLE 2 Six key regression model summaries, including mean *a posteriori* coefficients, estimate errors and 90% credibility intervals. Units in log odds for model 2.3 and LogMAR for models 2.1–2 and 2.4–6

Definition	Predictor	Estimate	Est. Error	Q5	Q95
2.1. Visual acuity ~1					
	Intercept	0.02	0.01	−0.00	0.05
2.2. Visual acuity ~1 + Age + Age^2					
	Intercept	0.18	0.09	0.04	0.32
	Age	−0.02	0.00	−0.02	−0.01
	Age^2	0.00	0.00	0.00	0.00
2.3. Myopia ~1 + Age + Age^2					
	Intercept	−1.07	1.70	−4.00	1.58
	Age	−0.13	0.09	−0.27	0.01
	Age^2	0.00	0.00	0.00	0.00
2.4. Visual acuity ~1 + Age + Age^2 + Decade					
	Intercept	0.21	0.08	0.07	0.34
	Decade (2010)	−0.09	0.03	−0.13	−0.04
	Age	−0.02	0.00	−0.02	−0.01
	Age^2	0.00	0.00	0.00	0.00
2.5. Visual acuity ~1 + Age + Age^2 + Gender					
	Intercept	0.26	0.08	0.13	0.40
	Gender (Male)	−0.10	0.03	−0.15	−0.06
	Age	−0.02	0.00	−0.02	−0.01
	Age^2	0.00	0.00	0.00	0.00
2.6. Visual acuity ~1 + Age + Age^2 + Decade + Gender					
	Intercept	0.26	0.08	0.12	0.39
	Decade (2010)	−0.05	0.03	−0.10	0.01
	Age	−0.02	0.00	−0.02	−0.01
	Age^2	0.00	0.00	0.00	0.00
	Gender (Male)	−0.08	0.03	−0.13	−0.02

TABLE 3 Leave-one-out model selection results including expected log-predictive density (ELPD) differences, standard errors (S) and Akaike weights

#	Definition	Weights	ELPD difference	SE
3.1 (visual acuity)				
	1 + Age + Age^2 + Decade + Gender	0.48	0.00	0.00
	1 + Age + Age^2 + Gender	0.44	−0.11	1.36
	1 + Age + Age^2 + Decade	0.08	−1.83	2.79
	1 + Age + Age^2	0.00	−6.24	3.81
	1 + Age	0.00	−15.75	6.15
	1 + Gender	0.00	−25.82	11.04
	1 + Decade	0.00	−27.86	11.88
	Mean	0.00	−28.55	11.14
3.2 (VA school attendance)				
	1 + Age + Age^2	0.67	0.00	0.00
	1 + Age + Age^2 + School	0.33	−0.72	1.25
	1 + Age	0.00	−8.13	5.52
	1 + Age + School	0.00	−8.14	5.13
	Mean	0.00	−17.64	9.54
	1 + School	0.00	−18.22	9.20
3.3 (Myopia Prevalence)				
	1 + Age + Age^2	0.88	0.00	0.00
	1 + Age	0.12	−2.01	1.89
	Mean	0.00	−8.61	5.54

Note: One and 2 take visual acuity as their outcome, 1 for the full sample, 2 for the sub-sample where schooling data were available. Three has myopia as the outcome. Left-side model definitions provided in BRMs linear syntax.

Last, it is standard practice to conduct two measurements for each eye. However, during piloting, participant fatigue was a frequent issue and participants were often frustrated at repeating tests. Participants completed the second tests more quickly and made more errors of inattention. There were frequent drop-outs. For this reason, in study data collection we opted to measure each eye only once. To remove the impact of inter-individual autocorrelation in analyses and reduce injury-related missing cases, we report "better-eye" visual acuity throughout.

2.7 | Statistical methods

All data were analyzed using R version 4.1.0 (R Core Team, 2021). Bayesian MCMC sampling was performed with STAN (Stan Development Team, 2021) using the Bayesian Regression Models package (Burkner, 2017). We modeled visual acuity using a linear regression, and modeled our binary myopia variable with a binomial (Bernoulli) regression. We added predictors stepwise, in order of their *a priori* theoretic importance; first a mean only model, then a model including age, then age as a quadratic, then schooling, then decade of data-collection, then gender. We compared models using a leave-one-out [LOO] model selection. To ensure results were reader-interpretable, we opted not to standardize variables by converting to z scores, but instead presented them in their natural units.

3 | RESULTS

3.1 | Visual acuity

We estimated better-eye visual acuity (LogMAR) with a linear model. First, we constructed a baseline (mean only) model. The mean *a priori* estimate for visual acuity in the study was 0.02 (90% CIs = 0.00–0.05) across ages and sexes (Table 2.1). Next, we explored the influence of age, first by adding age as a linear predictor, then as a quadratic (age + age^2). The quadratic regression model (Table 2.2) substantially outperformed both the linear and mean-only model in a leave-one-out model selection (Table 3). Coefficients for quadratic models are difficult to interpret but are visualized in Figure 1. In our best-fitting model, mean *a posteriori* model-estimated LogMAR scores were close to or below 0 (i.e., normal vision) for individuals under the age of 40, increasing thereafter.

3.2 | Myopia

We next estimated myopia prevalence with a binomial (Bernoulli) linear regression. We defined myopia as any individual with a LogMAR score of 0.3 or over in their better eye. We followed the same modeling procedure as the visual acuity analysis. First we fit a mean only model. The mean whole-population estimated myopia rate

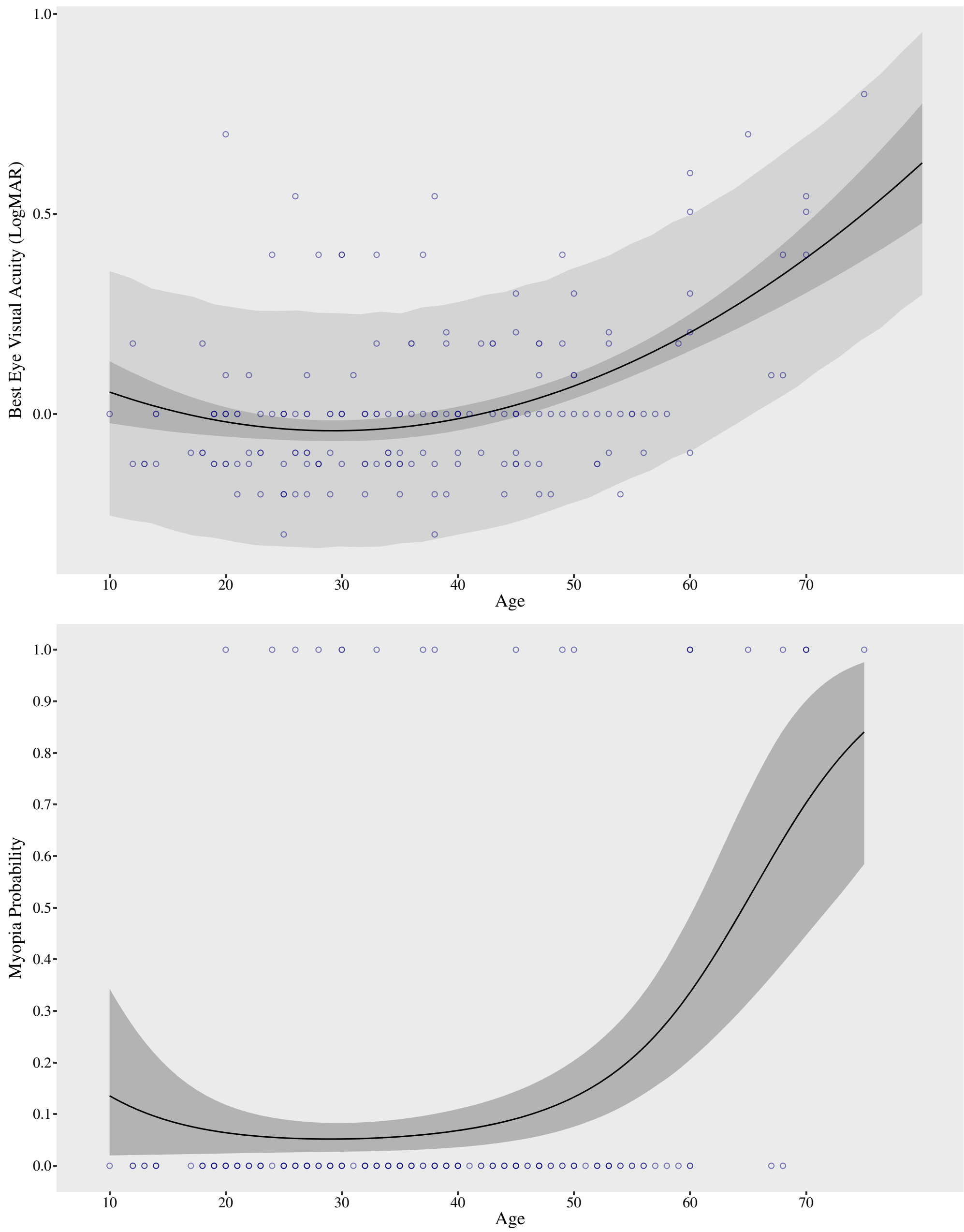

FIGURE 1 Scatterplots of age and visual acuity (LogMAR; above) and myopia (probability scaled; below) with quadratic regression curves and 90% fitted credibility intervals in dark gray. For our visual acuity model we also report the 90% predicted interval in light gray

(i.e. the estimated probability of any individual having myopia) was 0.12 (90% CI = 0.08–0.16) across ages. Next we added age as a linear and then a quadratic predictor. As with the visual acuity analysis, the model including age and age^2 (Table 2.3) substantially outperformed all other models in a leave-one-out model selection, although the model including age as a linear predictor was also allotted a small amount of model weight (Table 3.3).

3.3 | Schooling, gender and temporal comparisons

For 58 cases, from the 2013 to 14 dataset, we also had records of school attendance. To assess whether schooling had an impact on visual acuity, we reran all three visual acuity models using only the subset of cases where schooling data were available. We also ran each of these models with schooling included as a predictor. We conducted a leave-one-out model selection. We found no evidence for any negative impact of schooling on visual acuity in the current population. In no instances did the models including schooling outperform those excluding schooling (Table 3.2). Although the model including schooling was allotted some model weight, (1) the mean estimate was not in the expected direction, and each additional year of schooling resulted in a very small age-controlled increase in visual acuity (mean = −0.01, CIs = −0.03–0.01), (2) credibility intervals crossed zero and 17.5% of the distribution was positive. Moreover, as only 13 of 58 reported any schooling, this analysis lacked statistical power.

We also looked for temporal changes in visual acuity by comparing our 2006 data (n = 110) to our 2013–14 data (n = 72).

TABLE 4 Myopia prevalences from a range of studies compared to equivalent-age fitted Hadza myopia prevalence estimates from our best-fitting model

Country	Region	Sample	Average age	Age range	%	Hadza Est. % (90%CIs)	P.P. difference	Notes	Study
Singapore	E. Asia	28,908	19.80	17–29	81.60	6.48 (2.37–12.01%)	75.12	Non-cycloplegic autorefraction	Koh et al. (2014)
China	E. Asia	15,066	13.20	7–18	64.90	10.16 (2.14–23.49%)	54.74	Non-cycloplegic autorefraction	You et al. (2014)
UK	Europe	373	19.55	17–30	51.70	6.56 (2.35–12.26%)	45.14	UK Undergraduates; Non-cycloplegic autorefraction	Logan et al. (2005)
Australia	Meganesia	1202	17.00	17	30.80	7.62 (2.27–15.44%)	23.18	2011 Data; Cycloplegic autorefraction	French et al. (2013)
Argentine	S. America	1518	43.20	25–65	29.18	8.13 (4.33–12.98%)	21.05	Office Workers; Non-cycloplegic Subjective	Cortinez et al. (2008)
Nigeria	Africa	252	36.20	19–63	11.40	5.85 (3.08–9.38%)	5.55	Subjective refraction	Eze et al. (2012)
Ecuador	S. America	507	31.00	18–45*	4.70	5.23 (2.75–8.33%)	−0.53	Naporuna Community; Cycloplegic autorefraction	Jimenez et al. (2004)
Colombia	S. America	1228	11.40	8–17	11.20	11.9 (2.05–29.1%)	−0.70	Non-cycloplegic autorefraction	Galvis et al. (2017)
South Africa	Africa	1586	15.81	13–18	7.00	8.27 (2.23–17.5%)	−1.27	Non-cycloplegic autorefraction	Wajuihian and Hansraj (2017)
Mongolia	E. Asia	1057	12.27	7–17	5.80	11.01 (2.09–26.24%)	−5.21	Non-cycloplegic autorefraction	Narankhand et al. (2006)
Gabon	Africa	3624	42.20	20–65*	0.39	7.67 (4.06–12.27%)	−7.28	Per eye measures, 2364 individuals; Cycloplegic retinoscopy	Holm (1937)
USA (Alaska)	N. America	131	54.83	41–88	1.50	20.49 (12.32–30.2%)	−18.99	Right Eyes; Subjective refraction	Young et al. (1969)
Iran	W. Asia	1367	63.70	55–80	27.20	46.65 (28.53–66.06%)	−19.45	Mashad; Non-cycloplegic autorefraction	Yekta et al. (2009)

Note: Where study mean ages were not available, we used the centre of the study age range instead, indicated with asterisks. Most items were previously tabulated or summarized by Holden et al., (2016), Grzybowski et al., (2020) and Cordain et al., (2002).

We coded the two datasets as a binary factor variable, decade, which we included as a predictor in our visual acuity models. Contrary to expectations, we observe a statistically real decade-on-decade increase in visual acuity (Table 2.4), with CIs below zero. Moreover, the models including decade substantially outperformed the equivalent models excluding decade in a model selection (Table 3.1). However, the 2013–14 dataset was collected as part of a wider study on men's hunting (Stibbard-Hawkes, 2019; Stibbard-Hawkes et al., 2018; Stibbard-Hawkes et al., 2020) and, unlike the 2006 data, recruited no female participants.

Globally, sex is a risk factor in vision loss, due to both biological differences and to gendered variation in exposure to disease and access to care (Courtright & Lewallen, 2009). It is thus possible that sample gender disparities account for the difference. To test this we constructed three additional models: one including gender only, one with gender and age as a quadratic predictor, and finally a full model which included age, age^2, decade and gender. We found clear gender differences in visual acuity such that, after controlling for age, men had VA scores −0.10 better than women (Table 2.5). Controlling for gender greatly reduced estimated decade-on-decade decrease in visual acuity (Table 2.6), such that 90% CIs crossed zero. Moreover, the full model including age, age^2, gender and decade did not substantially improve upon the equivalent model excluding decade in a LOO model selection (Table 3.1).

4 | DISCUSSION

4.1 | Summary of findings

The present study yielded several notable findings. First, we found that Hadza visual acuity was typically good; across all ages, mean estimated visual acuity was LogMAR 0.02, or close to perfect vision. Visual acuity began declining after the age of 40. Estimated myopia prevalences were <12.5% for all ages under 45. However, at no ages were estimated prevalences <5%, and they were always substantially above myopia prevalences reported for other forager populations (e.g., Holm, 1937; Young et al., 1969). After controlling for age, women in our study had visual acuity LogMAR scores 0.1 higher than men. We find no clear evidence of an effect of schooling on visual acuity in the subset of our sample for whom schooling data were available. However, as only 13 of 58 had one or more years of school (six of which had completed primary education), this analysis was at the lower useful bound of statistical power and the estimate crossed zero. We also found no evidence of any decade-on-decade decreases in visual acuity between our two study periods. In fact, mean eyesight actually improved, although much of this difference resulted from a gender imbalance between the two samples.

4.2 | Absence of evidence for schooling effects

There is good evidence from several populations that myopia risk tracks educational attainment, and that each additional year of education increases myopia prevalence (e.g., see Harman, 1913; Jacobsen et al., 2007; Ku et al., 2019; Mountjoy et al., 2018).

A priori there was reason to believe this trend should be even more pronounced among the Hadza. Life for Hadza school attendees is very different to life in the bush. In the present dataset, those who attended school usually did so as weekly boarders, spending time away from the bush and only visiting nearby Hadza camps on weekends (Blurton Jones et al., 2002). As consequence, each additional academic year spent in school represents a year less engaged in the subsistence activities otherwise characteristic of a Hadza childhood (see Blurton Jones et al., 2002; Crittenden et al., 2013). In addition, boarders eat a different diet (Blurton Jones et al., 2002) and, although data are unavailable, probably also have greater exposure to electric light and spend more time indoors. Almost all risk factors for myopia are increased. Thus, the lack of an effect of schooling on visual acuity in the present study was unexpected. However, on closer examination of the data, this finding is less surprising.

First, although records of education were available for 58 individuals in our dataset, a reasonably large sample for forager research, the actual number who had any schooling was very low, only 22%. Second, even among individuals who had some schooling, fewer had attended school for an extended period. Only 6/13 had completed the full seven years of primary education, one person had completed six years and the remainder four or fewer. It is possible that it takes substantial schooling to impact visual acuity, and that most individuals have not exceeded this cut-off.

At present sample sizes, error and noise can impede inference. It is distinctly possible that the absence of clear evidence for schooling effects in this study represents a false negative. Indeed, though mean estimated change in visual acuity was not in the predicted direction, credibility intervals crossed zero, meaning our model did not rule out the possibility of a small decrease in visual acuity with each additional year of schooling.

Moreover, the association between schooling and myopia is probably consequence of the fact that children who attend school spend less time outdoors and more time involved in near-work (e.g., see Jacobsen et al., 2007). However, even among Hadza who attended school as boarders, most children probably spent extended periods outdoors during evenings, break-times and weekends, reducing its negative impact.

School participation is rapidly increasing among the Hadza. In a recent study, 37.5% of five to 14-year-old Hadza children surveyed in 2017 reported some school attendance (Pollom et al., 2020), more than the 22% of adults in the present 2013–14 dataset. To address the unexpected lack of clear evidence for schooling effects, it would be useful to collect repeat measurements, to see if the recent increased uptake has had any measurable impact on visual acuity.

4.3 | Absence of evidence for temporal changes

Throughout the 20th century, there were regular attempts to settle the Hadza and persuade people to take up full-time farming (see Marlowe, 2010, for review). At no point since the 1950s have all Hadza lived as full-time foragers. However, since the turn of the millennium, Hadza subsistence practices have yet begun to shift rapidly. Today, many Hadza in almost all regions are involved to a lesser or greater extent in the tourist trade, and augment their diets with cash-purchased grain. As consequence, many leave camp less often to forage and collect a lower diversity of foraged resources (see Pollom et al., 2020, for children's foraging). Village-bought alcohol has also become more widely available (Marlowe, 2013, pers. comm.). Changes in subsistence were especially pronounced between 2006 and 2013–14 (Marlowe, 2014, pers comm.). For this reason, if foraging lifestyles are associated with lower myopia prevalences, we expect to observe a decrease in visual acuity between the two study periods.

No such trend was observed in the present study. In fact, before controlling for gender imbalances between the two datasets, we observed a substantial decade-on-decade age-controlled increase in visual acuity. Controlling for gender substantially reduced this effect, although mean estimates still indicated an improvement in eyesight.

This was unexpected. It could be the result of methodological artifacts. Although methods and conditions were otherwise identical, the 2006 study used a tumbling E optotype, while the 2013–14 study used a Landolt C optotype. Chart type does have a measurable impact on visual acuity scores (Lai et al., 2021). However, where differences in results have been observed between the two charts, they are small in magnitude. Moreover, it is the tumbling E chart that typically yields better scores (e.g., see Lai et al., 2011; Lai et al., 2021), the reverse of the present pattern.

We find it more probable that, although Hadza lifestyles are changing, the specific risk factors involved in myopia remain consistent between decades. Even where individuals spend less time out of camp foraging, they are still involved in minimal near work and still spend much time outdoors. Moreover, although diets are changing, and people have more access to grain, those practicing mixed subsistence still eat a substantial amount of foraged foods and, by some measures a healthier and more consistent diet (Pollom et al., 2021). Finally, it may be that there are periods of development where visual acuity is more affected by environment. If so, it is possible that there have been changes, but that these were not well captured in our 2013–14 sample of over-16-year-olds.

4.4 | Hadza myopia rates compared to other populations

We also compared Hadza myopia prevalence estimates from our study to myopia prevalences from other populations representing a range of subsistence types (Table 4). We contrasted myopia prevalences in these studies with the corresponding fitted age-specific estimates from our best-fitting Hadza myopia model (Table 2.3). Age ranges differed between studies and, for most studies, rather than having raw data, we only had access to myopia prevalence summary statistics and mean ages, sometimes just age ranges. Moreover, methods differed between studies, and most used auto-refraction, which typically yields lower myopia prevalence estimates than those derived from our methods. For these reasons, the current comparisons are not exact though do provide useful, if crude, insights about how Hadza eyesight compares to other populations.

As expected, Hadza age-specific myopia prevalence estimates were far lower than age-specific rates in urban industrialized populations. Myopia rates for Beijing school children (You et al., 2014) were 55 percentage points higher than estimates for 13-year-olds in our dataset. Similarly, myopia rates for first-year UK university students (Logan et al., 2005) were 45 percentage points higher than our estimates for Hadza 19-year-olds, while rates for urban Australian 17-year-olds (French et al., 2013) were 23 percentage points higher than equivalent-age Hadza estimates. In short, even allowing for substantial error, Hadza myopia risk was much lower than the equivalent risk in urban industrialized populations.

However, despite this, Hadza myopia rates were substantially higher than those from previous studies of hunter-gatherers. For example, a 1937 study of Gabonese foragers (Holm, 1937) with an average age of 42.2 found that only 0.39% of 3624 eyes measured were myopic. Model estimates indicate that 42-year-olds in the present study were 7.28 percentage points or almost 20 times more likely to have myopia. To give further perspective, more individuals were myopic in their better eye ($n = 21$) in our dataset of $n = 182$ than were 3624 individual eyes measured in the 1937 study ($n = 14$ myopic eyes). Similarly, estimated myopia rates for Hadza 55-year-olds in our model were 20.5%, 19 percentage points or almost 14 times higher than mean myopia rates for those over the age of 40 (average age = 55) in Young et al.'s often cited study of Barrow Iñupiat. Even assuming some overestimation in present estimates, these differences are substantial.

Instead, present myopia rates here are more similar to those in rural farming communities from Africa and South America (see Table 4). Hadza estimates were within two percentage points of rural populations from Colombia (Galvis et al., 2017), Ecuador (Jimenez et al., 2004) and South Africa (Wajuihian & Hansraj, 2017), though older Hadza had considerably higher estimated myopia prevalences than those among an Iranian farming community (Yekta et al., 2009).

It should be noted that present methods may overestimate myopia compared to auto-refraction studies, especially among older individuals (40+). However, even allowing for some error in both measures and estimates, present data suggest substantially worse eyesight than previous studies of foragers. Although population visual acuity was greatly better among the Hadza than many urban populations the world over, we find no clear evidence that the Hadza exceptional or, indeed any different to other rural populations not engaged in for. This contrasts strongly with previous research among other foragers (e.g., Holm, 1937; Young et al., 1969), although without parity of methods and access to datasets from other studies, it is presently difficult to draw stronger conclusions.

4.5 | Selection for good vision?

There are several known SNPs and other genetic factors which may interact with environmental factors in contributing to myopia risk (Goldschmidt & Jacobsen, 2014; Nallasamy et al., 2007). The role of genetics in myopia has been divisive and the effects of individual SNPs are typically small (Morgan & Rose, 2005, 2019). There has also been some speculation that hunter-gatherer vision may be under strong selection (Barnicot & Woodburn, 1975; Cordain et al., 2002).

For instance, all types of color-blindness are rare among the Hadza. In a 1966–7 study using Ishihara plates, only three of 202 male participants were colorblind, all red-green (Barnicot & Woodburn, 1975). Lindsey et al. (2016), found that color-blindness was all but absent. Only one of 55 participants misidentified a Richmond HRR pseudosichromatic plate (29 men; 26 women), and this was probably a case of participant error, rather than colorblindness, as that person passed the test on a subsequent round. These rates are lower than those among boys in other parts of sub-Saharan Africa (~4%, e.g., Mashige & Van Staden, 2019; Zein, 1990) which are, in turn, lower than those in Europe and Asia (5%–8%, e.g., Chia et al., 2008; Modarres et al., 1996). Barnicot and Woodburn briefly speculated that the relatively low rates of Hadza color-blindness may be a "product of natural selection against color-blindness" (p. 2) though stressed that more data were needed.

There have also been suggestions that acute distance vision plays a pivotal role in foraging success, especially hunting success (Blurton Jones, 2016, p.281), and might be under strong selection (Cordain et al., 2002). However, in two independent studies, Hadza visual acuity was unrelated to both peer-reported hunting reputation and aim with a bow and arrow (Apicella, 2014; Stibbard-Hawkes et al., 2018) and it is likely that acute vision is of subsidiary importance to other aptitudes (Stibbard-Hawkes et al., 2018).

Present results show that Hadza age-specific myopia estimates are not atypical for a rural African population (see Table 4). Thus, findings do not indicate atypically strong selection for acute vision among the Hadza. However, Myopia is a complex disorder and causes are multifaceted; much more research is needed to comprehensively address this question.

5 | CONCLUSIONS

In summary, the present study shows that Hadza foragers had good vision, and low rates of myopia, although in neither case exceptional. While age-specific myopia rates are very low compared to most urban populations, they do not match the extremely low rates reported among other foragers (e.g., Holm, 1937; Young et al., 1969) especially among over-40-year-olds (see Young et al., 1969). Instead, Hadza myopia rates were more comparable to those reported in South-American and African rural farming communities. Our results support the idea that the recent myopia epidemic is related to patterns of work and education in highly industrialized economies (e.g., see Morgan, French, Ashby, et al., 2018) but we find no support here for the prediction (Cordain et al., 2002) that hunter-gatherer vision is otherwise remarkable.

We found that Hadza women had substantially worse visual acuity than Hadza men. This pattern is not uncommon, and has been observed the world over. Despite rapidly changing diets and subsistence practices, we did not observe any fall in visual acuity between 2006 and 2013/14 and, in fact, found weak evidence for a trend in the opposite direction. We suspect that, though subsistence is changing, myopia risk factors are not increasing.

Although schooling plays a substantial role in the global myopia epidemic (Morgan, French, Ashby, et al., 2018), contrary to expectations, we found no good evidence for a decrease in visual acuity with years of schooling here. Only six participants had completed the full seven years of primary education and it may be that more substantial schooling is required before vision is affected. Given the low uptake of schooling in our study data (13/58), it is similarly possible that our dataset lacked sufficient statistical power to detect an effect. Moreover, as credibility intervals crossed zero, findings did not rule out a small positive decrease in visual acuity with increased schooling. In the years since our data were collected, school participation among the Hadza has increased substantially (Pollom et al., 2020), and it would be enlightening to conduct another study to measure the effects.

The present study provides a broad picture of visual acuity in an important subsistence population, alongside preliminary, proximate myopia estimates. Further investigation into Hadza visual acuity, drawing on a larger and more recent sample, and incorporating autorefraction, would be worthwhile.

AUTHOR CONTRIBUTIONS

Duncan N.E. Stibbard-Hawkes: Conceptualization (lead); data curation (equal); formal analysis (lead); funding acquisition (equal); investigation (equal); methodology (equal); writing – original draft (lead). **Coren Lee Apicella:** Conceptualization (supporting); data curation (equal); formal analysis (supporting); funding acquisition (equal); investigation (equal); methodology (equal); supervision (equal); writing – original draft (supporting); writing – review and editing (equal).

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CONFLICT OF INTEREST

The author declares that there is no conflict of interest.

DATA AVAILABILITY STATEMENT

Anonymised study data alongside code for statistical analyses (D. N. E. Stibbard- Hawkes & Apicella 2022) are openly available online at the following url: https://github.com/DStibbardHawkes/HadzaEyesight.

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