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Halving of Australian children's naevus counts during 1992–2016 and change in sun behaviour

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Abstract

Background The lifetime risk of cutaneous melanoma in Australia is the highest in the world. The most important melanoma risk factor is the number of acquired cutaneous melanocytic naevi (AMN) on a person, the majority of these forming in adolescence. Childhood exposure to ultraviolet radiation (UVR) is a strong determinant of naevus count.

Objectives To examine childhood AMN and its risk factors over a 25-year period in the high-UVR environment of South-East Queensland.

Methods The Brisbane Twin Nevus Study recorded sun behaviours and counted naevi on annual new samples of 12-year-old twins (and siblings nearest in age) from 1992 to 2016. Participants were re-examined 2 years later, and a subset was seen 20 years after the initial exam.

Results Among 3957 participants (158 per year), we saw an approximate halving of naevus counts over the 25-year period, and examined multiple explanations for this trend. As this trend was seen for both large (> 5 mm) and smaller naevi, we inferred errors in counting were unlikely. There was an increase in the number of participants reporting non-European ancestry, but this explained only a small proportion of the change in naevus count.

Conclusions We propose that, in Queensland through the 1990s and 2000s, children's sun exposure has been altered by changes in behaviour. Looking at studies counting naevi in populations at different latitudes, we estimate the observed fall in naevus counts would be consistent with a 11.7% fall in average annual UVR dose (clear sky erythemal spectrum, from 1503 kJ m^{-2} to 1327 kJ m^{-2}). Based on published risk prediction equations, the fall in mean naevus number over time should lead to a fourfold drop in lifetime melanoma risk for those born after 2000 compared with those born in the 1980s.

Lay summary

The number of common moles a person has can be a strong predictor of lifetime risk of melanoma (skin cancer). Moles are most common in White-skinned populations in high ultraviolet light environments. Most moles develop during adolescence. It is thought this age is a key period for determining melanoma risk.

The Brisbane Twin Nevus Study looked at 12-year-old schoolchildren. These students were living in the subtropics. There were 3,957 participants in total. Moles were counted on a new sample of adolescents every year from 1992 to 2016. We found that by 2016, the average mole counts had fallen by 47% from 1992 levels. This wasn't due to changes in skin colour or ethnicity. Participants actually reported more time in the sun between the ages of 12 and 14 years over the same period in the study questionnaires. We thought that the most likely reason for the decreasing mole counts is that children are spending less time in the sun before the age of 12 years.

A number of studies of schoolchildren have looked at the relationship between where they live and the number of moles. The relationship between the latitude where they live and mole counts is not linear. We estimate it would only take an approximately 11% fall in sun exposure over 25 years to get the needed fall in mole numbers. Other published studies of skin cancer show that such a drop in mole count should also reduce later rates of melanoma by as much as fourfold.

What is already known about this topic?

- Acquired melanocytic naevi are common in Australian children and counts increase with decreasing latitude.
- They are a very strong risk factor for later melanoma.
- Australian schools and employers have implemented strategies to reduce ultraviolet light exposure at population and individual levels, with some evidence of success.

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What does this study add?

- From 1992 to 2016, we found that the average number of naevi on each new annual sample of 12-year-olds fell by 2% each year.
- We estimated that this fall was consistent with a 0.4% annual fall in earlier lifetime sun exposure, despite reported sun exposure after age 12 years in participants actually slightly increasing over the study period.
- Based on published case–control studies, this drop in mean naevus count should lead to as much as a fourfold drop in rates of melanoma in children born since 2000 compared with those born in the 1980s.

Aside from pale European skin, the greatest phenotypic risk factor for cutaneous melanoma is the number of acquired cutaneous melanocytic naevi (common moles, hereafter 'naevi') present on one's skin.[1–4] The presence of as few as five large naevi (i.e., >5 mm diameter) increases melanoma risk fourfold.[2] Acquired naevi start appearing in early childhood, with an acceleration in rate of increase of numbers around adolescence.[5] Childhood exposure to ultraviolet radiation (UVR) is a strong determinant of naevus count,[6,7] and subsequent risk of both melanoma and nonmelanoma skin cancer.[8] Each individual naevus almost certainly represents a single permissive mutation of a *BRAF* or *NRAS* gene in one melanocyte.[9]

Through a combination of having a largely Anglo-Celtic population, high ambient UVR exposure, and an outdoor-oriented lifestyle, Australia has had the highest rates of skin cancer in the world.[10] As a response to this, there have been various population-level interventions since the 1970s such as educational advertising campaigns and changes in school uniforms and play areas, children's swim wear and prescribed work wear, all with the intention of reducing UVR exposure.[11–13] Some sequential surveys have shown salutary changes in child and adult sun-protection behaviours[14,15] (e.g. doubling of hat wearing) that have led some researchers to interpret recent changes in melanoma rates in younger age groups as being caused by these public health campaigns.[16,17] Specifically, Whiteman and coworkers[16] report a 3% annual increase in cutaneous melanoma rates in US Whites, Britons, Swedes and Norwegians over the period 1982–2011 but a 1% annual decrease in rates in Australia. There is some argument as to whether these population-level changes reflect alterations in sun-exposure behaviours or changes in the ethnic mix, as information on the latter is usually not collected by cancer registries.

If melanoma rates are decreasing in the relevant white-skinned population, and because naevus count is such a potent melanoma risk factor, we would expect to see parallel decreases in naevus counts in the adolescent population over time (child naevus counts do parallel intercountry differences in cutaneous melanoma rate). In the present work, we address this hypothesis using the Brisbane Longitudinal Twin Study, originally the Brisbane Twin Nevus Study (BTNS), a cohort study that has recruited approximately 80 families a year from 1992 to 2016, each containing a pair of twins who had turned 12 years of age in that year. We describe secular trends in self-reported sun behaviours, observer-measured naevus counts at ages 12 and 14 years over that 25-year period, and their relationships with important known covariates, including ancestry-informative genotype frequencies, as well as skin reflectances at multiple body sites and serum vitamin D levels, two useful biologic proxies for recent sun exposure.

Patients and methods

From 1992 to the end of 2016, adolescent twins from Brisbane in Australia (latitude 27.5° S), their siblings and their parents were recruited into the BTNS, a study of genetic and environmental factors contributing to the development of pigmented naevi and other risk factors for skin cancer. Many details have been described previously.[18,19] The proband twins were recruited at age 12 years through schools around Brisbane and via public appeal and came to Queensland Institute of Medical Research where their moles were counted and other risk factors assessed by a research nurse. The twins were invited back 2 years later at age 14 years to repeat the protocol. We also endeavoured to recruit up to two near-age siblings.

Phenotype data

Mole counts

Total naevus counts (TNCs, excluding the genital area, chest and abdomen) summed across three size classes (< 2 mm, 2–5 mm, >5 mm) were obtained from the adolescent twins on two occasions by a trained nurse (at ages 12 and 14 years), and in near-age singleton siblings on one occasion (the first visit of the twins). Counting followed a standardized protocol (Methods S1 and Figure S1; see Supporting Information) and was performed by the same observer from 1992 to 2011, and from 2012 to 2016 by a second observer trained in the same protocol by the first observer. For the 204 participants examined by both (2 years apart), the inter-observer agreement was high ($r = 0.90$). Separate counts were obtained for flat, raised and atypical moles. The first measurement from the twins and siblings is from 3957 individuals in 1555 families, and the second measurement from 2663 twins in 1324 families.

Sun exposure and protective behaviours

Twins reported the number of hours they spent in the sun during a normal school week in summer, during a normal weekend in summer, and during the last summer holidays; how frequently they used sunscreen lotion and wore a shirt or top, or a hat; and how many painful sunburns they had experienced in the last 6 months (see Methods S1). We calculated weekday and weekend hours of sun exposure by averaging those four respective biannual reports, and summing for a weekly total, adjusted by the monthly UV Index for Brisbane[20] to generate a sun-exposure (UV-justified index) score.[21]

Skin reflectance

This is a direct measure of skin colour and melanin content and was evaluated at a single frequency of 650 nm

(Methods S1 and Figures S2 and S3; see Supporting Information). These were measured on the back of the hand (sun exposed) and inner upper arm (nonexposed).

Ancestry

This was measured via questions to either the individual or a parent about the country of birth and ancestry of each of the grandparents of the individual, and via genome-wide single nucleotide polymorphism (SNP) genotyping used to calculate genetic principal component scores representing ancestry (see Methods S1).

Vitamin D levels

We use plasma vitamin D levels here as a biologic proxy for sun exposure (see Methods S1). Detailed results for this analyte have been reported previously.[22]

Statistical methods

Most analyses have been carried out using the SPSS[23] and R[24] statistical packages. Naevus counts were log-transformed. We carried out linear regression adjustment of transformed counts for sex, age and age-squared terms, and estimated body surface area, so results are actually for body naevus density. Most analyses also include adjustment for the first five genetic principal components to adjust for ethnic confounding. Because the participants are recruited in family units, we have carried out mixed-model analysis of the key variables, using generalized additive mixed models in the R mgcv[25,26] and gamm4 packages.[27] Testing for parallel slopes for the relationship between counts of different sized naevi (< 2, 2–5, >5 mm diameter), we applied negative binomial vector generalized linear modelling.[28]

To estimate the effects of a secular change in naevus count on relative risk of melanoma, we predicted lifetime (to age 75 years) melanoma risk for study participants based on their naevus counts and birth year using Australian case–control data[4] and standardizing to Queensland population base rates (see Methods S1) using the R iCARE package.[29]

Calibration meta-analysis

We meta-analysed published studies counting cutaneous naevi on children and adolescents for the relationship between latitude of residence and naevus count,[5,7,30–32] several from Australia, via a simple sample-size-weighted linear regression[33] of study mean naevus count at age 12 years (adjusting to this age by linear regression within the study where possible) vs. latitude of recruitment region (see Methods S1).

Interpretation of these ecological analyses requires an assumption that the distribution of sun-exposure behaviours is reasonably homogeneous. For example, Lucas *et al.*[34] report that Australian adults from Brisbane (latitude 27.5° S) reported spending up to 40% *less* time in the summer sun than those from Tasmania (latitude 43° S), which would shrink any latitude–naevus association.

Results

Brisbane Twin Nevus Study

The TNC was measured for 3957 children in 1555 families from 1992 to 2016 (average 158 participants per year; Tables 1 and 2). Of this total, 2840 were 12-year-old twins, with a further 228 having already turned 13 by the time they were examined. There were an additional 849 singleton siblings examined, with ages ranging from 9 to 23 years (and a smattering of second pairs of twins). Males had a geometric mean TNC that was 6% higher than that for females: 81 vs. 76. This difference persisted after adjusting for multiple covariates that also exhibited sex differences, such as reported sun exposure (17 vs. 15 h per week) and vitamin D level (79 vs. 71 nmol L^{-1}; note that vitamin D level was available for 3214 individuals only). From age 12 years to age 14 years TNC increased by an average of 28% (from geometric mean 79 to 99), as we have previously reported.[18]

One of most striking findings was an approximate halving of naevus counts over the 25-year duration of the study (Figure 1 and Figure S1a–c). In the peak year, 1996, the geometric mean TNC for 12-year-olds was 112, falling to 46 in 2016 (59% decrease). From the 1992 geometric mean of 87, this is a 47% decrease. This affected the number of large naevi (> 5 mm) and smaller naevi to a similar extent, with a respective 67% (> 5 mm), 73% (2–5 mm) and 12% (1–2 mm) fall in geometric mean counts from 1992 to 2016 (see Figure S4; see Supporting Information). These numbers differ from the decrease for total naevi (> 1 mm) because of the different proportions of each class, although the difference between the 1–2-mm class trend and the trend in the two other classes is statistically significant. The variables that seemed most likely to explain the overall strong trend were changes over time in the ethnic composition of the studied population, and in sun exposure (upper triangle of Table 2). A possible unmeasured confounder would be a drift in examiner technique – although we might expect this

Table 1 Description of key variables measured on participants in the Brisbane Twin Nevus Study 1992–2016

Variables	*N*	Value	Range
Male sex, *n* (%)	3957	1909 (48%)	
Age at first visit (years)	3957	12.6	9–23
Age at second visit (years)	2663	14.15	14–16
Total naevus count, mean (SD)	3957	91.9 (54.1)	0–426
Decimal log total naevus count, mean (SD)	3957	1.90 (0.26)	0–2.63
Proportion in whom all eight great-grandparents were of Northern European ancestry, proportion (SD)	3924	0.60 (0.008)	0–1
Average diarized weekday sun exposure,[a] mean h per week (SD)	1901	10.1 (3.4)	0.05–24.0

[a]See also Methods S1 (Sun exposure and protective behaviours).

Table 2 Pearson correlation coefficients (pairwise complete) for study variables are shown in the upper triangle,[a] and partial Pearson correlation coefficients (complete data only, adjusting for all other variables in matrix) are shown in the lower triangle;[a] partial correlations between nongenetic variables ≥ 0.1 are marked in bold

				Genome-wide genetic PCs											
	log_{TNC}	Sex	Age	PC1	PC2	PC3	PC4	PC5	PC6	Sun hours	Vitamin D	Arm W650	Hand W650	Skin colour	Year
log_{TNC}	1.000	0.053	0.172	0.045	0.240	−0.200	−0.158	0.121	0.149	0.016	0.139	0.153	0.095	−0.252	−0.314
Sex	0.034	1.000	−0.019	−0.006	−0.008	0.007	0.016	0.008	−0.003	0.189	0.206	−0.047	−0.181	−0.021	−0.040
Age	0.175	−0.012	1.000	0.012	0.024	−0.020	−0.028	0.009	0.004	−0.056	−0.071	0.056	0.030	−0.066	−0.012
PC1	0.002	0.009	0.012	1.000	−0.143	−0.106	−0.078	0.018	0.218	−0.002	0.054	0.044	0.044	−0.077	−0.028
PC2	0.060	−0.010	−0.016	−0.268	1.000	−0.454	−0.416	0.293	0.098	0.023	0.091	0.273	0.199	−0.263	−0.046
PC3	−0.074	0.025	0.013	−0.159	−0.341	1.000	0.201	−0.220	−0.231	−0.010	−0.080	−0.211	−0.164	0.218	0.006
PC4	−0.028	−0.002	−0.025	−0.174	−0.361	0.050	1.000	−0.107	−0.063	0.002	−0.061	−0.150	−0.138	0.204	0.015
PC5	−0.008	0.008	−0.001	0.006	0.160	−0.053	0.022	1.000	0.307	0.020	0.085	0.076	0.052	−0.112	−0.041
PC6	0.076	−0.046	−0.013	0.200	−0.007	−0.133	0.049	0.258	1.000	0.029	0.119	0.044	0.037	−0.180	−0.020
SH	0.044	**0.154**	−0.048	0.011	0.055	0.005	0.013	0.008	0.023	1.000	0.216	−0.088	−0.128	0.095	0.030
vitD	**0.097**	**0.150**	−0.077	0.030	0.041	−0.018	−0.023	0.032	0.072	**0.164**	1.000	−0.037	−0.099	−0.021	−0.078
W650	0.051	0.091	0.028	0.058	0.153	−0.034	0.038	−0.002	−0.042	−0.019	−0.008	1.000	0.687	−0.414	0.156
hW650	0.021	**−0.209**	−0.035	0.009	−0.013	−0.016	−0.045	0.002	−0.011	−0.047	−0.051	**0.595**	1.000	−0.341	0.195
skincol	**−0.188**	−0.083	−0.013	−0.012	−0.051	0.020	0.069	−0.002	−0.119	0.086	0.011	**−0.229**	−0.093	1.000	−0.073
Year	**−0.276**	0.039	0.072	−0.052	−0.057	−0.014	−0.011	0.019	0.024	0.075	−0.030	0.078	**0.141**	0.019	1.000

[a]PC, principal component; TNC, total naevus count. Above or below the diagonal of 1.000 values.

to affect the counting of larger and smaller lesions differently due to relative difficulty. Self-reported four-point parental naevus counts actually increased over the same period.

Ethnic ancestry was measured both by reporting by parents of the participants of the ancestry and country of origin of their grandparents, and by genome-wide SNP genotyping. In addition, skin colour has been assessed by observer report and by skin reflectance, and is a key intermediate variable between ancestry and naevus count. Figure 2(a) shows that the proportion of twins who were of British and Northern European ancestries did fall over the duration of the study. Table 2 shows there were only small changes in the means of the genetic principal components over time.

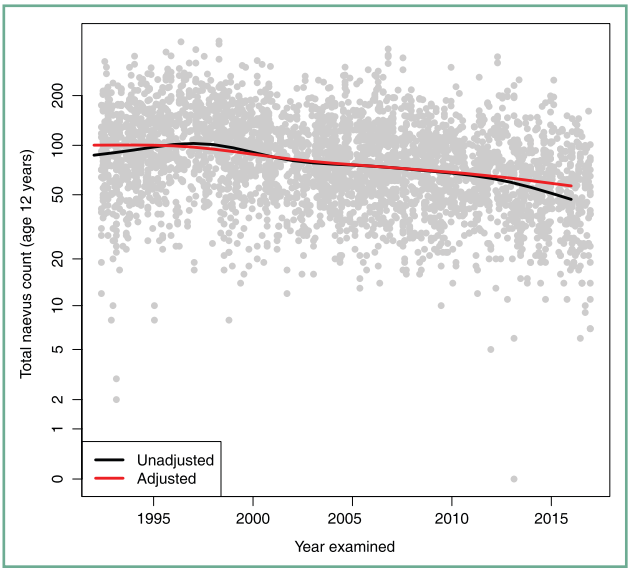

Figure 1 Total naevus count (> 1 mm diameter, TNC) vs. year examined for participants in the Brisbane Twin Nevus Study. TNC is presented on the log scale. The curves are fitted geometric means from a generalized additive mixed model. The black curve is unadjusted for covariates and the red curve is adjusted for age, sex, body surface area, the first 10 genome-wide association study-derived genetic principal components, reported ancestry of grandparents, skin colour, skin reflectance at two sites, estimated sun hours per week and vitamin D level.

The BTNS has collected a number of different measures of sun exposure. For example, Figure 2 (b, c) shows that sun-protective behaviours such as hat wearing or sunscreen cream usage were flat or decreasing, and Figure 3 shows reported weekly hours of sun exposure to be increasing over the period of the study. The calculated weekly hours of sun exposure was only slightly correlated with TNC (see Table 2). The vitamin D level can be used as a proxy for recent cumulative UVR exposure (previous 2–3 months) (Figure S5; see Supporting information), and was correlated with reported sun exposure (r = 0.2), giving some validation of this measure. The vitamin D level exhibited a weak relationship with TNC independent of reported sun exposure and of skin colour, the latter a strong potential confounder (partial r = 0.1). Vitamin D levels were found to diminish over the course of the study, but the magnitude of this relationship was far smaller than that between naevus count and year of study. The generalized additive mixed model predicting log_{TNC} (Tables 3 and 4) showed that year of study remained a highly significant predictor after adjusting for the same set of covariates but allowing nonlinear relationships for sun-exposure hours, plasma vitamin D and skin reflectances. Under this model, the 1992 to 2016 fall in covariate-adjusted TNC is still 43%, while the equivalent fall for the generalized additive mixed model including smoothed year alone is 46% (see Figure 1).

Calibration meta-analysis

For TNC, we see a raw Pearson correlation of 0.78 between latitude where the study population lived and mean log_{TNC} for that study (see Figure 4[5,7,30,31,35–37]). A more sophisticated analysis weighting on sample size estimated the standardized coefficient for the model regressing mean log_{TNC} on latitude and age of participants at adjusted r = 0.87

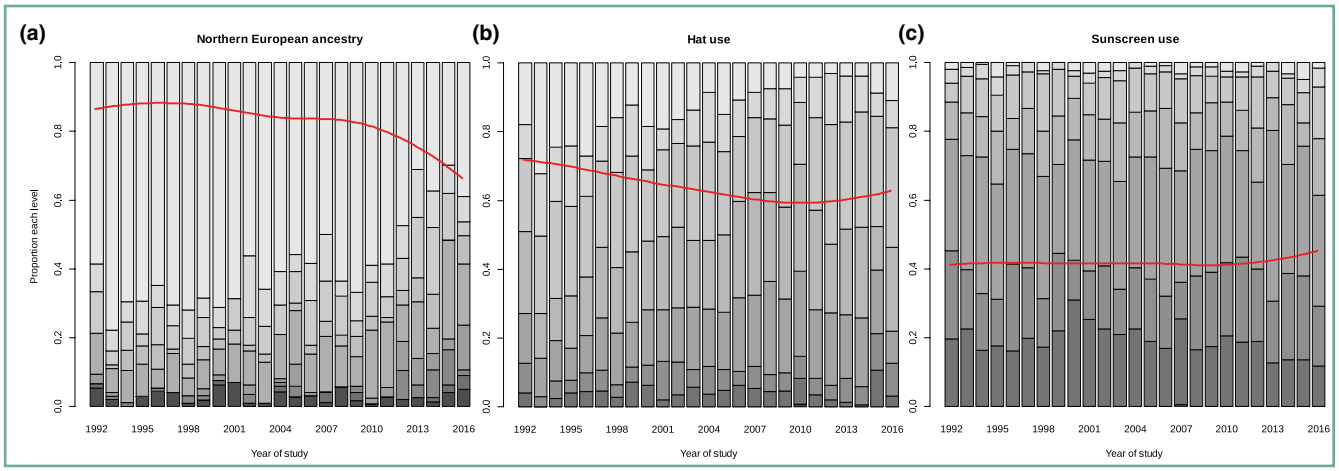

Figure 2 Levels of three putative modifiers of naevus count in children in the Brisbane Twin Nevus Study vs. year examined. (a) Ancestry: from dark to light, the shading of the bar represents 0 to 8 grandparents from the British Isles or Northern continental Europe, and the length of the segment the proportion of each group for that year. The red line is a localized regression of average ancestry vs. year. (b) Hat wearing: from dark to light, the shading of the bar represents how often a hat is worn on an 8-point scale from 'never' to 'always'. (c) Sunscreen use: from dark to light, the shading of the bar represents how frequently sunscreen is applied before going out in the sun on a 7-point scale.

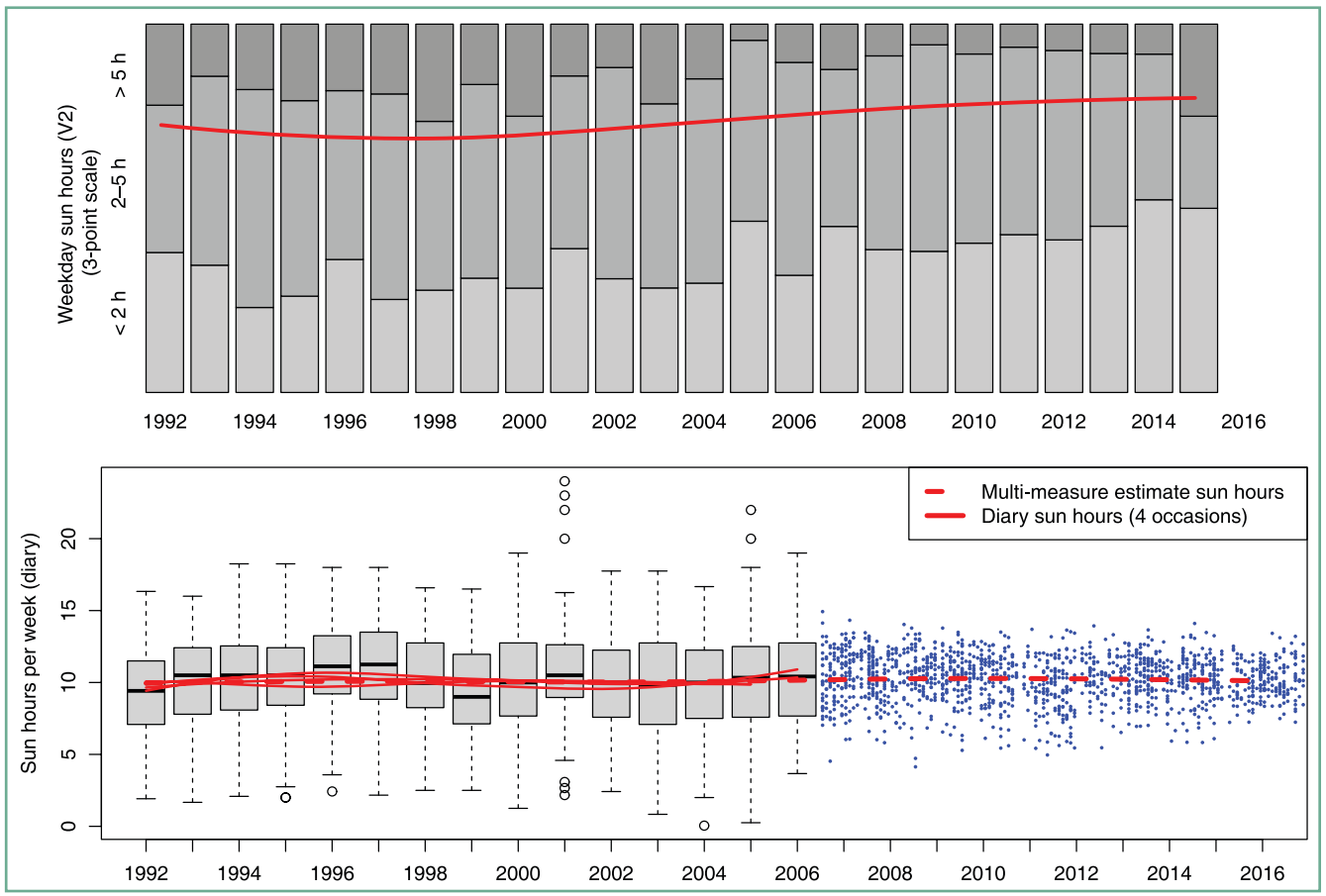

Figure 3 Self-reported sun exposure in Brisbane Twin Nevus Study (BTNS) children vs. year examined. The upper panel is the proportion reporting each level of a questionnaire item asking for an estimate of sun exposure during the school week completed at age 14 years. The lower panel represents average weekday sun exposure (hours per week) reported for children in the BTNS from sun diaries completed on four occasions between ages 12 and 14 years. This finished in 2007, so the blue dots and trend line represent imputed values based on retrospective questionnaire items (such as that in the upper panel) and skin reflectance.

Table 3 Fixed-effects parametric coefficients from generalized additive mixed model (fitted using R gamm4) of log total naevus count vs. key covariates. Random effect is family-specific intercept. The fixed effects are each a linear term

Term	Estimate	Standard error	Student's *t*-value	*P*-value
Intercept	1.213647	0.082253	14.755	< 2e-16***
Male sex	0.033059	0.007313	4.521	6.39e-06***
Age (years)	0.031236	0.002431	12.849	< 2e-16***
PC1	–2.248198	6.007982	–0.374	0.708279
PC2	5.388251	1.608015	3.351	0.000815***
PC3	–8.265650	2.378636	–3.475	0.000518***
PC4	–4.185192	2.152443	–1.944	0.051936
PC6	3.868007	0.764741	5.058	4.48e-07***

PC, principal component. ***$P < 0.001$.

(standardized $b_{latitude} = 0.90$). In the case of a log-normal model for the effects of age, naevus count increased by 7% (95% confidence interval 6–8%) for each additional year of age in the cross-sectional BTNS data, and 15% per year in the longitudinal twin data. In other studies there was a 13% (9–17%) increase per year in the longitudinal data of Darlington *et al.*,[5] 9% (3–14%) per year in the data of Kelly *et al.*[7] and 18% per year in Gallagher *et al.*,[32] where mean counts were much lower.

The fall in TNC from 1992 to 2016 can then be expressed as the equivalent of moving 4.8° of latitude away from the equator, or an 11.7% fall in cumulative sun exposure (from 1503 kJ m^{-2} to 1327 kJ m^{-2}).

Discussion

The Brisbane Twin Nevus Study is unique in measuring changes in naevus count across subsequent birth cohorts over a 25-year period using complete body examinations. We found that naevus counts on children in subtropical Brisbane roughly halved over this period. This magnitude of change is important in terms of resulting change in melanoma risk – applying the relative risks from the prediction equation of Vuong and coworkers[4] would imply a fourfold reduction in lifetime melanoma risk for those born after 2000 compared with those born in 1980.

Through the simultaneous collection of self-reported sun behaviours and ethnicity, along with genome-wide genotyping, we are able to test a variety of possible causes for this trend.

Table 4 Random effects and approximate significance of smooth terms from generalized additive mixed model (fitted using R gamm4) of log total naevus count vs. key covariates. Random effect is a family-specific intercept, and smooth terms are transformed by a penalized regression spline, where the degree of smoothness is estimated as part of fitting using generalized cross-validation. The effective degrees of freedom (edf) represents the 'wiggliness' of the smooth – where one is a straight line

Smooth term	edf	F	*P*-value
Sun hours	1.000	0.492	0.483149
Vitamin D	2.911	7.015	0.000165***
Arm W650	1.000	27.257	6.66e-07***
Hand W650	1.000	4.821	0.028179*
Year	5.769	31.410	< 2e-16***

edf, estimated degrees of freedom.*$P<0.05$; ***$P<0.001$

Because there is a significantly lower naevus count in those with darker constitutional skin colours, one might invoke changes in the ethnic composition of the Brisbane school-age population. The ethnic composition of the Australian population has shifted steadily over the duration of the BTNS. In the 1986 Census, 76% of the Australian population were of Anglo-Celtic ancestry, and 74% in 2001. By 2016, the population of Brisbane was 66% Anglo-Celtic. The trends seen among BTNS participants follow this reasonably closely. Similarly, plasma vitamin D levels showed a small drop over the same period, and a proportion of this was due more to individuals being of darker skin colour, a known risk factor for lower vitamin D. Despite this, adjustment of TNC for multiple measures of ethnicity and contemporaneous sun exposure had little effect on the decrease in TNC over time, with the correlation between year and TNC falling only from r = –0.31 to –0.28.

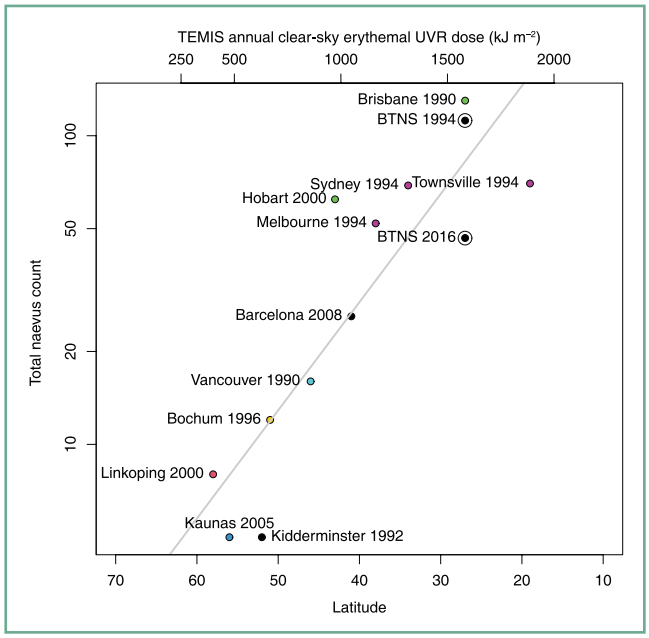

Figure 4 Meta-analysis of relationship between latitude of residence and mean (log-transformed) total naevus count in European-descended 12-year-olds in multiple studies[5,7,30,31,35–37] including the present work, which is represented by data from the 1994 and 2016 subsamples. BTNS, Brisbane Twin Nevus Study; TEMIS, Tropospheric Emission Monitoring Internet Service (https://www.temis.nl/); UVR, ultraviolet radiation.

Multiple lines of evidence suggest that changes in the skin examiner's naevus counting procedures do not explain the trend. Simultaneous counting on the same individuals by multiple examiners was performed only in the pilot phase of the study, and found a between-examiner correlation of 0.96 (n=66). There were 204 participants examined by two examiners 2 years apart around 2012, and the between-observer correlation was 0.90. A subset of 220 twins (born 1978–1986) were re-examined 15–20 years later and had large naevi (> 5 mm) counted using whole-body imaging using the Fotofinder device,[38] with a between-occasion correlation of 0.7. Looking just within the BTNS, we compared the year of visit regression for large naevi (> 5 mm diameter) with that for intermediate-sized naevi (2–5 mm diameter), and found these were parallel and decreasing, while that for smaller lesions 1–2 mm remained flat. If there were a factitious drift downwards in the counting procedure, we expected that this would disproportionately affect counts of small lesions.

Since the 1970s, there have been a series of public health measures aimed at reducing sun exposure in Australian children and thus the later burden of melanocytic and keratinocytic skin cancers, and if these have been influential, we would expect the average number of naevi to also fall. Child-care services and schools have increasingly taken up institutional sun-protection policies over the time course of the BTNS, such as under the National SunSmart Early-Childhood Program and Schools Program.[11–13] These typically involve erection of shade structures in play areas, 'no hat, no play' behavioural rules, and application of sun screen to small children.[39] However, trends in individual sun behaviours as tapped by surveys of adolescents have been less impressive in the same period,[40–42] showing them to be less sun avoiding than adult peers, and increasing rather than decreasing their sun exposure over time. Livingston and coworkers,[40,41] for example, utilized a stratified Australia-wide survey of school children aged 12–17 years (total N=101 449) to find that 'usually or always wears a hat, and covering clothes and sunscreen' fell from 12% in 1993 to 9% in 2002 for males and from 10% to 6% in females, a finding that was not due to changes in population phototype, and that two-thirds preferred a 'light' or 'moderate' tan over that entire decade. While in 1992, 64% of 12–13-year-olds had been sunburnt last summer, this rose to 78% by 1999.[40] In summary, the published data do not show a reduction in sun-exposure behaviours over time in the age group that the BTNS participants come from.

In the BTNS, the proportion of 12–13-year-olds who reported receiving a painful sunburn at least once in the previous 6 months was 38% in 1992, and 44% in 2002 (33% and 57% if restricted to those reporting in summer and autumn). In keeping with this, wearing a hat 'frequently' or 'always' fell from 18% in 1992 to 11% in 2002. The BTNS also collected more fine-grained estimates of sun-exposure time from multiple interviews of the same participants between ages 12 and 14 years – the estimated number of hours per week rose from a median of 9.5 h in 1992 to 10.7 h in 2002. These self-report measures (age 12–14 years) do predict serum vitamin D levels, but these reflect cumulative exposure over only 3 months or so.[43] Therefore, it is difficult to invoke contemporaneous sun-exposure changes as an explanation for the secular decline in TNC at age 12 years.

We have no retrospective data on earlier-childhood sun exposure in the BTNS, but know from other studies in Queensland populations that sun exposure under 3 years of age predicts increased naevus counts in children[44,45] that persist into adult life,[46] and further, from a randomized trial in Townsville Queensland (latitude 19.2° S), that sun-protective clothing and sunscreen in childcare centres reduced naevus counts by 22% compared with controls after 3 years of follow-up.[47]

From the foregoing, we hypothesize, given our exclusion of alternative mechanisms, that annual birth cohorts of Brisbane children experienced less cumulative UVR exposure prior to age 12 years over the two and a half decades since 1992, and that this is not strongly correlated with sun exposure at ages 12 and 14 years. By comparing adolescent naevus counts measured across different latitudes in Australia in a meta-analysis, we can estimate that it only requires the equivalent of a 12% fall in average clear-sky annual UVR dose to cause the observed 45% fall in (geometric) mean naevus count in our study. This should carry over to a 12% fall in the average sun-exposed number of hours per day in the Brisbane environment, and 0.5% for each birth year later than 1980. That is, because the relationship between UVR dose and naevus count is exponential in nature, small changes in sun exposure can cause large changes in TNC. This should also point to a probable future fall in melanoma rates in the more recently born birth cohorts in the Australian population.

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Conflicts of interest

None to declare.

Data availability

The data underlying this article will be shared on reasonable request to the corresponding author.

Ethics statement

All procedures in this study ('P193: Longitudinal study of the genetics of Melanocytic Naevi in twins') were approved by

the Human Research Ethics Committee of the Queensland Institute of Medical Research Berghofer Medical Research Institute and complied with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Legal guardians (as subjects were under the age of 18 years) gave written, informed consent prior to inclusion and testing for all participants.

Patient consent

Not applicable.

Supporting Information

Additional Supporting Information may be found in the online version of this article at the publisher's website.

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